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EUROPEAN SPACE AGENCY

INDUSTRIAL POLICY COMMITTEE

ROBOTIC EXPLORATION

TECHNOLOGY PLAN

Programme of Work 2009-2014 and relevant Procurement Plan

SUMMARY

This document presents the currently proposed activities in the Technology Research Programme (TRP), the Exploration Technology Programme (ETP, funded by MREP) and the Aurora Core Programme (ACP) that are supporting the implementation of ESA's Robotic Exploration Programme from 2009-2014.

REQUIRED ACTION

IPC is invited to approve the work plan for 2011 and the connected procurement proposals and to take note of the activities envisaged for 2012-2014, provided for information.

VOTING RIGHTS AND MAJORITY REQUIRED

For MREP funded activities: Simple majority of participating Member States, present and voting: Austria, Belgium, France, Greece, Italy, The Netherlands, Portugal, Spain, Sweden, Switzerland, United Kingdom and Canada.

For TRP funded activities: Simple majority of member States, present and voting.

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1 Background and Scope

The ESA Robotic Exploration Programme

The programme proposal MREP (Mars Robotic Exploration Preparation, ESA/PB-HME (2008) 43.Rev1) was widely supported at the last C-Min by ESA participating states. The MREP programme objective is to build, in the medium term, a European Robotic Exploration Programme, by concentrating first on Mars exploration and by making use of international collaboration, in particular with NASA.

The general approach is to consider a Mars Sample Return (MSR) mission as a long term objective and to progress step by step towards this objective through short and medium term MSR-related technology developments, which are validated during intermediate missions, and by developing Long Term enabling technologies, such as Novel Power Systems (NPS) and Propulsion engines.

ExoMars missions are currently under development and will be launched in 2016 and 2018. They constitute the first two missions of the ESA/NASA Mars programme. ExoMars (2016) includes a Trace Gas Orbiter and a European Entry, Descent and Landing (EDL) demonstrator module. ExoMars (2018) includes an ExoMars European rover and a second NASA rover, called Max-C. Both rovers will be delivered to the Martian surface using the NASA EDL system developed for MSL mission (to be launched in summer 2011). The 2018 NASA rover Max-C is currently envisaged as a sampling and caching rover, which will prepare cached samples to be retrieved and returned by a MSR lander mission in the early 2020's. As such, the 2018 mission can be considered as the first component of the joint ESA/NASA MSR mission. The latter will include at least two other space missions (MSR Orbiter and MSR Lander) and a ground component for the sample retrieving facility.

The Robotic Exploration Programme currently foresees five mission candidates for the post-Exomars launch slots (2020/2022), to be presented to the PB-HME for down-selection by end 2011. The candidate missions currently being considered are:

1. Network Science mission (4-6 probes), possibly including a high precision landing demonstration
2. Sample return from a moon of Mars (Deimos or Phobos)
3. Mars atmospheric sample return
4. Precision lander (< ~10 km) with sampling/fetching rover
5. MSR orbiter

Missions 1 to 4 are alternatives to cope with possible MSR delays, while Missions 4 and 5 are possible MSR segments under Europe lead.

Phase 0/A studies are being initiated in 2010 for the following:

1. Mars atmospheric sample return (subject to recent CDF study outcome)
2. Precision lander (< ~10 km) with sampling/fetching rover
3. MSR orbiter

The two other missions have already been subject to Phase 0/A studies, however focussed complementary studies may be implemented by ESA for preparing the down-selection before the next C-Min (2012).

The activities in this Technology Development Plan (TDP) have been grouped by MSR technology areas covering the potential European participation to MSR. These technology themes are naturally also relevant to the candidate missions. The Network Science mission is identified separately and the related activities cover the technologies related to the delivery of small landers onto the Martian surface (40-60 kg landed mass).

This technology work plan is an update of the work plan approved by the PB-HME and IPC in October and November 2009 respectively (ESA/PB-HME(2009)78 and ESA/IPC(2009)144). As for the previous plan, the programme of work was built using the ESA TECNET (TEChnology NETwork) process, in coordination with activities planned in other Directorates in particular HSF, and using for the best the industrial and internal studies achieved so far for Mars future missions. The work plan makes use essentially of MREP and TRP budgets.

Programme Implementation

Projects will follow the typical ESA project implementation approach and rules for the procurement of European contributions in Intermediate Missions once assignments of responsibility with NASA or any other cooperating agency are agreed. For the 2020 mission, phase A/B1 work is planned to be completed by 2012/2014, in order to confirm the baseline mission architecture and payload resources allocation, to consolidate the Mission-System requirements and to complete the preliminary mission design including the main spacecraft elements. The aim is also to prepare the required inputs for the next C-Min for enabling an implementation decision for the 2020/2022 mission(s).

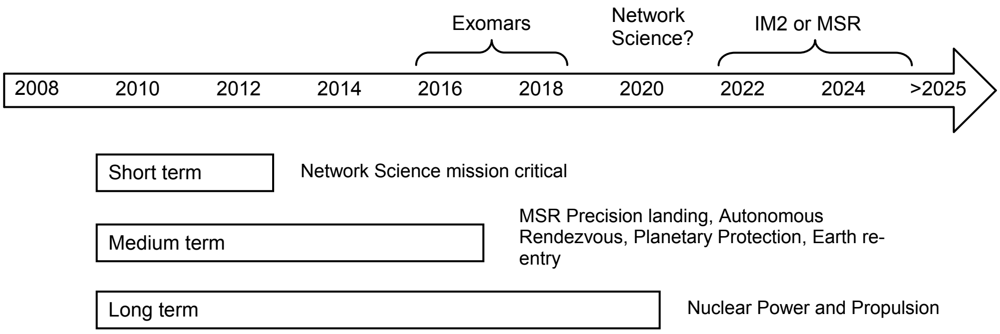
Technology developments

The MREP Programme technology developments can be grouped by the time period available for their implementation, which in turn directs the scheduling of the Technology Development Activities (TDAs):

i) Short term technology developments, in relation to the Network science landers mission preparation, which will serve the scientific and technological preparation of MSR. The aim of these developments is to reach TRL 5 for the space segment, prior to the decision of implementing the mission, therefore prior to entering phases B2/C/D for the spacecraft. The requested TRL is the minimum required for entering the Development Phase with controlled schedule and cost.

ii) Medium term technology developments, in preparation for the post-2020 intermediate missions and MSR. These developments initiate MSR related technologies for the potential European contribution to this mission. Some of these developments are a continuation of activities started within the previous Aurora Core Programme.

iii) Long term technology developments, which are defined as strategic and enabling technology developments for European robotic exploration. In line with the C-Min(2008) MREP proposal, the work plan focuses the effort on NPSs using radioisotope heat generation and a high thrust apogee engine for improving the spacecraft insertion in Mars orbit. These long term developments require an extended development effort (~7-9 years) and sustained budgets. The intermediate missions and MSR would naturally take advantage of these developments when they are completed.



MREP Programme Technology Development Timeline

2 The Robotic Exploration Technology Development Plan

2.1 This Technology Development Plan (TDP)

This update of the technology development plan mainly concerns the following:

1. Addition of a few new activities for implementation in 2011.
2. Limited updates in the NPS activities reflecting the progress made in 2010.

The present document covers three main topics:

i) Network mission critical technologies: Section 2.3 describes a Network Science landers mission, which could be launched in 2020. The activities have been defined by considering current ExoMars developments and by relying on the MarsNEXT industrial studies and on an additional internal study made by mid 2009 in coordination with NASA/JPL.

ii) MSR critical technologies: Sections 2.4 to 2.9 outline the major technology themes in preparation of MSR mission and covering European potential contribution to this mission. A number of new activities are proposed here, grouped by technology themes, and taking best benefit of the activities that have been conducted within the framework of Aurora since 2003.

The technology themes are the following:

- Precision Landing
- Robotics and rover technologies

- Planetary protection related activities
- Mars ascent vehicle (no activities proposed at this stage)
- Autonomous rendezvous and sample capture in-orbit
- Earth re-entry technologies

Consideration has been given to the development logic for phasing and structuring the activities in a consistent manner. For that purpose and for the case of elaborated activity proposals, technology roadmaps are provided with a 2014 horizon. *The activities proposed here are the minimum required in the 2010-2014 timeframe to bring the technologies to a sufficient Technology Readiness Level (TRL) in order to enable flight demonstrations of individual components and systems from 2020 onwards. They do not pre-figure the missions to be implemented from 2022 onwards.*

iii) Long term enabling technologies: These activities are described in Section 2.10 and were already addressed in the previous versions of the work plan (June and November 2009). The NPS developments aim at acquiring novel power sources in Europe, both electrical and thermal, using heat produced by radioisotope alpha–decay. A major step was achieved in 2010 activities by identifying Am(241) as a plausible and affordable radioisotope candidate for a European NPS. Following these encouraging results, the activities foreseen on radioisotope production demonstration and on power conversion have been maintained. The workplan has been strengthened on launcher accommodation and safety aspects, essentially by re-centering and enlarging the scope of the previously foreseen activity “Fuel encapsulation prototype development to TRL4”. The objective is to reach C-Min(2012) with a global understanding of the NPS requirements and of investment needs.

Notes on the Annexes to this TDP:
1. Annex I consists of summary tables listing all the TDAs that are approved and proposed within the Robotic Exploration Programme for the period 2009-2014.
2. Annex II consists of detailed descriptions of all the approved and proposed TDAs listed in the tables in Annex I.

2.2 Critical Technologies

Table 2-1 lists the critical technologies, as currently defined, needed to implement the Robotic Exploration Programme for 2009-2014.

Where useful, graphic representations of the technology roadmaps are provided, giving a rough overview and context of the individual activities. Details on the content, funding and duration are provided in the Annexes to this TDP.

Category	Technology Area	Technology Development Activities
Network Science Mission	EDL & GNC	EDLS GNC Optimisation and validation for small Mars landers including possible new EDL sensors/triggers
		Other required EDL technologies such as subsonic parachutes, retro-rocket system, unvented airbags and lowering system

	Power	Investigations to optimize low temperature batteries, solar cells optimized for Mars and power regulators.
	OBC	Tailored On-Board Computer EM for planetary landers together with a low power timer
	Communications	Lander Compact Dual UHF/X-band Frequency Communication Package
Mars Sample Return	EDL & GNC	Precision landing GNC optimisation
		Sensors (IMU, vision and lidar) for precision landing
		Hazard avoidance technologies
		Throttleable engine for soft landing
	Robotics	Sample Fetch Rover technologies
	Autonomous Rendezvous and Capture	Integrated GNC solution with sensors
		Sample Canister capture mechanism development
	Earth Re-Entry Capsule	High temperature TPS
		Shock absorbing structure
	Planetary protection	Biocontainment system development
		Sample receiving facility preparation
Long-term Technologies	Propulsion	High thrust engine
	Nuclear Power	Isotope evaluation, production, encapsulation and launch safety aspects.
		Thermo-electric and Stirling converters

Table 2-1: Critical technologies needed to implement the Robotic Exploration Programme for 2009-2014

2.3 Network Science Landers

For the Network Science mission, the mission objective would be a network of small landers for studying Mars geophysics.

A basic assumption of this work plan is that the Europe contribution will not be limited to the launcher procurement and will include the provision of at least some of the landers. For that purpose, a 3-year technology development plan has been initiated, aiming at TRL ≥ 5 prior to Phase B2/C/D.

Figure 1 gives a potential mission overview.

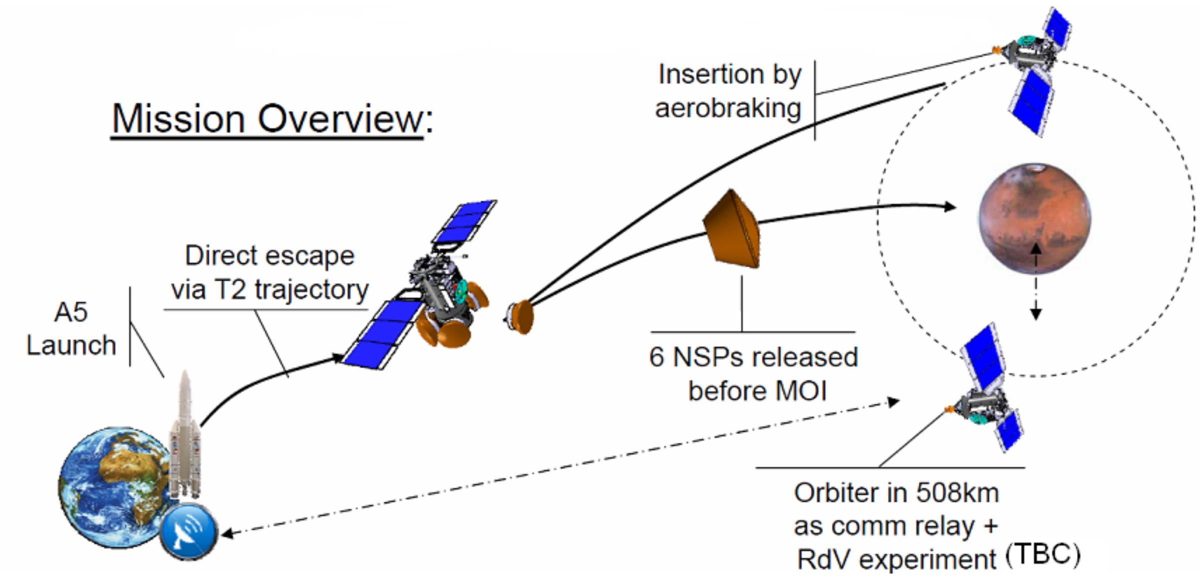


Figure 1: Potential Mission Architecture for a Network Science Mission

The mission assumptions used to derive the technology plan are summarised in Table 2-2.

Mission	• Ariane 5 single launch with 3363 kg launch mass (direct escape) • 7 month transfer • Lander release from hyperbolic orbit up to 23 days before Mars entry
Mission objectives	• To deploy a network of science landers on the Martian surface • To demonstrate key technological capabilities for Mars robotic exploration.
Landers	• Between 3 and 6 Network science landers • Each lander in the ~170kg range and requiring the simplest possible entry, descent and landing system • Payload mass: ~8 kg • Survival of 1 Martian year (including dust storm season) • UHF relay to orbiter and compatible with parallel Mars surface-to-ground data relay provided by the ESA/NASA Relay Orbiter(s) • X-band direct to Earth for EDL communications, contingency and science
Orbiter	• Lifetime: 3 Earth years (nominal) + 3 Earth years (extended) • Payload mass: ~33 kg

	• Requires aerobraking • Shall serve as a communication relay for the landers
Planetary protection	• Category IVa for the landers and Category III for the orbiter

Table 2-2: Network Science Mission assumptions

The key technology developments for enabling this mission concentrate on the Entry, Descent and Landing system. These are complemented by developments improving the power, communications and thermal system for the network science landers, to ensure a sufficient number of probes can be delivered to the surface.

NOTE: The technology plan described here for the Network Science mission takes into account the technology developments envisaged for the 2016 Exomars EDL Demonstrator Module.

2.3.1 TDAs proposed for 2011

ESA Ref.	Activity Title	Budget 2011
T921-001QE	Adaptation of Aerogel Materials for thermal insulation	300
E920-001MS	Airbags for small landers – Breadboard and Test	2000
E906-001ET	Compact dual UHF/X-band Proximity-1 Communication EM	1000
T911-001GR	Simulation tool for breakup/burnup analysis of Mars orbiters	300

Thermal

Due to the non-vacuum environment of the Martian surface, standard multi-layer insulation (MLI) does not serve as effective insulation for landers. Aerogel however offers a potentially attractive solution due to its low-mass and low-thermal conductivities. It has been considered in previous system studies for use on Mars lander missions, however the TRL has been too low to adopt it as a baseline. An activity (T921-001QE) is proposed to adapt aerogel developed for terrestrial use for use in Mars surface conditions.

Airbags

The activity proposed here for 2011 (E920-001MS) will follow on from the previous TRP activity initiated in 2010 (T319-035MC), to develop and test to TRL 5, a breadboard of the chosen airbag design for the Network Science mission.

Communications

Following from a TRP study initiated in 2009 on a compact dual UHF/X-band package for small landers (T306-044ET), an activity for 2011 is proposed to develop an engineering model of such a system. Such a compact package would allow maintaining communications directly with Earth during Entry, Descent and Landing (using the X-band part) as well as the use of the UHF Proximity-1 protocol during science mission operations for any future Mars lander mission.

Planetary Protection

A simulation tool is required to model the breakup/burnup of Mars orbiters in the case of uncontrolled entry (from hyperbolic trajectories or during aerobraking) for planetary protection purposes. Existing tools have been developed for the case of Earth re-entry but adaptation to the Mars scenario, including the effects of the Martian atmosphere/composition is needed in order to provide early feedback during Mars spacecraft design. An activity is proposed for 2011 (T911-001GR) to develop a generic tool that would allow the assessment of aerothermal/aerodynamic heating, delamination and breakup effects of a Mars orbiter.

2.3.2 TDAs planned for 2012-2014

Follow-on activities in support of the technology preparation for the network science mission are planned for the 2012-2014 timeframe (see roadmap in Figure 2 and Annexes I and II for further details of these TDAs). These include activities in the areas of aerobraking, GNC, EDL systems, power, communications, operations and planetary protection.

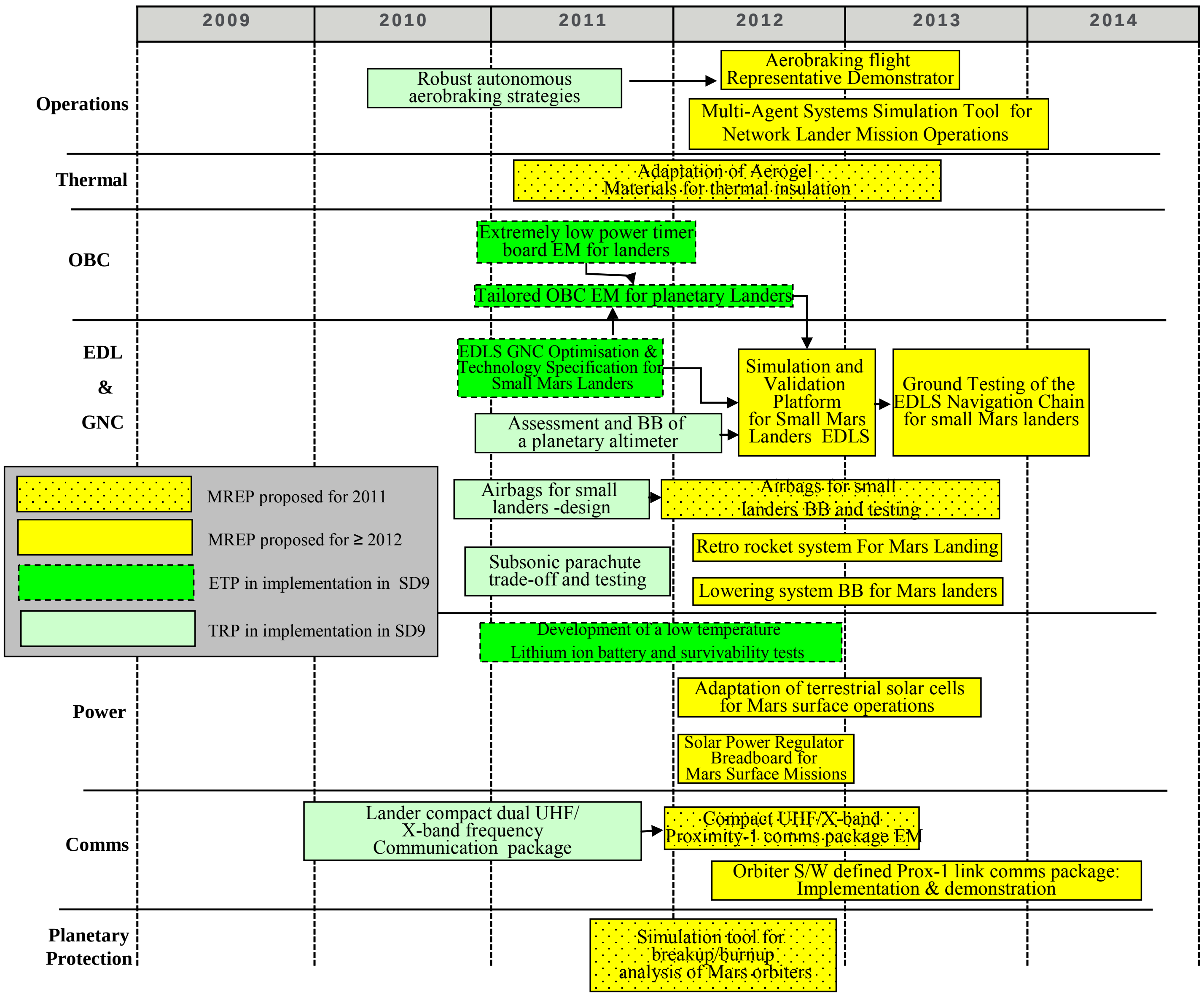


Figure 2: Technology Roadmap for the Network Science Mission

2.4 Entry, Descent and Landing for MSR

Objective: To design and demonstrate affordable strategies enabling high precision landing on Mars below 10 km accuracy with hazard avoidance. The approach will make best use of Aurora current developments, with the necessary adaptation of algorithms and sensors to MSR-like landers, and will include field testing of the high precision landing system in a representative environment.

On-going activities on Mars Entry, Descent and Landing (EDL) aim to demonstrate the feasibility of achieving a 10km landing accuracy, and possibly 3 km. Significant additional efforts are required, on each of the EDL phases, to further improve the GNC performance and decrease, below that level, the size of the final landing ellipse. Taking benefit of Aurora technology activities (previous and on-going), a roadmap is proposed to develop and demonstrate an optimised End to End solution for Mars precision landing.

2.4.1 TDAs proposed for 2011

ESA Ref.	Activity Title	Budget 2011
T905-008EC	Sensor Data Fusion for Hazard Mapping and Piloting	200

GNC

The proposed activity for 2011 (T905-008EC) aims to demonstrate how data from the the multiple sensors that may be required during a hazard avoidance manoeuvre (eg. Camera, LIDAR/altimeter) can be fused in an efficient manner to allow real-time re-targeting of a lander during the powered descent phase.

2.4.2 TDAs planned for 2012-2014

In the following years, the development of an Inertial Measurement Unit (IMU) will be initiated. An IMU is a critical, mission-enabling technology that is required for precision landing missions, particularly during the guided entry and powered descent phases. The proposed activity *T905-014EC European IMU breadboard* is the first part of an European IMU development which is considered of strategic importance for the Robotic Exploration programme. It will build on existing and ongoing gyro and accelerometer developments in Europe to demonstrate a breadboard of an IMU optimised to the MREP programme requirements.

Additionally, specific HW adaptations will be undertaken in other areas of EDL sensors taking benefit of the maturity reached by Aurora developments on Lidar and vision imaging sensors (see roadmap in Figure 3 and Annexes I and II for further details of these and other planned TDAs for 2012-2014).

The roadmap then foresees a field testing of the GNC system and image processing algorithms using the unmanned helicopter-based PLGTF (Precision Landing GNC Test Facility) developed under TRP and Aurora contracts.

In parallel, activities are planned to develop a European throttleable engine required to perform controlled, soft landing including hazard avoidance.

Relevance to the Robotic Exploration Programme and other ESA programmes
The development of Precision Landing Systems is an essential enabling technology which will serve the future ESA planetary and robotic exploration programmes. European capabilities need to be developed, in close synergy with the Moon Exploration programme.

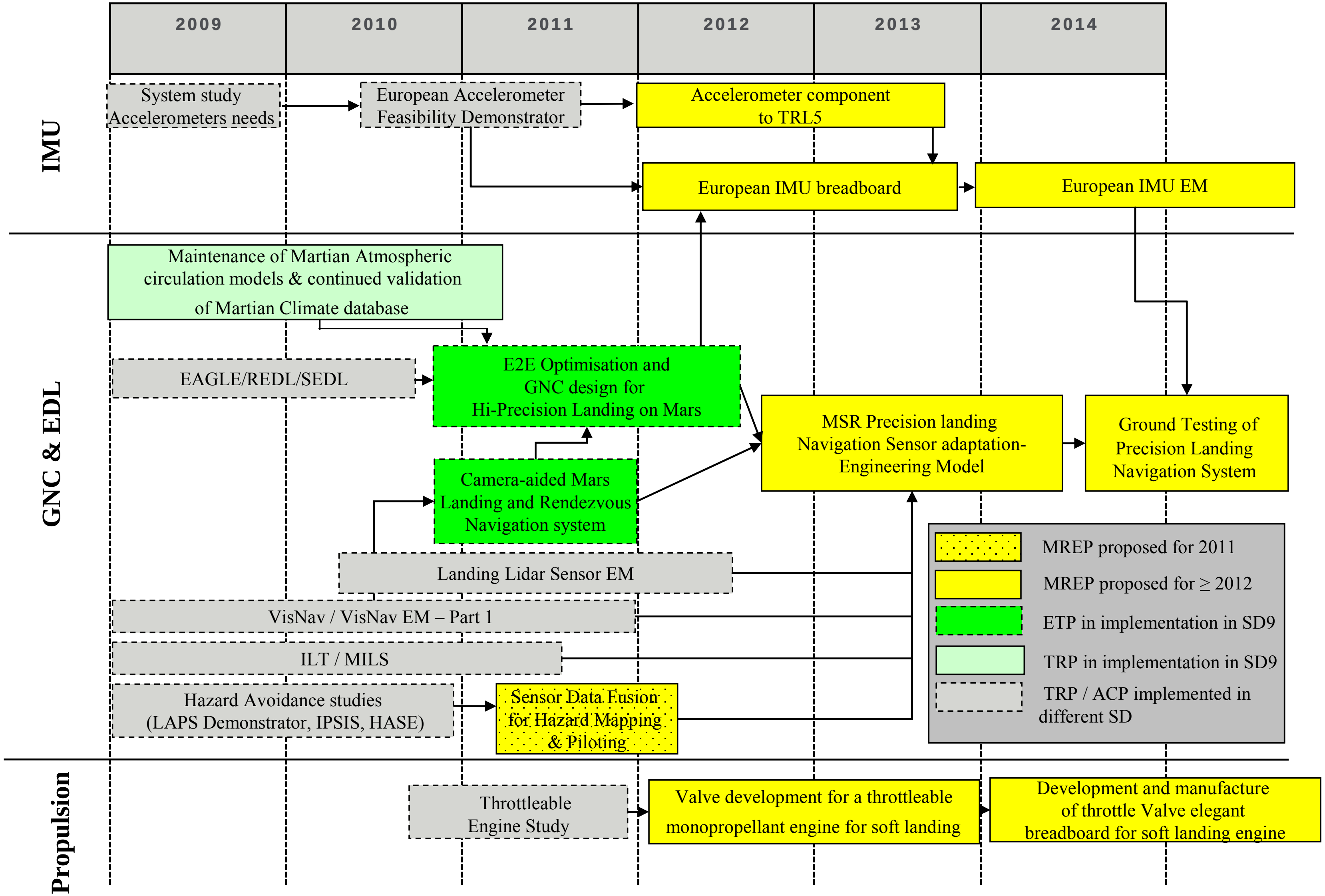


Figure 3: Technology Roadmap for Entry, Descent and Landing for MSR

2.5 Sample Fetching Rover, Robotics and Mechanisms

Objective: To develop robotic/rover capabilities for enabling sample acquisition and scientific investigations on the Martian surface.

The MSR scenario as proposed in the iMARS report includes a mobility option, i.e. a rover that would be used to find and fetch samples to return to the Mars Ascent Vehicle. Key elements for the rover are high-mobility and suitable robotic mechanisms (eg. robotic arm) to enable sample retrieval and possible transfer to the stationary platform.

2.5.1 TDAs proposed for 2011

ESA Ref.	Activity Title	Budget 2011
T913-004MM	Surface-Wheel Interaction Modeling for Faster Traverse (SWIFT)	400
T913-003MM	DExtrous LIghtweight Arm for exploratioN (DELIAN)	800
A915-002MS	Mechanisms technologies that operate at very low temperatures	475

Rover locomotion

The MSR fetch rover is likely to be small and lightweight, with a correspondingly lower power budget for locomotion and resistance to possible immobilisation in the fine Martian regolith. Hence, the design of the rover wheels is a critical and driving parameter in the locomotion system design. A validated tool, based on measured physical/minerological properties of Martian soil, is required to aid the design of the suspension and wheels of the SFR to optimize its energy consumption as well as reduce the risk of immobilisation. An activity proposed for 2011 (T913-004MM) shall develop a beta-version of such a tool to aid the design of the rover wheels.

Robotic arm

The MSR Sample Fetching Rover (SFR) would require a robotic arm to enable both direct sampling of material from the Martian surface as well as retrieval and transfer of any cached samples that may be available. The requirements on such an appendange for the SFR will be defined in a previous study on the SFR that has been initiated in 2010 within MREP (E913-002MM). In 2011, the activity proposed here (T913-003MM) shall develop the arm based on these requirements as well as to consider the needs for seismometer deployment for a Network Science mission.

Mechanisms technologies

One of the limitations of a small solar-powered SFR is the limited power budget available to pre-heat mechanisms prior to operation during the early part of a Martian sol. The development of technologies to allow mechanisms to operate at very low temperatures (< -60 degrees C) would dramatically increase the power and time available for locomotion or sample operations. It is deemed desirable to initiate such a development (A915-002MS) at the earliest stage due to its perceived importance in enabling a lightweight and mobile SFR, and is therefore proposed here for implementation in early 2011.

NB: This activity A915-002MS is proposed to be funded by ACP if the MREP geo-return to Austria has been satisfied prior to this activity being placed, otherwise it will be funded by ETP.

2.5.2 TDAs planned for 2012-2014

The locomotion, robotic arm and low-temperature mechanisms technologies developments in 2011 will be followed by investments in sample acquisition tools and improved rover structural materials (see roadmap in Figure 4 and Annexes I and II for further details of these and other planned TDAs for 2012-2014).

Relevance to the Robotic Exploration Programme and other ESA programmes

Robotic exploration of planetary surfaces is a key capability for ESA's Robotic exploration programme. Technologies developed in this area are widely applicable in all planetary exploration missions requiring sample acquisition, instrument placement and locomotion.

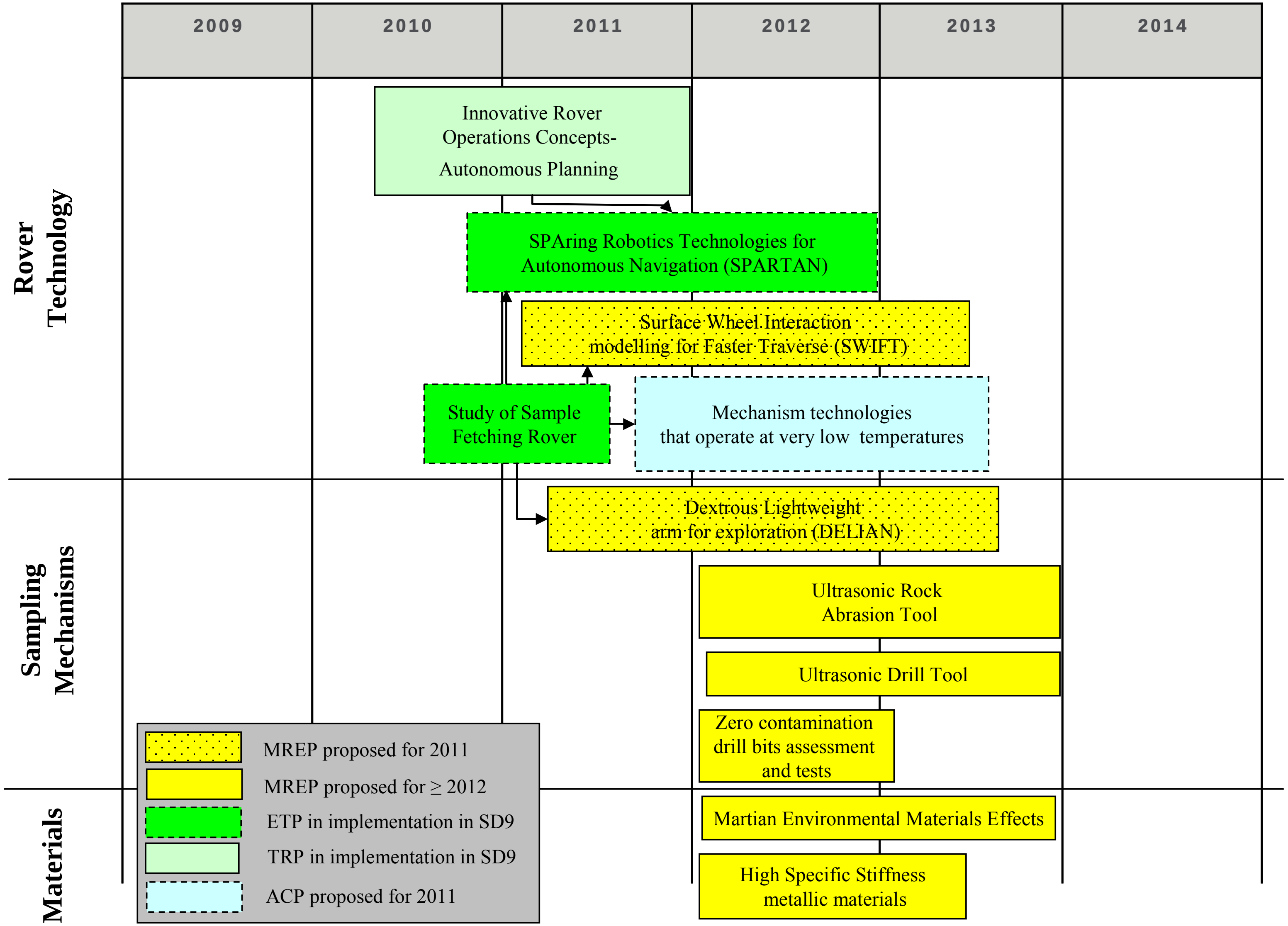


Figure 4: Technology Roadmap for Sample Fetching Rover, Robotics and Mechanisms

2.6 Planetary Protection Technology Developments for a MSR Mission

Objective: To develop the required flight and ground system containment and contamination control technologies for the MSR mission.

One essential aspect of a MSR mission is to break the chain of contact between Mars and Earth to avoid introducing a potential hazard to the terrestrial biosphere. This applies to the returned samples and flight hardware as well as to the ground facilities that will receive, handle and analyse such samples. Another essential aspect is indeed the preservation of the samples during and after their journey to Earth

The International Mars Architecture for the Return of Samples (IMARS) Working Group, under substantial ESA and NASA participation, has identified containment technologies that have to be developed for the flight and ground systems as one of the most critical and long-lead technology developments in preparation for an international MSR mission. Based on JPL and ESA experience, the expected individual Technology Readiness Level (TRL) steps are in the range of 3-5 years.

2.6.1 TDAs proposed for 2011

None. Awaiting completion of preceding activity from 2010 (E914-001MM).

2.6.2 TDAs planned for 2012-2014

The second phase of the containment technology and system development (about 5 years duration, reaching TRL-4 to TRL-5 for the containment system) has to focus on the detailed design issues of the entire containment system covering the test-intensive verification and the detailed interface issues to the higher and lower level systems. Figure 5 shows a roadmap of the activities that are envisaged in the area of Planetary Protection for 2012-2014.

Relevance to the Robotic Exploration Programme and other ESA programmes
Mastering the flight and ground containment technologies is an essential and strategic enabling technology for a MSR mission. Demonstrating this is a necessary input for the decision to initiate the MSR project. A delay in initiating these technology developments, for the flight and ground system, can jeopardize reaching the necessary TRL-5 for the MSR project decision in a timely manner.

Benefits for ESA
There are a number of mission critical elements in an international MSR mission. Some of these elements can be clearly associated to demonstrated competences of international partners. Until now, this is not the case for the spacecraft and the associated containment system that will return the samples from Mars.

Establishing the investment to build the right level of competence in the field of flight and ground containment technologies and systems will enable ESA to better negotiate for a major and mission critical contribution in the frame of an international MSR mission. It will also enable Europe to handle and analyse such samples, independent of the chosen landing location on Earth.

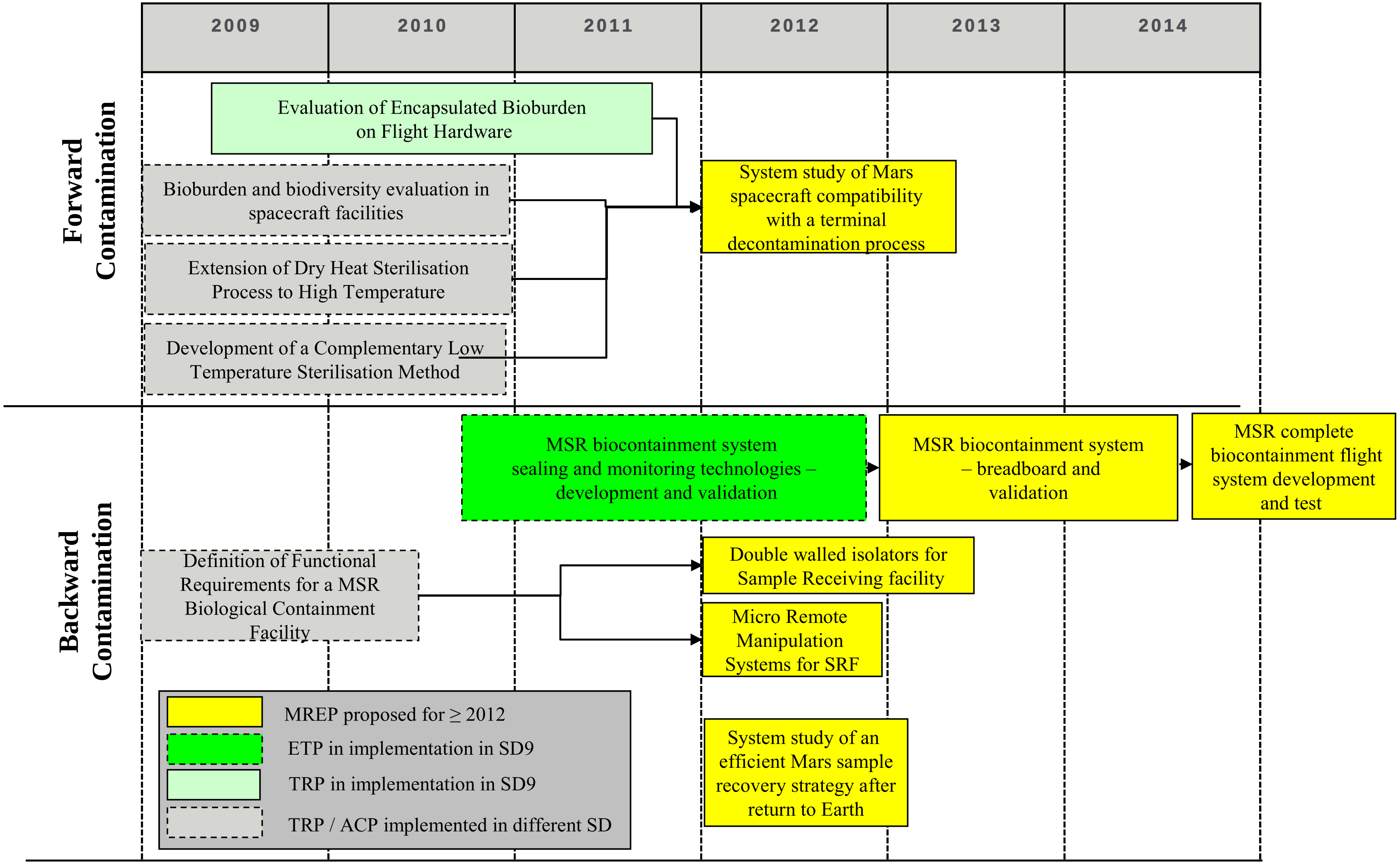


Figure 5: Technology Roadmap for Planetary Protection for MSR

2.7 Mars Ascent Vehicle

Technology development for the Mars Ascent Vehicle (MAV) is not foreseen as a high priority area of interest for ESA at this time. The Mars Ascent Vehicle would be provided by NASA, who is implementing a dedicated technology work plan for enabling a MSR joint programme decision by 2015.

2.8 Autonomous Rendezvous and Capture

Objective: To develop the complete solution of the autonomous GNC system, covering all the Rendezvous phases of the MSR mission, including HW Engineering Models and a ground testing of the RV system, in closed-loop and in a representative H/W dynamic environment.

The Jules Verne mission has demonstrated European capabilities in Automated Rendezvous and Docking in Low Earth Orbit, through a flawless ATV maiden flight, meeting international partners (US and Russia) Flight Safety requirements. A MSR mission raises new challenges to capture autonomously a small canister injected, possibly on an elliptical orbit, by a Mars Ascent Vehicle, and advanced GNC techniques and sensors need to be traded, developed and validated.

Based on the preliminary results gained from Mars Next studies and Aurora technology activities (High Autonomy Rendezvous Docking HARVD, Lidar and vision-based cameras), a roadmap is proposed to develop a full GNC solution.

2.8.1 TDAs proposed for 2011

ESA Ref.	Activity Title	Budget 2011
E915-005MS	Sample canister capture mechanism parabolic flight test	150

Sample canister capture mechanism
The breadboard of the sample canister capture mechanism, to be developed in a preceding activity (CG50), will undergo parabolic flight testing in the frame of the proposed 2011 activity (E915-005MS). Once the design is validated, a following activity will develop the mechanism to full engineering model level.

2.8.2 TDAs planned for 2012-2014

Over the next years the selected sensors will be developed at EM level and the roadmap then foresees a Proof-of-Concept testing of the integrated GNC system on dynamic test benches developed in running studies (national programmes and Aurora HARVD).

In parallel to the GNC and sensor suite, the sample capture mechanism will be further developed providing inputs to the above activities. See Figure 6 for a roadmap of activities for rendezvous and capture for 2012-2014.

Relevance to the Robotic Exploration Programme and other ESA programmes

The development of autonomous Rendezvous is an essential enabling technology which will serve the future ESA planetary and robotic exploration programmes. European capabilities have been well recognised by US partners during ATV development and qualification programme, and it is essential to further develop these capabilities in the area of far Earth environment and autonomy, canister capture and miniaturisation.

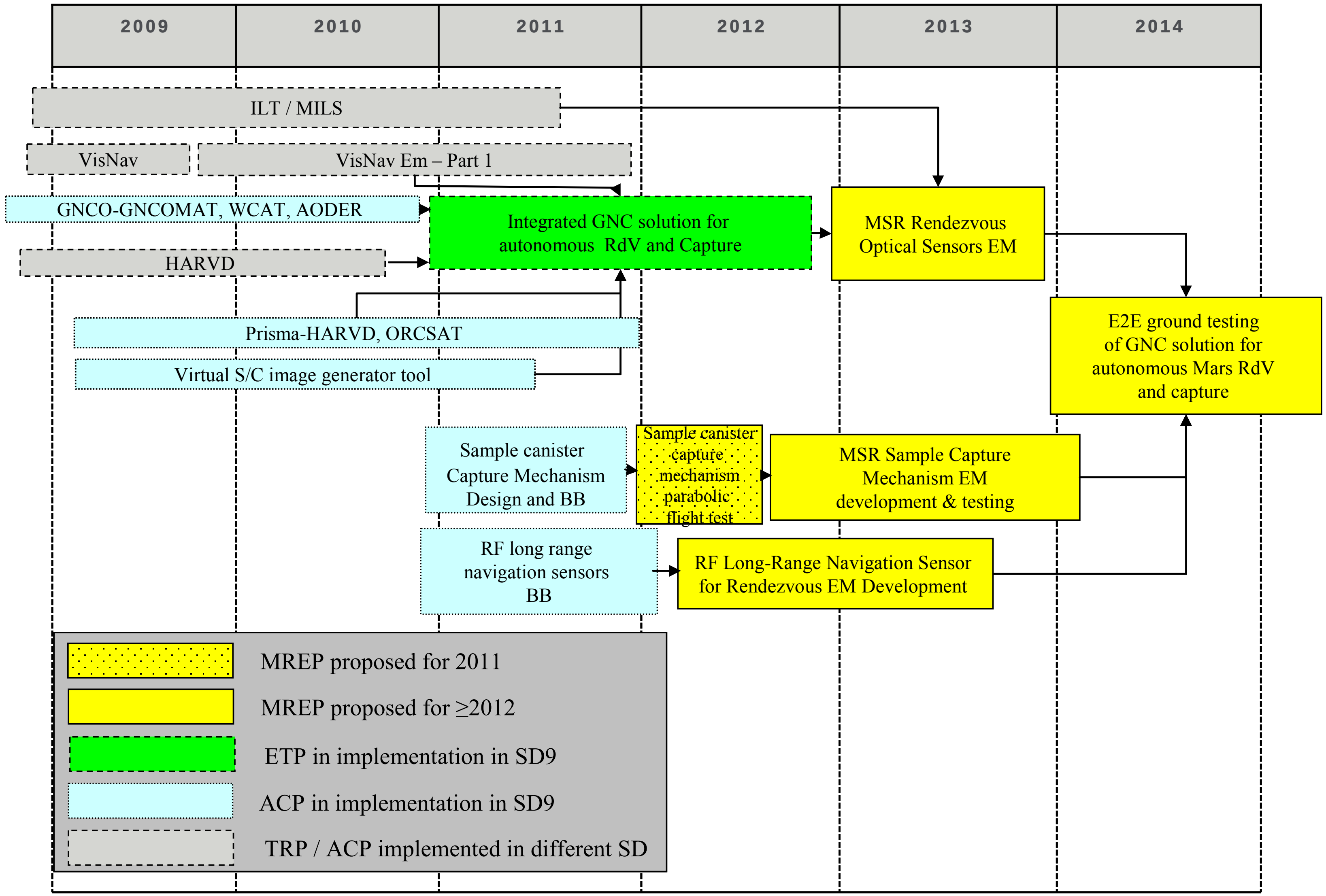


Figure 6: Technology Roadmap for Autonomous Rendezvous and Capture

2.9 Earth Re-entry Capsule for MSR

Objective: Development of technologies to enable the safe Earth re-entry and landing of a sample return capsule.

The Earth Re-entry Capsule (ERC) of an MSR mission would enter the atmosphere at speeds of around 12km/s resulting in extremely high heat fluxes on the thermal protection system (TPS) of the capsule. New ablative materials need to be developed to withstand such heat fluxes.

In addition, due to the planetary protection requirements, a hard landing is envisaged for this mission element (a soft-landing system cannot be made reliable enough). This requires the further development of extremely lightweight crushable materials to absorb the shock load on the sample canister at landing.

2.9.1 TDAs proposed for 2011

ESA Ref.	Activity Title	Budget 2011
E921-002PA	Delta-development of TPS for high heat loads	1000
T319-036MC	Design of a crushable TPS for the ERC	370
T920-002QT	Material development for a crushable TPS for the ERC	250

A delta-development (E921-002PA) of the new European ablative material developed within the frame of a previous TRP activity is required to characterise and pre-qualify this material to withstand the conditions expected for the MSR mission.

For the crushable TPS development, two activities (T319-036MC and T920-002QT) are planned to run in parallel looking at the overall design of the crushable structure as well as specific material developments.

2.9.2 TDAs planned for 2012-2014

The technology plan for 2012 onwards for the ERC includes an activity to investigate the use of the GPS/Galileo navigation system to guide the accurate release of the ERC from the carrier towards the Earth in order to enable an accurate landing and quick and efficient recovery of the sample container when it arrives back to the Earth. See Figure 7 for a roadmap of activities planned for 2012-2014 in the area of Earth Re-entry Capsule.

Relevance to the Robotic Exploration Programme and other ESA programmes

The development of crushable structures has applications in planetary lander missions in general whilst the TPS materials are relevant to all sample return missions from asteroids or other planetary bodies.

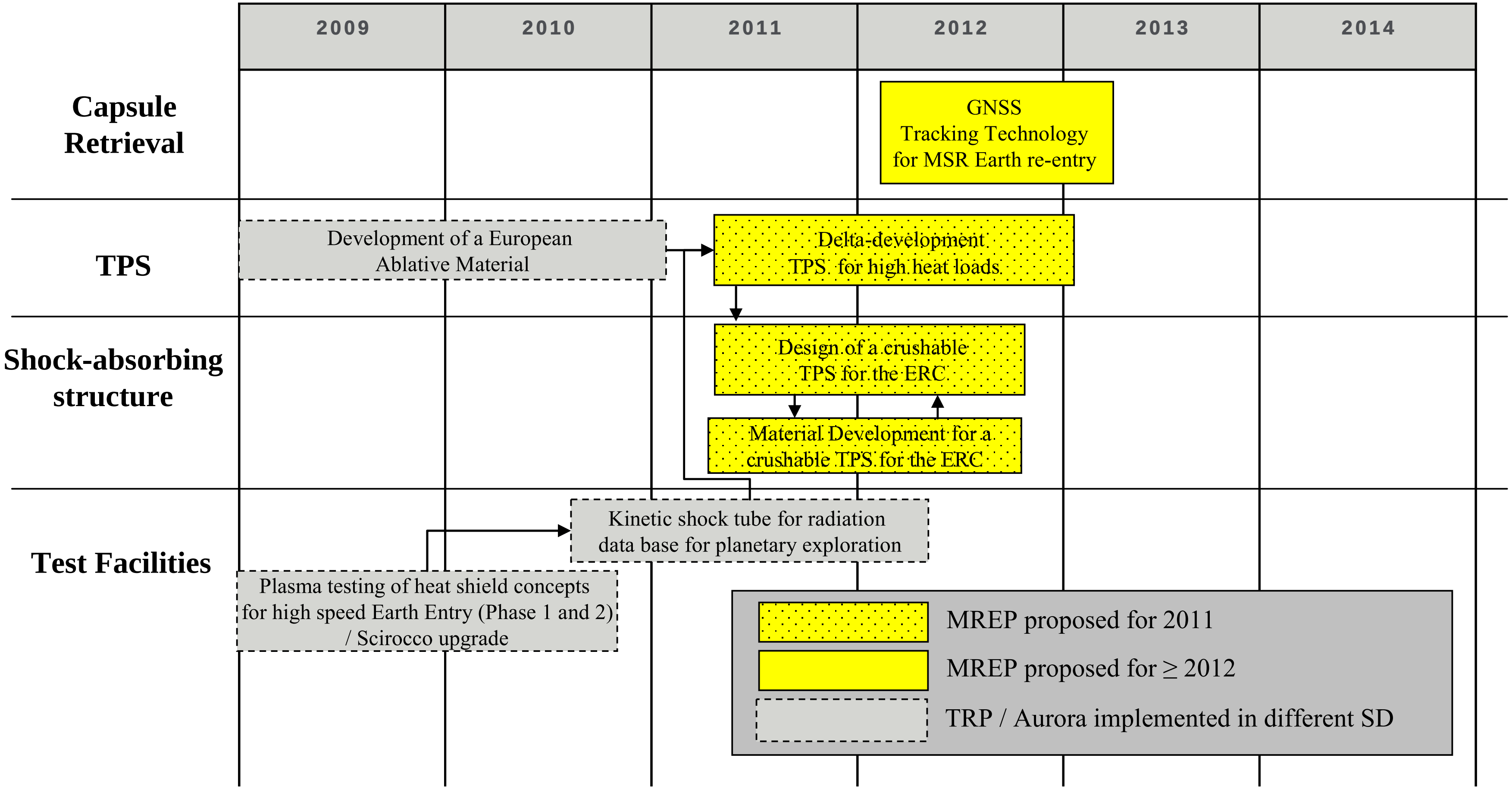


Figure 7: Technology Roadmap for Earth Re-Entry Capsule for MSR

2.10 Long-term technology developments

2.10.1 Nuclear Power Systems

Objective: To develop a Radioisotope Heating Unit (RHU) and a Radioisotope Power Source (RPS) in support of all exploration missions (e.g., Mars Sample Return mission).

Photovoltaic cells are well established as the appropriate power source for most space missions. For long duration flights that cannot rely on harnessing the external power of the Sun, and for efficient operations during night, electrochemical energy storage and chemical fuels have too low energy densities to provide useful amounts of energy. Nuclear processes, on the other hand can provide extremely high energy densities per unit mass and for this reason nuclear power sources are the only credible alternative to solar arrays for the long term generation of power in space.

The simplest Nuclear Power System (NPS) used in space is a Radioisotope Heater Unit (RHU). This device contains a modest amount of nuclear material (<100 g), which generates heat directly *via* natural radioactive decay. These units are required to maintain thermal control on missions to the outer solar systems and particularly on Landers which must operate over extended periods on a surface through many day/night cycles. Additionally, whilst RHUs do not generate electricity they do provide significant power savings by removing the need for electrical heaters.

A second application of a NPS is a Radioisotope Power Source (RPS) which transforms the heat generated by radioactive decay into electrical power by using a conversion technique. The most common type of such a unit is the RTG (Radioisotope Thermoelectric Generator) in which heat is turned directly into electricity, *via* the thermoelectric or Seebeck effect. Such devices typically contain a few kg of nuclear material, generate ~100W and are essential for the exploration of the outer solar system (*e.g.,* Ulysses, Cassini, New Horizons *etc*.). The use of Stirling engines is also considered for improving the conversion efficiency.

2.10.1.1 <u>Updated TDA proposed for 2011</u>

ESA Ref.	Activity Title	Budget 2011
E903-003EP	Nuclear Power Systems architecture study for safety management and fuel encapsulation prototype development.	1000

This TDA replaces the activity *E903-003EP Fuel Encapsulation Prototype development to TRL4* which was approved in the previous version of this TDP in November 2009. The TDA has been strengthened with respect to the assessment of the overall NPS system requirements and includes consideration of the end-end safety aspects of the production, transport, storage and launch of a European nuclear power source.

2.10.1.2 TDAs planned for 2012-2014

See Figure 8 for a roadmap of activities planned for 2012-2014 in the area of Nuclear Power Systems.

Relevance to the Robotic Exploration Programme and other ESA programmes
The development of a viable nuclear heating unit and electrical power source are essential enabling technologies which will define the future ESA planetary and robotic exploration programmes. To meet the prescribed goals of these programmes, both RHUs and RPSs will be required. RHUs are currently needed for Exomars, but will be procured from USA or Russia, It is mandatory that Europe develop its own capability.

Expected use of Nuclear Power Systems
Assuming successful implementation of the NPS program, the first RPS flight hardware could be available for a 2020 mission. Both RHUs and NPSs are seen as the key enabling technologies for the Robotic Exploration Programmes and would be used extensively.

On a longer term, these developments pave the way for nuclear propulsion development, should this technology be identified as necessary for future Human or Robotic exploration.

Benefits for ESA
The outcome of this activity will have a critical impact on the ESA planetary and robotic exploration programme and in particular the robotic exploration of the outer solar system and Mars. As such, it should be considered a strategic European enabling technology which will provide the Agency with significant flexibility in its choice of future missions and in the types of International collaborations it engages in..

2.10.2 Propulsion

Objective: The development of a high thrust apogee engine for future robotic exploration missions.

Orbit insertion manoeuvres are time critical and the delta V requirements are higher than the theoretical impulsive delta V. As such, burns need to start a significant distance from the planet and, as a result, significant work is done against the gravitational pull of the planetary body (Gravity losses).

Gravity losses on Mars Express accounted for around 15 % of the Delta V at orbit insertion. This mission used a classical apogee motor at 400N thrust level and an I_{sp} of 321s.

The current Exomars orbit insertion propulsion, if relying on a similar single 424N engine with the same I_{sp} of 321s, exhibits gravity losses of 25% (equating to around 240kg of propellant). Further, the Mars orbit insertion manoeuvre (MOI) requires an 85 minute burn. Other manoeuvres bring the total main engine burn time to nearly 160 minutes (excluding margins).

Past missions in the US, for example; the later Mariner craft (e.g. Mariner 9) and the Viking orbiters, used the now obsolete RS-2100 engine with a thrust level ~1384N and 306s I_{sp}. With this thrust level and considering the spacecraft masses, gravity losses were minimised at the time of these missions. Notably, the performance, though good at that point in time, is sub-optimal in the modern environment.

2.10.2.1 New TDAs proposed for 2011

None.

Note: A 2009 activity "Combustion chamber and injection technology development" (E919-011EP) which went to ITT in late 2009 has had the ITT re-issued in May 2010.

2.10.2.2 TDAs planned for 2012-2014

See roadmap in Figure 8 for follow-on activities in the area of a high-thrust propulsion engine development for 2011-2014.

Relevance to the Robotic Exploration Programme and other ESA programmes
A high thrust apogee engine (HTAE), 1000-1500N or similar, with current state-of-the-art performance (~320s Isp) would be of significant benefit for future exploration missions. Such an engine recovers half or more of the losses for an Exomars class mission while retaining acceleration levels similar to those seen on Mars Express. This increases the spacecraft dry mass available on orbit by a similar amount and hence the payload available for useful science. Further, such an approach leads to a relatively compact mass efficient propulsion system.

The Mars NEXT proposal involves an Earth escape phase in addition to the Mars orbit insertion. This is also subject to gravity losses and a similar figure could be expected. The mission currently baselines the same off the shelf apogee class motor as Exomars did.

A HTAE may also be used at a later date for the Mars Ascent Vehicle propulsion. The thrust level required at the Martian surface is 5.0-6.0 kN. No suitable engine in this class exists. The MSR phase B final design used a cluster of four USA (Mariner 9 derived) units needing full re-manufacture and re-qualification. The need could equally, and as cost effectively, be met by four new engines ~ 1.5 kN thrust.

This activity could take benefit from activities within the Future Launchers Preparatory Programme (FLPP).

Benefits for ESA
The application of such an engine is not limited to missions to Mars and could provide equally significant benefits to missions to any planetary body where an orbit insertion is required. Furthermore, in other applications, such engines could be a valuable asset, providing a large improvement in performance.

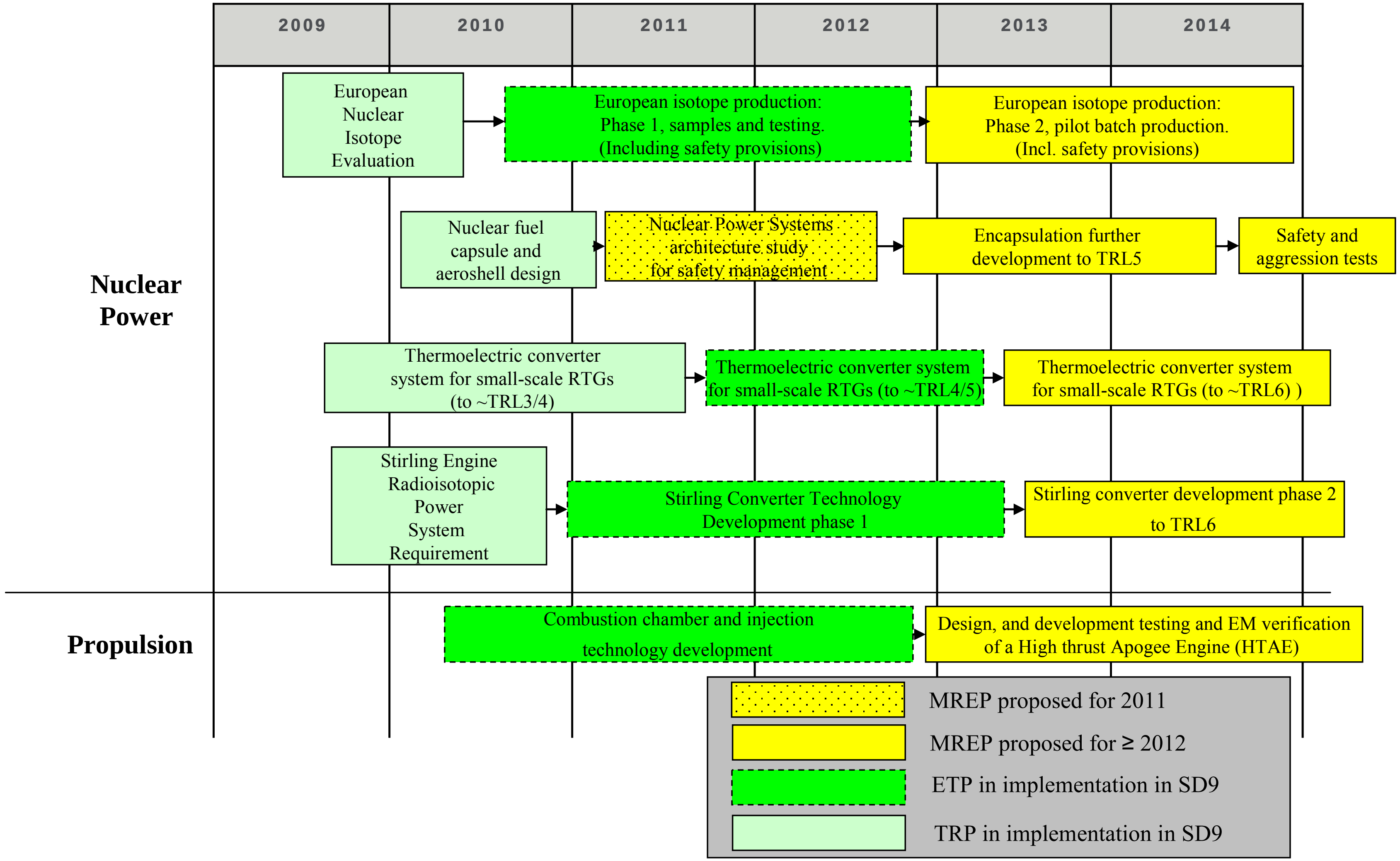


Figure 8: Technology Roadmap for Long Term Technology Developments

3 The Technology Plan

3.1 Elaboration of the Technology Plan

The Technology Plan has been defined using the ESA End-to-End process as described in ESA/IPC(2005)39, involving a Technology Network (TecNet) of technical and mission experts from ESA. The proposed technological activities are based on:

- The critical technology needs of a network science mission consisting of small landers potentially for the 2020 opportunity.
- The technology needs in medium-term preparation of a Mars Sample Return mission foreseen for the mid-2020's.
- An assessment of long-term mission-enabling technological needs.

For the practical implementation of ESA TDAs, years 2010-2011 are proposed for implementation, whereas the period 2012-2014 is provided for information only. It is planned to revisit this list on a regular basis and update the plan with the results of system studies and ongoing activities.

3.2 ESA Technology Development Activities: role of TRP and ETP

ESA technology activities in the framework of Robotic Exploration mainly rely on TRP and the ETP technology budgets.

The TRP budget is devoted to initial technology developments, leading to an experimental feasibility verification of critical functions or to a validation at breadboard level in laboratory environment (TRL 3). In case of components this might be extended e.g. radiation hardening, since otherwise a proof of feasibility is not possible.

The ETP is constituted of technology activities that are directly funded by the MREP programme. It will be used to fund robotic exploration-related activities at any TRL level. However, it focuses on TRL >3, building on earlier developments funded through TRP.

For ETP, the activities will be implemented so as to meet a geographical distribution reflecting the Participating States subscriptions. For both TRP/ETP funding, some changes in procurement policies are possible in the frame of the measures necessary to structurally recover georeturn deficits, e.g. by use of Special/Strategic Initiative.

3.3 Aurora Core Programme

As a consequence of the establishment of the MREP programme and the reorganisation of the responsibilities for Human and Robotic Exploration activities within the Directorates at ESA, some activities of the Aurora Core Programme have been transferred from Service Domain 3 (Human Spaceflight) to Service Domain 9 (Robotic Exploration). Table 3-3 lists the activities that have been transferred to SD9.

ESA Ref.	Activity Title	Remarks/status
CG50	Capture Control Dynamics Study	Redefined as "Sample Canister Capture Mechanism Design and Breadboard ".
CG80	RF Long Range Navigation Sensor Breadboard & Engineering Model Development	Rescoped for 300K for Spain.
CA10	On-Line Reconfiguration Control System and Avionics Technologies (ORCSAT)	Activity KO held at 01/09/2009
CG70	PRISMA-HARVD Experiment	Negotian meeting held. KO awaiting launch of Prisma mission.
CE60	Validation of Aerothermodynamics Experimental and Computational Tools for the Support of Future Mars Missions	Activity KO held in March 2009
CG10	GNC Maturation and Validation for Rendezvous in Elliptical Orbit (GNCOMAT)	Running since Q4 2008. CDR mid April 2010. End of study foreseen end 2010.
CG20	Automated Orbit Determination Techniques for Rendezvous (AODER)	Running since Q4 2008. CDR 17 April, end of activity end of 2010.
CG40	Worst Case & Safety Analysis Tools for Autonomous Rendezvous System	Running since Q2 2008. End of study foreseen end 2010.
CG60	Virtual Spacecraft Image Generator Tool	Started Q2 2009. End foreseen May 2011.
CK10	Bioburden and biodiversity evaluation in spacecraft facilities and lifetime test of rapid spore assay	End of study foreseen end 2010.
CK20	Extension of Dry Heat Sterilisation Process to High Temperature	End of study foreseen end 2010.
CK30	Development of a Complementary Low Temperature Sterilisation Method	End of study foreseen end 2010.
CK50	Definition of Functional Requirements for a MSR Biological Containment Facility	Completed in mid-2010
CR10	Mars Surface Sample Transfer / Manipulation	Kicked off 19 Jan 09. Expected end Dec 2010.

Table 3-3: Aurora Core Program activities transferred to SD9

All activities in Table 3-3 are running (*CG70 Prisma-HARVD Experiment* is ready but KO is awaiting the launch of the Prisma mission), except for the first two which are maintained, but have been refocused and updated to the needs of the MREP Programme. Title and budget changes are listed below:

Original Activity Title	**Original Budget**
CG50 Capture Control Dynamics Study	350K
New Activity Title	**New Budget**
CG50 Sample Canister Capture Mechanism Design and Breadboard	350K

Original Activity Title	**Original Budget**
CG80 RF Long Range Navigation Sensor Breadboard & Engineering Model Development	550K
New Activity Title	**New Budget**
CG80 RF Long Range Navigation Sensor Breadboard	300K

Note: Further details of these activities are given in Annex I and II of this TDP under the technology theme "Autonomous Rendezvous and Capture".

In addition to the activities mentioned above, a further 475 kEuros from the Aurora Core Programme earmarked for Austria has been transferred to SD9 to be implemented in 2010 (cf. ESA/PB-HME(2010)2). This will be used to fund the activity A915-002MS, as proposed in this TDP under the technology theme Sample Fetching Rover, Robotics and Mechanisms.

KEY TO TABLES

Each activity is given a programmatic reference, which will remain unchanged until completion. Additional planning elements associated with each of the activities are:

Programme:	Programme budget foreseen for the activity
Reference:	Unique ESA generated reference for TDA
Activity Title:	Title of the proposed TDA
Budget:	The total Contract Authorisation (CA) values are given in KEURO, at yearly economic conditions. The year for which the budget is intended is specified.
Procurement Policy (PP):	Procurement Types: C = Open Competitive Tender; (Ref. Article 5.1 ESA Contract Regulations) C(1)* = Activity restricted to non-prime contractors (incl. SMEs). C(2)* = A relevant participation (in terms of quality and quantity) of non-primes (incl. SMEs) is required. C(3)* = Activity restricted to SMEs & R&D Entities C(4)* = Activity subject to SME subcontracting clause C(R) = Competition is restricted to a few companies, indicated in the "Remarks" column; (Ref. Article 5.2 ESA Contract Regulations) DN/C = Direct Negotiation/Continuation; the contract will be awarded in continuation to an existing contract; (Ref. Article 6.1.C ESA Contract Regulations) DN/S = Direct Negotiation/Specialisation; the contract will be awarded by direct negotiation in implementation of a defined industrial policy or resulting from a sole supplier situation; (Ref. Articles 6.1.A,D,F ESA Contract Regulations) * See ESA/IPC(2001)29, Industry has been informed, through the EMITS "News", of the content of that document.
SW clause applicability:	Special approval is required for activities labelled: either *“Operational Software”* or *“Open Source Code”*, for which the Clauses/sub-clauses 42.8 and 42.9 (“Operational Software”) and 42.10 and 42.11 (“Open Source Code”) of the General Clauses and Conditions for ESA Contracts (ESA/C/290, rev.6), respectively, are applicable.
Objectives:	The aims of the proposed TDA.
Description:	Overview of the work to be performed.
Deliverables:	Provides a short description of the tangible outcome e.g. breadboard, demonstrator, S/W, test data. **A final report is standard for every activity.**
Current TRL:	Describes the current Technology Readiness Level of the product that is going to be developed in this activity.
Target TRL:	The TRL expected for the product at the **end of the activity**. For equipments TRP usually concludes with TRL 3, ETP at TRL 5/6. However in the case of components target TRL in

	TRP could be higher. It is also understood that TRLs do not apply to S/W and tools. For these cases description of SW quality, i.e.: architecture, beta version, prototype, or full operational, achieved at the end of the activity.
Application Need/Date:	Describes the required TRL and date for the technology development of which the respective activity is part of on the base of the maturity required by the application. The general rule is that a requirement specifies the need date for a product. For equipments/payloads this is in general TRL **5/6, -** the level generally required for **Phase B of a project.** The exceptions are components, where TRL 8 (flight readiness) should be achieved. For S/W and tools separate readiness levels are defined below
Technology Readiness Level	TRL1 - Basic principles observed and reported TRL2 - Technology concept and/or application formulated TRL3 - Analytical and experimental critical function and/or characteristic proof-of-concept TRL4 - Component and/or breadboard validation in laboratory environment TRL5 - Component and/or breadboard validation in relevant environment TRL6 - System/subsystem model or prototype demonstration in a relevant environment (ground or space) TRL7 - System prototype demonstration in a space environment TRL8 - Actual system completed and "flight qualified" through test and demonstration (ground or space) TRL9 - Actual system "flight proven" through successful mission operations
Technology Readiness Levels for S/W and tools	Algorithm: Single algorithms are implemented and tested to allow their characterisation and feasibility demonstration. Prototype: A subset of the overall functionality is implemented to allow e.g. the demonstration of performance. Beta Version: Implementation of all the software (software tool) functionality is complete. Verification & Validation process is partially completed (or completed for only a subset of the functionality). S/W Release: Verification and Validation process is complete for the intended scope. The software (software tool) can be used in an operational context.
Application Mission:	Possible mission application/follow-on.
Contract Duration:	Duration of the activity in months.
Reference to ESTER:	Identifies the related requirement in the ESTER database
Consistency with Harmonisation Roadmap and conclusion:	Identifies the related Harmonisation Roadmap Requirement

Annex 0:
Budget summary tables

Application/Mission	Progr.	2009	2010	2011	Total for impl.	2012	Total
9-01 Network Science Mission							
	ETP (13)		1750	3000	4750	6200	10950
	TRP (10)	600	1950	600	3150	850	4000
Total		**600**	**3700**	**3600**	**7900**	**7050**	**14950**
9-02 Entry, Descent and Landing for MSR							
	ETP (8)		850		850	4500	5350
	TRP (3)	300		200	500	800	1300
Total		**300**	**850**	**200**	**1350**	**5300**	**6650**
9-03 Sample Fetching Rover, Robotics and Mechanisms							
	ETP (4)		550		550	850	1400
	TRP (6)		400	1200	1600	1050	2650
Total			**950**	**1200**	**2150**	**1900**	**4050**
9-04 Planetary Protection Technologies for MSR							
	GSP (2)				0	400	400
	ETP (5)		1500		1500	3400	4900
	TRP (1)	300			300		300
Total		**300**	**1500**		**1800**	**3800**	**5600**
9-05 Autonomous Rendezvous and Capture							
	ETP (6)		750	150	900	2300	3200
Total			**750**	**150**	**900**	**2300**	**3200**
9-06 Earth Re-entry Capsule for MSR							
	ETP (2)			1000	1000	100	1100
	TRP (2)			620	620		620
Total				**1620**	**1620**	**100**	**1720**
9-07 Long term technologies - Nuclear Power							
	ETP (9)		3200	1700	4900	2700	7600
	TRP (6)	1500	200		1700		1700
Total		**1500**	**3400**	**1700**	**6600**	**2700**	**9300**
9-08 Long term technologies - Propulsion							
	ETP (2)		2000		2000	5000	7000
Total			**2000**		**2000**	**5000**	**7000**
Grand Total TRP		**2700**	**2550**	**2620**	**7870**	**2700**	**10570**
Grand Total ETP			**10600**	**5850**	**16450**	**25050**	**41500**
Grand Total ESA		**2700**	**13150**	**8470**	**24320**	**28150**	**52470**

Annex I:
List of ESA Robotic Exploration Technology Development Activities

Summary of all new activities seeking approval for 2011

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget 2009	Budget 2010	Budget 2011	Budget 2012	PP	C'try	SW Clause applicab.	Remarks
Network Science Mission											
TRP	N/A	T921-001QE	Adaptation of Aerogel Materials for thermal insulation	0	0	300	0	C(1)		N/A	
ETP	IPC	E920-001MS	Airbags for small landers - Breadboard and Test	0	0	2000	0	C(2)		N/A	
ETP	IPC	E906-001ET	Compact dual UHF/X-band Proximity-1 Communication EM	0	0	1000	0	C		N/A	
TRP	N/A	T911-001GR	Simulation tool for breakup/burnup analysis of Mars orbiters	0	0	300	0	C		Operational Software	
Entry, Descent and Landing for MSR											
TRP	N/A	T905-008EC	Sensor Data Fusion for Hazard Mapping and Piloting	0	0	200	0	C		N/A	
Sample Fetching Rover, Robotics and Mechanisms											
TRP	IPC	T913-003MM	DExtrous LIghtweight Arm for exploratioN (DELIAN)	0	0	800	0	C		N/A	
TRP	N/A	T913-004MM	Surface-Wheel Interaction modelling for Faster Traverse (SWIFT)	0	0	400	0	C(1)		N/A	
ACP	N/A	A915-002MS	Mechanisms technologies that operate at very low temperatures	0	0	475	0	C(1)		N/A	Brought forward from 2012 and to be funded by ACP (on the assumption that Austrian geo-return for MREP is fulfilled before placing this activity, otherwise to be funded by ETP)
Autonomous Rendezvous and Capture											
ETP	N/A	E915-005MS	Sample canister capture mechanism parabolic flight test	0	0	150	0	C		N/A	
Earth Re-entry Capsule for MSR											
TRP	N/A	T319-036MC	Design of a crushable TPS for the ERC	0	0	370	0	C		N/A	
TRP	N/A	T920-002QT	Material development for a crushable TPS for the ERC	0	0	250	0	C(2)		N/A	
ETP	IPC	E921-002PA	Delta-development of TPS for high heat loads	0	0	1000	0	C(2)		N/A	
Long term technologies - Nuclear Power											

ETP	IPC	E903-003EP	Nuclear Power Systems architecture study for safety management and fuel encapsulation prototype development.	0	0	1000	0	C(2)		N/A	Formerly "E903-003EP Fuel encapsulation prototype development to TRL4", 800 kEuros.
Total of all 2011 activities				**0**	**0**	**8245**	**0**				

Removed activities

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget				PP	C'try	SW Clause applicab.	Remarks
				2009	2010	2011	2012				
Network Science Mission											
TRP	Y2008	T305-032EC	Planetary Micro Navigator Definition Study	350	0	0	0	C		N/A	
Long term technologies - Nuclear Power											
ETP	Y2009	E903-003EP	Fuel encapsulation prototype development to TRL4	0	800	0	0	C(2)		N/A	

All activities (2009 onwards) in this Technology Development Plan listed by technology theme.

Network Science Mission

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget				PP	C'try	SW Clause applicab.	Remarks
				2009	2010	2011	2012				
TRP	Y2008	T305-031EC	Robust Autonomous Aerobraking Strategies	300	0	0	0	C	Fr	N/A	Running activity with Astrium (F). Parallel contract to T305-031EC-B.
TRP	Y2008	T305-031EC-B	Robust Autonomous Aerobraking Strategies	300	0	0	0	C	Fr	N/A	Running activity with TAS (F). Parallel contract to T305-031EC.
ETP	N/A	E905-001EC	Aerobraking Flight Representative Demonstrator	0	0	0	350			N/A	
TRP	N/A	T921-001QE	Adaptation of Aerogel Materials for thermal insulation	0	0	300	0	C(1)		N/A	
ETP	Y2009	E901-001ED	Extremely low power timer board EM for landers	0	300	0	0	C(1)		N/A	
ETP	Y2009	E901-002ED	Tailored On-Board Computer EM for planetary landers	0	700	0	0	C		Operational Software	
TRP	Y2009	T918-001MP	Subsonic Parachute Trade-Off and Testing	0	500	0	0	C(2)		N/A	
ETP	Y2009	E905-002EC	EDLS GNC Optimisation and Technology Specification for small Mars landers	0	250	0	0	C(1)		N/A	
TRP	Y2009	T905-003EC	Assessment and breadboarding of a planetary Altimeter	0	900	0	0	C(1)		N/A	
ETP	N/A	E905-004EC	Simulation and Validation Platform for small Mars landers EDLS	0	0	0	200			Operational SW	
ETP	N/A	E905-005EC	Ground Testing of the EDLS Navigation Chain for small Mars landers	0	0	0	0			N/A	Proposed for 2013 (450k)
ETP	N/A	E915-001MS	Lowering system Breadboard for Mars landers	0	0	0	500			N/A	
ETP	N/A	E919-001MP	Retro Rockets for Mars landing	0	0	0	4000			N/A	
TRP	Y2009	T319-035MC	Airbags for small landers - Design	0	300	0	0	C(1)		N/A	
ETP	IPC	E920-001MS	Airbags for small landers - Breadboard and Test	0	0	2000	0	C(2)		N/A	
ETP	N/A	E903-011EP	Adaptation of terrestrial solar cells for Mars surface operations	0	0	0	750			N/A	
ETP	N/A	E903-012EP	Solar Power Regulator Breadboard for Mars Surface Missions	0	0	0	400			N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget				PP	C'try	SW Clause applicab.	Remarks
				2009	2010	2011	2012				
ETP	Y2009	E903-013EP	Development of a low temperature Lithium ion battery and survivability tests	0	500	0	0	C(1)		N/A	
TRP	Y2008	T306-044ET	Lander Compact Dual UHF/X-band Frequency Communication Package Study	0	250	0	0	C(2)		N/A	
ETP	IPC	E906-001ET	Compact dual UHF/X-band Proximity-1 Communication EM	0	0	1000	0	C		N/A	
TRP	N/A	T306-043ET	Orbiter Software Defined Radio Proximity-1 Link Communications package- implementation and demonstration	0	0	0	300			Operational SW	
TRP	N/A	T909-001HS	Multi-Agent Systems Simulation Tool for Network Lander Mission Operations	0	0	0	550			N/A	
TRP	N/A	T911-001GR	Simulation tool for breakup/burnup analysis of Mars orbiters	0	0	300	0	C		Operational Software	
Total Network Science Mission				**600**	**3700**	**3600**	**7050**				

Entry, Descent and Landing for MSR

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget				PP	C'try	SW Clause applicab.	Remarks
				2009	2010	2011	2012				
TRP	Y2008	T304-038EE	Maintenance of Martian Atmospheric circulation models (large scale, mesoscale, upper atmosphere) and continued validation of Martian Climate database	300	0	0	0	DN/C	Fr	N/A	LMD (F), OU (UK), IAA (E)
ETP	Y2009	E905-006EC	End to end Optimisation and GNC design for High Precision Landing on Mars	0	500	0	0	C		N/A	
TRP	IPC	T905-014EC	European IMU breadboard	0	0	0	800			N/A	
ETP	N/A	E905-015EC	European IMU EM	0	0	0	0			N/A	Proposed for 2013 (2000k)
ETP	N/A	E905-016EC	Accelerometer component to TRL5	0	0	0	1500			N/A	
ETP	Y2009	E905-007EC	Camera-aided Mars Landing and Rendezvous navigation system	0	350	0	0	C		N/A	
ETP	N/A	E916-001MM	MSR Precision landing navigation sensor adaptation - Engineering Model	0	0	0	1000			N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget				PP	C'try	SW Clause applicab.	Remarks
				2009	2010	2011	2012				
TRP	N/A	T905-008EC	Sensor Data Fusion for Hazard Mapping and Piloting	0	0	200	0	C		N/A	
ETP	N/A	E905-009EC	Ground Testing of Precision Landing navigation system	0	0	0	0			N/A	Proposed for 2014 (500k)
ETP	N/A	E919-002MP	Valve development for a throttleable monopropellant engine for soft landing	0	0	0	2000			N/A	
ETP	N/A	E919-003MP	Design, development and testing of a throttleable monopropellant engine for soft landing	0	0	0	0			N/A	Proposed for 2014 (4000k)
Total Entry, Descent and Landing for MSR				**300**	**850**	**200**	**5300**				

Sample Fetching Rover, Robotics and Mechanisms

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget				PP	C'try	SW Clause applicab.	Remarks
				2009	2010	2011	2012				
TRP	Y2007	T309-002HS	Innovative Rover Operations Concepts- Autonomous Planning	0	400	0	0	C		Operational SW	
ETP	Y2009	E913-001MM	SPAring Robotics Technologies for Autonomous Navigation (SPARTAN)	0	250	0	0	C		Operational Software	
ETP	Y2009	E913-002MM	Study of a Sample Fetching Rover for MSR	0	300	0	0	C		N/A	
TRP	IPC	T913-003MM	DExtrous LIghtweight Arm for exploratioN (DELIAN)	0	0	800	0	C		N/A	
TRP	N/A	T913-004MM	Surface-Wheel Interaction modelling for Faster Traverse (SWIFT)	0	0	400	0	C(1)		N/A	
ACP	N/A	A915-002MS	Mechanisms technologies that operate at very low temperatures	0	0	475	0	C(1)		N/A	Brought forward from 2012 and to be funded by ACP (on the assumption that Austrian geo-return for MREP is fulfilled before placing this activity, otherwise to be funded by ETP)
TRP	N/A	T924-001QT	Zero contamination drill bits assessment and tests	0	0	0	200			N/A	
ETP	N/A	E915-003MS	Ultrasonic Drill Tool (UDT) - Engineering Model	0	0	0	500			N/A	
ETP	N/A	E915-004MS	Ultrasonic Rock Abrasion Tool (RAT) - Engineering Model	0	0	0	350			N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget				PP	C'try	SW Clause applicab.	Remarks
				2009	2010	2011	2012				
TRP	N/A	T924-002QT	High specific stiffness metallic materials	0	0	0	500			N/A	
TRP	N/A	T924-003QE	Martian Environmental Materials Effects	0	0	0	350			N/A	
Total Sample Fetching Rover, Robotics and Mechanisms				**0**	**950**	**1675**	**1900**				

Planetary Protection Technologies for MSR

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget				PP	C'try	SW Clause applicab.	Remarks
				2009	2010	2011	2012				
TRP	Y2008	T314-033MM	Evaluation of Encapsulated Bioburden on Flight Hardware	300	0	0	0	C(2)	Germany	N/A	Running activity with CMSM (D)
ETP	Y2009	E914-001MM	MSR biocontainment system sealing and monitoring technologies - development and validation	0	1500	0	0	C(2)		N/A	
ETP	N/A	E914-002MM	MSR biocontainment system - breadboard and validation	0	0	0	2000			N/A	
ETP	N/A	E914-003MM	MSR complete biocontainment flight system development and test	0	0	0	0			N/A	Proposed for 2014 (TBDk)
GSP	N/A	G914-004SY	System study of Mars spacecraft compatibility with a terminal decontamination process	0	0	0	200			N/A	
GSP	N/A	G909-002SY	System study of an efficient Mars sample recovery strategy after return to Earth	0	0	0	200			N/A	
ETP	N/A	E914-005MM	Double walled isolators for MSR Sample Receiving facility	0	0	0	1000			N/A	
ETP	N/A	E914-006MM	Micro remote manipulation systems for MSR Sample Receiving Facility	0	0	0	400			N/A	
Total Planetary Protection Technologies for MSR				**300**	**1500**	**0**	**3800**				

Autonomous Rendezvous and Capture

Prog.	IPC	ESA Ref.	Activity Title	Budget	PP	C'try	SW Clause	Remarks

				2009	2010	2011	2012				
ETP	Y2009	E905-010EC	Integrated GNC solution for Autonomous Mars Rendezvous and Capture	0	750	0	0	C		N/A	
ETP	N/A	E905-011EC	MSR Rendezvous Optical Sensors EM development	0	0	0	800			N/A	
ACP	Y2007	CG80	RF Long Range Navigation Sensor Breadboard	0	300	0	0	C	Spain	N/A	Previous ACP activity with geo-return constraints. Rescoped for 300K for Spain.
ETP	N/A	E906-002ET	RF Long-Range Navigation Sensor for Rendezvous EM Development	0	0	0	1000			N/A	
ETP	N/A	E905-012EC	End to end ground testing of GNC solution for Autonomous Mars Rendezvous and Capture	0	0	0	0	C		N/A	Proposed for 2013 (800k)
ACP	Y2007	CG50	Sample Canister Capture Mechanism Design and Breadboard	0	350	0	0	C	Italy, Belgium	N/A	Formerly ACP "Capture Control Dynamics Study", with geo-return constraints.
ETP	N/A	E915-005MS	Sample canister capture mechanism parabolic flight test	0	0	150	0	C		N/A	
ETP	N/A	E915-006MS	MSR Sample capture mechanism EM development and testing	0	0	0	500			N/A	
Total Autonomous Rendezvous and Capture				**0**	**1400**	**150**	**2300**				

Earth Re-entry Capsule for MSR

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget				PP	C'try	SW Clause applicab.	Remarks
				2009	2010	2011	2012				
ETP	N/A	E905-013EC	GNSS Tracking Technology for MSR Earth re-entry	0	0	0	100			N/A	
TRP	N/A	T319-036MC	Design of a crushable TPS for the ERC	0	0	370	0	C		N/A	
TRP	N/A	T920-002QT	Material development for a crushable TPS for the ERC	0	0	250	0	C(2)		N/A	
ETP	IPC	E921-002PA	Delta-development of TPS for high heat loads	0	0	1000	0	C(2)		N/A	
Total Earth Re-entry Capsule for MSR				**0**	**0**	**1620**	**100**				

Long term technologies - Nuclear Power

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget				PP	C'try	SW Clause applicab.	Remarks
				2009	2010	2011	2012				
TRP	Y2008	T303-039EP	European Nuclear Isotope Evaluation, Selection and Feasibility Study	150	0	0	0	C(1)		N/A	Completed activity with SEA (UK). Parallel contract to T303-039EP-B
TRP	Y2008	T303-039EP-B	European Nuclear Isotope Evaluation, Selection and Feasibility Study	150	0	0	0	C(1)		N/A	Completed activity with Areva (F). Parallel contract to T303-039EP
ETP	Y2009	E903-001EP	European isotope production: Phase 1, samples and testing. (Including safety provisions)	0	1200	0	0	C(1)		N/A	
ETP	N/A	E903-002EP	European isotope production: Phase 2, pilot batch production. (Including safety provisions)	0	0	0	1500			N/A	
TRP	Y2009	T303-040EP	Nuclear fuel capsule and aeroshell design study	0	200	0	0	C(2)		N/A	
ETP	IPC	E903-003EP	Nuclear Power Systems architecture study for safety management and fuel encapsulation prototype development.	0	0	1000	0	C(2)		N/A	Formerly "E903-003EP Fuel encapsulation prototype development to TRL4", 800 kEuros.
ETP	N/A	E903-004EP	Encapsulation further development to TRL5	0	0	0	1200			N/A	
ETP	N/A	E903-005EP	Safety and aggression tests & demonstrations	0	0	0	0			N/A	Proposed for 2013 (2000k)
TRP	Y2009	T903-006EP	Thermoelectric converter system for small-scale RTGs (to ~TRL3/4)	550	0	0	0	C	UK	N/A	Running activity with Univ. Leicester (UK). Parallel contract to T903-006EP-B.
TRP	Y2009	T903-006EP-B	Thermoelectric converter system for small-scale RTGs (to ~TRL3/4)	550	0	0	0	C	France	N/A	Running activity with Areva (F). Parallel contract to T903-006EP.
ETP	Y2009	E903-007EP	Thermoelectric converter system for small-scale RTGs (to ~TRL4/5)	0	0	700	0	C(1)		N/A	
ETP	N/A	E903-008EP	Thermoelectric converter system for small-scale RTGs (to ~TRL6)	0	0	0	0			N/A	Proposed for 2014 (3000k)
TRP	Y2008	T203-006EP	Stirling Engine Radioisotopic Power System Requirement Study	100	0	0	0	C	UK	N/A	Running activity with SEA (UK)
ETP	Y2009	E903-009EP	Stirling Converter Technology Development phase 1	0	2000	0	0	C		N/A	
ETP	N/A	E903-010EP	Stirling converter development phase 2 to TRL6	0	0	0	0			N/A	Proposed for 2013 (3300k)
Total Long term technologies - Nuclear Power				**1500**	**3400**	**1700**	**2700**				

Long term technologies - Propulsion

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget				PP	C'try	SW Clause applicab.	Remarks
				2009	2010	2011	2012				
ETP	Y2009	E919-011EP	Combustion chamber and injection technology development	0	2000	0	0	C	UK, Ireland	N/A	Under Special Initiative to Ireland and UK (ETP < 800kEuros)
ETP	N/A	E919-012MP	Design, and development testing and EM verification of a High thrust Apogee Engine (HTAE)	0	0	0	5000			N/A	
Total Long term technologies - Propulsion				**0**	**2000**	**0**	**5000**				

Annex II:
Detailed Descriptions of ESA Robotic Exploration Technology Development Activities

Network Science Mission

Robust Autonomous Aerobraking Strategies			
Programme:	TRP	**Reference:**	T305-031EC
Title:	Robust Autonomous Aerobraking Strategies		
Total Budget:	300		

Objectives

The main objectives of the activity are:
1 - To study various autonomous aerobraking strategies and to identify the associated system requirements and constraints down to AOCS level, including equipments such as accelerometer.
2 - To study robust AOCS safe mode (triggered before and during the atmospheric pass) and aerobraking contingency mode (protection against excessive Solar Array temperatures).
3 - To develop, assess the robustness performance and validate the most promising autonomous aerobraking solutions, including AOCS safe mode and aerobraking contingency mode, on a validated high-fidelity end-to-end simulator including interactions between spacecraft and atmosphere through thermal loads.
4 - To assess the benefits of the proposed solutions from an operational point of view.
5 - To provide complementary inputs to the high accuracy European accelerometer development to be initiated in 2009 (Generic Technology Service Domain 7).

Description

This activity shall include the following main tasks:
- Analysis of the mission and the main system engineering tasks, including requirements and constraints; analysis and trade-off of candidate autonomous aerobraking strategies, leading to the selection of the most promising ones and algorithms satisfying functional, performance and operational requirements. The selected solutions shall allow a step-wise performance assessment of various automation levels of the aerobraking process. The analysis will include, but will not be limited to, the share between on-board autonomy and ground involvement, the specification of aerobraking phase operational sequence, such as attitude orientation, delta-v manoeuvres, the spacecraft pointing requirements, the sensors and actuators performance characteristics, the required on-board processing capability, the required contingency modes, etc.
- Using a reference mission, e.g. Mars NEXT, the detailed design of the selected autonomous aerobraking algorithms will be performed, as well as AOCS safe mode and aerobraking contingency mode.
- The performance and robustness of the most promising autonomous aerobraking strategies will be assessed using a validated high fidelity simulation environment. Monte Carlo test campaign will be carried out to ensure that the spacecraft achieves the mission requirements for nominal and contingency (i.e. safe mode triggering) scenarios.
- A profiling of the most promising autonomous aerobraking algorithms will be conducted in order to assess the real-time requirements and onboard processing needs in view of their implementation on a representative flight processor at a later stage.

Deliverables

ESA will be provided with validated autonomous aerobraking strategies and algorithms as well as with a high fidelity aerobraking AOCS simulator. Full technical documentations will be delivered, covering specifications, architecture, algorithms, modelling, simulation test results and profiling analysis results. All software developed during the activity will be delivered (source and binary codes).

Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2011

Application Mission:	Network Science, MSR	**Contract Duration:**	12
S/W Clause:	N/A	**Reference to ESTER**	"Aero-braking"

Consistency with Harmonisation Roadmap and conclusion:

N/A

Robust Autonomous Aerobraking Strategies			
Programme:	TRP	**Reference:**	T305-031EC-B
Title:	Robust Autonomous Aerobraking Strategies		
Total Budget:	300		

Objectives

The main objectives of the activity are:
1 - To study various autonomous aerobraking strategies and to identify the associated system requirements and constraints down to AOCS level, including equipments such as accelerometer.
2 - To study robust AOCS safe mode (triggered before and during the atmospheric pass) and aerobraking contingency mode

(protection against excessive Solar Array temperatures). 3 - To develop, assess the robustness performance and validate the most promising autonomous aerobraking solutions, including AOCS safe mode and aerobraking contingency mode, on a validated high-fidelity end-to-end simulator including interactions between spacecraft and atmosphere through thermal loads. 4 - To assess the benefits of the proposed solutions from an operational point of view. 5 - To provide complementary inputs to the high accuracy European accelerometer development to be initiated in 2009 (Generic Technology Service Domain 7).
Description
This activity shall include the following main tasks: - Analysis of the mission and the main system engineering tasks, including requirements and constraints; analysis and trade-off of candidate autonomous aerobraking strategies, leading to the selection of the most promising ones and algorithms satisfying functional, performance and operational requirements. The selected solutions shall allow a step-wise performance assessment of various automation levels of the aerobraking process. The analysis will include, but will not be limited to, the share between on-board autonomy and ground involvement, the specification of aerobraking phase operational sequence, such as attitude orientation, delta-v manoeuvres, the spacecraft pointing requirements, the sensors and actuators performance characteristics, the required on-board processing capability, the required contingency modes, etc. - Using a reference mission, e.g. Mars NEXT, the detailed design of the selected autonomous aerobraking algorithms will be performed, as well as AOCS safe mode and aerobraking contingency mode. - The performance and robustness of the most promising autonomous aerobraking strategies will be assessed using a validated high fidelity simulation environment. Monte Carlo test campaign will be carried out to ensure that the spacecraft achieves the mission requirements for nominal and contingency (i.e. safe mode triggering) scenarios. - A profiling of the most promising autonomous aerobraking algorithms will be conducted in order to assess the real-time requirements and onboard processing needs in view of their implementation on a representative flight processor at a later stage.
Deliverables
ESA will be provided with validated autonomous aerobraking strategies and algorithms as well as with a high fidelity aerobraking AOCS simulator. Full technical documentations will be delivered, covering specifications, architecture, algorithms, modelling, simulation test results and profiling analysis results. All software developed during the activity will be delivered (source and binary codes).

Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2011
Application Mission:	Network Science, MSR		**Contract Duration:**	12	
S/W Clause:	N/A		**Reference to ESTER**	"Aero-braking"	
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Aerobraking Flight Representative Demonstrator			
Programme:	ETP	**Reference:**	E905-001EC
Title:	Aerobraking Flight Representative Demonstrator		
Total Budget:	350		
Objectives			
The main objectives of the activity is to implement a AOCS/GNC & avionics demonstrator to evaluate in a flight-representative environment Aerobraking Strategies in preparation of IM1, IM2 and subsequent missions.			
Description			
The activity consists in developing a flight-representative Aerobraking demonstrator, in order to support the real-time evaluation of Aerobraking Strategies as analyzed and designed in the activity "Robust Autonomous Aerobraking Strategies" (ref T305-031EC), assess their adequation with mission requirements, to support the preparation of their subsequent implementation on IM 1 and/or 2, and following missions. In that purpose, following tasks will be carried on : - detailed design of relevant AOCS/GNC algorithms (including Aerobraking algorithms) and their implementation on a flight-representative processor - detailed HW design of the avionics subsystem, including flight-representative communications (protocols, delays, signal attenuation?) - detailed Aerobraking FDIR design to validate failure detection, isolation and reconfiguration in Aerobraking contingency cases. - detailed design of Dynamics, Kinematics, Environment and Sensor Models for their implementation on a real-time kernel (like dSpace) Note : the avionics detailed design will be based on ESA Reference Avionics System Architecture for exploration (RASTA). AOCS/GNC testbench based on RASTA kernel and dSpace-like real-time environment			

A set of flight-representative AOCS/GNC SW covering Aerobraking strategies as selected in the activity "Robust Autonomous Aerobraking Strategies" (ref T305-031EC) Technical Documentation according to ECSS-E40 tailored for this application.					
Deliverables					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	TRL 5 by 2015
Application Mission:	Network Science, MSR		**Contract Duration:**	12	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					

Adaptation of Aerogel Materials for thermal insulation					
Programme:	TRP		**Reference:**	T921-001QE	
Title:	Adaptation of Aerogel Materials for thermal insulation				
Total Budget:	300				
Objectives					
Develop and test of multifunctional aerogel for Mars exploration (landers and rovers) to reduce mass of the thermal insulators.					
Description					
Aerogel are produced by sol-gel processing and are the lighest solids known (with density down to 3times that of air). It has been shown in the past that they outperform MLI as a thermal insulation in a low pressure environment as existing on Mars. The objective of the study is to tune the properties of a suitable Aerogel such that also other desireable properties (flexibility, damping,) can be achieved. By controlling the pore size and distribution such materials will outperform both MLI as well as classical foams in a low pressure environment. This can be achieved by adapting the materials processing window and by incorporating for instance hybrid compounds into an inorganic Aerogel network. After that key functional properties shall be evaluated and performance improvement shall be quantified.					
Deliverables					
Trade-off and selection of target properties, material processing, tuneable property assessment, test plans, test reports, test samples and technical notes					
Current TRL:	2 - 3	**Target TRL:**	3-4	**Application Need/Date:**	2013
Application Mission:	IM, MSR		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**	None	
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Extremely low power timer board EM for landers			
Programme:	ETP	**Reference:**	E901-001ED
Title:	Extremely low power timer board EM for landers		
Total Budget:	300		
Objectives			
The objective of this activity is to develop an engineering model of an extremely low power configurable timer board designed to wake-up the onboard computer of a lander before atmospheric entry.			
Description			
Driven by the robotic exploration programme, there is a requirement to provide a timer system to wake up a lander's electronics before atmospheric entry. During an approach cruise phase that may last up to 23 days, the autonomous lander has to rely solely on batteries which consequently implies a very constraintive power budget. For this reason, most systems are powered-OFF until entry becomes imminent; the timer board is required to switch the systems ON after a pre-configured elapsed period and is therefore a			

mission critical component.The timer board shall be highly reliable and consume less than 10mW. Three timer devices are to be implemented in hot redundancy and their output shall be fed into a simple but reliable majority voting device. The timers shall be independent to each other and provide separate communication links and connectors to the spacecraft onboard computers. Before the spacecraft-lander separation phase, the spacecraft shall communicate with each timer device with the goal of programming the accurate length of the timer period. The spacecraft shall also have the means to verify the stored period length for each timer. The majority voting device on the timer board triggers an external relay that will power ON the lander's main systems. It shall also take signals from external g-switches as inputs that will serve as backup. In regard to dimensions and mass constraints, a single board/module hosting the redundant components is foreseen to be the baseline design. The Timer board/module has to be developed in order to be an independent box. The timer board shall convert the voltage it receives from the lander's battery to a more suitable and power-saving voltage. A trade-off shall also be made regarding the board's DC-DC converters redundancy scheme in order to investigate if cold redundancy could be used between the converters to further reduce current consumption.					
Deliverables					
An Engineering Model (EM) of the highly reliable and low-power timer board.					
Current TRL:	2	**Target TRL:**	6	**Application Need/Date:**	2012
Application Mission:	Network Science		**Contract Duration:**	12	
S/W Clause:	N/A		**Reference to ESTER**	None	
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Tailored On-Board Computer EM for planetary landers			
Programme:	ETP	**Reference:**	E901-002ED
Title:	Tailored On-Board Computer EM for planetary landers		
Total Budget:	700		
Objectives			
The main objective of this activity is to develop an engineering model of a tailored, highly integrated, low mass and low power On Board Computer core to be used in planetary landers.			
Description			
The Robotic exploration programme requires the use of on board computers in planetary landers where mass, power and sizes are critical constraints. In particular the Network Science mission concept asks for a drastic mass miniaturization of the lander (approx. 150kg entry mass with P/L). Existing on board computers cannot satisfy these requirements and there is the need to rationalise the computer architecture with the prospect of a significant mass, power and dimensions reduction. This activity will study and develop the concept of an architecture based on SCOC3 ASIC (SoC) and to be used as part of the On Board Computer of a lander in robotic exploration programs. One of main objectives of the activity shall be to optimise as much as possible the mass/volume/power of the Controller and the needed surrounding electronics (memories, power supplies regulators, etc.) whilst keeping an acceptable level of performances. The Controller shall include the TM/TC, the reconfiguration and the main computer functions and shall provide standardised hardware and software interfaces (SpW, 1553, CAN, but also future evolution like SpaceFibre) with the other Space Segment S/s. The On Board Computer shall implement a modular architecture that allows to include additional modules (like Mass Memory, HK modules, Motion Control module) controlled by the On board Controller. Also power distribution modules can be added to the OBC (e.g. to supply the GNC units). The modular architecture could be physically implemented into a single unit or as a decentralized one (i.e. more modules/units). In both the cases standardized electrical interfaces (e.g. SpW) shall be used also as internal I/Fs. The use of miniaturized connectors, highly-integrated interfaces and wireless technologies (for debugging purposes at least on ground) shall be exploited. Hardware and software power saving techniques (such as processor-frequency scaling and software driven off-idle-operative states individually selectable for the various implemented functions) shall be investigated in order to optimise the power consumption and leave the Controller in the lowest power state that satisfy the functional requirements during each phase of the mission. Depending on the mission scenarios the Controller shall be able to be configured as a reliable computing system or as high available system. In the first case the Controller must be operational for a long period of time and in case of failure a reconfiguration outage is acceptable. In the second case the availability of the Controller during critical phases like entry, descent and landing shall be guaranteed also in case of failure. Configurability according to the availability requirements shall be a driver for the design of the Controller and different redundancies schemes shall be properly addressed at hardware and software level.			

The activity shall start with the definition of the requirements for a Tailored OBC for Small Landers.					
Deliverables					
1) Requirements Specification and Design & Analysis docs 2) AIT procedures and reports 3) An Engineering Model (EM) of a miniaturised on Board Controller unit.					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2012
Application Mission:	Network Science		**Contract Duration:**	18	
S/W Clause:	Operational Software		**Reference to ESTER**	T-8382 ,T-7803,	
Consistency with Harmonisation Roadmap and conclusion:					
A highly integrated core built up into few large ASICSs is mentioned in the Data Systems and OBCs harmonization dossier.					

Subsonic Parachute Trade-Off and Testing					
Programme:	TRP		**Reference:**	T918-001MP	
Title:	Subsonic Parachute Trade-Off and Testing				
Total Budget:	500				
Objectives					
To provide information for the selection of subsonic parachutes for Mars entry to deed in the overall trade-off for the EDL system. To develop methodologies for the understanding of inflation methods and development of aerodynamic databases including static and dynamic coefficients					
Description					
The activity shall start with a selection of a limited number of parachute concepts, based on a trade-off between different candidate parachute shapes and features. For the selected candidates: - Initial databases for static and dynamic aerodynamic coefficients shall be developed. - Inflation properties shall also be reviewed. - CFD (Computational Fluid Dynamics) estimates of aerodynamic coefficients shall be performed. - Wind tunnel or free flight tests shall be performed for the further development of databases. Scaling laws shall be developed. These databases shall also provide information for the validation of CFD. - CFD validation for a limited number of conditions shall be undertaken. - Preliminary development plans and costs shall be provided					
Deliverables					
Test models, databases, software and technical notes.					
Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2012
Application Mission:	Network Science		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**	None	
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

EDLS GNC Optimisation and Technology Specification for small Mars landers			
Programme:	ETP	**Reference:**	E905-002EC
Title:	EDLS GNC Optimisation and Technology Specification for small Mars landers		
Total Budget:	250		
Objectives			
The successful landing of planetary probes on Mars is a capability yet to be demonstrated by Europe. Time- and cost-optimal delivery of multiple probes, within the 150kg class and widely spatially separated requires that dedicated optimisation tasks and trade-offs be conducted to rigorously define an optimised design of the EDLS. The main objective of the proposed activity is thus to define the complete EDL chain, benchmarking of the available technological solutions and specification of required technology developments in order to baseline a robust, optimised (in terms of cost, mass and reliability) EDLS design of the Mars Science Network mission			

Description					
Building up on recent industry and CDF studies (Mars NEXT, MarsGEN), the proposed activity will perform a detailed review and a quantitative benchmarking of existing and affordable EDLS strategies for a Mars Science Network mission. The selected architecture will be the result of an end-to-end optimisation of the entire multi-probe EDL sequence. At system level, special attention shall be given to: the logic of the triggering events since separation, the nature of the deceleration systems (1-stage vs. 2-stage parachute systems, presence of retro-rockets, nature of the airbags), the terrain relative navigation specifications (including an assessment on the need of lateral velocities control and of the benefits of using some descent imagery), the detailed specification of the selected altimetric sensor and to the overall robustness of the EDLS and of its components w.r.t. the environment conditions and the missions requirements. For the preferred solution, a technology development plan will be derived together with the specification of future technology development activities. At implementation level, efforts will be made towards mass and volume optimisation of the EDLS components (D&L components, GNC equipments and data handling). The selection of the proposed architecture, as well as the justification of the redundancy strategy, will rely on the use of a set of dedicated analysis tools allowing end-to-end parametric trades within an appropriate envelope of the landers and trajectories characteristics.					
Deliverables					
The Agency will be delivered with a detailed and comprehensive EDLS analyses including the lessons learned from previous missions and activities. A consolidated EDLS architecture and technology specification for 150kg-class Mars landers will be provided with its justification, as well as a detailed development and testing plan for European technology of the EDLS and of its components.					
Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2011
Application Mission:	Network Science		**Contract Duration:**	9	
S/W Clause:	N/A		**Reference to ESTER**	None	
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Assessment and breadboarding of a planetary Altimeter			
Programme:	TRP	**Reference:**	T905-003EC
Title:	Assessment and breadboarding of a planetary Altimeter		
Total Budget:	900		
Objectives			
The proposed 2-part activity will study the concept and develop at breadboard level a mass and power-optimized GNC altimeter for use during the spacecraft descent and landing phase of 150kg-class landers of the Mars Science Network mission.			
Description			
A direct and reliable measurement of the ground distance by an altimeter is a key asset for any planetary Descent and Landing system that allows the trigerring of key events of the Entry, Descent and Landing sequence. The first phase (6 months, 100K) shall compare and benchmark the two natural candidate technologies (radar and laser) that could produce such as an altimetric sensor. A detailed analysis of the equipment performance and robustness under engineering constraints (mass, power, cost), mission requirements (accuracy, range, continuous measurements vs. discrete triggerings) and environment constraints (dust and plume effects, terrain roughness) shall be performed. The study phase 1 shall also consider the integration of the altimetric measurements in the complete navigation chain and will derive a set of sensor requirements that will form the basis for follow-on developments in phase 2 once the most promising solution has been identified and selected. Depending on phase 1 results, the altimetric sensor design will be furthered to breadboard level in phase 2 (10 months, 800K). The phase 2 study shall develop any sensor level critical technology, and the breadboard model shall be constructed based on requirements established in the earlier system study part. A time and cost-effective approach for a complete sensor development, its qualification and the integrated avionics testing shall be identified and specified.			
Deliverables			
Phase 1: feasability and comparative analyses, technology selection and specification, development plan Phase 2: breadboard model ready for testing in realistic environment, available test equipment and documentation.			

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2012
Application Mission:	Network Science		**Contract Duration:**	16	
S/W Clause:	N/A		**Reference to ESTER**	None	

Consistency with Harmonisation Roadmap and conclusion:
N/A

Simulation and Validation Platform for small Mars landers EDLS					
Programme:	ETP		**Reference:**	E905-004EC	
Title:	Simulation and Validation Platform for small Mars landers EDLS				
Total Budget:	200				
Objectives					
The main objective of the proposed activity is to develop a dedicated platform able to simulate and validate at a high-fidelity level the EDLS of a European, multi-probe, Mars Science Network mission.					
Description					
The cost of replicating the environment and dynamic conditions experienced by Martian landers calls for an extensive use of simulation tools in the analysis, design and validation of their Entry, Descent and Landing systems (EDLS). Taking as a reference the consolidated baseline EDLS architecture for 150kg-class Mars landers, a detailed, high-fidelity simulation and testing environment shall be developed. This platform could be an extension of the AURORA EAGLE/Scalable EDL platform, due for completion in mid-2010. This platform will allow a high-fidelity, physics based, assessment of the EDLS performance and robustness in both nominal and degraded scenarios. The assessment shall be conducted from end-to-end (i.e. from separation to final rest) in both real time and non-real time simulations. The non-real time version will include some worst-case and Monte-Carlo capabilities, the real time version will function as an avionics test bench with hardware-in-the-loop capabilities (including representative electrical interfaces of the EDLS components and a flight-like processor in charge of triggering the events defining the EDL sequence).					
Deliverables					
The Agency will be delivered with a high-fidelity EDLS simulation environment tailored for the consolidated EDLS architecture of a Mars Science Network mission with 150kg-class Mars landers. The simulation platform and the tests campaigns performed will allow to verify and to validate the EDLS as well as quantify its end-to-end performance and robustness.					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2013
Application Mission:	Network Science		**Contract Duration:**	10	
S/W Clause:	Operational SW		**Reference to ESTER**	None	
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Ground Testing of the EDLS Navigation Chain for small Mars landers			
Programme:	ETP	**Reference:**	E905-005EC
Title:	Ground Testing of the EDLS Navigation Chain for small Mars landers		
Total Budget:	450		
Objectives			
One of the key steps in the verification of the Entry, Descent and Landing systems (EDLS) is the testing of its mission critical navigation chain. This testing can be conducted through simulation, laboratory experiments and field testing. The main objective of the proposed activity is to conduct a series of field tests in order to evaluate the performance and behaviour of the navigation part of the EDLS under flight-like conditions for a European Mars Science Network mission.			
Description			
Following the release of the thermal protection system, the navigation chain primary purpose is to fuse altimetric information with inertial measurements and possibly descent imagery in order to trigger the various time-critical events like the deployment of the landing system and the retro-rockets ignition. An airborne platform like the ESA Planetary Landing GNC Test Facility (PLGTF) is an adequate environment to perform tests of an EDLS navigation chain and its components (inertial measurement unit, altimetric sensor, possibly a camera). A series of field experiments using the PLGTF and the associated Electrical Ground Support Equipment (EGSE) will be performed in order to demonstrate the good behaviour of the navigation chain w.r.t. mission-like descent dynamics and terrain characteristics. The tests will nominally be conducted in open-loop as they aim at the validation of the navigation function and no retargeting of the platform is required. The possibility of closed-loop tests using the extended PLGTF platform (ePLGTF) shall however be considered in the case the baseline EDLS include the necessity to control lateral velocities.			

Deliverables					
The Agency will be delivered with field tests allowing verification of the performance and robustness of the navigation chain for 150kg-class Mars landers. The experiment results will be provided in a format allowing post-flight processing and the tuning of the EDLS GNC sensors (especially the altimetric sensor) high fidelity models under realistic flight-like conditions and for various terrain characteristics.					
Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2015
Application Mission:	Network Science		**Contract Duration:**	10	
S/W Clause:	N/A		**Reference to ESTER**	None	
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Lowering system Breadboard for Mars landers					
Programme:	ETP		**Reference:**	E915-001MS	
Title:	Lowering system Breadboard for Mars landers				
Total Budget:	500				
Objectives					
To design and prototype a lowering system for the EDL chain for the Network science mission					
Description					
The Network Science Probes likely will require a lowering system that lowers the lander from the back cover before using its potential retro-rocket system. A trade-off will be performed between different lowering systems such as the US bridle and descent rate limiter or an integrated system as proposed for the Netlander mission. Based on the requirements derived in the systems study abnd the EDLS GNC study, a prototype will be build of the lowering system and its performance tested.					
Deliverables					
Technotes Lowering system breadboard					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2013
Application Mission:	Network Science		**Contract Duration:**	9	
S/W Clause:	N/A		**Reference to ESTER**	None	
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Retro Rockets for Mars landing			
Programme:	ETP	**Reference:**	E919-001MP
Title:	Retro Rockets for Mars landing		
Total Budget:	4000		
Objectives			
To develop a retro-rocket system for application during landing on a Network science lander mission.			
Description			
Solid propellant rocket motors that are usually mounted in a back shell for Descend and Landing applications where solely parachutes and airbags are not sufficient or are too heavy. The need for such motors has been identified during the CDF MarsGEN study (as well as during other CDF studies) in the past. Overall (system) working principle: Parachute terminal velocity is reduced to 0 by Solid Rocket Motors at a certain altitude above ground from which the Lander drops down to the surface. This way the landing airbags can be sized for a certain "fixed" velocity that is lower than the terminal velocity of a reasonable sized parachute). Solid Rocket Motors burn for a short duration to generate the required thrust for slowing down the lander. There exist some scaling possibilities that make the application of a once developed motor possible to a wider range of			

missions. Pre PDR level activities in Europe for such motors as well as semi throttle able motors (these motors have a minimum thrust and thrust can be increased by additional liquid propellant injection) have been conducted in the scope of a project, but were rejected. The exact technology with the application of landing on Mars is not available in Europe. HOWEVER: Since these are just retro rockets, very similar applications can be found in booster separation motors and stage separation motors of which many have been produced in Europe for the Ariane 5,4,3,2 and 1 launch vehicles as well as their predecessors. In addition a large military experience exists within Europe on the development and large scale manufacturing and use of solid propellant motors. The application in the Martian atmosphere is different, the working principle is the same. Development estimate for "standard" retro rockets only: 4 Million Development estimates for as well a "standard" version as a throttleable derivative (see principle described above): 10 million.					
Deliverables					
Demonstration of retro-rockets tailored to requirements of a Network Science lander mission.					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2014
Application Mission:	Network Science		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**	None	
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Airbags for small landers - Design					
Programme:	TRP		**Reference:**	T319-035MC	
Title:	Airbags for small landers - Design				
Total Budget:	300				
Objectives					
Design airbags for small landers					
Description					
Review of the requirements, and previous studies on airbags. Define trade-off criteria for the type of airbag (vented, non-vented) depending on the mass/landing velocities of the payload. Investigate the scale effect from Exomars to smaller payloads and the need for delta developments. Trade-off the possibilities to vent the airbag. Design an airbag for a given mission (Network Science lander type). A second phase (not part of this proposal) should cover the manufacturing and testing of a breadboard of the airbag.					
Deliverables					
A design for an airbag landing system for a Network lander mission. Documentation (Final Report, Summary Report, and Technical Data Package)					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2011
Application Mission:	Network Science		**Contract Duration:**	12	
S/W Clause:	N/A		**Reference to ESTER**	EDL: Landing System for Touchdown of Small Surface Probes (i.e. airbags)	
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Airbags for small landers - Breadboard and Test			
Programme:	ETP	**Reference:**	E920-001MS
Title:	Airbags for small landers - Breadboard and Test		
Total Budget:	2000		
Objectives			
Design, manufacture and test an airbag breadboard in relevant environment for a 150kg-class Mars lander.			

Description					
Following phase 1 (airbags design and justification by analyses), Phase 2 focuses on breadboard manufacturing and tests. The activity shall include: 1) Design and justify the airbag breadboard. 2) Define and justify the test plan, including elementary tests if necessary and full scale breadboard test in relevant environment (Mars pressure). 3) Manufacture the breadboard. 4) Prepare and conduct landing tests. 5) Evaluate the results and correlate the models					
Deliverables					
Documentation (Final Report, Summary Report, and Technical Data Package) Abstract Breadboard model tested in relevant environment to TRL5.					
Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2013
Application Mission:	Network Science		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**	EDL: Landing System for Touchdown of Small Surface Probes (i.e. airbags)	
Consistency with Harmonisation Roadmap and conclusion:					

Adaptation of terrestrial solar cells for Mars surface operations			
Programme:	ETP	**Reference:**	E903-011EP
Title:	Adaptation of terrestrial solar cells for Mars surface operations		
Total Budget:	750		
Objectives			
To adapt terrestrial solar cells for optimal use during Mars surface operations			
Description			
Solar cells which are optimised for earth orbit do not behave optimally at Mars surface due the 'red shifted' spectrum and lower operating temperature range. Scope for improvement of solar cells under specific Mars conditions has been recognised eg. in TRP contract 20509/07/NL/GLC, which showed that 'lattice mismatched' cells can achieve significantly more power than currently produced cells under dusty conditons (up to 50% improvement in the case of an extremely cold, dusty atmosphere) while retaining a slight performance advantage under more likely nominal conditions close to Mars equator around mid-day. Depending upon the mission scenario and schedule, the most cost effective option to produce a 'lattice mismatched' cell is likely to adapt solar cells which have been designed for use on the earth surface. The lifecycle associated with the development (including development, pilot production and qualification) will depend upon the status of the technology. Hence the information below assumes availability of a solar cell design for terrestrial applications, at TRL3. The scope of the adaptation for Mars surface applications and associated cost-benefit trade-off can be tailored by envisaging adaptations which offer progressively more optimal performance but which have progressively greater impact upon the heritage design and hence progressively greater cost. The following is a 'rough order' estimate: - Major changes (eg. major re-optimisation of solar cell epitaxial layers but retaining the 'nucleation layer' design of a terrestrial cell: 750K - Intermediate changes (eg. minor adjustments to the solar cell epitaxial layers but retaining the 'nucleation layer' of a terestrial cell: 400K euros - Superficial changes (eg. excluding changes to epitaxial layers but including eg. redesign of front grid metalisation: 250K euros The most appropriate compromise will depend upon the status of the solar cell technology and available budget when the decision has to be made. Qualification / delta qualification of solar cell technology for a Mars surface application in order to achieve TRL8 needs to be anticipated as a separate delta cost which is applicable also in the case of a space qualified cell (ROM cost for full qualification at bare solar cell, solar cell sub-assembly and photovoltaic assembly level is 1MEu).			
Deliverables			

100 solar cells, engineering test data					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2014
Application Mission:	ExoMars		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					

Solar Power Regulator Breadboard for Mars Surface Missions					
Programme:	ETP		**Reference:**	E903-012EP	
Title:	Solar Power Regulator Breadboard for Mars Surface Missions				
Total Budget:	400				
Objectives					
The main objective is the optimisation of power system topologies and control to achieve the maximum photovoltaic power transfer to the platform and the payload for Mars Surface Missions.					
Description					
Solar Array on the Mars Surface are facing harsh, non homogenous and highly unpredictable environments due to suspended dust in the atmosphere, dust deposition, occurrence of dust storms, high daily thermal excursion and sun incidence evolution during the daytime. Compared to conventional shunt switching regulators, regulators based on Pulse Width Modulation (PWM) converters and Maximum Power Point (MPP) Trackers (MPPTs) would enable a significant increase of photovoltaic power transferred by the conditioning electronics to the platform and the payload. In TEC-EP power laboratory, specific power topologies are currently being studied and tested which should allow efficiency and mass/size improvements over more conventional designs.The existing MPPT tracking algorithms are not well suited due to their inability to differentiate a local MPP to the absolute MPP, and other principles can be investigated and plugged into the conditioning electronics to be able to track maximum solar array power in any condition. This activity consists of 4 main tasks: - system analysis to identify the most promising power conditioning designs and MPPT solutions; - trade offs and simulations for the identification of the most suited Solar Array Regulators and MPPT designs; - detailed design of the innovative Solar Array Regulators and MPPT; - breadboarding & testing of the selected design.					
Deliverables					
Breadboards, test results and study reports					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2013
Application Mission:	Network Science		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**	None	
Consistency with Harmonisation Roadmap and conclusion:					
consistent with Harmonisation Power Management and Distribution second semester 2008					

Development of a low temperature Lithium ion battery and survivability tests			
Programme:	ETP	**Reference:**	E903-013EP
Title:	Development of a low temperature Lithium ion battery and survivability tests		
Total Budget:	500		
Objectives			
Development and life test of a Li ion battery at low temperature, after selection of cells by characterisation tests; and Assessment of the possibility of the Li ion battery recovery after storage at very low temperature (-50?C or colder)			

Description					
In applications such as landers and rovers, the battery has to deliver high energy at low temperature. ABSL Space products (UK) evaluated in 2007 the best COTS Li ion cells operating at -20?C for Exomars. A cell was selected and a battery was assembled and tested at Estec. Li ion cells are evolving quickly, due to terrestrial markets needs (electronics, automotive,...) and new cells with higher specific energy are now available and should be evaluated at low temperatures. Some manufacturers are also developing Li ion cells for low temperatures conditions; such cells could be of interest if they offer sufficient specific energy. After characterisation of available cells, the survivability of the cells in extreme temperatures will be assessed. In case of malfunction, or dust storm on Mars leading to loss of power and loss of thermal management, the Li ion battery could be exposed to very low temperatures. The recovery of a battery after exposure to temperatures below freezing point of the electrolyte, is not known. The proposed activity will include two phases: Phase1 - Thorough evaluation of high specific energy COTS cells at low temperature, and of available prototype of cells optimised for low temperatures, - Selection of the best candidates, - Battery design and assembly, - Life-test at low temperature. Phase 2: - Very low temperature storage Test: storage at very low temperature at different state of charge, for different durations; - Test of different recovery scenarios (i.e Charge conditions; rate, minimum temperature required).					
Deliverables					
Technical Notes, characterisation tests results, Battery breadboard, battery tests results, recovery plan					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2012
Application Mission:	Network Science		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**	None	
Consistency with Harmonisation Roadmap and conclusion:					
Yes. Follow-on from Battery roadmap issue 1 revision 3 September 24 2006. Activity D1					

Lander Compact Dual UHF/X-band Frequency Communication Package Study			
Programme:	TRP	**Reference:**	T306-044ET
Title:	Lander Compact Dual UHF/X-band Frequency Communication Package Study		
Total Budget:	250		
Objectives			
The objective of this activity is to investigate a communication package that can communicate both with an Orbiter (for data relay) and directly to/from the Earth from Planet surface.			
Description			
This activity is related to the feasibility/design of communications systems to be used on planetary probes/landers/rovers and communicating both with an Orbiter (for data relay) and directly to the Earth from Planet surface. In the ExoMars mission, the UHF proximity-link with a data-relay Orbiter will be the primary link for returning science data. The use of relay links is attractive for reasons of power efficiency and higher possible data-rates compared to direct-to-Earth links. Nevertheless, the ExoMars rover includes also a direct link to/from the Earth next to this UHF proximity link to the Orbiter. The direct link with Earth will be in the X-band Deep Space frequency allocation and used in emergency situations and for contingency operations, as well as during the entry, descent an landing phase to transmit health status beacon tones. In addition, the direct to Earth link might be useful also for navigation and RadioScience Experiment. Different architectural approaches might be considered as to implement both UHF and X-band capability: - dedicated X/X band transponder and dedicated UHF transceiver - single unit using frequency translator (from UHF to X-band) . In the second case the same communication unit can handle both UHF link as well as direct to/from Earth X-band links, which means possible savings in mass and volume on resource limited landers/rovers. In addition, this implementation would open up the possibility to use the proximity link in the X-band, making use of directive antennas already in place for the direct to Earth link (see ExoMars baseline). Nowadays, this architecture would be possible thanks to the advances in digital signal processing which allows easily processing the UHF Proximity-1 protocol and the classical X-band TT&C signals. The target of this study is to analyse/design the Compact Dual Frequency Architecture and to quantify the overall performances including mass, volume and power saving.			
Deliverables			

TN notes and Final Report. Software BBs					
Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2012
Application Mission:	Network Science and all Mars lander missions		**Contract Duration:**	15	
S/W Clause:	N/A		**Reference to ESTER**	T-7725	
Consistency with Harmonisation Roadmap and conclusion:					
"Harmonisation dossier for TT&C transponder and payload data transmitters" (22 January 2007) - Consistent - Activity B2 Lander Compact Dual Frequency Communication Package Study					

Compact dual UHF/X-band Proximity-1 Communication EM					
Programme:	ETP		**Reference:**	E906-001ET	
Title:	Compact dual UHF/X-band Proximity-1 Communication EM				
Total Budget:	1000				
Objectives					
The objective is to develop an Engineering Model (EM) of a standardised compact dual frequency (UHF/X-band) communication package for lander/rover exploration missions.					
Description					
This activity targets the design and development (up to EM model) of a communications package for planetary probes/landers/rovers able of communicating both with an Orbiter (for data relay) and directly to the Earth from Planet surface. Mars missions typically implement a UHF proximity-link with a data-relay Orbiter as their primary link for returning science data. The use of relay links is attractive for reasons of power efficiency and higher possible data-rates compared to direct-to-Earth links. Nevertheless, in order to support communications during EDL the inclusion of a direct link to/from the Earth in the X-band is foreseen. The direct link with Earth will be in the X-band Deep Space frequency allocation and could potentially be used in emergency situations and for contingency operations, as well as during the entry, descent an landing (EDL) phase to transmit health status beacon tones. Instead of fitting two separate transponders into the constrained lander/rover, a single unit serving both UHF and X-band links would bring important savings in mass and volume without sacrificing functionality or mission safety. The target of this activity is to design and develop a dual UHF/X-band frequency transceiver. This activity is based on the outcomes of the TRP study 'Lander Compact Dual Frequency Communications Package' (Reference number T306-044ET)					
Deliverables					
An Engineering Model (EM) of a dual frequency UHF/X-band communication package.					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2013
Application Mission:	Network Science and all Mars lander missions		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**	T-7725	
Consistency with Harmonisation Roadmap and conclusion:					
Listed in TT&C Transponder and Payload Data Transmitter Harmonisation Dossier					

Orbiter Software Defined Radio Proximity-1 Link Communications package- implementation and demonstration			
Programme:	TRP	**Reference:**	T306-043ET
Title:	Orbiter Software Defined Radio Proximity-1 Link Communications package- implementation and demonstration		
Total Budget:	300		
Objectives			
The objective of this activity is to start the development of a flexible and multimission data-relay communication package based on CCSDS Proximity-1 protocol and using Software Defined Radio (SDR) as the enabling technology.			

Description					
The current European proximity-link transceivers (as developed in the previous ESA missions, for instance Beagle) are limited in flexibility as they are based on a low level of integration between the RF and the digital part. Using the Software Defined Radio technology, SDR, (similar to that implemented by NASA/JPL for the Electra transceiver) allows a higher level of flexibility with the possibility of unit reconfiguration. Using the software defined approach provides the capability to add/change functionality by simply changing the software version. This software upload (software patch) can be done pre-launch or in orbit, which makes the unit very flexible and provides the capability to support multiple missions. This multimission approach is particularly interesting in case of an Orbiter with data-relay capabilities and a long lifetime (such as Mars Express). This way it can support different lander missions (European, American and other international space agencies) even the ones it wasn?t intended to serve in the first place. Allowing post-launch reconfigurability of the protocol and signal processing functions over the Orbiter lifetime supports protocol updates and provides the possibility to respond to unanticipated mission scenarios. Secondly, by ensuring a standardised and interoperable data-relay infrastructure allows any lander to make use of multiple data-relay assets, thereby increasing the science return while at the same time reducing mass and power requirements on the lander. The ultimate goal would be to equip every science Orbiter with a standardised relay package, taking away some of the technology burden of small lander missions. The scope of the activity is to implement a reprogrammable Proximity-1 transponder based on a software defined radio architecture. The transponder shall support the Proximity-1 protocol in its entirety including support for full duplex operation. The transmit and receive carrier frequencies shall be programmable (by software uploads) to any frequency in the range used by the Proximity-1 protocol (i.e. 390 ? 450 MHz). The transponder shall be designed in a modular manner that allows tailoring of the basic transponder to future missions. Finally, the proximity-link transponder to be developed shall also support higher data-rates than those currently available on European hardware, in order to increase the science return. Consideration shall be given to the architecture proposed in order to reduce mass, power and volume envelopes as much as possible.					
Deliverables					
TN notes and Final Report. Software Defined Radio architecture H/W: Breadboard demonstrating over the air reconfiguration using software uploads/patches.					
Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2013
Application Mission:	Network Science and all Mars lander missions		**Contract Duration:**	12	
S/W Clause:	Operational SW		**Reference to ESTER**	T-7725	
Consistency with Harmonisation Roadmap and conclusion:					
"Harmonisation dossier for TT&C transponder and payload data transmitters" (22 January 2007) - Consistent - Activity B1 Software Defined Radio Proximity-1 Link Communications Package design					

Multi-Agent Systems Simulation Tool for Network Lander Mission Operations			
Programme:	TRP	**Reference:**	T909-001HS
Title:	Multi-Agent Systems Simulation Tool for Network Lander Mission Operations		
Total Budget:	550		
Objectives			
To investigate, define, deploy and validate a multi-agent system as a paradigm for distributed-element missions. This can be the case of lander networks to planetary exploration or orbiting satellite constellations with additional elements such as aerobots and rover(s) to be coordinated for a common exploratory goal. The scenario can well contemplate multi-agency contributing elements. A Multi-Agent approach will provide engineers with a higher level of abstraction enabling a natural step forward in the software engineering approach.			
Description			
In the near future several space missions will be based on a multi-element concept. This can be the case of lander networks to planetary exploration or orbiting satellite constellations with additional elements such as aerobots and rover(s) to be coordinated for a common exploratory goal. A promising paradigm to deal with the complexity of these missions is the Multi-agent Systems (MAS). Over the years, MAS research has developed a wide body of knowledge on foundations and engineering principles for designing and developing complex distributed systems. Despite the enormous research efforts and a number of successful industrial applications, the state-of-the-art in MAS research and engineering is insufficiently reflected in state-of-the-practice in complex distributed systems. This activity aims at defining and developing a Multi-Agent system to manage future multi-element space missions, where each			

agent will be in charge or representing a specific element of the mission (or sub-element in case it is deemed necessary). The proposed system shall be able to support the analysis and assessment of the operability of different identified scenarios for multi-element exploratory robotic missions.					
Deliverables					
The deployment of the Multi-Agent System concept shall entail the definition of the following aspects - definition and refinement of the MAS concept for distributed element missions - to refine the current standards and interfaces to define the new concepts - procedures to establish how to use the new concept - validate competing scenarios test-beds					
Current TRL:	2	**Target TRL:**	4/5	**Application Need/Date:**	2014
Application Mission:	Network Science		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**	None	
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Simulation tool for breakup/burnup analysis of Mars orbiters			
Programme:	TRP	**Reference:**	T911-001GR
Title:	Simulation tool for breakup/burnup analysis of Mars orbiters		
Total Budget:	300		
Objectives			
Development and application of a generic simulator for the entry into Mars atmosphere from Mars-bound and hyperbolic initial orbits, modelling the aerothermal/aerodynamic heating, delamination and breakup effects in response to identify solutions for meeting planetary protection constraints as well as potential collision hazards during entry.			
Description			
As the validation of existing tools and models are based upon Earth break-ups, they need to be adapted to a Mars entry with particular attention to a lower density CO2 atmopshere and use of CFRP or high temperature alloys (e.g. titanium-based) structural materials. In order to improve knowledge of a non-controlled entry with related destruction, the existing models need to be extended to validate their use for Mars entries: a. improving the destructive entry analysis of non-tumbling and tumbling objects. This includes both rarefied and continuum flow in the related atmosphere with built in criteria for the transition region from rarefied to continuum flow and aerodynamic heating model for that regime. b. CFD/DSMC solvers and possibly specific windtunnel tests shall be used to extend the database. For each selected free stream condition also the angle of flow incidence has to be varied between 0 and 180 ° with a step size of 15°. This will allow determining mean aerodynamic loads for one tumbling motion period. Based on this data base the tumbling entry and impact of these objects shall be analyzed. In order to assess the possible improvements the results shall be compared with results obtained by a well validated break-up tool with its present modelling system using some generic shapes. c. To set up a database on the behaviour of specific materials for a Mars entry vehicle which consists of typical S/C material, including CFRPs and high temperature alloys (during entry in the Mars atmosphere, i.e. their ablation-rate and coupled thermal-material characteristics. d. Investigate contribution of above models in implementing them into an existing break-up tool adapted to Mars atmosphere to better support modelling of fragmentation mechanisms including time dependency, in particular regarding the level of definition required to simulate relevant local destruction mechanisms which by local melting, perforation allow aero-thermal flux to penetrate in the spacecraft, induce loss of connections, large scale destructions, and finally fragmentation. Also, the tool shall be able to provide thermal heating information (time dependent temperature profiles) of the assemblies and components during entry and after break-up, so that the natural sterilization due to heating during entry can be evaluated and compared with the Planetary Protection bioburden requirements. If simple model used (few nodes), validation of a few generic cases (e.g., internal heating of a few electronic modules) is required. Assume tumbling and use average heat flux for input. f. Validate tool by comparison with MRO entry analysis. e. Apply the extended tool on some typical entry scenarios, including uncontrolled entry of the MSR Orbiter. The goal is to have a reliable tool that can be used already for the mission and S/C design and reduce the impact of bioburden control (delta-qualification of parts) and mission operation by avoiding excessive margins currently applicable because of the non-optimized simulation tools.			

Deliverables					
Test results to verify new parameters used in the simulation. Updated simulation tool. Results of typical entry scenarios.					
Current TRL:	3	**Target TRL:**	3-4	**Application Need/Date:**	2012
Application Mission:	Network Science and all other Mars missions		**Contract Duration:**	9	
S/W Clause:	Operational Software		**Reference to ESTER**	T-1103	
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Entry, Descent and Landing for MSR

<table>
<tr><th colspan="6">Maintenance of Martian Atmospheric circulation models (large scale, mesoscale, upper atmosphere) and continued validation of Martian Climate database</th></tr>
<tr><td>Programme:</td><td colspan="2">TRP</td><td>Reference:</td><td colspan="2">T304-038EE</td></tr>
<tr><td>Title:</td><td colspan="5">Maintenance of Martian Atmospheric circulation models (large scale, mesoscale, upper atmosphere) and continued validation of Martian Climate database</td></tr>
<tr><td>Total Budget:</td><td colspan="5">300</td></tr>
<tr><td colspan="6">Objectives</td></tr>
<tr><td colspan="6">Improve engineering models of Martian atmosphere in regions of importance for descent/ascent. Improve and validate models of Martian upper atmosphere for aeroassist / aerobraking.</td></tr>
<tr><td colspan="6">Description</td></tr>
<tr><td colspan="6">Current models of the Mars atmosphere do not adequately deal with the processes responsible for dust lifting and in particular vertical winds. The study will investigate the mechanisms of dust lifting to allow large-scale modelling of the Martian dust cycle, of crucial importance for descent planning and design. The resulting models will provide quantitative estimates of vertical updraft and downdraft velocities in the Martian boundary-layer between 0 and 8 km. The outputs will allow GNC systems to be designed and tested for landing and take-off. Also new data on Mars is being continuously acquired and this data must be used to improve and validate the current database. For the validation of the thermosphere model the possibility of using the data form the foreseen aerobraking of Venus Express will be studied.</td></tr>
<tr><td colspan="6">Deliverables</td></tr>
<tr><td colspan="6">Updated Circulation Models (large-scale, mesoscale); validation; climate database.</td></tr>
<tr><td>Current TRL:</td><td>1</td><td>Target TRL:</td><td>3</td><td>Application Need/Date:</td><td>2011</td></tr>
<tr><td>Application Mission:</td><td colspan="2">Mars missions</td><td>Contract Duration:</td><td colspan="2">24</td></tr>
<tr><td>S/W Clause:</td><td colspan="2">N/A</td><td>Reference to ESTER</td><td colspan="2">Three SD3 TRQs: (i)Aero-capture; (ii)Aero-braking; (iii)EDL: Planetary Entry Technologies, plus T-8101 (Descent)</td></tr>
<tr><td colspan="6">Consistency with Harmonisation Roadmap and conclusion:</td></tr>
<tr><td colspan="6">N/A</td></tr>
</table>

<table>
<tr><th colspan="4">End to end Optimisation and GNC design for High Precision Landing on Mars</th></tr>
<tr><td>Programme:</td><td>ETP</td><td>Reference:</td><td>E905-006EC</td></tr>
<tr><td>Title:</td><td colspan="3">End to end Optimisation and GNC design for High Precision Landing on Mars</td></tr>
<tr><td>Total Budget:</td><td colspan="3">500</td></tr>
<tr><td colspan="4">Objectives</td></tr>
<tr><td colspan="4">The objective of this activity is to optimise and design complete (entry to touchdown) GNC solutions for High Precision Landing on Mars.</td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">On-going activities on Mars entry, descent and landing (EDL) aim to demonstrate the feasibility of achieving a 10 km landing accuracy with a possibility that improved navigation at Entry and a smart parachute deployment strategy might reduce this accuracy to 3 km. Significant additional efforts are however required, on each of the EDL phases, to further improve the GNC performance and decrease, below that level, the size of the final landing ellipse of MSR-like landers.

Based on the MSR mission characteristics, the study will perform the optimisation of the each of the EDL phases and their chaining. It will include an analysis of affordable strategies for improving the controlled entry until parachute deployment, the control of the descent phases (parachute and powered), as well as the definition of an innovative end-to-end navigation architecture. A detailed design of the selected GNC solutions for all the phases of a fully controlled Martian EDL sequence will then be performed. The study shall more particularly address the optimisation of the approach and insertion strategies, the use of advanced guidance techniques during the hypersonic entry, smart parachute deployment, efficient drift compensation systems during Descent, and optimised powered landing with some divert and hazard avoidance capabilities Benefits of on-line identification and reconfiguration solutions throughout the EDL sequence shall also be investigated, as well as control during the descent phase that will be dealt within a robust, multi-variable control setting. The limits of performance of the GNC design shall be established. Requirements for the terrain relative sensors shall be established and high fidelity simulation models will be developed. The robustness and performance assessment of the GNC solutions will be conducted on an end-to-end high fidelity simulation environment</td></tr>
</table>

demonstrating the implementability of the selected algorithms and strategies on flight-like processors.					
Deliverables					
The Agency will be delivered with a set of GNC solutions for high-precision landing on Mars. The testing and benchmarking of these solutions at simulation will identify and prepare further TRL increasing and the development phases of the corresponding EDLS components.					
Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2012
Application Mission:	Precision lander, MSR		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					

European IMU breadboard					
Programme:	TRP		**Reference:**	T905-014EC	
Title:	European IMU breadboard				
Total Budget:	800				
Objectives					
Breadboard and demonstrate the performance of an IMU for Mars exploration					
Description					
There is a clear need of a European IMU for the Robotic exploration programme. This is considered a critical technology to enable the future exploration missions during cruise, Aerobraking, Entry, Descent and Landing and in-orbit Rendezvous. The available European gyro products are not optimised for the exploration requirements. Current low mass products have low performance while available high performance products have a hig mass. Furthermore, there is no European space qualified accelerometer (US space qualified off the shelf products are available) however a TRP-funded European accelerometer feasibility demonstrator has just been launched in 2010, and may form a basis for the European IMU development pending confirmation of its performance vs. MREP requirements. This activity intends to invite industry to propose an optimised IMU concept, based on an existing design, with gyro and accelerometer functions compliant with the MREP programme exploration needs. PDR stage shall be reached at the end of this activity with bread boarding to demonstrate the critical functions and performances. The activity would include: - analysis of the driving requirements and major constraints based on IMU specifications provided from the MREP High-precision landing GNC optimisation TDA (E905-006EC) and MREP Precision Lander system study. - main design modification trade-offs - detailed interfaces with the accelerometer and gyro preparatory work based on reuse of existing gyros building blocks and necessary delta-developments - early prototyping and testing of critical functions to demonstrate feasibility of meeting the key MREP performance requirements - development plan till EQM qualification and estimation of the recurring cost of the IMU					
Deliverables					
Technical Data pack - Test reports of IMU breadboard - Development plan of IMU to EQM H/W: Breadboard of IMU					
Current TRL:	2	**Target TRL:**	3-4	**Application Need/Date:**	2013
Application Mission:	Precision lander, MSR		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					
AOCS sensors and actuators Gyros and IMUs. AIM E1					

European IMU EM					
Programme:	ETP		**Reference:**	E905-015EC	
Title:	European IMU EM				
Total Budget:	2000				
Objectives					
To develop and test to TRL5, an European IMU for the MREP Programme.					
Description					
The activity shall develop an EM of an European IMU following from a previous breadboarding activity for the gyro and a separate accelerometer development activity. The IMU design shall be based on the gyro prototype architecture and the accelerometer component development. An EM shall be manufactured and tested in a relevant environment simulating its use on a Mars precision landing mission.					
Deliverables					
H/W: An IMU EM meeting the MREP programme performance specifications					
Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2015
Application Mission:	Precision lander, MSR		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**	T-7818	
Consistency with Harmonisation Roadmap and conclusion:					
AOCS Sensors and Actuators harmonisation 2009 - Gyros and IMUs Aim E1 & E2					

Accelerometer component to TRL5					
Programme:	ETP		**Reference:**	E905-016EC	
Title:	Accelerometer component to TRL5				
Total Budget:	1500				
Objectives					
To develop an accelerometer detector with read out electronics to TRL5					
Description					
This activity shall be based on the TRP accelerometer feasibility demonstrator protoyping (T705-032EC). The activity shall develop, manufacture and test to TRL5, an accelerometer detector. This shall beside the accelerometer detector also include the read out electronics (analogue ASIC). The accelerometer detector (including read out electronics) shall undergo an evaluation in a Mars mission environment at component level.					
Deliverables					
Accelerometer component for MREP missions developed to TRL5.					
Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2013
Application Mission:	All Mars Exploration missions		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**	T-7818	
Consistency with Harmonisation Roadmap and conclusion:					
AOCS Sensors and Actuators harmonisation 2009 - Accelerometers Aim A2 & A3					

Camera-aided Mars Landing and Rendezvous navigation system			
Programme:	ETP	**Reference:**	E905-007EC
Title:	Camera-aided Mars Landing and Rendezvous navigation system		
Total Budget:	350		
Objectives			
To assess the impact of the specific Martian and landing vehicle environment (dust, atmosphere, thrusters plume, etc.) on a camera-			

aided navigation system and to define the functional, performance and operational specifications of a camera navigation system for Mars landing or rendezvous, consolidating the GNC and image processing approach and algorithms and to evaluate in a high-fidelity simulation environment the closed-loop performance robustness of the candidate camera-aided GNC system..					
Description					
Future candidate missions of the MREP programme require the delivery of valuable payload on the Martian surface or in the case of the Mars Sample Return (MSR) mission, the capture of a sample container in Mars orbit. Previous MSR system definition studies have identified that a vision-based navigation system is an attractive solution for fulfilling the mission performance requirements. Previous generic activities have demonstrated the suitability of camera-aided measurements to assist the GNC system. This needs to be specifically addressed in the context of a Mars mission and its environment. Building on previous activities, specific camera requirements (e.g. optical, sensor, image processing, mass, power, autonomy) for the above scenarios shall be refined taking into account Mars specific operational conditions with respect to (for example but not only): * The dynamics during Mars entry, descent and landing (e.g. use of camera system during the parachute descent, transition to powered descent) * The specific atmospheric and dust environment as well as thrusters plume impingement (subsequent decrease of the SNR and distortion effects will be assessed) * The particular surface conditions taking into account the latest findings from ongoing Mars missions (e.g. MEX, MRO) * The requirements associated with a surface landmark database (built up by previous missions) for very high precision landing and its implications on the GNC during the camera-aided descent * Illumination and viewing conditions * Orbital conditions (e.g. canister Sun illumination for rendezvous) Critical analysis of the accommodation of the system (e.g. presence of airbags, aeroshell, etc.) for the two reference applications will be done together with analysis of all external error sources having an impact on the system performances. Subsequently, candidate image processing (IP) and navigation algorithms will be identified, analysed and traded-off. Investigations in the possibility to perform hazard detection (slope, rocks, craters, etc.) with a camera system during the descent, might also be addressed. For an agreed reference application (i.e. Mars landing or rendezvous and capture), a baseline navigation chain solution, including IMU and complementary navigation sensors such as laser altimeter for landing applications, will be selected in agreement with the Agency. The adapted GNC components and algorithms will be validated in open loop for the agreed reference case. Upon successful completion of this activity, closed-loop performance robustness of the candidate camera-aided GNC will be evaluated against requirements in a high fidelity simulation environment.					
Deliverables					
Full technical documentation, covering as a minimum, requirements specifications, architecture, IP and navigation algorithms, performance and physical-based simulation model, and simulation test campaign results All software developed during the activity (source and binary code) Library of validated autonomous GNC components tailored to a Mars reference mission scenario (e.g. landing or rendezvous)					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2011
Application Mission:	Precision lander, MSR		**Contract Duration:**	10	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					

MSR Precision landing navigation sensor adaptation - Engineering Model			
Programme:	ETP	**Reference:**	E916-001MM
Title:	MSR Precision landing navigation sensor adaptation - Engineering Model		
Total Budget:	1000		
Objectives			
Based on the results and requirements of the End to End optimisation and GNC design study, this activity will further develop the EDLS sensors for MSR High Precision Landing, building on the pre-developments performed under the Aurora program. An elegant prototype shall be manufactured to demonstrate the successful incorporation of HW and SW modifications and to be used in the MSR precision landing field testing which is a next step.			

Description					
Optical based navigation systems are required on several key stages of future exploration missions. Such systems allow autonomous navigation manoeuvres to be performed during the precise landing of a descent module in order to allow high precision landing and avoid hazards. This task can be performed by a vision based camera systems and LIDARs. Both systems have been explored and breadboards have been developed for demonstration purpose under other ESA activities, in particular the NPAL/VisNav breadboard for a vision based navigation demonstration, and an imaging LIDAR breadboard. Other studies are planned to further define and refine the EDLS GNC for hi-precision landing on Mars and the optimum methods of data fusion between different sensors to assist the Hazard mapping and subsequent avoidance piloting that ensure such landings can be performed safely and with a high reliability. These studies are expected to have impacts on the sensing hardware by refining the requirements on accuracy, resolution, update rate, range, power, mass and hardware to software (GNC s/w to Sensor hardware/s/w) interfaces. This updated information will be fed into the development of the sensor design and the hardware and software of the sensors will be upgraded to meet them. An elegant prototype of the upgraded design will be manufactured and validated, ready for its integration into the MSR Precision Landing Field testing which occurs in a next step.					
Deliverables					
MSR Precision landing EDL Sensor elegant prototype					
Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2014
Application Mission:	MSR		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**	T-7860	
Consistency with Harmonisation Roadmap and conclusion:					

Sensor Data Fusion for Hazard Mapping and Piloting					
Programme:	TRP		**Reference:**	T905-008EC	
Title:	Sensor Data Fusion for Hazard Mapping and Piloting				
Total Budget:	200				
Objectives					
An hazard detection and avoidance system contains a hazard mapping function that identifies the terrain characteristics and a piloting function that fuse the maps information and select the landing site. The main objective of the activity is to mature the data fusion techniques required when both active and passive optical sensors to perfom the hazard mapping and piloting tasks inside the hazard detection and avoidance function that will fly on future Mars landing missions.					
Description					
Redundancy and the proper addressing of the illumination conditions for hazard detection and hazard avoidance in planetary landing applications using the current optical sensors technology often require the simultaneous use of both a passive sensor and of an active LIDAR. The various Agency-led activities on hazard avoidance considered either the fusion of camera-based (plus some altimetric data) images or LIDAR images with inertial measurements. It never considered the synergetic use of both LIDAR and camera or more generally of tiered fusion involving several heteregenous imaging sensors (optical, radar) where a sensor limitation can be compensated by the characteristics of another and while this can increase both robustness and the features set of the terrain sensing. The activity will : - trade-off the possible terrain sensors fusion solutions for hazard detection & avoidance for planetary D & L applications - develop the hazard mapping data fusion and their integration into some existing simulation environment (including the piloting function) - perform the benchmarking of the proposed solutions based on their complexity, performance and robustness. - assess the applicability of the methods to terrrain relative navigation.					
Deliverables					
The Agency will be provided with a technical dossier containing the performance test results, the hazard mapping functions implementated inside a complete hazard detection and avoidance function, the TNs describing all the development.					
Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2012
Application	MSR		**Contract Duration:**	12	

Mission:			
S/W Clause:	N/A	**Reference to ESTER**	TBD
Consistency with Harmonisation Roadmap and conclusion:			

Ground Testing of Precision Landing navigation system					
Programme:	ETP		**Reference:**	E905-009EC	
Title:	Ground Testing of Precision Landing navigation system				
Total Budget:	500				
Objectives					
The main objectives of the activity are to perform the field testing, in flight-like conditions, of the GNC and image processing algorithms developed for the Hazard avoidance and Terrain-relative navigation functions enabling high precision landing at Mars					
Description					
Based on the GNC solutions retained for high precision at Mars and the upgraded sensors prototype developed in preceding activities, a series of field experiments using the extended PLGTF platform and the corresponding Electrical Ground Support Equipment (EGSE) will be performed. The tests will demonstrate via closed-loop experiments the performance and robustness of the terrain relative navigation and hazard avoidance functions previously developed on a flight-representative breadboard (e.g. EAGLE Avionics Test Bench). The experiment results will be provided in a format allowing post-processing and an evaluation of the navigation performance achieved under realistic flight-like conditions and for various terrain characteristics.					
Deliverables					
The Agency will be delivered with validated navigation and hazard avoidance functions from field tests results allowing verification of the performance and robustness of the MSR high precision landing navigation sensors					
Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2015
Application Mission:	IM		**Contract Duration:**	12	
S/W Clause:	N/A		**Reference to ESTER**	TBD	
Consistency with Harmonisation Roadmap and conclusion:					
AOCS Sensor and Actuator Harmonisation Roadmap Issue 3, 3D Cameras, Aim D, System Study					

Valve development for a throttleable monopropellant engine for soft landing			
Programme:	ETP	**Reference:**	E919-002MP
Title:	Valve development for a throttleable monopropellant engine for soft landing		
Total Budget:	2000		
Objectives			
Phase 1 development of a European 2.5-3.5 kN throttleable monopropellant engine for use as part of a Mars Entry Descent and Landing System (EDLS)			
Description			
The MSR mission (and any proposed landing on the Martian surface with a large payload) requires a soft landing. The precision of this landing is also of increasing importance as site selection becomes a driver for science. Automatic hazard avoidance also becomes desirable. Both these requirements are best met with a propulsion system with a capacity for thrust modulation. Any exploration robotic missions requiring a soft landing such as MSR and its precursors will require dedicated engines that represent a clear case for European independence. A European product development in this area can be based on initial know-how built in the past by European industry and needs to be front loaded to cover throttle valve development which is an essential component of the overall engine design. Engine chamber technology already exists at a stand alone TRL of 5, however, the combined TRL is at best 3. The funding and outline work breakdown are as follows: (Note: This activity relates to period 1 only)			

Period 1 Period 2 Period 3
Year 12 - 14 14-15 15-18
Target TRL 4 6 8
Budget [M] 2 4 9

Expected outputs per Period:

Period 1:
- Trade off throttle valve design, bread-boarding of candidate technologies, hydraulic test and evaluation against preliminary functional environmental requirements
- Development of valve driver logic and principles
- Demonstration of combined valve and controller in conjunction with battleship chamber and catalyst bed.

Period 2:
- Design development and manufacture of throttle valve elegant breadboard DM
- Design and manufacture of valve driver electronics elegant breadboard DM
- Design of mission specific chamberand catalyst bed - verification at DM level
- Performance verification at DM level

Period 3:
- Manufacture of EM valve, electronics and chamber and testing
- QM generic qualification of valve and chamber unit with valve driver electronics

Deliverables

This activity relates to period 1 only and deliverables are as follows:

DM engine, valve and drive electronics models
PDR/ data pack (based on a generic URD)

Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2014
Application Mission:	IM		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**	T-7715, T-8268	

Consistency with Harmonisation Roadmap and conclusion:

C3: 1-3 KN Throttable Engine(s) The decent engine is likely to require mono-propellant for Mars applications (though bi-propellant remains an option for lunar landing)

Design, development and testing of a throttleable monopropellant engine for soft landing			
Programme:	ETP	**Reference:**	E919-003MP
Title:	Design, development and testing of a throttleable monopropellant engine for soft landing		
Total Budget:	4000		

Objectives

Phase 2 development to CDR of an all European 2.5-3.5 kN throttleable monopropellant engine for use as part of an all European Martian Entry Descent and Landing System (EDLS)

Description

The propulsion for the Exomars decent module is subject to a unique set of requirements and is a first of its kind in Europe. Between parachute release and touch down the propulsion system must provide a large braking thrust (~10.5 kN) to slow the payload in its final decent phase (~40s). Further, the capability to modulate thrust to around 20 percent of the above value is required in order to ensure that the vertical decent rate remains inside design limits. This throttleable/modulated thrust capability is a new challenge and critical to the success of the mission.

Throttleable Monopropellant solutions are required due to landing site contamination considerations. Further, the relative simplicity of the monopropellant solutions leads to a more mass efficient propulsion subsystem.

The current baseline design employs 4 3.5 kN throttleable mono-propellant engines from the USA. However, the design would most likely have followed a different approach if a European alternative was available and secured.

The MSR mission (and any proposed landing on the Martian surface with a large payload) requires a soft landing. The precision of this landing is also of increasing importance as site selection becomes a driver for science Automatic hazard avoidance also

becomes desirable. Both these requirements are best met with a propulsion system with a capacity for thrust modulation. Any exploration robotic missions requiring a soft landing such as MSR and its precursors e.g. IM-2 will require dedicated engines that represent a clear case for European independence. The activity described here in is a follow on from a Phase 1 activity. The key technology in the proposed design concept is a proportional valve to be used in a close-coupled manner with a large monopropellant thrust chamber. Whereas the initial phase (already detailed in a separate TDA) concentrates on the development of the proportional valve technology, this second phase focuses on the integration of that valve technology with the chamber in a flight like configuration (DM2/EM level) and the development of the necessary front-side propulsion drive electronics A third phase is envisaged to complete the qualification (Note: This activity relates to period 2 only) Expected outputs: Period 2: ? Design development and manufacture of throttle valve elegant breadboard DM ? Design and manufacture of valve driver electronics elegant breadboard DM ? Design of mission specific chamberand catalyst bed - verification at DM level ? Performance verification at DM level					
Deliverables					
This activity relates to period 2 only and deliverables are as follows: DM2/EM engine, valve and drive electronics models CDR/ data pack (based on a generic URD)					
Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2016
Application Mission:	IM/MSR		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**	T-7715, T-8268	
Consistency with Harmonisation Roadmap and conclusion:					
C3: 1-3 KN Throttable Engine(s) The decent engine is likely to require mono-propellant for Mars applications (though bi-propellant remains an option for lunar landing)					

Sample Fetching Rover, Robotics and Mechanisms

Innovative Rover Operations Concepts- Autonomous Planning					
Programme:	TRP		**Reference:**	T309-002HS	
Title:	Innovative Rover Operations Concepts- Autonomous Planning				
Total Budget:	400				
Objectives					
Preparing for future robotic missions in the long-term. Investigation and prototyping of autonomy concepts and operations concepts and technologies.					
Description					
ESA has supported the definition of standards for model definition within the simulator domain (e.g. SMP2, ECSS E-40-07). This study will investigate how these standards can be used within an Exploration Family of Missions mission control environment and how existing models can be re-engineered to use the standard interfaces. This study will incorporate some existing simulator models into an example control system and explore how the enhanced ground models can increase operations effectiveness under different circumstances such as limited return-link bandwidth, time delays and complexity.					
Deliverables					
Report on the investigation on spacecraft and rover operations concepts. Proposals for new concepts for operations of autonomous rovers. Software prototype system. Operational validation document.					
Current TRL:	1	**Target TRL:**	3-4	**Application Need/Date:**	2012
Application Mission:	Exomars follow-on		**Contract Duration:**	12	
S/W Clause:	Operational SW		**Reference to ESTER**	T-8430, T-8431	
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

SPAring Robotics Technologies for Autonomous Navigation (SPARTAN)			
Programme:	ETP	**Reference:**	E913-001MM
Title:	SPAring Robotics Technologies for Autonomous Navigation (SPARTAN)		
Total Budget:	250		
Objectives			
Development of high performance robotics navigation technologies that make minimal use of resources (i.e. frugal or spartan) through the exploitation of highly-parallel processing (by means of suitable algorithms and RAM-FPGA devices) and smart cameras.			
Description			
The activity shall: - identify recent robotic navigation algorithms (in the field of computer vision and path planning) that have the potential for implementation into parallel processing chains while having high performance (i.e. accuracy, frame rate) - trade off the algorithms w.r.t. potential for realisation in space-rated devices - implement the algorithms in a demonstration setup - test and demonstrate the implemented algorithms Rationale: Martian rovers must rely on autonomous navigation and localisation, based on the extensive use of computer vision, in order to attain mission success. Navigation and localisation are the main users of computer resources in a rover. With present technology, for every navigation cycle, a large number of images are collected from navigation and localisation cameras, transferred to a central computer and there processed. Camera communication links, storage and computer power are barely sized to cope with this massive task. However the inherent parallelism of many computer vision algorithms and the possibility of having dedicated processors located at the back of the imagers (i.e. smart camera) allows for implementing a much more efficient navigation system in terms of computing power, memory print, communication needs and finally energy. The subject activity aims at a 30% reduction of all navigation related budgets with respect to present state of the art (ExoMars) while improving with the performance (i.e. accuracy of terrain reconstruction, probability to find paths)			

Deliverables					
Documents:Catalogue of recent robotic navigation algorithms, Algorithm trade-off document, Design Document, User Manual, Test Report Hardware: off-the-shelf avionics to support software/firmware Software: Prototype of navigation system integrated in one of TEC-MMA rovers					
Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2013
Application Mission:	IM		**Contract Duration:**	24	
S/W Clause:	Operational Software		**Reference to ESTER**	T-801	
Consistency with Harmonisation Roadmap and conclusion:					
The activity is consistent with activity B1 (Autonomous Controller) of roadmap 1 produced during the 2007 harmonisation exercise on Automation and Robotics.					

Study of a Sample Fetching Rover for MSR					
Programme:	ETP		**Reference:**	E913-002MM	
Title:	Study of a Sample Fetching Rover for MSR				
Total Budget:	300				
Objectives					
This study will preliminary design a Sample Fetching Rover (SFR) for MSR and will contribute to future MSR architecture studies. It will also concentrate on deriving requirements for future technologies such as the a robotic arm and sampling and transfer system.					
Description					
It is widely acknowledged that an international "Mars Sample Return" (MSR) mission will feature at least two surface elements: a Lander hosting an ascent vehicle and a Sample Fetching- Rover (SFR). The SFR will collect soil samples from the surface/underground while traveling from its landing place towards the Lander. ESA, thanks to the development of the ExoMars drill, is well positioned to provide at least the SFR sample collection system, which will likely feature a drill and a robot arm. The activity shall elaborate on the needs and use of a robot arm on a SFR to allow further development activities. The activity shall include a preliminary design of a Mars Sample Fetch rover concentrating on required resources and performance characteristics that are needed for the overall MSR architecture trade-offs. In addition, the activity will elaborate on the needs and use of a robot arm on a SFR to allow further development activities. It is assumed that the rover will need to acquire soil samples by scooping and by coring. Samples produced by both means will need to be packaged in the same type of 'container' as produced by the drill. It is also assumed that the arm will participate in the transfer of samples from the SFR to the Lander. The arm is likely to require ultra-light mass and high payload capability. The arm and the SFR rover at large will also require mechanism technology that enables safe operating temperatures below -40C, and as low as -100C without any significant pre-heating. The subject activity shall identify a technology roadmap for the SFR and for the key elements such as the robotic arm: - collate user requirements on the arm from various sources (provided by the SOW) - perform an activity analysis to define the elemental fuctions the arm has to provide - derive system requirements - perform a conceptual design and subsystem definition - identify state of the art technologies that will be needed to implement the design, given the likely challenging requirements - define the focus and details of a cornerstone activity on low temperature mechanisms technology to be initiated in 2012 - produce a roadmap for increasing the TRL of such technologies in time for the needs of MSR					
Deliverables					
Sample Fetch Rover Design report, Technology Plan Specific tor follow up robotic arm activity: User Requirement Document, Activity Analysis Document, Conceptual Design document and file, Technology Survey Document, TRL increase roadmap					
Current TRL:	0	**Target TRL:**	1	**Application Need/Date:**	2011
Application Mission:	MSR		**Contract Duration:**	9	
S/W Clause:	N/A		**Reference to ESTER**		

Consistency with Harmonisation Roadmap and conclusion:

DExtrous LIghtweight Arm for exploratioN (DELIAN)					
Programme:	TRP		**Reference:**	T913-003MM	
Title:	DExtrous LIghtweight Arm for exploratioN (DELIAN)				
Total Budget:	800				
Objectives					
Development of a breadboard of robot arm (including annexed tool exchange device) capable of implementing 1) deployment and operation/application of scientific instruments/tools on surface soil/rock, 2) escavation/trenching/scooping of granular soil 3) support for coring 4) transfer of samples within and in/out of the arm base platform.					
Description					
The activity is a follow-on from a previous system study on a Sample Fetching Rover for MSR. The activity shall: 1) further detail the system requirements related to the robotic arm produced by the SFR system activity, include additional requirements that will be provided by the SOW, define verification requirements 2) re-visit the conceptual design on the basis of the updated requirements 3) design and validate by simulation the design 4) Manufacture, assemble and integrate the arm 5) test and demonstrate the breadboard 6) provide recommendations on technology development The breadboard is needed: 1) to verify attainable performance and identify technological issues, 2) to provide a platform for integrated testing of sampling tools, sampling procedures, and the overall system.					
Deliverables					
Documentation: System Requirement Document, Detailed Design Document, User Manual, test report, video describing the development and documenting the tests Hardware: breadboard of robot arm Software: executable code to enable use and testing					
Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2013
Application Mission:	IM		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**	T-2, T-7717	
Consistency with Harmonisation Roadmap and conclusion:					

Surface-Wheel Interaction modelling for Faster Traverse (SWIFT)			
Programme:	TRP	**Reference:**	T913-004MM
Title:	Surface-Wheel Interaction modelling for Faster Traverse (SWIFT)		
Total Budget:	400		
Objectives			
Development and validation of a software modelling tool using state-of-the-art numerical modelling techniques of the relevant physical properties of Martian soil and its interaction with planetary rovers, in support of the design of energy efficient surface mobility and subsurface sample acquisition.			
Description			
A validated tool, based on measured physical/mineralogical properties of Martian soil, is required for design of suspension and wheels of MREP programme's future Sample Fetching Rover (SFR) to optimize energy consumption as well as reduce risk of immobilisation. Interaction of soil with sampling acquisition/handling equipment (important for the SFR) is also an area that can be modeled using the same numerical methods proposed here. This activity will: - Develop a beta version (working implementation) of a S/W modelling tool for use in predicting rover/lander vehicle-soil			

performances and to aid in the design of better wheels. A future extension for sample handling/processing tools can be envisaged; - Use modern FEM methods to create models of Martian soil mechanics properties based on extracted in-situ data of the Martian soil from previous Mars orbital and surface missions complemented by terrestrial experimental data on representative simulants; - Validate the simulation tool through tests under controlled conditions on existing testbeds, and through utilisation of the extensive test results from the ExoMars wheel and loco system tests to be undertaken from starting Oct 2010; - Produce a parametric tool useable by non-experts at ESA and in aerospace industry based on outcomes of a large number of simulation runs. A following activity would be desirable to further validate and strengthen the tool through additional testing using new data (from flight missions i.e., MEX, MRO, MSL) and new Martian soil hypotheses. Phase 1: Review of state-of-the-art and identification of centres of expertise, existing numerical simulation tools and test equipment of the useable parts of soil mechanics and terramechanics for numerical modelling of terrain-vehicle interaction. This includes analysis of effects of gravity and Mars surface environment conditions such as atmospheric composition and temperature. Relevant literature, sources of experimental data and relevant facilities shall be identified and a validation plan shall be set up in order to correlate the simulation results with experimental data. Phase 2: Development, Validation and Application of Numerical Simulation Tools. Work shall be organized as a S/W project with involvement of selected experts, shall include requirements elicitation for simulation tools and test equipment, procurement and implementation of simulation tools, their validation by means of existing testbeds. Based on the outcome of the literature survey and analysis, if required, dedicated equipment shall be used to assess possible effects of Martian atmospheric and temperature conditions on soil behaviour and these effects shall be included in the s/w model if they are shown to impact the soil behaviour significantly. Definition of conditions for terrestrial tests, e.g. relative density for the simulants and the means to realize these conditions in practice ,is part of the work. Note: This activity could also benefit ESA's lunar lander/ rover mission.
Deliverables
1. Validated Soil mechanics models of martian soil 2. Experimentally determined soil parameters of martian soil simulants 3. State-of-the art numerical techniques for modelling vehicle-terrain interaction 4. An easy-to-use, validated parametric model for system engineering of locomotion subsystem design purposes by non-expert users, at ESA and in industry.

Current TRL:	1	**Target TRL:**	4	**Application Need/Date:**	2013
Application Mission:	Mars Sample Return,		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with harmonisation on Automation and Robotics exercise 2001.					

Mechanisms technologies that operate at very low temperatures			
Programme:	ACP	**Reference:**	A915-002MS
Title:	Mechanisms technologies that operate at very low temperatures		
Total Budget:	475		
Objectives			
Development of mechanisms technologies (e.g. solid lubrication, surface treatments, bearings etc) that allow mechanisms to have safe operating temperatures below -40C, and as low as -100C (with flight allowable temperatures even lower than that) to allow the operation of rover locomotion systems, robotic arms, and other such deployable systems without significant pre-heating.			
Description			
The current pre-heating requirements of deployable mechanisms on Mars landers and rovers can require a considerable power budget if operation is needed from the early morning on a Martian sol, even at equatorial latitudes. The MERs were rated to safely operate at -55C while the Beagle 2 arm was rated to -40C. On small rovers and landers, the constraints on battery and solar array size limits the power available for mechanism preheating as the available power has to be shared with locomotion and robot arm operations. Mechanisms (including actuators with motors and gearboxes, etc) that have safe operating temperatures below -40C, and as low as -100C (with flight allowable temperatures even lower than that) are in need of development to allow the operation of rover locomotion systems, robotic arms, and other such			

deployable systems without significant pre-heating. This activity proposes the development of technologies (using inputs from an earlier system study that would identify required technology developments in this area) that would enable mechanisms to operate at very low temperature.					
Deliverables					
Qualified technologies that allow mechanisms used in landers/rovers to operate at very low temperatures.					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2013
Application Mission:	IM		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					

Zero contamination drill bits assessment and tests					
Programme:	TRP		**Reference:**	T924-001QT	
Title:	Zero contamination drill bits assessment and tests				
Total Budget:	200				
Objectives					
To ensure the relevance of the scientific data obtained by ensuring that the drill bit used for sampling Martian soil are not inducing sample contamination.					
Description					
To select and test specific alloys - with or without surface treatment with respect to the degradation they would suffer during drilling of the Martian soil. The induced contamination of the samples will be established and strategies for zero-contamination or, alternatively, well defined contamination falling far out of the soil composition will be established.					
Deliverables					
Test reports, test plan, technical notes, test samples.					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2013
Application Mission:	MSR		**Contract Duration:**	12	
S/W Clause:	N/A		**Reference to ESTER**	T-8392	
Consistency with Harmonisation Roadmap and conclusion:					

Ultrasonic Drill Tool (UDT) - Engineering Model			
Programme:	ETP	**Reference:**	E915-003MS
Title:	Ultrasonic Drill Tool (UDT) - Engineering Model		
Total Budget:	500		
Objectives			
Development and Test of an Engineering Model UDT			
Description			
The ability to reliably drill and retrieve samples from various mediums on and below the Martian surface is a recognised functionality required for Mars exploration. An alternative to conventional rotary or hammer drilling is the use of ultrasonic vibration, which has the following potential benefits - Low axial (thrust) force required. - Lower power consumption than conventional percussion drilling. - The possibility of operation from far less massive and stable drill platforms. - Low sensitivity to axial (thrust) force variations, which is very significant when considering an autonomous, relatively flexible drilling platform. - Low drill bit wear. - Good material removal rates. - Lower bit temperatures, reducing the possibility of damage to the sample. - Clean cutting. - Potentially higher efficiency. - Smaller envelope.			

In 2009, a TEC-MMM led TRP has been completed resulting in a UDT concept which has been tested at advanced BB level. This has demonstrated the viability of the technology and highlighted the areas requiring further development, as well as design improvement recommendations and a development plan. The requirements for the UDT have been set such that the UDT can replace the conventional drill tool currently baselined within the Exomars drill and thus shall be available as an alternative technology to the currently envisaged sub-surface sampling and drilling system.					
Deliverables					
UDT concept development and Tested Engineering Model in representative environments (Pre-qualification of Mechanism and Electronics)					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2014
Application Mission:	MSR		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Ultrasonic Rock Abrasion Tool (RAT) - Engineering Model					
Programme:	ETP		**Reference:**	E915-004MS	
Title:	Ultrasonic Rock Abrasion Tool (RAT) - Engineering Model				
Total Budget:	350				
Objectives					
Development and Test of an Engineering Model RAT					
Description					
The ability to reliably abrade surface rocks to allow contact instrument science to be performed is a recognised functionality required for Mars exploration. An alternative to conventional rotary (mechanical) abrasion techniques is the use of ultrasonic vibration, which has the following potential benefits - Low axial (thrust) force required. - Lower power consumption than conventional percussion drilling. - The possibility of operation from far less stable platforms. - Low sensitivity to axial (thrust) force variations, which is very significant when considering an autonomous, relatively flexible mounting platform. . - Good material removal rates. - Potentially higher efficiency. In 2009, a TEC-MMM led TRP activity was completed resulting in a RAT concept which has been tested at BB level. This has demonstrated the viability of the technology and highlighted the areas requiring further development, as well as design improvement recommendations and a development plan which recommends building and testing an EM. The requirements for the RAT have been set such that the RAT can be mounted on the intended Exomas Instrument Arm. The RAT utilises the same ultrasonic contol electronics and technique as that of the Ultrasonic Drill Tool and therefore can benefit from the electronics development within the UDT development. It is assumed that the Electronics package is developed within the UDT development activity and not within this activity					
Deliverables					
RAT concept development and Tested Engineering Model in representative environments (Pre-qualification of Mechanism)					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2014
Application Mission:	MSR		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

High specific stiffness metallic materials			
Programme:	TRP	**Reference:**	T924-002QT
Title:	High specific stiffness metallic materials		
Total Budget:	500		

Objectives					
To select and characterise metallic based materials having specific stiffness above currently used metals in view of reducing lander/ rover structural mass.					
Description					
The specific stiffness of all metals widely used in space application is about 24 GPa cm3/g. Hence, the benefit of using one metal instead of another is limited when dealing with stiffness driven applications. In this study the metallic reinforcement state of the art will be reviewed for aluminium and titanium alloys; only means of increasing steadily specific stiffness for metallic materials. The in-situ formation of TiB reinforcement in titanium alloy, the Oxide Dispertion Strengthening (ODS) in Aluminium alloys and the concept of Metal Matrix Composites (MMCs) for both Aluminium and Titanium will be traded-off and the most promising materials will be selected for further development and characterisation. Characterisation will be performed according to Martian mission conditions. With the hypothesis that the current design can be retained with highest specific stifffness alloy the weight saving could be up to 70% (probably quite optimisic) - With the hypothesis that current design has to be modified to accommodate processing limitations of the high specific stiffness material weight saving could be 50% (less optimistic). With the hypothesis that only some high stiffness ODS alloy is used, weitht saving would be 20% (pessimistic). Upon adequate characterisation of materials and associated processes, design could be refined to allow additional weight saving. As example, data in literature show: MMC based Ti alloys specific stifffness increased from 40 to 70%. For aluminium alloys, specific stiffness doubled. This leads to a 50% weight saving. With ODS aluminium, increase is 20% in specific stiffness. These types of technologies are required to reach the mass target value of landers / rover. Such high performances alloys could be used also in less demanding application reducing further the mass. NB: This TDA is not competing with the activities on magnesium alloys currently led by David Jarvis, where the structural aspects are not the primarily objectives					
Deliverables					
Technical notes, test-plan, test report, test-samples					
Current TRL:	3	**Target TRL:**	5/6	**Application Need/Date:**	2014
Application Mission:	IM		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**	T8393	
Consistency with Harmonisation Roadmap and conclusion:					

Martian Environmental Materials Effects			
Programme:	TRP	**Reference:**	T924-003QE
Title:	Martian Environmental Materials Effects		
Total Budget:	350		
Objectives			
The objective of this activity is to characterise the impact of the Martian environment on various materials planned to be used on future MSR missions.			
Description			
Mars provides two unusual environmental parameters, i.e. the low vacuum atmosphere and dust/sand storm environment. Both can have detrimental effects on the performance of spacecrafts. This activity aims at characterising the impact of these parameters on materials properties relevant for the success of the mission. Specific emphasis shall be given to materials used for the propulsion elements of MSR. One key critical parameter is the successful launch of the sample return module. Areas of concern are surface contamination, gas (inter)diffusion or abrasion/surface cracking caused by sand storms that all could impair the functioning of the propulsion materials (e.g. nozzle) during ignition after storage on Mars. These paramters are to be assessed on a materials level tested in a relevant simulated Mars environment. (The definition of the materials and interaction shall be done in collaboration with TEC MPE.) Results shall be used to assess the criticality of the Mars environrment on the materials' compatbility and it shall highlight whether the functioning of critical materials can be guaranteed under the Martian atmosphere.			
Deliverables			

All experimental and analysis results in technical notes, test plans and procedures, TN on assessment of criticality.					
Current TRL:	3	**Target TRL:**	6	**Application Need/Date:**	2014
Application Mission:	IM		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					

Planetary Protection Technologies for MSR

Evaluation of Encapsulated Bioburden on Flight Hardware					
Programme:	TRP		**Reference:**	T314-033MM	
Title:	Evaluation of Encapsulated Bioburden on Flight Hardware				
Total Budget:	300				
Objectives					
Develop experimental and statistical approach, test plan, process qualification, evaluation of encapsulated bioburden in modern, generic non-metallic flight hardware.					
Description					
The bioburden limit for flight projects with planetary protection requirements is applicable to surface and encapsulated bioburden. The surface bioburden can be easily measured and controlled. The last time encapsulated bioburden has been measured on typical spacecraft materials was during the Viking project in the 70?s. New materials and processes developed since than have not been evaluated for encapsulated bioburden. This activity will characterise encapsulated bioburden on modern spacecraft materials considering new processes and analysis methods. Using real data instead of conservative estimates will relax the bioburden requirements for flight systems, which is of particular importance for larger flight systems because the bioburden constraints are independent of the spacecraft size and therefore more difficult to meet for large spacecraft's.					
Deliverables					
Test plan, qualified process, test data on specific materials					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2011
Application Mission:	Exomars follow-on		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**	T-7718	
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

MSR biocontainment system sealing and monitoring technologies - development and validation			
Programme:	ETP	**Reference:**	E914-001MM
Title:	MSR biocontainment system sealing and monitoring technologies - development and validation		
Total Budget:	1500		
Objectives			
The objectives of the activity are to: i) to define the sealing technologies for the flight containment system required to ensure a safe return of Mars samples with respect to planetary protection category V, restricted Earth return, within the resources available. ii) develop, test and verify the selected technologies; iii) Update the design concept for the MSR Bio-Containment System; provide recommendations to the MSR system studies.			
Description			
The biocontainment system for a Mars Sample Return mission is one of the key technologies identified by the iMARS that require development. Robust sealing and containment verification is paramount during such a mission prior to a decision being made to allow a return capsule to be placed on a trajectory to enter the Earth. Earlier studies have shown that multiple levels of containment and sealing may be required to break the chain of contact between Mars and Earth. A precursor activity (contract No.:20047/06/nl) demonstrated the basic feasibility of using explosive welding as methods of sealing of the Bio Container (BC). A TRL level 2 was achieved. Use of brazing methods was also explored. The proposed activity includes: i) Consideration and evaluation of the biocontainment requirements (including planetary protection) and of the mission requirements, including environmental aspects. Definition of a concept for the MSR Bio-Containment System, including appropriate scaling laws and their consequences in view of the early definitions available for MSR; identification of the required sealing technologies, definition of selected samples and tests; ii) Development of sealing technologies and processes and their testing. The tests will: - use representative test samples/models for the individual technologies and use flight-like materials; - demonstrate the implications of the sealing processes on the spacecraft (e.g. heat and debris generation, shock loads, etc.); iii) Update the design concept for the MSR Bio-Containment System and provide recommendations to the system design.			

It is expected that a follow-on activity (not part of the present proposal) will then apply the validated technologies to a flight representative containment system breadboard for integrated testing					
Deliverables					
Documentation Test Samples Software models					
Current TRL:	2	**Target TRL:**	5	**Application Need/Date:**	2012
Application Mission:	MSR		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**	N/A	
Consistency with Harmonisation Roadmap and conclusion:					
not known					

MSR biocontainment system - breadboard and validation					
Programme:	ETP		**Reference:**	E914-002MM	
Title:	MSR biocontainment system - breadboard and validation				
Total Budget:	2000				
Objectives					
The objective of the activity is to adapt the verified sealing technologies developed in a previous activity, to an integrated breadboard for a Mars Sample Return flight containment system validating the integrated technology breadboard in a relevant environment.					
Description					
A previous activity to this proposal aims at selecting and testing the sealing and closure technologies that will be required for the Mars Sample return biocontainment system. Also, results of the MSR system studies are expected to be available and with them the MSR environmental conditions and the inputs to a detailed design of the Mars Sample Return Containment System. Building on these results, the present activity will: - Design an integrated and flight representative Mars Sample Return Flight Containment System breadboard - Build the Mars Sample Return Flight Containment System breadboard - Test and validate the breadboard. - Produce a set of recommendations and requirements to the MSR flight return container detailed design.					
Deliverables					
Documentation Breadboard					
Current TRL:	2	**Target TRL:**	5	**Application Need/Date:**	2014
Application Mission:	MSR		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

MSR complete biocontainment flight system development and test				
Programme:	ETP	**Reference:**	E914-003MM	
Title:	MSR complete biocontainment flight system development and test			
Total Budget:	0			
Objectives				
The objective of this activity is to design and build the MSR flight retun containment system on the basis of the previously developed technologies.				
Description				

In this activity the contractor shall design and build the containment system(s) required to bring back a sample from Mars cosisting of: Sample vessel (SV) = containing the sample Sample container (SC)= transport vehicle for SV from Mars to the ERC BioSeal (BS)=breaking the link to the martian environment BioContainer (BC) = Safety containment for the SV Monitoring and data logging system and integration The contractor has to take into account the actual PPRs and shall make use of the technologies developed for this task in previous studies. Special attention shall be paid as well to the re-opening techniques of the containers. Further it is required that the contractor maintains QS and H/W log. The Cost of this activity is to be defined when relevant information from precursor TDAs are available.
Deliverables
A completely build and tested flight return containment system for a sample from Mars. All required functions (seals, mechanics, monitorung and data storage, interfacing/interacting of the single vessels and containers) demonstrated and verified under TBD conditions.

Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2019
Application Mission:	MSR		**Contract Duration:**	80	
S/W Clause:	N/A		**Reference to ESTER**	n.a.	
Consistency with Harmonisation Roadmap and conclusion:					
not known					

System study of Mars spacecraft compatibility with a terminal decontamination process			
Programme:	GSP	**Reference:**	G914-004SY
Title:	System study of Mars spacecraft compatibility with a terminal decontamination process		
Total Budget:	200		
Objectives			
Verify the use of a terminal decontamination process on a Mars Lander for compliance to planetary protection requirements. Review of impact of such process on the Lander design and the qualification of parts and assemblies. Identification of required technology developments to allow terminal decontamination (roadmap)			
Description			
To comply with the stringent planetray protection requirements on number of bio-contaminants allowed, the Viking project applied a terminal (e.g. right before launch) contamination reduction process to the whole lander and with all the sub-systems already installed, including the RTG, batteries, pyros, payload, etc. The process consisted on a 111?C, 50 hour bake under constant nitrogen flow within a specifically designed oven. Recontamination was prevented by using a bioshield that encapsulated the entire lander and was deployed after launch. This approach was successful for both Viking lander systems but required a very substantial and costly development and test effort. The facility has been later dismantled as no further Mars mission had to cope with the same level of requirements to date. However, a MSR mission would have similar contamination control requirements than Viking with the additional complexity of a more complex sample transfer system and Lander (drill, rover, MAV, sample container). It is likely that a terminal process over all these elements assembled together has to be used. Applying high temperature for a significant duration to an assembled spacecraft may have severe consequence on the design as it has to be ensured that each part (including insulated ones) reach a level consistent with sterilisation. This may generate thermal distortion or damage to units. In addition, spacecraft components will need a delta-qualification or specific developments to cope with the process. It is proposed to perform a detailed system study taking as reference the MSR phase A Lander design and existing Lander untis (e.g., ExoMars parts and assembly list) to identify: a) driver for the design of such Lander through a detailed thermal analysis, b) the critical sub-systems and components that would require a dedicated technology development, c) adaptation of the terminal sterilisation process to cope with possible spacecraft shortcomings and to reduce cost.			
Deliverables			
Technical Notes describing: a) Lander sterilisation thermal analysis and suggestions on Lander design, b) parts and assemblies which			

are compatible/not-compatible with a terminal contamination reduction process, c) Technology development roadmap for parts/assemblies that require delta-qualification, new qualification or substitution, d) possible alternative (to Viking) sterilisation process parameters.					
Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2013
Application Mission:	MSR		**Contract Duration:**	12	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					

System study of an efficient Mars sample recovery strategy after return to Earth					
Programme:	GSP		**Reference:**	G909-002SY	
Title:	System study of an efficient Mars sample recovery strategy after return to Earth				
Total Budget:	200				
Objectives					
Definition of the end-to-end operations, technologies and devices for MSR sample recovery from targeting Earth re-entry to safe delivery of sample to biocontainment facility					
Description					
The activity consists in a system study of the MSR sample recovery to identify any required development in operations, technologies for recovery, technologies for tracking and hardware for transportation to biocontainment facility. The study shall build upon and complement the MSR mission Phase A studies at ESA and NASA (which normally assume end of mission at Earth landing) and the activities performed on biocontainment facility (which assume sample delivered at the facility). The activity shall include: 1. Trade-offs on recovery operations/techniques for minimum time and maximum probability of recovery (examples of such options are e.g. helicopter snatching vs landing and search, parachute landing versus completely passive landing, location techniques, etc.) 2. Assessment of designs of hardware onboard the Earth Return Capsule (ERC) for location (e.g. beacon) 3. Assessment of required safety procedures at the landing site and safety certification of operations/landing site 4. Assessment of transportation and handling means for the sample container after landing 5. Assessment of navigation techniques for precise entry targeting and high landing accuracy to reduce area to be searched and to be made safe (for information, the present MSR studies have calculated a landing accuracy of 200 Km with conventional navigation techniques) 6. Assessment of impact of recovery operations on mission/system design (e.g. recovery time is a driver for the ERC battery, whose mass in turn is a mission driver as it "sees" a double delta-V, to Mars and back) Because of the critical feedback loop to flight system and ground system this activity has been identified by the joint ESA-NASA iMARS group as a critical activity for a MSR mission.					
Deliverables					
Recovery techniques trade-off report Baseline recovery operations report Recovery techniques and technology development plan Transportation and handling device design report					
Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2013
Application Mission:	MSR		**Contract Duration:**	9	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					

Double walled isolators for MSR Sample Receiving facility				
Programme:	ETP	**Reference:**	E914-005MM	

Title:	Double walled isolators for MSR Sample Receiving facility				
Total Budget:	1000				
Objectives					
Design, breadboard and validate double walled isolators to receive and analyse MSR samples in clean and ultra clean environment.					
Description					
The challenge of the MSR Sample receiving facility (MSR SRF) is to comply with planetary protection measures and hence prevent any release of material or contamination of the earth environment with hazardous material potentially present in the MSR samples. The concept of low pressure facility like Bio Safety level 4 laboratories is adequate. But no one wants the priceless samples to be contaminated by earth organic molecules or microbes that would definitely spoil the scientific value of the sample, so leak-in is out of question. In order to maintain a clean, contained environment for curation and analysis of returned Mars samples, a double walled isolator with a controlled, inert atmosphere has been identified as a crucial concept. The isolator must provide an atmosphere carefully controlled for: - Composition (ultra pure N2 TBC/inert gas) - Low Relative humidity - Low temperatures - Control of electrostatic environment The isolator must provide a negative pressure environment for containment, with the void between the walls controlled at a positive pressure to the interior and lab environment to aid in minimising the entrance of terrestrial contamination. Interfaces must be available to pass the samples into and out of the isolator. The isolator must be capable of housing a robotic remote manipulation system, and interfacing with a broad range of scientific instrumentation. In conjonction, the prevention of terrestrial contamination, control of cross contamination between samples and recovery of valuable Martian material following handling processes is of high importance within the MSR SRF. As such a decontamination process and ultra cleaning technologies must be developed that can: - Clean thoroughly all equipement in contact with the MSR hardware and samples - Recover solid materials from surfaces (to the return vault) - Sterilise and clean extensively all isolators surfaces between each sample Bio Hazard Assessment protocol and Life detection analysis, to a level of ng/cm2 - Work within environmental conditions imposed within the MSR BCF (Could be Mars-like, low temperature, low RH) - Be administered by automated process - Be able to be validated after operation (either by direct validation or process qualification)					
Deliverables					
Design, reduced scale demonstrator of the double walled isolator concept, verification of cleanliness and contamination control					
Current TRL:	1	**Target TRL:**	5	**Application Need/Date:**	2013
Application Mission:	2020+		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					

Micro remote manipulation systems for MSR Sample Receiving Facility			
Programme:	ETP	**Reference:**	E914-006MM
Title:	Micro remote manipulation systems for MSR Sample Receiving Facility		
Total Budget:	400		
Objectives			
Identify new robotic technologies to perform micro manipulation of MSR samples in low temperature and non contaminating environment			
Description			
To handle returned Mars samples for biological hazard assessment, whilst maintaining the science contained within them, it will be necessary to make use of remote manipulation systems to remove contaminating humans as much as possible from the process. These systems will need to be able to: - Handle the samples and sub samples (order of grams down to micro grams) - Operate in a freezer temperature (~250K), ambient or low pressure, dry Nitrogen /(other inert gaz TBC) environment - Produce a minimum of contamination into the sample environment from the materials and lubricants used in their construction.			

- Be able to be sterilised via a qualified process prior to installation in the containment area - Be able to operate for a minimum of 6 months with a minimum of planned servicing - Operate in a double walled isolator with minimal through wall intrusion.					
Deliverables					
Feasibility study + proof of concept					
Current TRL:	0	**Target TRL:**	3	**Application Need/Date:**	2013
Application Mission:	MSR		**Contract Duration:**	12	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					

Autonomous Rendezvous and Capture

Integrated GNC solution for Autonomous Mars Rendezvous and Capture					
Programme:	ETP		**Reference:**	E905-010EC	
Title:	Integrated GNC solution for Autonomous Mars Rendezvous and Capture				
Total Budget:	750				
Objectives					
To develop the complete design of the GNC system covering all the RVD phases of the MSR mission, capable to demonstrate the capture of a Martian canister. This will be done by reusing where applicable and further the available RVD development and experience in Europe. The complete GNC system will be designed, from the optimisation of the GNC strategies to the selection and specification of the rendezvous sensors suite, tailored to the current MSR scenari					
Description					
The activity shall start from past studies (incl. the 2 HARVD and Mars NEXT ones) and experiences and the GNC requirements for such systems. In particular, the synthesis and analysis of the multivariable GNC system. The design shall make use of sensors (cameras, RF sensors and LIDAR) and actuators developed in parallel activities with special emphasis on the design of the end-to-end rendezvous navigation chain for which dedicated feasibility analysis and preliminary requirements shall be provided. Model uncertainties shall be identified, quantified and used in the design process. All the MSR rendezvous phases from finding the target in space to the capture shall be covered with the corresponding modes transition. A sofware simulation and validation platform with real-time and hardware-in-the-loop capabilities will be further developed starting from an existing one. FDIR needs and solutions shall be identified and developed to make the system failure tolerant beyond its inherent robustness by design. Identified alternative techniques that can benefit to the success and optimisation of the MSR rendezvous strategy shall be considered to the level where comparative trade offs can be performed. This does include the study of elliptical scenarios in a dedicated WP (GNCO heritage), including an assessment of the maximal orbital parameters boundaries that can be handled by an autonomous GNC in the initial phases fo the MSR rendezvous. Plans shall be elaborated for the development of the selected architecture for early prototyping prior to potential adoptation by a project at TRL6.					
Deliverables					
A fully functional GNC system for all the MSR RVD phases with all algorithms implemented on a real-time test-bench. Requirements for the MSR rendezvous sensors. A fully functional GNC performance simulator in both RT and non real time version.					
Current TRL:	3-4	**Target TRL:**	5	**Application Need/Date:**	2012
Application Mission:	IM		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					

MSR Rendezvous Optical Sensors EM development			
Programme:	ETP	**Reference:**	E905-011EC
Title:	MSR Rendezvous Optical Sensors EM development		
Total Budget:	800		
Objectives			
The objective is to design and develop EMs of the specific optical sensors required for sample canister location and tracking during autonomous Mars rendezvous			
Description			
An optimised suite of sensing equipment, meeting the multi-range requirements of the MSR rendezvous, is derived in an earlier iGNC Solution for MSR RDV and Capture activity. Based on the sensors requirements of the integrated GNC design activity, this activity will examine firstly the sensor requirements for canister rendezvous and capture, then perform the detailed design of the optical based sensors meeting those requirements. Currently it is expected that two types of optical sensor will need to be developed alongside an initial RF location sensor in order to provide all required information over the full RDV range.			

The core technology on which to base the most likely candidate sensors is either currently in development (e.g. Lidar, VisNav) or has already been developed (e.g. STR, ATV sensors, Rosetta navigation camera). This activity will build on that background knowledge and experience to design, manufacture and test an EM sensor of each of the required types. The sensor hardware as well as software and embedded algorithms will be implemented as an EM and the actual performance, mass, dimensions, power and environmental compatibilities will be tested and validated. The EM will also be compatible with later integration into the exisiting GNC RDV on ground test system and used to validate the end-to-end RDV GNC system in a next step.					
Deliverables					
Analysis, definition and development plan for an optimised MSR rendezvous sensing equipment suite. Breadboard to demonstrate laboratory performance and subsequent end-to-end GNC testing.					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2013
Application Mission:	IM, MSR		**Contract Duration:**	12	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					
AOCS Sensor and Actuator Harmonisation Roadmap Issue 3, 3D Cameras, Aim C, Activity C1(to be adapted versus selected technology)					

RF Long Range Navigation Sensor Breadboard					
Programme:	ACP		**Reference:**	CG80	
Title:	RF Long Range Navigation Sensor Breadboard				
Total Budget:	300				
Objectives					
Design and Development of a breadboard of an RF Long Range Navigation Sensor for Long-Range Rendez-Vous stages in the Mars Sample Return.					
Description					
From Mars Sample Return mission analyses it has been shown that the best technology to support the Long-Range Rendez-Vous operations is the one based on RF. This activity will elaborate the necessary trade-offs to find the most suitable RF technology (transponder-like two-way ranging, Formation-Flying-like RF metrology, radar). The starting point will be the mission requirements (nominal plus a wide range of degraded mission scenarios) and a 1st-version of the technical specifications of the RF sensor. The contractor will also consolidate the technical specification based on the afore-mentioned trade-offs, and produce an architectural design. From this architectural design, a breadboard will be developed. This breadboard will be representative of the critical subsystems contained in the architectural design. The breadboard will be used by the contractor to demonstrate on the feasibility of the chosen technology and architecture for the Mars Sample Return Mission.					
Deliverables					
Technical Notes and breadboard to demonstrate on critical technologies.					
Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2012
Application Mission:	Mars Sample Return and missions alike with long-range Rendezvous requirements		**Contract Duration:**	12	
S/W Clause:	N/A		**Reference to ESTER**	T-7723, T-7745, T-8070	
Consistency with Harmonisation Roadmap and conclusion:					
FF Radio Frequency Metrology. Technical Dossier and Roadmap. TEC-ETN/2007.64					

RF Long-Range Navigation Sensor for Rendezvous EM Development			
Programme:	ETP	**Reference:**	E906-002ET
Title:	RF Long-Range Navigation Sensor for Rendezvous EM Development		
Total Budget:	1000		
Objectives			

The development to Engineering Model level of a sensor able to provide long range sample canister location during MSR rendezvous.					
Description					
The MSR cannister of samples (target vehicle) will be launched from the Martian surface and injected in a stable orbit, with severe limitations on payload capacity and resources. Injection accuracy relative to the target vehicle waiting in orbit will be limited by the navigation means of the ascent stage, its surface location, timing and the target vehicle navigation. The target vehicle shall be then detected and tracked by an orbiter (chaser) that will subsequently performed the corresponding rendez-vous manoeuvres. In the detection of the target vehicle, a significant dispersion is expected, which will require therefore in-orbit navigation means from up to thousands of kilometers. Previous studies at mission analysis level and preparatory work for the Aurora Core Programme activity CG80 "RF Long-Range Navigation Sensor Breadboard and Engineering Model" (temporarily on hold) has shown that RF-based sensors in chaser and target vehicles are the optimal approach in order to achieve navigation across long ranges. Activity CG80 (to be shortly resumed with a re-arranged scope) targets the trade-offs, design and bread-boarding aspects. The next logical step is the development of the engineering model in the proposed activity as a follow-on of CG80. The CG80 activity (in its new scope) will achieve TRL3. The proposed activity will go from TRL3 to TRL5. The objective of this activity is the development of the Engineering Model based of the RF Long-Range sensor based on the results of the previous Aurora CG80 activity, together with the corresponding lab testing and the necessary design consolidation. The engineering Model comprises two units. One to be installed in the chaser and the other to be installed in the target vehicle. Both units will be architecturally very different due to different nature of the platforms (chaser and target vehicle). This EM can be also used to study feasibility of the same concept for long-range rendezvous in other planetary/Moon missions.					
Deliverables					
Engineering model of the long-range RF sensor (two units: one to be on-board of orbiter and the other to be on-board of sample container vehicle).					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2013
Application Mission:	IM,MSR		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					

End to end ground testing of GNC solution for Autonomous Mars Rendezvous and Capture					
Programme:	ETP		**Reference:**	E905-012EC	
Title:	End to end ground testing of GNC solution for Autonomous Mars Rendezvous and Capture				
Total Budget:	800				
Objectives					
To perform an end-to-end integrated testing of the GNC system covering all the RVD and capture phases for a MSR and precursor type mission. The tests will be conducted in closed-loop in an existing dedicated ground facility, reproducing as much as possible flight-like conditions.					
Description					
Building on the dynamic test benches with hardware-in-the-loop capabilities developed in past studies (HARVD), the activity shall conduct ground validation campaigns of the previously developed GNC systems for Mars rendezvous. The goal will be to perform an integrated testing covering all the phases of the MSR rendezvous: search & detection, homing and terminal rendezvous in a representative dynamics environment and using mature GNC avionics.					
Deliverables					
Open and closed-loop tests results. Validated rendezvous system in a ground representative environment.					
Current TRL:	5	**Target TRL:**	6	**Application Need/Date:**	2015
Application Mission:	IM,MSR		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					

Sample Canister Capture Mechanism Design and Breadboard			
Programme:	ACP	**Reference:**	CG50
Title:	Sample Canister Capture Mechanism Design and Breadboard		
Total Budget:	350		
Objectives			
Develop alternatives concepts and BBM testing of a MSR capture mechanism (CM), not involving inflatable structures.			
Description			
The Mars Sample Return (MSR) mission will send a Lander to Mars, to acquire samples of Martian soil and return them to Earth. During the return phase, a Sample Container (SC) carried by a Mars Ascent Vehicle (MAV) shall be transferred to a Mars Orbiter and then to the Earth Return Capsule (ERC). The Phase A2 MSR system studies consider that the transfer of the SC from the MAV to the Orbiter could be performed either by Capture or by Docking, i.e. with: - a Capture mechanism (CM), catching a free-flying, passive SC, - a Docking mechanism (DM), mating the MAV on the Orbiter to take the SC. In the capture scenario, the SC (quasi-spherical) will be released by the MAV into a free flying Mars orbit. The Orbiter will manoeuvre to approach the incoming SC with adequate position, velocity and attitude and the SC will be captured by the CM. The CM will transfer the captured SC through its outlet toward the trap, an enclosure in the Orbiter, in which it will be secured; from the trap, subsequent SC processing operations will be performed by other subsystems - essentially bio-sealing and transfer to the ERC. In a previous ESA activity (Aurora Capture / Docking Mechanism - ACDM) a conceptual study of CM and DM candidates was carried out, and an Inflatable Capture mechanism (ICM), with a rigid frame, was selected and developed: a Breadboard Model was built and tested successfully on ground at ambient. In a follow-on ESA activity (Capture / Docking Mechanism Testing), a modified, fully inflatable ICM was developed at EM level for TV testing: following successful functional testing at ambient, the inflatable envelope was found leaking in several places after vibration testing; eventually, thermal vacuum testing could not be performed. The aim of this activity is to investigate alternatives concepts for the CM, not involving inflatable structures. Relevant earlier concepts from ACDM will be revisited. A BBM with 0-g simulation GSE for SC will be tested in laboratory environment. Follow-on activities will be proposed, to develop the CM up to TRL 5, including thermal vacuum (TV) and parabolic flight (PF) testing. Note: the requirements of a CM with limited stowed volume imposed a deployable capture cone, which later favoured the selection of an inflatable CM. Alternatively, allowing a larger stowed envelope, a simpler CM with a solid, non-deployable capture cone has been developed for NASA-JPL by Honeybee Robotics and successfully tested in parabolic flight. A similar increase of the CM stowed envelope requirement would be beneficial for simplicity and mass.			
Deliverables			
BBM of CM, SC GSE ejection device with 0-g simulation, electronics, harness and required mechanical and electrical GSE for laboratory testing.			

Current TRL:	2-3	**Target TRL:**	4	**Application Need/Date:**	2012
Application Mission:	MSR		**Contract Duration:**	12	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					

Sample canister capture mechanism parabolic flight test			
Programme:	ETP	**Reference:**	E915-005MS
Title:	Sample canister capture mechanism parabolic flight test		
Total Budget:	150		
Objectives			
Parabolic Flight testing of a non-inflatable sample capture mechanism breadboard for automated Mars orbit rendezvous			
Description			
The current baseline for a MSR mission requires a rendezvous of the Mars orbiter with the Mars Ascent Vehicle (MAV)			

or free-flying Sample Container (SC) to capture and transfer the SC to the Earth Return Capsule (ERC). A previous activity under the Aurora Core Programme will have developed a breadboard of a non-inflatable sample canister capture mechanism. This activity is aimed at parabolic flight testing of the breadboard to demonstrate the terminal phase of autonomous sample capture during Mars orbit rendezvous. The contractor shall be responsible of relations with the French ?Centre d?essais en vol? and with Novespace for the organization of a parabolic flight test campaign.					
Deliverables					
Test results from parabolic flight test campaign of the capture mechanism breadboard.					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2012
Application Mission:	MSR		**Contract Duration:**	6	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					

MSR Sample capture mechanism EM development and testing					
Programme:	ETP		**Reference:**	E915-006MS	
Title:	MSR Sample capture mechanism EM development and testing				
Total Budget:	500				
Objectives					
EM development and testing of a capture mechanism (CM), not involving inflatable structures.					
Description					
The Mars Sample Return (MSR) mission will send a Lander to Mars, to acquire samples of Martian soil and return them to Earth. During the return phase, a Sample Container (SC) carried by a Mars Ascent Vehicle (MAV) shall be transferred to a Mars Orbiter and then to the Earth Return Capsule (ERC). The Phase A2 MSR system studies consider that the transfer of the SC from the MAV to the Orbiter could be performed either by Capture or by Docking, i.e. with: - a Capture mechanism (CM), catching a free-flying, passive SC, - a Docking mechanism (DM), mating the MAV on the Orbiter to take the SC. In the capture scenario, the SC (quasi-spherical) will be released by the MAV into a free flying Mars orbit. The Orbiter will manoeuvre to approach the incoming SC with adequate position, velocity and attitude and the SC will be captured by the CM. The CM will transfer the captured SC through its outlet toward the trap, an enclosure in the Orbiter, in which it will be secured; from the trap, subsequent SC processing operations will be performed by other subsystems - essentially bio-sealing and transfer to the ERC. The proposed activity will follow-on from a parabolic flight test campaign (proposed as a preceeding activity within the MREP programme)of a CM breadboard, developed in an earlier Aurora Core Programme activity. In this proposed activity, the existing BBM will be upgraded to EM level and tested to develop it up to TRL 5-6, this including thermal vacuum (TV) and parabolic flight (PF) testing. The PF test bench will include a SC ejector allowing variable SC velocity and angle; it will be free-floating to minimize disturbances.					
Deliverables					
EM of CM, SC GSE ejection device with 0-g simulation, electronics, harness and required mechanical and electrical GSE for laboratory testing					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2014
Application Mission:	IM		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					

Earth Re-entry Capsule for MSR

GNSS Tracking Technology for MSR Earth re-entry					
Programme:	ETP		**Reference:**	E905-013EC	
Title:	GNSS Tracking Technology for MSR Earth re-entry				
Total Budget:	100				
Objectives					
The main objectives of the activity is to assess the feasibility of using Global Navigation Satellite Systems (GNSS) measurements for MSR Earth re-entry, hybridized with other measurements such as IMU and STR.					
Description					
After the capture of the canister around Mars, MSR is put back on an Earth Avoidance orbit, and the canister is released again in Earth vicinity a few days before re-entry. At that time, the release accuracy of the canister is of primary importance to ensure the canister falls in the right geographical zone. Even if the landing zone is quite large, safe landing and recovering the capsule containing the sample is challenging considering the high re-entry velocity (greater than 10 km/s), the fact that the re-entry will be uncontrolled (ballistic entry) , and the long duration since carrier separation (a few days). Ground restitution techniques can enable to estimate accurately the orbit before the capsule release ; however, this requires important ground involvement, and may not be robust to last-moment events (such as outgasing, debris or micro-meteoritic impact). An alternative could be the use of GNSS measurements to improve the pre-release navigation performance. GNSS systems provide continuous measurements, virtually available anywhere in Earth vicinity, the power of the received signal decreasing as the square of the distance. Fusion with other measurements might improve a GNSS receiver acquisition & tracking capability : for example, an Ultra-tight integration of GNSS with IMU measurements has shown to provide a 10 dB increased tracking capability compared with standalone receivers (cf HiNAV TRP study), which could be used to sustain low C/N0 tracking conditions in MSR re-entry case. The present activity consists in assessing the feasibility of using GNSS measurements, possibly hybridized with other sensors (IMU, STR), to perform the accurate release of the capsule containing the sample before Earth re-entry. The activity will first analyze the possible use of GALILEO and/or GPS constellations, then design receiver architecture (incl. antennae design, RF Front End, Asic) to sustain low C/N0 signal processing, the level of fusion required with other sensors and develop the navigation algorithms. The possibility to have a single RF sensor design to handle both Re-entry measurements (GNSS) and canister capture in Mars orbit will also be part of present activity: such a design would offer the benefit of having a unique but dual RF equipment. The RF-sensor preliminary design, and a RF-sensor model, as well as the navigation algorithms will be developed in the frame of this activity, and validated on a dedicated simulator .					
Deliverables					
Technical documentation and SW : RF sensor simulator model, navigation algorithms, and simulator.					
Current TRL:	1	**Target TRL:**	2	**Application Need/Date:**	2013
Application Mission:	MSR		**Contract Duration:**	10	
S/W Clause:	N/A		**Reference to ESTER**	TBD	
Consistency with Harmonisation Roadmap and conclusion:					

Design of a crushable TPS for the ERC			
Programme:	TRP	**Reference:**	T319-036MC
Title:	Design of a crushable TPS for the ERC		
Total Budget:	370		
Objectives			
The objective of the proposed activity is to investigate ways of building a multifunctional structure, that acts as a heatshield for planetary re-entry (supporting Thermal Protection System, TPS), but also brings damping capability for hard landing.			
Description			
For the re-entry phase, the TPS is sized to limit the temperature on the inner side of the lander, i.e. a thermal insulation is needed between the external surface and the inside "cold" structure and payload. During the hard landing phase, mechanical decoupling is needed between the external surface that hits the ground at high velocity and the inner payload for which deceleration load shall be limited. This dual thermal/mechanical insulation need leads to the idea of using one single structure, possibly a composite made of several materials, e.g. CFRP foam, honeycomb or the titanium hollow spheres to be developed, to achieve both isolation functions.			

Such a multifunctional structure would allow simplifying the lander architecture, reducing the number of sub-assemblies and thus reducing the mass and complexity. - Review of the MSR requirements for heatshield and earth impact after re-entry. - Investigate solutions to combine the structural/thermal and impact damping functions of the heatshield. Identify the material characteristics needed and potential candidates, including foams, honeycomb and hollow spheres. Trade-off the solutions. - Provide a material specification as input for the activity on low conductivity/high temperature crushable material using hollow spheres - Design and analyses of a MSR integrated heatshield and earth impact damping structure, possibly using titanium hollow spheres if this material proves best suited and sufficiently mature. - Manufacturing and impact tests of a breadboard (several might be needed for several destructive tests).					
Deliverables					
Documentation (Final Report, Summary Report, and Technical Data Package, incl. Photographic Documentation). Hardware (breadboard).					
Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2012
Application Mission:	NEXT, MSR (>2016)		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**	High Speed Earth Re-Entry of Sample Capsules: Advanced Heat Shield Concepts	
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Material development for a crushable TPS for the ERC					
Programme:	TRP		**Reference:**	T920-002QT	
Title:	Material development for a crushable TPS for the ERC				
Total Budget:	250				
Objectives					
To establish manufacturing technology and scale-up of crushable hollow-sphere made of Ti alloy for use in a crushable TPS for Earth landing during an MSR mission. To characterise the static and dynamic mechanical properties of the material, as well as the physical and chemical properties. To develop and characterise joining techniques of the Ti alloy hollow-sphere to conventional materials used in space applications.					
Description					
The crushable materials are today either honeycomb or polymeric (or carbon) foams. The honeycomb can sustain only compressive stresses and looses its effectiveness when stressed in the nominal direction, the foam are limited to low temperature or procured outside Europe. In this activity, the pure Ti hollow-sphere technology (contract 18167) will be transferred to a high performance Ti alloy. The mechanical and physical characteristics of the material will be established at high and room temperature, the technologies for joining the Ti hollow-sphere to other materials will be developed and characterised. This material is theoretically far better than any existing ones for such passive landing applications as it combines high specific stroke properties with high in-service temperature (about 600C) and a low thermal conductivity.					
Deliverables					
Technical notes - Test samples - Test reports - Breadboard - industrial development roadmap					
Current TRL:	2 - 3	**Target TRL:**	3-4	**Application Need/Date:**	2012
Application Mission:	MSR		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**	T-8148	
Consistency with Harmonisation Roadmap and conclusion:					

Delta-development of TPS for high heat loads					
Programme:	ETP		**Reference:**	E921-002PA	
Title:	Delta-development of TPS for high heat loads				
Total Budget:	1000				
Objectives					
The objective is to complete the development, and subsequently characterise and pre-qualify a European ablative heatshield TPS material for the Earth re-entry capsule, able to cope with the stringent environment (typical peak heat fluxes of 15-20MW/m2 and heat loads up to 200MJ/m2) while conforming to the mass budget. The development shall be based on the material developed in a previous TRP-activity. The pre-qualification shall include an extensive plasma test campaign.					
Description					
This activity shall also investigate aerodynamics issues such as static, dynamic stability, etc. and thus include wind tunnel tests with a representative demonstrator of the MSR re-entry capsule (on which the selected TPS material can be mounted) at different flight regimes taking into account ablation and pyrolysis effects which should be an outcome of the ablative material characterization phase described above. The TRL shall be brought from 4 to 5 during this activity. Technology Heritage 1) Low-density TPS - TRP activity: "Development of a European Ablative Material". The ongoing activity will prepare the ground (requirements consolidation, development of manufacturing routes, preliminary material development and characterisation). The activity proposed here will represent the logical follow-on to complete the material development and pre-qualification. 2) High-density TPS - SEPCORE concept (1990's CNSR development), ARD and military applications (restricted access to the data)					
Deliverables					
Material samples, documentation					
Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2013
Application Mission:	MSR		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**	T-8283, T-8538	
Consistency with Harmonisation Roadmap and conclusion:					

Long term technologies - Nuclear Power

European Nuclear Isotope Evaluation, Selection and Feasibility Study					
Programme:	TRP		**Reference:**	T303-039EP	
Title:	European Nuclear Isotope Evaluation, Selection and Feasibility Study				
Total Budget:	150				
Objectives					
Identify the most appropriate Nuclear Power System (NPS) radionuclide (radioactive element) for production within ESA member states. Determine the feasibility, cost and timescale of production for a pre-specified radionuclide within ESA member states.					
Description					
During Phase 1 the various radioisotopes with potential for use in decay-heat space nuclear power systems shall be considered and technically evaluated along their performance. Similarly, the feasibility and cost of production, within the ESA member states, shall be considered. A trade-off analysis shall be performed, resulting in a recommendation of the best (if any) isotope. Synergies with other (non-ESA) applications will be considered. During Phase 2 the Contractor shall examine and report upon the feasibility, cost impacts and timescale of production for this radionuclide within ESA member states.					
Deliverables					
Phase 1 Report with recommended isotope. Phase 2 report with feasibility assessment including identification of production facilities and cost impacts.					
Current TRL:	1	**Target TRL:**	2	**Application Need/Date:**	TRL5-6 by 2014-2015
Application Mission:	All exploration missions e.g. Mars Sample Return (>2016) and following exploration missions		**Contract Duration:**	6	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with the nuclear power dossier and proposed roadmap					

European Nuclear Isotope Evaluation, Selection and Feasibility Study					
Programme:	TRP		**Reference:**	T303-039EP-B	
Title:	European Nuclear Isotope Evaluation, Selection and Feasibility Study				
Total Budget:	150				
Objectives					
Identify the most appropriate Nuclear Power System (NPS) radionuclide (radioactive element) for production within ESA member states. Determine the feasibility, cost and timescale of production for a pre-specified radionuclide within ESA member states.					
Description					
During Phase 1 the various radioisotopes with potential for use in decay-heat space nuclear power systems shall be considered and technically evaluated along their performance. Similarly, the feasibility and cost of production, within the ESA member states, shall be considered. A trade-off analysis shall be performed, resulting in a recommendation of the best (if any) isotope. Synergies with other (non-ESA) applications will be considered. During Phase 2 the Contractor shall examine and report upon the feasibility, cost impacts and timescale of production for this radionuclide within ESA member states.					
Deliverables					
Phase 1 Report with recommended isotope. Phase 2 report with feasibility assessment including identification of production facilities and cost impacts.					
Current TRL:	1	**Target TRL:**	2	**Application Need/Date:**	TRL5-6 by 2014-2015
Application Mission:	All exploration missions e.g. Mars Sample Return (>2016) and following exploration missions		**Contract Duration:**	6	
S/W Clause:	N/A		**Reference to ESTER**		

Consistency with Harmonisation Roadmap and conclusion:
Consistent with the nuclear power dossier and proposed roadmap

European isotope production: Phase 1, samples and testing. (Including safety provisions)					
Programme:	ETP		**Reference:**	E903-001EP	
Title:	European isotope production: Phase 1, samples and testing. (Including safety provisions)				
Total Budget:	1200				
Objectives					
To produce and test prototype samples of a radionuclide suitable for use in a Radioisotopic Power System (e.g. RHU or RTG).					
Description					
This contract covers the production and/or separation of sample quantities of radionuclide suitable for use in a Radioisotopic Power Source (e.g. RHU or RTG), followed by appropriate testing and analysis. This can only be carried out in a certified laboratory (A subsequent phase 2, funded by a following contract in 2012, will cover the pilot production of a quantity suitable for use in a prototype space nuclear power system.) These activities shall be performed in close harmonisation with parallel activities on safety issues of nuclear sources.					
Deliverables					
Deliverables shall include full documentation and test report (no physical delivery of nuclear material).					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2012
Application Mission:	All exploration missions e.g. Mars Sample Return (>2016) and following exploration missions		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with the nuclear power dossier and proposed roadmap					

European isotope production: Phase 2, pilot batch production. (Including safety provisions)					
Programme:	ETP		**Reference:**	E903-002EP	
Title:	European isotope production: Phase 2, pilot batch production. (Including safety provisions)				
Total Budget:	1500				
Objectives					
Pilot production of a quantity of radioisotope suitable for use in a single prototype space nuclear power system.					
Description					
Assuming the successful production and testing of laboratory-scale samples in Phase 1, Phase 2 covers the pilot production of a quantity of radioisotope suitable for use in a single prototype space nuclear power system. The activity is to include the provision of any required physical and/or safety-case infrastructure that may remain in place for the production of subsequent batches.					
Deliverables					
A quantity of radioisotope suitable for use in a single prototype space nuclear power system (which is under development).					
Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2015
Application Mission:	All exploration missions e.g. Mars Sample Return and following exploration missions		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with the nuclear power dossier and proposed roadmap					

Nuclear fuel capsule and aeroshell design study					
Programme:	TRP	**Reference:**	T303-040EP		
Title:	Nuclear fuel capsule and aeroshell design study				
Total Budget:	200				
Objectives					
This activity shall cover the preliminary design of a complete encapsulation structure for radionuclide fuel.					
Description					
The activity shall produce a preliminary design or designs suitable for stand-alone use as a Radionuclide Heat Unit (RHU), and compatible for use with radioisotopic power generation systems based on thermoelectric and Stirling cycle conversion. A modular approach shall be considered, to allow the application of various power outputs without redesign and re-qualification of the encapsulation.					
Deliverables					
Design Report					
Current TRL:	1	**Target TRL:**	2	**Application Need/Date:**	2011
Application Mission:	All exploration missions e.g. Mars Sample Return (>2016) and following exploration missions	**Contract Duration:**	8		
S/W Clause:	N/A	**Reference to ESTER**			
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with the nuclear power dossier and proposed roadmap					

Nuclear Power Systems architecture study for safety management and fuel encapsulation prototype development.					
Programme:	ETP	**Reference:**	E903-003EP		
Title:	Nuclear Power Systems architecture study for safety management and fuel encapsulation prototype development.				
Total Budget:	1000				
Objectives					
To develop the NPS reference architectures for a European ASRG and small RTG, study its accommodation on spacecraft and launcher; to derive the end-to-end requirements including storage, transport and launch safety requirements for the fuel encapsulation and develop its design and start breadboarding and testing of the encapsulation, by using consolidated information from previous and ongoing activities.					
Description					
This activity aims to: 1) Consolidate existing information from ongoing and previous activities (e.g. ExoMars RHU accommodation and T303-040EP Nuclear fuel capsule and aeroshell design study) 2) Establish a reference design for a small European RTG and a Sterling RPS. 3) Study its accommodation on spacecraft (orbiter, lander, rover, small surface stations) and in the launch vehicle to derive the consolidated end-to-end requirements for the fuel encapsulation under consideration of all required safety issues and overall system aspects. 4) Investigate and consider all relevant safety and system aspects of the encapsulation from fuel delivery to launch and transfer to Mars. 5) Design the encapsulation and develop a breadboard and perform critical tests					
Deliverables					
Technical data package - System architecture of (1) Sterling converter RPS and (2) a small RTG - End-to-End system requirements for encapsulation of nuclear material for space NPSs. - Summary on space nuclear safety issues related to the encapsulation - Test report - Mathematical models H/W: Encapsulation prototype.					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2012

Application Mission:	Mars exploration, (>2018)	**Contract Duration:**	15
S/W Clause:	N/A	**Reference to ESTER**	
Consistency with Harmonisation Roadmap and conclusion:			
Consistent with the nuclear power dossier and proposed roadmap			

Encapsulation further development to TRL5					
Programme:	ETP		**Reference:**	E903-004EP	
Title:	Encapsulation further development to TRL5				
Total Budget:	1200				
Objectives					
To develop, from TRL4 to TRL5, a radioisotope fuel encapsulation system.					
Description					
Continued development of RHU and RTG modular encapsulation system (see above) to TRL5.					
Deliverables					
EQMs shall be produced of sufficient design maturity that safety qualification testing can begin immediately.					
Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2014
Application Mission:	Mars exploration, (>2018)		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with the nuclear power dossier and proposed roadmap					

Safety and aggression tests & demonstrations					
Programme:	ETP		**Reference:**	E903-005EP	
Title:	Safety and aggression tests & demonstrations				
Total Budget:	2000				
Objectives					
To safety test a radioisotope fuel encapsulation system.					
Description					
Modern RPS fuel must inevitably conform to the "intact re-entry, intact impact" model, in which the fuel module is robust against launcher and/or re-entry accident.					
Deliverables					
Qualification Test Plans, Test Procedures and Test Reports.					
Current TRL:	6	**Target TRL:**	6	**Application Need/Date:**	2017
Application Mission:	Mars exploration, (>2018)		**Contract Duration:**	36	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with the nuclear power dossier and proposed roadmap					

Thermoelectric converter system for small-scale RTGs (to ~TRL3/4)			
Programme:	TRP	**Reference:**	T903-006EP

Title:	Thermoelectric converter system for small-scale RTGs (to ~TRL3/4)				
Total Budget:	1100				
Objectives					
Demonstrate a low-power thermoelectric power conversion system					
Description					
Smaller RTG systems based on (several) RHUs (e.g. Russian Angel RHUs with 8 W thermal output (mass ~200g) or US RHUs with 1 W thermal output (mass 40 g)) can be used with thermoelectric conversion to provide electrical energy for long life/low activity measurement and communication for in-situ systems. Typical required electrical power is in the order 500 mW to several Watts, mission duration 9 to 11 years transfer and at least 1 year of operations. Contract is split into 3 activities:1. Study of the application range and preliminary definition of architecture and interfaces of a thermoelectric converter system for use with small nuclear heat sources (i.e. RHUs). Some competences on this or related subjects have already been developed in Europe through previous studies (funded at individual national level). 2. Thermocouple design study for small RTGs. A comprehensive review of modern thermoelectric materials will be conducted. This shall make assessments and trade-offs of the various materials and construction options (including, e.g, n-type, p-type, segmentation and coatings), and make a clear recommendation of the material(s) and thermocouple type to be selected. 3. Production of a preliminary breadboard model small-scale thermoelectric converter, using simulated (non-nuclear) heat source.					
Deliverables					
Breadboard model small-scale thermoelectric converter, using simulated (non-nuclear) heat source.					
Current TRL:	1	**Target TRL:**	3-4	**Application Need/Date:**	2011
Application Mission:	Mars exploration, (>2018)		**Contract Duration:**	15	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with the nuclear power dossier and proposed roadmap					

Thermoelectric converter system for small-scale RTGs (to ~TRL3/4)					
Programme:	TRP		**Reference:**	T903-006EP-B	
Title:	Thermoelectric converter system for small-scale RTGs (to ~TRL3/4)				
Total Budget:	1100				
Objectives					
Demonstrate a low-power thermoelectric power conversion system					
Description					
Smaller RTG systems based on (several) RHUs (e.g. Russian Angel RHUs with 8 W thermal output (mass ~200g) or US RHUs with 1 W thermal output (mass 40 g)) can be used with thermoelectric conversion to provide electrical energy for long life/low activity measurement and communication for in-situ systems. Typical required electrical power is in the order 500 mW to several Watts, mission duration 9 to 11 years transfer and at least 1 year of operations. Contract is split into 3 activities:1. Study of the application range and preliminary definition of architecture and interfaces of a thermoelectric converter system for use with small nuclear heat sources (i.e. RHUs). Some competences on this or related subjects have already been developed in Europe through previous studies (funded at individual national level). 2. Thermocouple design study for small RTGs. A comprehensive review of modern thermoelectric materials will be conducted. This shall make assessments and trade-offs of the various materials and construction options (including, e.g, n-type, p-type, segmentation and coatings), and make a clear recommendation of the material(s) and thermocouple type to be selected. 3. Production of a preliminary breadboard model small-scale thermoelectric converter, using simulated (non-nuclear) heat source.					
Deliverables					
Breadboard model small-scale thermoelectric converter, using simulated (non-nuclear) heat source.					
Current TRL:	1	**Target TRL:**	3-4	**Application Need/Date:**	2011
Application Mission:	Mars exploration, (>2018)		**Contract Duration:**	15	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with the nuclear power dossier and proposed roadmap					

Thermoelectric converter system for small-scale RTGs (to ~TRL4/5)					
Programme:	ETP		**Reference:**	E903-007EP	
Title:	Thermoelectric converter system for small-scale RTGs (to ~TRL4/5)				
Total Budget:	700				
Objectives					
Continued development of small scale thermoelectric converter, producing an elegant breadboard model.					
Description					
Major work will focus on improving system efficiency and reliability/longevity aspects, and detailed design of the interface with the radioisotopic heat source.					
Deliverables					
Engineering model small-scale thermoelectric converter, using simulated (non-nuclear) heat source.					
Current TRL:	3-4	**Target TRL:**	4-5	**Application Need/Date:**	2013
Application Mission:	Mars exploration, (>2018)		**Contract Duration:**	18	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with the nuclear power dossier and proposed roadmap					

Thermoelectric converter system for small-scale RTGs (to ~TRL6)					
Programme:	ETP		**Reference:**	E903-008EP	
Title:	Thermoelectric converter system for small-scale RTGs (to ~TRL6)				
Total Budget:	3000				
Objectives					
Produce an EQM suitable for fuelling with radioisotope material.					
Description					
Further thermoelectric converter development, and qualification, within the 2011-2015 timeframe. Shall result in production of an EQM suitable for fuelling with radioisotope material.					
Deliverables					
An EQM suitable for fuelling with radioisotope material with test reports.					
Current TRL:	4-5	**Target TRL:**	6	**Application Need/Date:**	2017
Application Mission:	Mars exploration, (>2018)		**Contract Duration:**	48	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with the nuclear power dossier and proposed roadmap					

Stirling Engine Radioisotopic Power System Requirement Study			
Programme:	TRP	**Reference:**	T203-006EP
Title:	Stirling Engine Radioisotopic Power System Requirement Study		
Total Budget:	100		
Objectives			
This activity will cover the definition of requirements and basic architecture and specification of a Stirling cycle power converter.			
Description			
Existing European experience with Stirling cryocoolers may provide a starting point for the work. The main focus will be on application to radioisotopic power systems.			

Deliverables					
Document on Sterling converter baseline requirements and architecture definition report.					
Current TRL:	1	**Target TRL:**	2	**Application Need/Date:**	2011
Application Mission:	Outer Planets, Mars exploration, (>2018)		**Contract Duration:**	6	
S/W Clause:	N/A		**Reference to ESTER**	T-8534	
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with nuclear power dossier and roadmap					

Stirling Converter Technology Development phase 1					
Programme:	ETP		**Reference:**	E903-009EP	
Title:	Stirling Converter Technology Development phase 1				
Total Budget:	2000				
Objectives					
To develop a breadboard model of a Stirling cycle power converter system for use with radioisotopic heat sources.					
Description					
This contract covers the initial development of a Stirling cycle power converter system for space applications, considering use with radioisotopic heat sources. Electrical output in the ~100 W range. A breadboard will be developed and tested in laboratory conditions (using a simulated, non-nuclear, heat source).					
Deliverables					
Consolidated requirements and design documentation. Breadboard model with test reports.					
Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2013
Application Mission:	Outer Planets, Mars exploration, (>2018)		**Contract Duration:**	27	
S/W Clause:	N/A		**Reference to ESTER**	T-8534	
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with nuclear power dossier					

Stirling converter development phase 2 to TRL6					
Programme:	ETP		**Reference:**	E903-010EP	
Title:	Stirling converter development phase 2 to TRL6				
Total Budget:	3300				
Objectives					
Continued development of the Stirling converter system, including its interfaces with the radioisotopic fuel, and the spacecraft					
Description					
Continued development of the Stirling converter system, including its interfaces with the radioisotopic fuel, and the spacecraft.					
Deliverables					
Shall result in production of EQM suitable for fuelling with radioisotope material with test reports.					
Current TRL:	3/4	**Target TRL:**	6	**Application Need/Date:**	2017
Application Mission:	Outer Planets, Mars exploration, (>2018)		**Contract Duration:**	48	
S/W Clause:	N/A		**Reference to ESTER**		
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with nuclear power dossier					

Long term technologies - Propulsion

Combustion chamber and injection technology development			
Programme:	ETP	**Reference:**	E919-011EP
Title:	Combustion chamber and injection technology development		
Total Budget:	2000		

Objectives

To conduct the necessary preliminary development work for a high thrust (1000-1500N) engine for planetary science and exploration.

Description

A high thrust apogee engine (HTAE) has been identified as a key technology to provide Europe with an enhanced independent capability for planetary science and exploration.

Gravity losses on Mars Express (MEX) accounted for around 4 % of the Delta V at orbit insertion. This mission used a classical high reliability apogee motor at 400N thrust level and 321s specific impulse (ISP)
The current Exomars (EXM) orbit insertion propulsion relies on a similar single 424N engine with an ISP of 321s. The Mars orbit insertion manoeuvre (MOI) and other manoeuvres bring the total main engine burn time to nearly 6 hours. Furthermore, significant gravity losses are involved in the Mars orbit insertion manoeuvre: 30% delta V or around 300 kg in terms of propellant mass.

A higher thrust apogee engine, 1.0-1.5 kN or similar, with current State of the art performance (~321s ISP) would be of significant benefit. Such an engine recovers more than half of the losses for an EXM class mission while retaining acceleration levels similar to those seen on Mars Express. This, in turn, increases the spacecraft dry mass available on orbit by a similar amount and hence the payload available for useful science. Further, such an approach leads to a relatively compact and mass efficient propulsion system.

A classical apogee engine design is considered for the HTAE. The design will consist of:

- Propellant flow control valves
- Injector assembly
- Combustion chamber
- Expansion nozzle
- Heat shield

The overall development requires three phases. Phase 1 is aimed at the verification, by test, of the key elements of such a design with a particular focus on the chamber and injector technology. Phase 2 targets the optimisation and finalisation of the design to critical design review (CDR) status. Finally, phase 3 addresses the qualification of the engine on ground. The activity outlined here relates to phase 1 of the development.

Phase 1 - of the high thrust apogee engine HTAE development is split into two further sub-phases; A and B.

Phase 1-A is constructed to take the development to a program requirements review (PRR) with a traded concept and supporting analysis confirming the feasibility of the deign.

Phase 1-B is split into three development strands for the three key components; valve, chamber and injector. Phase 1-B is designed to demonstrate the feasibility of the injector design and to address chamber compatibility issues with an agreed injector reference design. Further, significant emphasis is placed on the injector and chamber development to allow an initial performance optimisation loop and to give good margins w.r.t combustion stability.

The phase closes with three separate intermediate preliminary design reviews (IPDR) for the Valve Chamber and Injector respectively.

Deliverables

Phase 1-A Activities

- Definition of requirements in terms of performance, physical properties and test facilities.

- Definition of options for engine designs.

- Result from trade of engine options based on relevant analysis.

- Initial design and supporting analysis.

- Provision of PRR data pack.

Phase 1-B Activities - Development of HTAE technical specification. - Valve technology demonstrator - model design and manufacture. - Injector technology demonstrator - Design and manufacture of development model injector elements. Testing injectors for the performance optimisation loop. - Chamber technology demonstrator - Chamber development model design, manufacture including testing with reference injector. - Provision of I-PDR data packs for valve, injector and chamber.

Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2012
Application Mission:	All exploration missions e.g. Mars Sample Return (>2016) and following exploration missions		**Contract Duration:**	24	
S/W Clause:	N/A		**Reference to ESTER**	T-8324	
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with the Technical Dossier - Chemical Propulsion Components (Aim C3)					

Design, and development testing and EM verification of a High thrust Apogee Engine (HTAE)			
Programme:	ETP	**Reference:**	E919-012MP
Title:	Design, and development testing and EM verification of a High thrust Apogee Engine (HTAE)		
Total Budget:	5000		
Objectives			
To conduct the detailed design development, and optimisation work for a high thrust (1000-1500N) engine for planetary science and exploration. See description for further information. The overall development requires three phases. Phase 1 is assumed complete at the end of 2011. Phase 2 (detailed here in) targets the optimisation of the overall engine design and development to CDR status. This is foreseen over a 3 year period. Qualification will be made subsequent to this activity in a 2015 timeframe			
Description			
A high thrust apogee engine has been identified as a key technology to provide Europe with an enhanced independent capability for planetary science and exploration. Gravity losses on Mars Express (MEX) accounted for around 4 % of the Delta V at orbit insertion. This mission used a classical high reliability apogee motor at 400N thrust level and 321s specific impulse (ISP) The current Exomars (EXM) orbit insertion propulsion relies on a similar single 424N engine with an ISP of 321s. The Mars orbit insertion manoeuvre (MOI) and other manoeuvres bring the total main engine burn time to nearly 6 hours. Furthermore, significant gravity losses are involved in the Mars orbit insertion manoeuvre: 30% delta V or around 300 kg in terms of propellant mass. A higher thrust apogee engine, 1.0-1.5 kN or similar, with current State of the art performance (~321s ISP) would be of significant benefit. Such an engine recovers more than half of the losses for an EXM class mission while retaining acceleration levels similar to those seen on Mars Express. This, in turn, increases the spacecraft dry mass available on orbit by a similar amount and hence the payload available for useful science. Further, such an approach leads to a relatively compact and mass efficient propulsion system Phase 2 is expected to last 36 months. The phase continues with further development activities at sub-component level but also focuses on the integration of the elements and global performance testing and optimization at engine level (using development test model(s) DM(s)). By this approach the phase also addresses the formal interfacing of sub-components. The PDR is held subsequent to the subcomponent and DM test activities and EM test activities are defined based on the output of this review. The phase is formally completed after a successful CDR where the results from the previously defined EM testing are reviewed and the final qualification approach is decided. The finalisation of the overall engine design at valve, injector and chamber level is expected by way of the EM unit			
Deliverables			

This activity relates to period 2 only and deliverables are as follows: - PDR Datapack - Holding of PDR - DM2/EM engine/valve assemblies - CDR data pack - Holding of CDR					
Current TRL:	5	**Target TRL:**	6	**Application Need/Date:**	2015
Application Mission:	IM/MSR		**Contract Duration:**	36	
S/W Clause:	N/A		**Reference to ESTER**	T-7722, T-8126, T-8324	
Consistency with Harmonisation Roadmap and conclusion:					