DOCUMENT

MarcoPolo-R Mission Requirements Document

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1   INTRODUCTION

1.1   Background

In 2011, after a meeting of the Space Science Advisory Committee, the M3 candidate missions for the Cosmic-Vision 2015-2025 programme were selected for further assessment and consideration for launch in the early 2020's. The MarcoPolo-R Near-Earth Asteroid sample return mission was selected as one of the M-class candidate missions. The nominal launch date for M-class missions is now 2024, but the missions shall also be compatible with opportunities in 2022.

During the fall 2011 the mission concept was studied in the Concurrent Design Facility at ESTEC (internal pre-assessment) in order to prepare a thorough industrial assessment phase. The purpose of the ongoing assessment phase is to assess the feasibility of this mission. After the assessment phase ending in 2013, one M-class mission will be selected. If adopted, the mission would proceed into definition and implementation (Phases B1/B2/C/D). In parallel with the system level activities, an Announcement of Opportunity will be issued calling for the provision of scientific instruments by the science community through ESA. It is anticipated that the selection of the science instruments will be confirmed by February 2013.

Currently, references to the payload point to the Payload Resources and Requirements Document (PRRD, [RD16]). After the payload for MarcoPolo-R is selected, this will be replaced by individual Experiment Interface Documents – Part B (EID-B) for each instrument.

The overall mission development planning is shown in the figure below. The dates and various activities are indicative only. The planning will be updated following the assessment phase and the Contractor shall provide its own bottom-up development schedule.
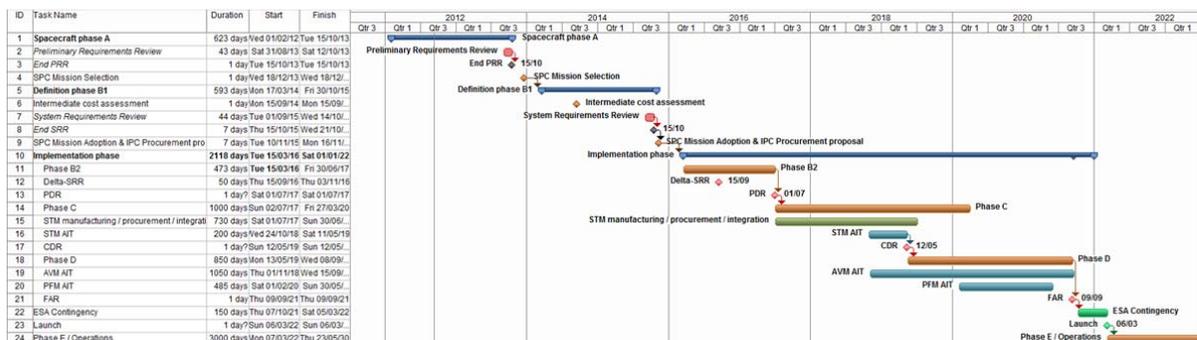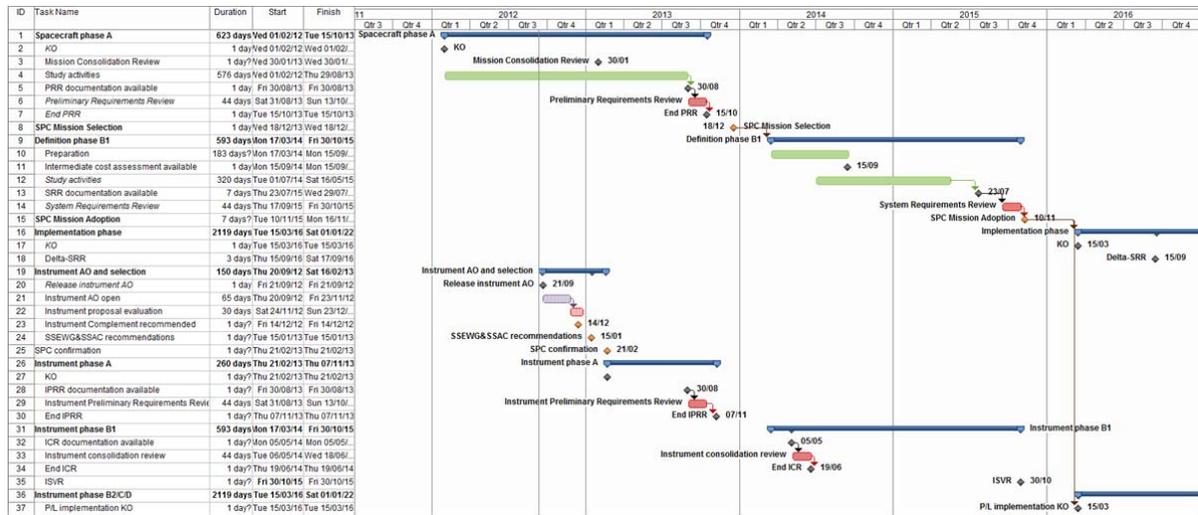

Figure 1-1: Mission development planning (indicative only and if JUICE launch is 2024)

ID	Task Name	Duration	Start	Finish
1	Spacecraft phase A	623 days	Wed 01/02/12	Tue 15/10/13
2	KO	1 day	Wed 01/02/12	Wed 01/02/...
3	Mission Consolidation Review	1 day?	Wed 30/01/13	Wed 30/01/...
4	Study activities	576 days	Wed 01/02/12	Thu 29/08/13
5	PRR documentation available	1 day	Fri 30/08/13	Fri 30/08/13
6	Preliminary Requirements Review	44 days	Sat 31/08/13	Sun 13/10/...
7	End PRR	1 day	Tue 15/10/13	Tue 15/10/13
8	SPC Mission Selection	1 day	Wed 18/12/13	Wed 18/12/...
9	Definition phase B1	593 days	Mon 17/03/14	Fri 30/10/15
10	Preparation	183 days?	Mon 17/03/14	Mon 15/09/...
11	Intermediate cost assessment available	1 day	Mon 15/09/14	Mon 15/09/...
12	Study activities	320 days	Tue 01/07/14	Sat 16/05/15
13	SRR documentation available	7 days	Thu 23/07/15	Wed 29/07/...
14	System Requirements Review	44 days	Thu 17/09/15	Fri 30/10/15
15	SPC Mission Adoption	7 days?	Tue 10/11/15	Mon 16/11/1...
16	Implementation phase	2119 days	Tue 15/03/16	Sat 01/01/22
17	KO	1 day	Tue 15/03/16	Tue 15/03/16
18	Delta-SRR	3 days	Thu 15/09/16	Sat 17/09/16
19	Instrument AO and selection	150 days	Thu 20/09/12	Sat 16/02/13
20	Release instrument AO	1 day	Fri 21/09/12	Fri 21/09/12
21	Instrument AO open	65 days	Thu 20/09/12	Fri 23/11/12
22	Instrument proposal evaluation	30 days	Sat 24/11/12	Sun 23/12/...
23	Instrument Complement recommended	1 day?	Fri 14/12/12	Fri 14/12/12
24	SSEWG&SSAC recommendations	1 day?	Tue 15/01/13	Tue 15/01/13
25	SPC confirmation	1 day?	Thu 21/02/13	Thu 21/02/13
26	Instrument phase A	260 days	Thu 21/02/13	Thu 07/11/13
27	KO	1 day	Thu 21/02/13	Thu 21/02/13
28	IPRR documentation available	1 day?	Fri 30/08/13	Fri 30/08/13
29	Instrument Preliminary Requirements Revie	44 days	Sat 31/08/13	Sun 13/10/...
30	End IPRR	1 day?	Thu 07/11/13	Thu 07/11/13
31	Instrument phase B1	593 days	Mon 17/03/14	Fri 30/10/15
32	ICR documentation available	1 day?	Mon 05/05/14	Mon 05/05/...
33	Instrument consolidation review	44 days	Tue 06/05/14	Wed 18/06/...
34	End ICR	1 day?	Thu 19/06/14	Thu 19/06/14
35	ISVR	1 day?	Fri 30/10/15	Fri 30/10/15
36	Instrument phase B2/C/D	2119 days	Tue 15/03/16	Sat 01/01/22
37	P/L implementation KO	1 day?	Tue 15/03/16	Tue 15/03/16

Figure 1-2: MarcoPolo-R Phase A/B1 schedule, major milestones for spacecraft and payload development (indicative only)

1.2   Scope of Document

This is a Mission Requirements Document (MRD) to be used as an Applicable Document in the MarcoPolo-R industrial assessment study. The purpose of the MRD is to provide all high-level mission-level requirements (including S/C and payload, launcher, ground segment and operations) necessary to achieve the science goals detailed in [AD2] for the MarcoPolo-R industrial system design studies running through 2012/2013. It includes functional and performance requirements down to the sub-system level which can be defined at this stage.

Later on in the course of the definition phase, it will result into two self-standing documents, i.e. the Mission Requirements Document and the System Requirements Document.

Recording and tracking of changes as well as giving a brief rationale is very important. The traceability of the requirements is paramount in order to make this document and its associated requirements easy to read and to understand at any stage of the mission assessment and possibly later definition phase, should this mission be selected.

This is issue 3.2 of the MRD. It has been updated after the baseline selection review in the course of the assessment phase. It will be reviewed as part of the assessment phase and will be updated following the Preliminary Requirement Review at the end of 2013.

1.3   Documentation architecture

The mission requirements document is one of the documents that constitute the foundations of the mission profile for MarcoPolo-R.
This MRD is specifically supported by:

- MarcoPolo-R Science Requirements Document [AD2]
- MarcoPolo-R Mission Environment Document [AD4]
- MarcoPolo-R Planetary Protection Document [AD5]
- MarcoPolo-R Consolidated Reference Mission Analysis Document [AD6] (to be provided in the course of task 2, [RD1] to be used prior to that)
- MarcoPolo-R Payload Resources and Requirements Document [RD16] (note that this document supersedes the Payload Definition Document, previously referred to as [AD3], no longer applicable)
- MarcoPolo-R Margin philosophy Document [AD13]

The mission document tree is given here below for information and lists the envisaged documentation (to be confirmed) available by the time of the Preliminary Requirements Review.
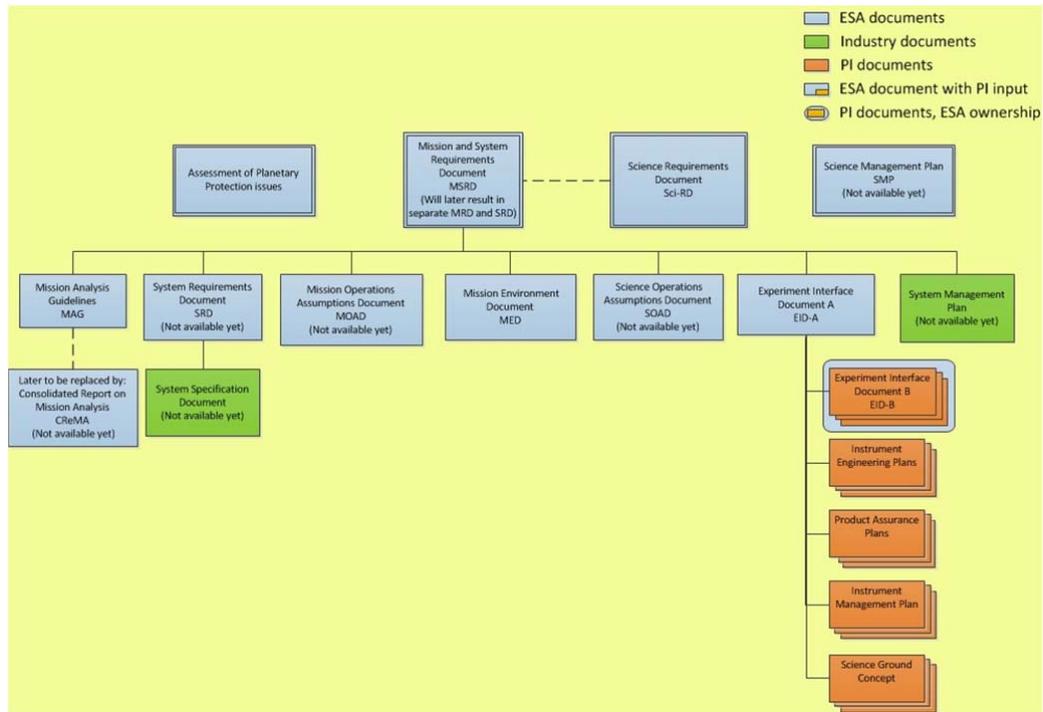
Figure 1-3: Preliminary MarcoPolo-R mission document tree

1.4   Issue schedule

This issue of the Mission Requirements Document has been established in support of the Industrial Studies of the system design of the MarcoPolo-R mission. The document is (currently) an open document and regular updates are expected. Particularly, iterative steps with industrial or internal study partners and the ESA study manager are foreseen. Revisions will be published, as required, at the start of, as well as during the system design. The book captain of this document is the MarcoPolo-R study manager and any comment on this document should be directly reported to him. Any conflict between requirements in this document shall be reported to ESA and any modification requires his/her prior approval.

1.5   Requirements nomenclature

Items included in this MRD are classified according to the following categories.

1.5.1   Requirements and goals

R-   "Shall" Requirements noted R- are mandatory, shall be verified with an accepted verification method and shall be complied with. If not complied with, the Agency shall immediately be notified.

G-   "Should" Requirements (or Goals) noted G- are desirable requirements with the objective to increase the scientific return or performance of the mission. Their impact on the mission technical complexity and programmatic aspects (e.g. cost, risk) shall be limited so as to stay within the M-class boundaries. Goals may be fulfilled under limited favourable conditions. They are highlighted in italic in order to be easily identified.

A requirement may need an explanation. Such an explanation can be found in italic below the requirement itself. This is intended only to assist the understanding of the requirement or its origin (the Parent requirement ID might be sometimes included wherever applicable).

1.5.2   Requirement ID

The requirement ID, preceded by **R**- or **G**-, belongs to the following category:

- **AIV**:   AIV
- **AUT**:   Autonomy and FDIR
- **COM**:   Communication sub-system
- **CON**:   Contamination
- **DHS**:   DHS sub-system
- **ENV**:   Environmental
- **GNC**:   GNC/AOCS sub-system
- **GRS**:   Ground Segment
- **LAS**:   Launch Segment
- **MEC**:   Mechanism sub-system
- **MIS**:   Mission
- **OPS**:   Operational
- **PLD**:   Payload
- **POW**:   Power sub-system
- **PPR**:   Planetary Protection
- **PRM**:   Programmatic
- **PRO**:   Propulsion sub-system
- **PQA**:   Product/Quality Assurance, RAMS
- **SCI**:   Science
- **STD**:   Study
- **STR**:   Structure/Mechanical sub-system
- **SYS**:   Space Segment System
- **TEC**:   Technology
- **THE**:   Thermal sub-system

Should a requirement be deleted in a later update of this document, its number will not be reused and should a requirement be introduced in between other requirements, the last digit will be used (e.g. R-YYY-115 between R-YYY-110 and R-YYY-120).
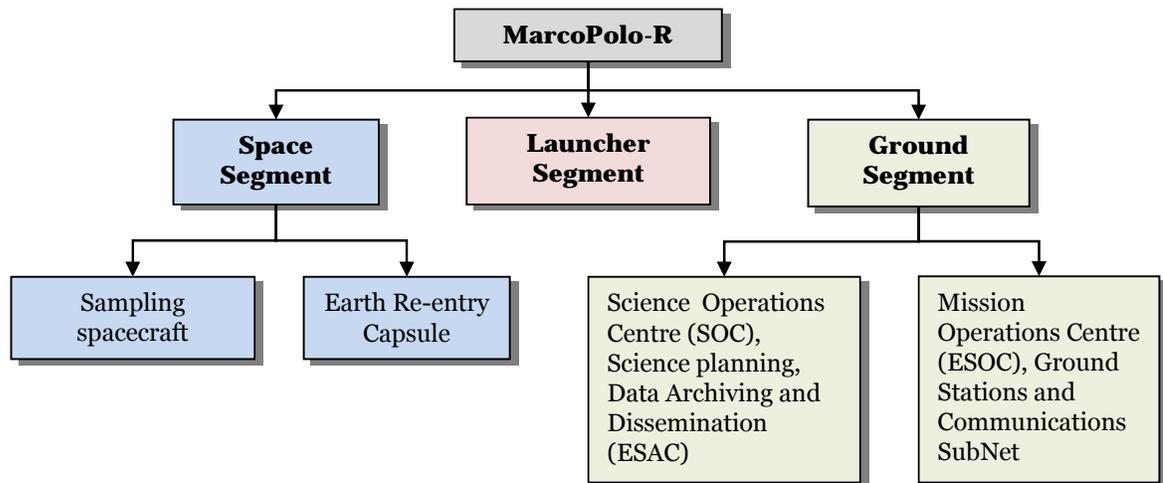
2 MISSION OVERVIEW

2.1 Mission Profile

This paragraph describes the baseline MarcoPolo-R system and its mission profile selected at the Baseline Selection Review of the assessment phase in June 2012, in consultation with the European Science Study Team, the industrial teams and through an ESA internal review process.

2.1.1 System definition

The system breakdown is defined in the diagram below.

Figure 2-1: Block diagram of the MarcoPolo-R mission

2.1.2 Mission overview

MarcoPolo-R is a sample return mission to the primitive Near-Earth Asteroid (NEA) 1996 FG3 which is a binary system. A spacecraft composite made of a main spacecraft, also called the sampling spacecraft and carrying the Earth re-entry capsule (ERC), will be launched by a Soyuz-Fregat MT 2-1b launch vehicle from Kourou on a direct escape trajectory to 1996 JU3.

The mission design and its development needs to be compatible with launch opportunities from 2022 onwards up to 2025 for programmatic reasons. Therefore, appropriate transfers for the launch slots between 2022 and 2025 have been identified with relevant backup opportunities and are all described in [RD1].

The 2022 mission scenario is described hereafter. Mission transfers, swing-bys and associated dates and duration slightly vary across the various opportunities. The reader will refer to [RD1] for the full analysis and the requirements in this document refer to the most demanding case for each parameter.

The launch takes place in March 2022. After one Venus Swing-by in October 2024, the spacecraft rendezvous with the NEA in February 2026.

In the 2022 scenario the proximity operations last for ~ 190 days (but for other opportunities it ranges from 180 through 390 days). The proximity/science operations are described in 2.1.4. In a nutshell, this phase will include instrument calibration, far and close observations of the binary system with the various science instruments, gravity field determination and hazard mapping above roughly 5 km altitude. Five sampling site candidates are then characterized at high resolution at about 250 m (TBC) distance to the surface during a few minutes in order to determine the most suitable sampling site (i.e. yielding the best compromise between science return and risk-mitigation).

After one successful sampling rehearsal, the spacecraft, which will be designed to cope with surface hazards (e.g. large clearance to the surface), navigates towards the finally selected touchdown/sampling site and collects hundreds of g of surface material. The sampling strategy is based on a touch and go approach to lower cost and risk. Therefore the spacecraft performs a soft touchdown of the surface for a few seconds (in the order of 2-5 seconds) and then takes-off immediately after that to move into a safe position away from the surface.

If it is confirmed, via a reliable verification technique, that a scientifically meaningful sample has been collected, the sample is transferred to the re-entry capsule and sealed. The spacecraft is then ready for departure back to Earth or can carry on orbital science if desired. If the sampling operation was not successful, the spacecraft can undertake 2 more attempts (3 attempts in total).

The spacecraft departs from the asteroid in August 2026 and returns to Earth in April 2029 after one Venus swing-by in November 2027. The re-entry capsule is then released and undertakes a high-speed Earth re-entry at V_{entry} of maximum ~ 13 km·s^{-1} (in other scenarios the re-entry velocity is lower ~ 11-12.6 km.s^{-1}). The capsule will be retrieved on the ground at the Woomera test range which has already been used for Hayabusa landing.

2.1.3   Mission phases and operations

Phase name	Su-phase name	Orbit/location	Main events
Launch	Pre-launch	Launch pad	• L-8 hours to launch
	Launch and escape (LEOP)	Ascent trajectory and direct escape	• Duration: Launch + 3 days • Launch into direct escape orbit by Fregat MT
	S/C Acquisition (LEOP + S/C commissioning).	Interplanetary	• Separation from Fregat MT upper stage • Deployment of solar panels • S/C and P/L commissioning • Electric propulsion sub-system commissioning • 1st determination of S/C trajectory • 1st launcher dispersion correction manoeuvre
Outbound cruise	Interplanetary cruise	Interplanetary	• Various electric propulsion thrust and coast phases • 1st year: daily contact with S/C to monitor health status of electric propulsion system • After one year, only weekly coverage of the S/C • System and P/L check-out
	Venus (x0 or x1 or x2) or Earth fly-by (x0 or x1) (generic)	Venus/Earth fly-by	• Interruption of electric propulsion • Possible targeting manoeuvres with chemical propulsion • Determination of post fly-by S/C trajectory • Possible recovery manoeuvre
Asteroid rendezvous	Rendezvous with 1996 FG3	Approach trajectory, from ~ 2000000 km (TBC) to 500 km	• SEP and far approach • Far range imaging (both for science and navigation) • Asteroid localization • Targeting manoeuvres

Phase name	Su-phase name	Orbit/location	Main events
	Arrival at 1996 FG3	500 km distance to asteroid	▪ S/C checks ▪ Date of arrival in the 2022 scenario: 8th February 2026
Proximity operations	**Close approach trajectory**	500 to 100 km distance to asteroid	▪ Start of proximity operations ▪ P/L commissioning and calibration ▪ 7 days
	Transition to far global characterization	100 to 10 km distance to asteroid	▪ Start of asteroid mapping ▪ 10 days ▪ Binary system mapping
	Far global characterization	Far "formation-flying" (~10 km) between the Sun and the asteroid	▪ Initial characterization ▪ Initial mapping and determination of physical properties ▪ Orbit maintenance ▪ 10 days
	Radio science	~ 3 to 5 km distance to the asteroid surface	▪ Gravity field campaign on a radio science orbit ▪ Preliminary mapping when favourable conditions ▪ 20 days
	Global characterization, GCP	~ 5km distance to the asteroid surface	▪ Global mapping of the asteroid primary and secondary at medium spatial resolution on a TBD orbit with a local solar elevation between 30 and 60 degrees ▪ All instruments on (except CuC) ▪ Communication to Earth via HGA (~ 8 hours/day) ▪ No science during communication ▪ Orbit maintenance on a regular basis ▪ 35 days
	Local characterization, LCP	250 m distance to the asteroid surface	▪ Local mapping of 5 selected sampling sites at high spatial resolution ▪ 15 days, ~ 3 days/site
	Sampling/descent rehearsals	Descent phase up to ~ 100 m	▪ Sampling attempt down to at least 100 m ▪ Up to validation of critical events/GNC algorithms, except sampling
	Descent and sampling, SAM	Descent and surface	▪ Switch to autonomous descent mode ▪ Descent ▪ Descent interruption ▪ S/C position check by Earth via pictures analysis ▪ Descent continuation ▪ Touchdown ▪ Sampling ▪ CuC operations ▪ 21 days, ~ 3 attempts, 7 days/attempt
	Ascent	Re-ascent to safe position	▪ Ascent burn ▪ Transition to Safe Position
	Post-sampling LCP	250 m distance to the asteroid surface	▪ Local mapping of the site which has been sampled ▪ 3 days
	Extended GCP	Same as GCP	▪ Same as GCP ▪ Transfer of the collected sample to ERC
	Departure from 1996 FG3	Far distance to the surface	▪ Start-up of the SEP system ▪ Injection of return trajectory ▪ Date of departure in the 2022 scenario: 16th August 2026
Inbound cruise	**Interplanetary cruise**	Interplanetary	▪ Same as outbound cruise
	Venus fly-by	Same as outbound fly-by	▪ Same as outbound Venus fly-by
	ERC release	Cis-lunar space	▪ S/C wake-up

Phase name	Su-phase name	Orbit/location	Main events
			▪ Release and spinning of ERC 4 hours before entry
Earth arrival	**Direct Earth re-entry**	Entry point TBD Landing site: Woomera test range	▪ 4 hour coast arc by ERC ▪ S/C Earth avoidance manoeuvre ▪ Entry at 120 km altitude ▪ Parachute-free entry ▪ Landing at Woomera ▪ Date of Earth arrival in 2022 scenario: 18th April 2029
	ERC recovery operations		▪ Observations of re-entry ▪ Localization and recovery of capsule ▪ Transfer to curation facilities

Table 2-1: Overview of baseline mission phases

2.1.4 Asteroid proximity operations

The proximity operations shall serve the previously defined high-level mission requirements as well as science requirements defined in [AD2]. In particular three phases have been identified as follows: Global Characterization Phase (GCP), Local Characterization Phase (LCP) and context measurements, the latter being performed during sampling operations (SAM) and therefore very short (in the orders of seconds). A so-called radio science phase is also implemented in order to get the gravity field of the binary system to the level required in [AD2].

The science operations around the asteroid, to be further defined in [AD15], are part of the proximity operations. Other operations are: instrument commissioning, descent and sampling, etc. All proximity operations for the 2022 scenario are shown in the figure below.

Mission scenarios in 2024 and 2025 are less demanding as the duration of the proximity operations is far longer, i.e. resp. 275 and 290 days. In the 2023 scenario, the proximity operations last for 180 days. The latter is the sizing case. So, the 18 days margins shown in the figure below become 9 days in the 2023 scenario.

The detailed description of the proximity and science operations as well as the associated requirements will be detailed in the Science Assumptions Document and the Mission Operations Assumptions Document ([AD14] and [AD15]).
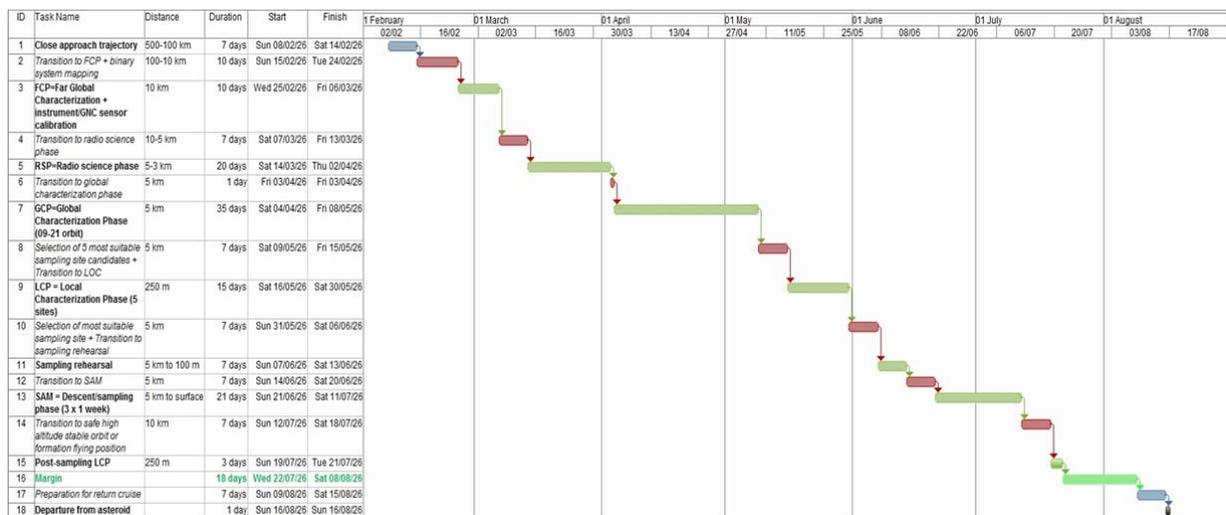
Figure 2-2: Asteroid proximity operations for the 2022 mission scenario (indicative only)

3 MISSION REQUIREMENTS

The MarcoPolo-R mission has two main top-level objectives which relate to its science objectives:

R-MIS-010 MarcoPolo-R shall safely return to Earth a sample from the primitive Near-Earth Asteroid 1996 FG3.

Main objective of the mission.

R-MIS-020 The mission shall perform global and local characterization of the Near-Earth Asteroid to retrieve the sample context information at the resolutions defined below.

	Spatial resolution for imaging in the visual range	Spatial resolution for VIS/IR spectrometer	Spatial resolution for mid-IR instrument
Global characterisation	Order of dm	Order of m	Order of 10 m
Local characterisation	Order of mm	Order of dm	Order of dm
Context measurements	1 mm	-	-

Table 3-1: Resolution requirements for global characterisation, local characterisation, and context measurements

- *'Global characterisation' means to measure the properties of the complete NEA, on a global scale;*
- *'Local characterisation' is the high-resolution characterisation of up to 5 dedicated areas which are identified as potential sampling sites;*
- *'Sample context' are measurements being performed at the actual sampling site.*

*Besides the science objectives, in-situ investigations defined in **R-MIS-020** are meant to support the safe operation of the S/C in close proximity to the NEA and the safe collection of the sample(s).*

4 PROGRAMMATICS REQUIREMENTS

The following requirements are related to the schedule, planning and development of the mission as a whole.

R-PRM-010 The launch of the MarcoPolo-R baseline mission to the binary asteroid 1996 FG3 shall nominally occur by 2022.

Note: The M3 mission is intended as a backup candidate for the 2022 launch slot, depending on JUICE schedule. Although in the science programme the baseline launch slot for M3 is 2024, all current study planning should remain compatible with a 2022 launch. The final decision on the nominal launch date will be made following JUICE mission adoption.

R-PRM-020 The MarcoPolo-R mission shall also be compatible, in all ways, with launch opportunities in 2024 and 2025.

"All ways": Launch mass; Sizing of: propellant tanks, thermal control, power, data downlink, etc.

G-PRM-030 The MarcoPolo-R mission should also be compatible, in all ways, with launch opportunities in 2023.

R-PRM-040 The total mission duration shall not exceed 8 years.

Mission duration is defined as the time between launch and landing of the Earth re-entry capsule at the end of mission.

R-PRM-050 *Deleted.*

R-PRM-060 *Deleted.*

R-PRM-070 *Deleted.*

R-PRM-080 *Deleted.*

R-PRM-090 *Deleted.*

5 PLANETARY PROTECTION AND SAMPLE CONTAMINATION REQUIREMENTS

5.1 Planetary Protection requirements

These are the high-level requirements related to planetary protection and sample contamination (e.g. PP category, S/C cleanliness, contaminant tracking, etc.). The engineering requirements related to it will be specified in the relevant category requirements (e.g. AIV for clean room environment, spacecraft for level of sterilization, etc.).

R-PPR-010 The MarcoPolo-R mission shall comply with all planetary protection measures listed in [AD5].

R-PPR-020 The MarcoPolo-R mission shall fulfil the requirements of planetary protection **category II.**

R-PPR-030 The return leg of the MarcoPolo-R mission shall be classified as planetary protection **category V unrestricted return.**

R-PPR-040 *Deleted.*

5.1.1 Science contamination requirements

R-CON-010 Contaminants or undesired particles (TBD) generated by the spacecraft (e.g. propellant plume, outgassing, etc.) shall have a density lower than 10^{14} (10^{13} as a goal) molecules/cm^2 on the asteroid surface and/or on the collected sample.

Typical unwanted contaminants TBD by the science team. See [AD2]

R-CON-020 The potential contaminants shall be identified, controlled, tracked, documented and readily identifiable from the asteroid sample material. The tracking of these contaminants shall start as of the S/C manufacturing process.

Ref. [AD2] & [AD5]. Relates to the science contamination.

R-CON-030 Witness plates shall be implemented in order to track the possible contaminants throughout the AIV/AIT and various mission phases and shall be returned to Earth.

E.g. propellant, S/C outgassing, etc. See [AD2].

R-CON-040 The spacecraft elements shall cope with the following sterilization and cleaning procedures in order to keep low-levels of forward contamination:
- Alcohol cleaning,
- TBD.

Ref. [AD2].

6 PAYLOAD DESCRIPTION AND REQUIREMENTS

6.1 Model payload instruments

Here is a brief description of the model payload instruments. The reader is referred to the Payload Resources and Requirements Document [RD16] for more detailed data (interfaces, performances, requirements, etc.). This model payload has been defined by the MarcoPolo-R Science Study Team such as to fulfil the science requirements defined in [AD2]. Only the core orbital payload is recalled here. Complementary instruments may also be envisaged but are not part of the model payload. It will be determined at a later stage (Instrument AO – 2012) by the Science Programme Committee whether the complementary instruments shall and can be accommodated.

Core Payload	
Wide Angle Camera	Necessary to image the whole NEA, build the shape model and retrieve context for the NAC from the science orbit.
Narrow Angle Camera	Used for high-resolution science measurement and hazard mapping from orbit.
Visible/Near Infrared Spectrometer	Spectrometer used to determine the mineralogy on the NEA surface.
Mid-Infrared Spectrometer	Spectrometer used to determine the mineralogy on the NEA surface and the surface temperatures.
Radio Science Experiment	Radio Science Experiment making use of the communication system of the spacecraft to accurately determine the gravitational field of the NEA.
Neutral Particle Analyzer	Used to identify the processes related to the exposure to space environment and collisions.
Close-up camera	Provides the local microscopic context of the sampling area.

Table 6-1: List of instruments, all located on the sampling spacecraft

6.2 Payload requirements

R-PLD-010 The model payload as defined in the PRRD [RD16] shall be assumed.

The model payload will be replaced by the selected instruments after the payload Announcement of Opportunity.

R-PLD-020 Science instruments shall not be used as baseline GNC sensors.

R-PLD-030 *Deleted.*

R-PLD-040 *Deleted.*

R-PLD-050 The Absolute Pointing Error (APE) of the payload, during data acquisition, shall be less than 0.1 mrad 3-σ, for the yaw, roll and pitch angles (TBC).

R-PLD-060 The Relative Pointing Error (RPE) of the payload shall be less than 0.03 mrad over 1 s 3-σ, deg for the yaw, roll and pitch angles (TBC).

R-PLD-070 The sampling spacecraft shall provide a payload mass allocation of 36 kg (TBC).

Including maturity margins, but no systems margin.

R-PLD-080 During science operations in orbit around the asteroid, the spacecraft shall provide an operating payload power allocation of 76.8 W (TBC).

Including maturity margins, but no systems margin.

R-PLD-090 During non-science operations in orbit around the asteroid, the spacecraft shall provide a stand-by payload power allocation of 28.8 W (TBC).

Including maturity margins, but no systems margin.

R-PLD-100 During descent and sampling operations the spacecraft shall provide a power allocation of 15 W (TBC) to the close-up camera. All other instruments are in off (if allowed by their thermal requirements) or stand-by mode.

Including maturity margins, but no systems margin. CuC only.

R-PLD-110 The spacecraft shall provide 10.8 W (TBC) of power to the close-up camera when it is in stand-by mode.

10.8 W is the power consumption of the camera set CCSU, no systems margin. This power is common to WAC, NAC and CuC and should always only be counted once.

R-PLD-120 *Deleted.*

R-PLD-130 *Deleted.*

R-PLD-140 *Deleted.*

R-PLD-150 *Deleted.*
.

7   TECHNOLOGY REQUIREMENTS

R-TEC-010 Only technologies at a minimum of TRL 5 by the time of the SPC Mission selection (right after PRR) shall be implemented in the mission design.

R-TEC-020   Technologies not fulfilling **R-TEC-010** may be used in specific cases after approval by the Agency, if and only if:
- No alternative fulfilling **R-TEC-010** has been identified,
- Activities with a low development risk are ongoing/planned to bring the considered technology up to TRL 5 by the end of the Definition Phase.

The following table defines the generic ESA TRL levels which have to be used in the frame of this study.

ESA Technology Readiness Levels	
9	Actual system "flight proven" through successful mission operations
8	Actual system completed and "flight qualified" through test and demonstration (ground or flight)
7	System prototype demonstration in a space environment
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
5	Component and/or breadboard validation in relevant environment
4	Component and/or breadboard validation in laboratory environment
3	Analytical and experimental critical function and/or characteristic proof-of-concept
2	Technology concept and/or application formulated
1	Basic principles observed and reported
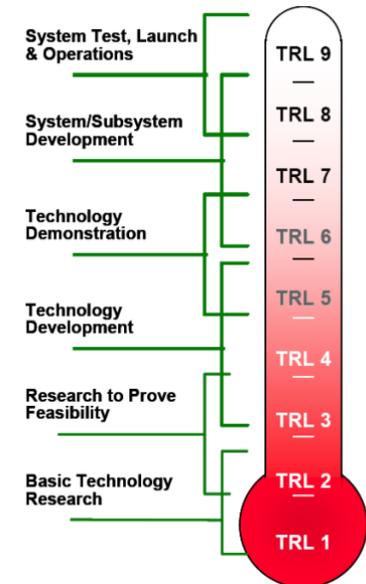
Table 7-1: Definition of ESA Technology Readiness Levels and TRL scale

8   LAUNCH SEGMENT REQUIREMENTS

For performances of the launch vehicle it is referred to [RD1].

R-LAS-010   The launch vehicle shall be Soyuz-Fregat 2-1b with the Fregat-MT upper stage.

R-LAS-020   A launch mass margin of 8% shall be considered (TBC).

Recall of [AD13].
Launch mass margin defined as ratio in percent between:
- *Launcher performance for the target orbit ([RD1])*
  and
- *Total spacecraft wet mass (incl. all other margins: maturity, system, propellant, etc.) + launch adapter.*

R-LAS-030   *Deleted.*

R-LAS-040   Launch site shall be CSG (Kourou, French Guyana).

R-LAS-050   *Deleted.*

9 OPERATIONS AND MISSION ANALYSIS REQUIREMENTS

This chapter defines the mission operations requirements. The following phases are covered in this chapter: post-launch or LEOP, cruise (outbound/inbound), DSM, GA, rendezvous, proximity operations, cislunar and re-entry.

R-OPS-010 The jettisoning strategy of any element shall ensure collision avoidance with the sampling spacecraft and the ERC or the asteroid at any stage of the mission with a TBD margin.

E.g. Soyuz-Fregat stage, ERC, P/L cover, etc.

R-OPS-020 No critical S/C operations shall be performed if the Sun-Earth-S/C angle is lower than 5°.

e.g. descent, sampling, local characterization, etc. Data downlink is not considered to be a critical operation and therefore can be envisaged down to 3°.

R-OPS-030 No standard S/C operations shall be performed if the Sun-Earth-S/C angle is lower than 2°.

R-OPS-040 The ERC shall be released by the sampling spacecraft from the return hyperbolic trajectory and directly enter the Earth atmosphere.

R-OPS-050 The mission design shall cope with the minimum distances to the Sun during all mission phases, i.e. coast and thrust arcs and asteroid proximity operations as specified in [RD1].

R-OPS-060 The mission design shall cope with the maximum distances to the Sun during all mission phases, i.e. coast and thrust arcs and asteroid proximity operations as specified in [RD1].

R-OPS-070 The mission design shall cope with the maximum distances to Earth during all mission phases, cruise and asteroid proximity operations as specified in [RD1].

R-OPS-080 The duration of a Solar conjunction or when the Sun-Earth-S/C angle is lower than 2° during the transfer to and from the asteroid and during proximity operations shall be limited to 50 days.

R-OPS-090 Mission analysis shall ensure ERC re-entry velocity and flight path angle such that heat fluxes during re-entry do not exceed 15 MW/m² (incl. margins as defined in [AD13]) and total pressure at stagnation point does not exceed 80 kPa.

Re-entry conditions to be defined at 120 km altitude. To remain within a feasible domain for plasma testing of thermal protection system.

G-OPS-100 Mission analysis should ensure a night re-entry of the ERC.

To ensure good observations of the chemical species involved in re-entry and limit temperature increase after ERC landing.

R-OPS-110   The duration of the proximity operations about the asteroid shall be at least 180 days.

Mitigation of risk, feasibility of science operations, maximizing rehearsals, etc.

R-OPS-120   The proximity operations shall allow 5 local characterization phases (LCP) before the first sampling attempt to image the 5 candidate sampling sites at high resolution and one LCP after a successful sampling attempt above the sampled site. 3 days (TBC) shall be allocated to each LCP.

R-OPS-130   The global characterization orbit or position shall be such that all surface features (rocks, boulders, steep slopes, crater rims, etc.) larger than 1 meter (TBC) can be identified and located with a 20 meter (TBC) absolute precision on the asteroid global scale.

Global mapping of features (+ global shape model).

R-OPS-140   The local characterization campaign shall be such that all surface features larger than 20 cm (TBC) can be identified and located within a 10 meter (TBC) absolute precision on the 5 sampling site candidates.

Mapping of features on the sampling site candidates (+ local digital elevation model for slope estimation).

R-OPS-150   A minimum of 3 sampling attempts shall be foreseen throughout the whole proximity operations phase.

R-OPS-160   Proximity operations shall be planned so as to avoid collision with the primary asteroid and its secondary in case of temporary failures of the S/C or the ground segment.

*See also, **R-AUT-030** through **R-AUT-070, R-PQA-080**.*

R-OPS-170   The proximity operations shall be such as to fulfil the resolution requirements listed in [AD2].

R-OPS-180   At least 2 weeks shall be included at the end of the proximity operations for margin purposes.

R-OPS-190   *Deleted.*

R-OPS-200   The minimum duration of the global characterization phase before sampling shall be 35 days (TBC).

R-OPS-210   The proximity operations shall be compatible with a binary body as defined in **R-ENV-070/090/120/130/140/150**.

G-OPS-220   Between two sampling attempts one week should be dedicated to review of the first sampling/attempt operations.

In order to evaluate the science interest of the first acquired sample and analyse telemetry data from the previous sampling phase.

R-OPS-230 During descent a minimum of 5 pictures of the surface shall be taken and shall be stored in the spacecraft onboard memory for later transmission.

Complementary to minimum TM + outreach.

R-OPS-240 A full sampling attempt shall be preceded by at least one successful descent rehearsal.

A descent rehearsal does not need to involve surface touchdown. Its aim is to validate the convergence of the navigation filter. Details TBD.

R-OPS-250 The mission analysis and overall design shall enable asteroid surface touchdown and sampling operations at any latitude and longitude.

R-OPS-260 The sampling operations on the asteroid shall occur on a fully illuminated location.

In order to get context information in the visible range (close-up camera).

R-OPS-270 The sampling operations shall be based on a touch and go approach (a few seconds touchdown, see definition of "touch and go" in 13.2).

R-OPS-280 The descent/touchdown operations shall be such as to prevent the creation of dust before sampling operations.

R-OPS-290 *Deleted.*

R-OPS-300 *Deleted.*

R-OPS-310 The Earth Re-entry Capsule shall be released by the sampling spacecraft TBD hours before Earth re-entry.

R-OPS-320 The measurements in the visible range shall be performed with a local solar elevation angle between 30 and 60 degrees. Visible range instruments shall nevertheless be on even during observations at other Sun aspect angles.

R-OPS-330 The radio science experiment shall be conducted from a "Radio-science" orbit and allow to fulfil gravity-related science requirements defined in [AD2].

See definition of "Radio-science" orbit in chapter 13.2. Note that, if possible and of compatible with the instrument measurement requirements, other science measurements can be performed in parallel.

R-OPS-340 The selected sampling site shall be at least ~ 50 m diameter (TBC) (assuming that the asteroid surface has at least one such a site).

See definition of sampling site in chapter 13.2. For such a large km-sized body, a 50 m area safe of hazards for a touch and go approach is very likely, see [RD13]

G-OPS-350 The selected sampling site should be free of features larger than TBD cm.

Sampling site minimizing risk. Operational requirement on the sampling site selection

10 SPACE SEGMENT REQUIREMENTS

10.1 Spacecraft system requirements

This chapter defines the general system requirements applicable to the sampling spacecraft and the ERC or the space segment as a whole (general, margin, etc.). They are derived from the science requirements, the mission safety, the general space design standards or more specific aspects of the mission applicable at system-level.

R-SYS-010 The spacecraft lifetime shall be 8 years in space and 2 years for pre-launch ground activities (AIT/AIV/storage) in a controlled environment and all space-based elements shall be designed and sized for this duration.

R-SYS-020 *Deleted.*

R-SYS-030 The space segment shall be sized for the mission scenario which is most demanding (i.e. worst case ΔV, launch mass, thermal and sun illumination environment) as defined in [RD1], covering the full launch window as defined in [AD13]/**R-DV-4**.

R-SYS-040 In this assessment study, the mission design shall follow the margin philosophy defined in [AD13]. The margin philosophy and margin depletion scheme will be firmly defined at a later stage.

R-SYS-050 The space segment shall cope with the integration procedures on a Soyuz-Fregat 2-1 b from CSG in Kourou.

e.g. vertical integration atop the Soyuz third stage on the launch pad, etc.

R-SYS-060 *Deleted.*

R-SYS-070 The space segment shall be composed of 2 modules: Sampling spacecraft + Earth Re-entry Capsule (ERC).

See Figure 13-1.

R-SYS-080 All spacecraft shall be designed according to [RD4], [RD5], [RD6] and [RD7] unless otherwise specified in this document.

Any conflict between the requirements in this document and the ECSS standards shall be reported to ESA.

R-SYS-090 The spacecraft system shall accommodate all necessary equipments and sub-systems, including mass and volume margins as defined in [AD13] and compatible with launch windows as defined in [RD1].

R-SYS-095 The maximum spacecraft dry mass, respectively wet mass shall be TBD kg, TBD kg.

R-SYS-100 The sampling spacecraft shall accommodate the science payload and enable fulfilling all primary science measurements.

See [AD2] and payload as defined in [RD16].

R-SYS-110 A design-to-cost and risk minimization mission design approach shall be followed.

R-**SYS**-**120**   The sampling spacecraft shall accommodate and transport the ERC throughout the whole mission until release upon arrival at Earth.

G-**SYS**-**130**   The sampling spacecraft should take images of the separated ERC after release.

R-**SYS**-**140**   The design of the sampling spacecraft and ERC shall be robust against damage due to debris and dust encountered during all proximity operations.

   E.g. in-orbit dust/debris, touchdown/sampling on asteroid, etc.

R-**SYS**-**150**   The S/C shall be designed to withstand the predicted micro-meteorite environment throughout the mission with a probability larger than 0.998.

   The micro-meteorite environment is as defined in [AD4].

R-**SYS**-**160**   The main spacecraft shall allow for commissioning and calibration of the orbital science instruments during the transfer to the NEA, including during fly-bys.

R-**SYS**-**170**   *Deleted.*

R-**SYS**-**180**   *Deleted.*

R-**SYS**-**190**   During the touch and go sampling operations, the sampling spacecraft shall approach the surface with a maximum horizontal velocity of 5 cm.s^{-1} (TBC) at touchdown.

   To limit the magnitude of forces on the touchdown/sampling system and to mitigate toppling.

R-**SYS**-**200**   During the touch and go sampling operations, the sampling spacecraft shall approach the surface with a maximum vertical velocity of 10 cm.s^{-1} (TBC) at touchdown.

R-**SYS**-**210**   The sampling spacecraft shall have a maximum attitude of +/-10° with respect to the local surface at touchdown (TBC).

   To mitigate toppling and to limit constraints on spacecraft geometry (e.g. solar panels).

R-**SYS**-**220**   *Deleted.*

R-**SYS**-**230**   *Deleted.*

R-**SYS**-**240**   The touchdown accuracy of the sampling spacecraft with respect to the targeted sampling site shall be better than 50 meters, 3-σ value (TBC).

R-**SYS**-**250**   The sampling spacecraft shall accommodate the ERC in a safe location such that the risk of collision of the ERC Thermal Protection System with the asteroid surface is minimized.

R-**SYS**-**260**   After touchdown the full set of telemetry data acquired during descent shall be protected from overwriting until receipt on Earth is confirmed.

R-**SYS**-**270**   The ERC shall be designed such as to limit the total heat flux to 15 MW/m² and total pressure at stagnation point to 80 kPa.

To remain within a feasible domain for plasma testing of thermal protection system. Heat fluxes including margins as per [AD13].

R-**SYS**-**280**   The ERC shall perform a fully passive re-entry (i.e. no parachute, no propulsion, no active control).

R-**SYS**-**290**   *Deleted.*

R-**SYS**-**300**   The ERC and its sub-systems shall be designed such that the shock loads on the sample are lower than 2000 g quasi-static load (TBC) for any angle of attack up to 20 degrees (TBC).

Limit adequate for the sample. See [AD2].

G-**SYS**-**310**   The ERC and its sub-systems should be designed such that the shock loads on the sample are lower than 800 g quasi-static load (TBC) for any angle of attack up to 20 degrees (TBC).

R-**SYS**-**320**   The ERC shall allow simple access to and recovery of the sample within the capsule without damaging the sample container seal.

R-**SYS**-**330**   The ERC shall be statically stable and its dynamic instabilities, if any, shall be such that angle of attack variations are limited to 20 degrees (TBC) at all aerodynamic regimes after the peak of dynamic pressure.

ERC dimensions, inertia, mass and CoM, CoP location. Before peak of dynamic pressure, angle of attack variations are less critical.

R-**SYS**-**340**   The maximum deceleration of the ERC through re-entry shall be 80 g, quasi-static load (TBC).

To ensure integrity of the ERC up to (excluded) landing.

G-**SYS**-**350**   The ERC design should ensure that the sample is never exposed to temperatures higher than +40ºC. For less than one minute, +80ºC is acceptable.

See [AD2].

G-**SYS**-**360**   The ERC should be equipped with a flight instrumentation package to perform the following measurements during entry and descent: heat flux, temperature and pressure on both front and back shields at a frequency of 0.5 Hz (TBC).

*This information will be stored. If implemented, the maximum allowable shocks on the memory shall be defined and included in **R**-**SYS**-**300**.*

R-**SYS**-**370**   The sample sealing system shall prevent:
- Less than 0.1 ppm of terrestrial water,
- Dust or liquid particles larger than 0.3 μm,

to contaminate the sample up to storage of the capsule in the suitable sample curation facility after return.

See [AD2].

R-SYS-380 The sample sealing system shall withstand a shock load up to 2000 g quasi-static load (TBC).

*See **R-SYS-300** and [AD2].*

G-SYS-390 The sample sealing system should withstand a shock load up to 800 g quasi-static load (TBC).

*See **G-SYS-310** and [AD2].*

R-SYS-400 *Deleted.*

R-SYS-410 The spacecraft design and operations shall transmit back to Earth a minimum total payload data volume of 122.35 GBit (TBC) before the end of the asteroid proximity operations.

Without any margins ([AD13] guidelines to be implemented), compressed data volume.

R-SYS-420 110.8 Gbit (TBC) of science data shall be transmitted back to Earth 2 weeks before the start of sampling operations (SAM).

Without any margins ([AD13] guidelines to be implemented), compressed data volume. Includes data from all phases, including GCP and LCP.

R-SYS-430 TBD Gbit of science data shall be transmitted back to Earth 2 weeks before the start of LCP operations.

10.2   Platform sub-system requirements

This chapter defines all key S/C sub-system requirements (pointing, thermal, power, data handling, telecommunications, etc.). They are derived from the system requirements or are requirements specific to a sub-system derived from space design standards or mission-specific need.

10.2.1 Thermal requirements

R-THE-010 The spacecraft thermal control system shall cope with the thermal needs of the various spacecraft sub-systems as required, including P/L, at any stage of the mission as a function of the spacecraft thermal modes, including safe mode.

R-THE-020 The spacecraft thermal control system shall cope with the space environment throughout the mission (incl. asteroid surface operations).

See [AD4]. Specific attention to be given to asteroid IR flux and closest distance to the Sun during transfer.

R-THE-030 Sufficient telemetry and housekeeping information shall be provided for monitoring of thermal equipment (e.g. radiators, heaters, etc.).

Lessons learns from Rosetta (e.g. need to thoroughly monitor the effect of pointing/solar aspect angle for the radiators).

R-THE-040 The ERC heat shield thermal protection system material shall be able to withstand entry conditions defined in **R-SYS-270.**

Qualification margins for the TPS material are TBD.

10.2.2 Power requirements

R-POW-010 The spacecraft power system shall be made of solar arrays and batteries and shall cope with the power needs of the various spacecraft sub-systems as required, including P/L, at any stage of the mission as a function of the spacecraft power modes, including safe mode.

I.e. power generation, storage, conditioning and distribution.

R-POW-020 The spacecraft battery shall be sized for worst case eclipses and the descent/touchdown/re-ascent phase.

Eclipses due to the asteroid will be avoided for nominal operations but may be encountered if control of the spacecraft is lost or Earth eclipses during LEOP.

R-POW-030 The sizing of the solar arrays shall allow the S/C to stay on a "Radio-science" orbit and safe position as defined in 13.2.

To avoid asteroid escape via solar radiation pressure.

R-POW-040 *Deleted.*

R-POW-050 The electrical design shall comply with the requirements of [RD6]. Tailoring of these requirements may be proposed and need to be justified.

10.2.3 GNC/AOCS requirements

R-GNC-010 *Deleted.*

R-GNC-020 *Deleted.*

R-GNC-030 *Deleted.*

R-GNC-040 Asteroid acquisition (i.e. identification of the target) shall be performed one week (TBC) before the start of proximity operations.

Start of proximity operations defined in chapter 13.2.

R-GNC-050 During sampling operations, the AOCS/GNC system shall prevent total attitude excursions larger than 30 degrees (TBC) (with respect to the local vertical) and attitude rates larger than 5 deg/s (TBC).

For instance to avoid the solar panels to hit the surface and further re-ascent with a safe attitude.

R-GNC-060 The AOCS system shall be able to maintain during safe mode the composite in a Sun-pointing attitude using a minimum of the onboard resources while ensuring power generation, a survivable thermal environment and ground communication for vital equipment.

R-GNC-070 In the event of unavailability of the star trackers, the AOCS/GNC shall have the capability to maintain and propagate attitude estimation whilst meeting the relevant pointing requirements.

R-GNC-080 *Deleted.*

R-GNC-090 *Deleted.*

G-GNC-100 Asteroid acquisition (i.e. identification of the target) should be performed two weeks (TBC) before the start of proximity operations..

> *R-GNC-040 guarantees a minimum detection time.*

R-GNC-110 After separation from the launcher upper stage, the AOCS shall:
- Damp out the residual angular rates,
- Bring the S/C into a power safe pointing attitude within a time compatible with the S/C internal electrical energy capability,
- Maintain the S/C attitude to allow communications with the ground as planned for LEOP operations.

R-GNC-120 *Deleted.*

10.2.4 DHS requirements

R-DHS-010 The spacecraft data handling system shall cope with the data transfer and storage requirements of the various spacecraft sub-systems, including payload, at any stage of the mission.

R-DHS-020 The DHS shall be able to receive TC and send TM from/to ground at the same time.

R-DHS-030 The DHS shall be able to command the instruments and equipment onboard.

R-DHS-040 The DHS shall provide reconfiguration capabilities in case of failure detection.

R-DHS-050 The DHS shall manage the redundancy for the relevant sub-systems.

R-DHS-060 During touchdown/sampling operations, the DHS shall provide the capability to store the scientific and housekeeping data generated by the complete close-up camera and sampling operations cycle.

R-DHS-070 The DHS system shall support uplink and downlink file transfer.

R-**DHS**-**080** The DHS shall provide the storage capability such that all science data can be downlinked (**R-SYS-410/420/430**) during proximity operations and assuming 2 consecutive downlink windows (i.e. 2 consecutive daily windows) are missed.

R-**DHS**-**090** The DHS system shall be compatible with the maximum data rates of each instrument as specified in [RD16].

R-**DHS**-**100** The DHS system shall implement system-level failure FDIR of the P/L and platform.

10.2.5 Propulsion requirements

R-**PRO**-**010** *Deleted.*

R-**PRO**-**020** The propulsion system shall cope with all operations and associated Delta-V/thrust requirements incl.: transfer (MCC, DSM, etc.), asteroid proximity operations, initial fly-bys, gravity field campaign, controlled orbits, local characterization phase, sampling rehearsals, descent/touchdown and re-ascent phases, etc.

R-**PRO**-**030** The by-products of the propulsion system shall be characterized and reported at ppb level prior to the mission.

R-**PRO**-**040** The propulsion sub-system shall be designed to be compatible with any operational S/C attitude. The main engine and any reaction control thruster shall be thermally qualified for such environmental conditions.

Particularly for the asteroid surface environment.

R-**PRO**-**050** The propulsion sub-system thermal design shall assure that the minimum predicted temperatures of any wetted component or surface contacting the propellant remain at least 10°C above the maximum freezing point of the onboard propellant.

R-**PRO**-**060** The performances of the propulsion system in terms of total impulse and margin shall satisfy the requirements imposed by the mission, the trajectory analysis and the overall system requirements.

10.2.6 Communications requirements

R-**COM**-**010** *Deleted.*

R-**COM**-**020** Real-time data shall be provided directly to Earth during descent and sampling allowing monitoring of the major events. A data rate of 100 bit/s shall be possible (TBC).

Beagle 2 recommendations: get a minimum health status of the S/C throughout descent. 100 bit/s in line with MER data.

R-**COM**-**030** The mission design shall comply with ESA ECSS telecommunication standards ([RD14]).

R-COM-040 The communication system shall support the two-way Ranging and Doppler measurements of the S/C throughout all mission phases and ΔDOR if high-precision navigation is required (e.g. RSE campaign) TBC.

R-COM-050 The link budgets of the spacecraft to ground shall be calculated for a weather availability of 95%.

R-COM-060 Science data shall be downlinked by the spacecraft in X-band.

R-COM-070 The maximum bit error rate during data downlink shall be better than 10^{-5}.

R-COM-080 *Deleted.*

R-COM-090 The telecommunication system shall be capable of simultaneously handling telemetry, ranging and telecommands.

R-COM-100 *Deleted.*

R-COM-110 The telecommunication equipment shall support the RSE as specified in [RD16].

If Ka-band is required for science, this shall be considered as a science instrument.

R-COM-120 The telecommunications system shall be able to downlink all science data as per **R-SYS-410/420/430**.

R-COM-130 All images taken by navigation cameras and required to be sent to ground (e.g. asteroid shape model, local slopes around sampling sites, etc.), if any, shall be downloaded.

10.2.7 Structure requirements

R-STR-010 The spacecraft structure shall support the launch environment [AD8] with MOS as defined in [RD5] which will be agreed with the agency.

R-STR-020 The spacecraft structure shall support the mechanical static and dynamic loads encountered during its entire lifetime, including: manufacturing, handling, transportation, testing, launch and in-orbit operations (incl. touchdown on the asteroid).

R-STR-030 The structure directly containing the sample (sample container) shall be able to withstand the loads (i.e. still fulfilling **R-SYS-380**) as defined in **R-SYS-300**.

R-STR-040 The structural stiffness shall guarantee fundamental frequencies of the S/C within the requirements of the LV to avoid dynamic coupling.

R-STR-050 The structural design shall be based on simple load paths.

R-STR-060 The structural design shall provide a minimum margin of 15% over the minimum frequencies specified by the Launcher User Manual [AD8] before verification of S/C dynamic properties by test.

10.2.8 Mechanism requirements

R-**MEC**-**010**   The sampling mechanism shall have the capability to collect hundreds of grams of material.

See [AD2].

R-**MEC**-**020**   The sampling mechanism shall have the capability to collect cm-sized fragments, plus a large amount (minimum several grams) of small particles (100s of μm-sized to mms-sized).

See [AD2].

R-**MEC**-**030**   The sampling mechanism shall be compatible with asteroid material having the properties defined in **R**-**ENV**-**100** and [AD2].

R-**MEC**-**040**   The sampling device (or any other part of the spacecraft) shall be equipped with autonomous means of verifying suitable sampling with a 95% probability (TBC).

Determine whether the sampling operation was successful or not.

G-**MEC**-**050**   The sampling device (or any other part of the spacecraft) should have the capability to provide a rough estimate of the collected sample mass and volume.

R-**MEC**-**060**   All mechanisms involved in the SATCS chain shall be cleaned so as to fulfil levels specified in **R**-**CON**-**010/R**-**SYS**-**370** and according to the standards defined in **R**-**CON**-**040**.

R-**MEC**-**070**   *Deleted.*

R-**MEC**-**080**   All mechanisms shall be protected against debris generated by touchdown and sampling on the asteroid.

R-**MEC**-**090**   The SATCS system shall be able to monitor its torque, thrust and penetration depth (if applicable).

R-**MEC**-**100**   It shall be possible to detect blockage of a sampling unit and release it before re-ascent in case it gets stuck during the touchdown/sampling operations.

R-**MEC**-**110**   *Deleted.*

G-**MEC**-**120**   The design of the sample collection and distribution unit (incl. container) should ensure that the sample, after collection, is never exposed to temperatures higher than +40°C. For less than one minute +80°C is acceptable.

Sample temperature and collection process. See [AD2].

G-**MEC**-**130**   Through the monitoring of its various sensors' information as a function of penetration progress, the SATCS should support the determination/estimation of the soil's mechanical properties.

Soil properties: density, porosity/compaction, hardness/cohesion, cementation, etc. To be coupled with **R**-**MEC**-**090**.

R-**MEC**-**140** The design of the touchdown mechanism system as well as the sampling mechanism shall be such that total attitude excursions are lower than 30 degrees (TBC) (with respect to the local vertical) and attitude rates lower than 5 deg/s (TBC).

*See **R-GNC-050***.

10.3 Autonomy and FDIR requirements

R-**AUT**-**010** Operations of the spacecraft shall be possible during all mission phases via the execution of pre-programmed sequence, or via onboard autonomy during the descent and sampling phase. Level of autonomy and detailed spacecraft operations throughout the various spacecraft operations are TBD.

R-**AUT**-**020** S/C autonomy shall ensure achievement of all mission goals.

R-**AUT**-**030** During asteroid proximity operations, if a ground TC is expected for the S/C to proceed with its nominal manoeuvre and this TC is not received within a TBD time, the S/C shall be able to perform a valid transition into an asteroid Collision Avoidance Mode.

R-**AUT**-**040** During descent/sampling operations on the asteroid, in case of any failure or non-nominal S/C equipment TM (sub-system or system) the spacecraft shall autonomously be able to perform a valid transition into an asteroid Collision Avoidance Mode.

R-**AUT**-**050** After TBD minutes in Collision Avoidance Mode and no ground feedback the spacecraft shall be able to perform a valid transition into Safe Mode.

R-**AUT**-**060** The S/C shall be able to receive a TC from the ground to switch from Collision Avoidance Mode to Safe Mode.

R-**AUT**-**070** In any operations other than descent/sampling, in case of major system failure (or non-recoverable single failure) the spacecraft shall be able to survive in Safe Mode without the need for ground contact in:
- A "safe position" if during asteroid proximity operations phase,
- On its transfer trajectory in case of LEOP or interplanetary cruise phase.

R-**AUT**-**080** The spacecraft operating modes shall include a system-level Safe Mode that ensures the following properties are fulfilled:
- Uninterrupted power supply,
- Safe thermal conditions,
- Continuous communication with ground,
- Predictable configuration minimising the onboard power demand and data traffic.

R-**AUT**-**090** The spacecraft operating modes shall include a system-level Collision Avoidance Mode that ensures the following properties are fulfilled:
- Autonomously go into a "safe position",
- Guarantee of no collision with the asteroid before switching to Safe Mode,
- Uninterrupted power supply,

- ▪ Safe thermal conditions,
- ▪ Predictable configuration minimising the onboard power demand and data traffic.

R-AUT-100 When in Safe Mode the spacecraft shall have the capability to transmit a predefined set of data parameters at a rate of up to TBD b.s^{-1}.

R-AUT-110 The spacecraft shall be able to perform a valid mode transition upon receipt of a telecommand at all times and in all spacecraft modes.

R-AUT-120 The fault management systems shall be intrinsically fail-safe.

R-AUT-130 The spacecraft shall function autonomously throughout any solar conjunctions on cruise to and back from the asteroid.

R-AUT-140 The system (or FDIR) shall provide the capability for automatic detection, isolation and recovery of any credible system or subsystem anomaly.

R-AUT-150 Sampling site targeting and last go/no-go decision during actual descent and sampling shall be ground-based. Autonomous sampling site re-targeting shall not be allowed (see **R-AUT-040** instead).

10.4   Environmental requirements

The following defines the environment-related requirements that the spacecraft has to comply with throughout the mission, whether that is the launch, interplanetary, spacecraft, asteroid or Earth re-entry environment.

R-ENV-010 The spacecraft composite and all its sub-systems, including payload, shall be compatible with the launch environment as defined in ([AD8]).

R-ENV-020 The mission design shall be compliant with the general space environment (cruise) requirements defined in [RD4] and the mission-specific (e.g. asteroid) environment requirements defined in [AD4].

R-ENV-030 *Deleted.*

R-ENV-040 The sample shall never be exposed to magnetic field larger than 200 μT.

R-ENV-050 The spacecraft shall satisfy the electric and magnetic cleanliness (EMC) requirements specified by the payload (TBD reference).

R-ENV-060 *Deleted.*

R-ENV-070 The maximum surface temperature of the sampling site to be considered for the design of the spacecraft shall be 500 K (TBC).

G-ENV-080 *Deleted.*

R-ENV-090 The mission design shall be compatible with the rotation period of the primary asteroid of ~ 3.6 hours +/- 0.1%.

R-ENV-100   The surface properties which shall be assumed for the design of the sampling mechanism are as follows:
- No solid rock. Only loose material shall be assumed,
- <u>Grain Size</u>: µm → up to 3 cm,
- <u>Shape</u>: any (rounded, tabular, elongated, etc.),
- <u>Cohesion</u>: 0.1 – 5 kPa,
- <u>Compressive strength</u>: Up to 30 MPa,
- <u>Bulk density</u>: <1 – 2.2 g.cm^{-3},
- <u>Angle of internal friction</u>: 20° - 40°.

R-ENV-110   *Deleted.*

R-ENV-120   The asteroid body density shall be assumed to be 1300 ± 600 kg.m^{-3}. This also applies to the secondary body.

   See [AD4].

R-ENV-130   A diameter of 1550 m – 2110 m shall be assumed for the primary body.

   See [AD4].

R-ENV-140   A diameter of 430 m – 590 m shall be assumed for the secondary body.

   See [AD4].

R-ENV-150   A binary with the following properties shall be assumed:
- Secondary orbital semi-major axis: 2.8 + 1.7/-0.7 km,
- Secondary orbital eccentricity: 0.05 ± 0.05,
- Secondary orbital period around primary: 16.15 ± 0.02 hours.

   See [AD4].

10.5   AIV and testing requirements

R-AIV-010   The AIV activities of the S/C shall be compliant with the integration requirements of a Soyuz-Fregat 2-1 b in CSG Kourou.

R-AIV-020   The AIV facilities shall enable the implementation of sterilization and cleaning procedures as defined in **R-CON-040**.

10.6   Ground segment

R-GRS-010   The mission shall use and be compatible with the standards of the ESA deep space network as well as the NASA deep space network.

R-GRS-020   The MarcoPolo-R mission shall be operated by ESA/ESOC.

R-GRS-030   During LEOP, TBD ESA ground stations shall be used for contact with the spacecraft.

   LEOP is defined as the first 72 hours (TBC) after the separation of the spacecraft from the Fregat upper stage.

R-GRS-040 After LEOP, the ESA station at TBD location shall be the primary station used for contact with the spacecraft, with TBD location as backup.

R-GRS-050 The ground segment shall provide for a 24 hour coverage capability for asteroid descent, touchdown, sampling and local characterization operations.

R-GRS-060 The ground segment shall cope with the data volume defined in **R-SYS-410/420/430**.

R-GRS-070 It shall be possible to retrieve the ERC within 4 hours (TBC) after landing on Earth without the aid of tracking devices onboard the ERC.

Also to be taken into account for ERC landing site selection.

R-GRS-080 It shall be possible to track the ERC re-entry during the whole re-entry operation.

G-GRS-090 It shall be possible to retrieve the ERC within 2 hours (TBC) after landing on Earth without the aid of tracking devices onboard the ERC.

To limit thermal excursion on the sample.

R-GRS-100 The ground segment shall support the on-orbit calibration of the satellite autonomous pointing capabilities.

R-GRS-110 The ground segment shall elaborate an operational concept based on multiple uplink and downlink attempts and a respective timing for the preparation of the orbit timeline to enable standard operations under superior solar conjunction conditions with a Sun-Earth-Spacecraft angle as low as 2° (TBC). The required success rate sets of commands (number of commands in set: 50 TBC) and for telemetry packets is TBD.

Probability to be calculated for space weather conditions typical for the solar cycle at the time of the conjunction.

R-GRS-120 The ground segment shall be able to support at least 4 (including rehearsals) touchdown and sampling attempts during the asteroid proximity phase.

R-GRS-130 The ground segment shall be able to support at least the 5 local characterization phases before sampling and the last one after sampling (above the sampled site).

R-GRS-140 The ground segment shall provide for a flexible re-planning capability during the asteroid phase. The manoeuvre planning for new asteroid proximity orbits and new sampling site targets shall be available within 4 days (TBC) after reception of the respective request.

R-GRS-150 The ground segment shall construct a global asteroid map and a global Digital Elevation Model with a 1-m spatial resolution (TBC) of the whole asteroid during the GCP phase primarily based on the navigation sensor information.

*See **R-OPS-130**.*

R-GRS-160   The ground segment shall construct a local map and a local Digital Elevation Model with a 20-cm spatial resolution (TBC) of the sampling site candidates during the LCP phase primarily based on the navigation sensor information.

  *See **R-OPS-140**.*

R-GRS-170   The ground segment shall be able to obtain the position information relative to the targeted sampling site sent by the spacecraft as a package of "images" and AOCS housekeeping data, process this data and upload an appropriate "guidance" telecommand within one hour (TBC) of reception of the images in order to either reach the sampling site or to abort the descent.

10.7   Product assurance and RAMS requirements

R-PQA-010   *Deleted.*

R-PQA-020   *Deleted.*

R-PQA-030   The mission design shall be free of Single Point Failures, shall be one-failure tolerant and shall ensure avoidance of failure propagation. .

R-PQA-040   Instrument failures shall not cause failure or damage to other instruments or other spacecraft subsystems.

R-PQA-050   Instrument failures shall not cause the spacecraft to enter a Collision Avoidance or Safe Mode.

R-PQA-060   *Deleted.*

R-PQA-070   Where redundancy is employed, the design shall allow operation and verification of the redundant item/function independent of nominal use.

R-PQA-080   In case of anomalies or failures from which the spacecraft cannot recover autonomously, the spacecraft shall be able to autonomously perform a valid transition into:
  - Collision Avoidance Mode and later on Safe Mode if during descent/sampling operation,
  - Safe Mode if during any other phase than descent/sampling operations.

R-PQA-090   The overall mission reliability shall be better than 90% (TBC).

R-PQA-100   The design philosophy for all mechanisms shall be as defined in [RD5].

R-PQA-110   The risk of casualty resulting from the ERC re-entry shall be 1:10000 (TBC).

R-PQA-120   *Deleted.*

R-PQA-130   The communication system shall implement full redundancy except for the main antenna dishes (e.g. HGA).

R-PQA-140   A highly reliable backup sampling method shall be implemented to ensure a sample can be collected should the main sampling mechanism fail.

> *For the backup sampling method, degraded amount of mass (i.e. TBD grams) are*
> *acceptable*

11   COORDINATE SYSTEM

R-COR-010   For the description of the MarcoPolo-R spacecraft and of its major components, the following S/C Reference Coordinate Frame shall be used:
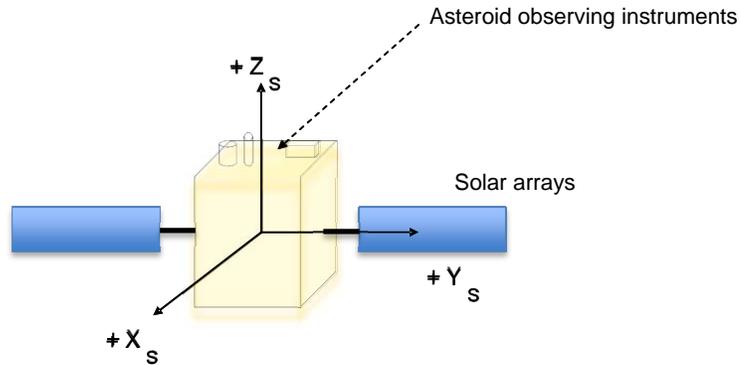
Figure 11-1: Main spacecraft reference frame

R-COR-020   For the definition of the MarcoPolo-R spacecraft attitude along its orbit, the following Local Orbital Reference Frame shall be used:
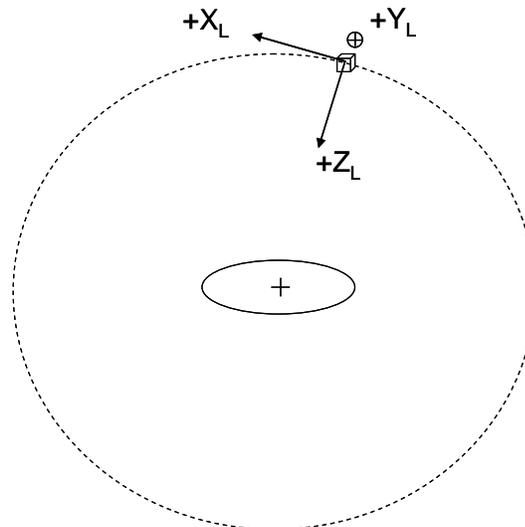
Figure 11-2: Local orbital reference frame

$+Z_L$ is oriented towards nadir and $+X_L$ is oriented along the velocity vector of the spacecraft.

12 APPLICABLE AND REFERENCE DOCUMENTS

The Applicable Documents (AD's) listed below shall be complied with, unless conflicting with the mission MSRD itself or where specifically stated. Their contents shall be considered as parts of the requirements of this document. A conflict between these documents and the MSRD shall be brought to the attention of ESA for clarification.

The published ECSS (European Cooperation for Space Standardisation) space standards documents quoted in the MSRD shall be used as design references throughout the MarcoPolo-R assessment phase and are available on the Internet at: www.ecss.nl.

12.1 Applicable documents

[AD1]	Deleted
[AD2]	**MarcoPolo-R Science Requirements Document**, [MPR-RSSD-RS-001], issue 1.4, Document providing Science objectives and science requirements, including measurement specifications
[AD3]	Deleted
[AD4]	**MarcoPolo-R Environment Document**, [SRE-PA/2011.077], issue 1.2
[AD5]	**MarcoPolo-R – Assessment of Planetary Protection issues**, [SRE-PA/2011.078], issue 1.0, Document providing recommendations on Planetary Protection issues relating to the potential NEA targets
[AD6]	**MarcoPolo-R Consolidated Report on Mission Analysis**, [Reference TBD], issue 1.0, ESOC, document describing the detailed reference transfers and orbits as well as navigation analysis to be used in task 2. Note: will be provided by ESA in the course of task 2
[AD7]	Deleted
[AD8]	**Soyuz-Fregat 2-1b from the Guiana Space Centre User's Manual,** issue 2.0, March 2012. Note: The launch vehicle performances to be used in this study are defined in [AD6] (or [RD1] if [AD6] is not available)
[AD9]	Deleted
[AD10]	**Technology Readiness levels handbook**, [TEC-SHS/5551/MG/ap], issue 1.6, September 2008
[AD11]	Deleted
[AD12]	Deleted
[AD13]	**MarcoPolo-R margin philosophy document**, v1.1, [SRE-F/2012.088]
[AD14]	**MarcoPolo-R Mission Operations Assumptions Document**, [TBD]
[AD15]	**MarcoPolo-R Science Operations Assumptions Document**, [TBD]

12.2   Reference document

The Reference Documents (RD's) listed below are given as complementary information and background data related to the MarcoPolo-R Mission or the ESA standards.

|	
[RD1]	**MarcoPolo-R Mission Analysis Guidelines (MAG)**, SRE-F/2012.041, issue 2.0
[RD2]	**MarcoPolo-R CDF IFP material**
[RD3]	**MarcoPolo-R CDF study report**, CDF-123(A)
[RD4]	**ECSS-E-ST-10 series**, available from http://www.ecss.nl
[RD5]	**ECSS-E-ST-30, 31, 32, 33 and 35 series**, available from http://www.ecss.nl
[RD6]	**ECSS-E-ST-20 series**, available from http://www.ecss.nl
[RD7]	**ECSS-M-ST-10**, available from http://www.ecss.nl
[RD8]	**MarcoPolo-R: NEA Sample Return Mission proposal**, M.A. Barucci et al.
[RD9]	**Marco Polo Assessment Study Report**, ESA/SRE(2009)3, Dec. 2009
[RD10]	**The Marco Polo executive summary report**, MP.ASU.ES, issue 1
[RD11]	**Marco Polo executive summary**, MPL-OHB-TN-014, issue 1
[RD12]	**Marco Polo mission executive summary**, SD-RP-AI-0673, issue 1
[RD13]	**Marco Polo – Technical and programmatic review report**, SRE-PA/2009.069/Marco-Polo, issue 1.0
[RD14]	**ECSS-E-ST-50 series**, available from http://www.ecss.nl
[RD15]	**MarcoPolo-R cost estimate template**, Excel file
[RD16]	**MarcoPolo-R Payload Resources and Requirements Document**, [SRE-F/2012.089], issue 1.3, July 2012
[RD17]	**CDF Model Input Specification**, [CDF-IFS-001], issue 3.1, and associated Excel workbooks 'Mission Input Issue 3 rev 1.xls' and 'data exchange.xls'

13 ACRONYMS AND TERMINOLOGY

13.1 Acronyms

AD	Applicable Document
AIV (AV)	Assembly, Integration and Verification
AME	Absolute Measurement Error
AO	Announcement of Opportunity
AOCS	Attitude and Orbit Control System
APE	Absolute Pointing Error
AUT	Autonomy requirement
BSR	Baseline Selection Review
CAM	Collision Avoidance Mode
CDF	Concurrent Design Facility
CoG	Centre of Gravity
CoM	Centre of Mass
COM	Communication Requirement
CoP	Centre of Pressure
COTS	Commercial Off-The-Shelf
CSG	Centre Spatial Guyanais (Kourou, French Guyana)
CuC	Close-up Camera
DEM	Digital Elevation Model
DHS	Data Handling System
DOR	Differential One-way Ranging
DSM	Deep Space Manoeuvre
ECSS	European Cooperation for Space Standardisation
ENV	Environment requirement
ERC	Earth Re-entry Capsule
ESA	European Space Agency
ESTEC	European Space research and TEchnology Center
FCP	Far global Characterization Phase
FEM	Finite Element Model
FMECA	Failure Modes, Effects and Criticality Analysis
GA	Gravity Assist
GCP	Global Characterization Phase
GNC	Guidance, Navigation and Control
GRS	Ground Segment Requirement
HGA	High Gain Antenna
IR	Infrared
ITT	Invitation To Tender
LAS	Launch Segment Requirement
LCP	Local Characterization Phase
LEOP	Low Earth Orbit Phase
MCC	Mid-Course Correction
M-class	Medium Class
MCR	Mission Consolidate Review
MEC	Mechanism Requirement
MIS	Mission Requirement
MOS	Margin Of Safety
MSRD	Mission Requirements Document
NEA	Near Earth Asteroid (also sometimes referred to as Near-Earth Objects)
NPA	Neutral Particle Analyser

OPS	Operational requirement
P/L	Payload
PLD	Payload Requirement
POW	Power Requirement
PP	Planetary Protection
PPR	Planetary protection Requirement
ppb	particle per billion (10^{-9})
ppm	particle per million
PRM	Programmatic Requirement
PRO	Propulsion System Requirement
PQA	Product/Quality Assurance Requirement
RAMS	Reliability, Availability, Maintainability and Safety
RD	Reference Document
RF	Radio Frequency
RPE	Relative Pointing Error
RSE	Radio Science Experiment
RSP	Radio Science Phase
SAM	Descent/Sampling Phase
SATCS	Sample Acquisition, Transfer and Containment System
SRE-F	Advanced Studies and Technology Preparation Office
S/C	Spacecraft
SCI	Science Requirement
STD	Study requirement
SEP	Solar Electric Propulsion
SPF	Single Point Failure
SRP	Solar Radiation Pressure
SS	Sub-System
SSAC	Space Science Advisory Committee
STD	Study Requirement
STR	Star Tracker
STR	Structure and Mechanical Requirement
SYS	System Requirement
TBC	To Be Confirmed
TBD	To Be Determined
THE	Thermal Requirement
TPS	Thermal Protection System
TRL	Technology Readiness Level
TRS	Technology Reference Study
VIS	Visible

13.2 Terminology

The following spacecraft architecture was selected at the Baseline Selection Review of the assessment phase in June 2012:
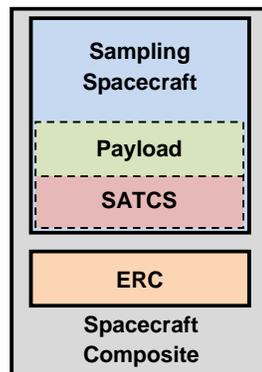
Figure 13-1: Baseline spacecraft architecture (note that the sealing function of the SATCS might also be performed within the ERC)

The role of each element is briefly described below.

- Spacecraft Composite: The combination of the sampling spacecraft and the Earth re-entry capsule, stacked together from launch through asteroid surface and proximity operations and cruises phases up until the release of the ERC. Note: the Spacecraft Composite does not include the launch vehicle adaptor.
- Sampling Spacecraft: Module used for outbound and inbound transfer to and from the asteroid, orbital operations around the asteroid, descent, sampling and re-ascent operations to and from the asteroid surface as well as release of the Earth re-entry capsule. Sometimes also referred to as the main spacecraft in the assessment phase. Note: the Sampling Spacecraft does include the spacecraft mechanical interface to the LV adaptor (but not the adaptor itself).
- Earth Re-Entry Capsule (ERC): The capsule which performs the re-entry through the Earth atmosphere. The retrieved sample container is located inside the ERC.

In addition, the following definitions/clarifications apply:

- Sample Acquisition, Transfer and Containment System (SATCS): All equipments involved in the sampling, sample transfer, sealing and containment functions of the spacecraft. This is considered to be a spacecraft sub-system (i.e. not a payload element) and thus should be under ESA responsibility (incl. development and procurement cost).
- Touch And Go: Sampling strategy defined by the following characteristics:
    - Sampling operations during GNC guided impact,
    - Surface contact by sampling mechanism only and any possible skirt around it to mitigate dust and debris impact,
    - The impact energy may or not be used for sampling/ascent,
    - The sampling contact with the asteroid is in the order of seconds (e.g. maximum 5-10 seconds).
- Payload: The payload is defined as the ensemble of physical element from the input signal collection up to the digital electronic signal production.
- Absolute pointing error: Angular separation between the actual instantaneous generalised pointing vectors of the S/C and the commanded or desired generalised pointing vectors.
- Relative pointing error: Angular separation between the actual instantaneous generalised pointing vectors of the S/C and the median generalised pointing vectors defined over a time interval containing the reference time instant. Also known as pointing stability.

- <u>Absolute measurement error</u>: Angular separation between the actual and measured generalised pointing vectors of the S/C.
- <u>Horizontal or Lateral touchdown velocity</u>: The component of the touchdown velocity parallel to the average local slope at the asteroid sampling site.
- <u>Vertical touchdown velocity</u>: The component of the touchdown velocity perpendicular to the average local slope at the asteroid sampling site.
- <u>Sampling site (candidate)</u>: Safe area operationally (on an illuminated part such as to enable vision-based navigation and with hazards compatible with the S/C capability) and scientifically suitable for sample collection, defined on the asteroid surface by the ground teams.
- <u>Touchdown accuracy</u>: Downrange major axis of the touchdown ellipse.
- <u>Touchdown ellipse</u>: Ellipse centred on the sampling site which envelops all possible touchdown locations reachable by the spacecraft at 3-σ confidence level taking into account the variation/error of input parameters: navigation (sensors, filter, etc.), gravity model and physical property (rotation axis, period, etc.), solar radiation pressure, control (thruster), S/C modelling (thruster alignment, etc.), etc.
- <u>Proximity operations</u>: The asteroid proximity operations are arbitrarily defined at the start of the close asteroid approach, i.e. at a distance of 500 km from the asteroid and end when the SEP system is switched on and the S/C leaves the asteroid system. See Figure 2-2.
- <u>Radio-science orbit</u>: In the context of MarcoPolo-R, a Radio-science orbit is an asteroid-bound orbit, favourable to radio science measurements, where the S/C does not require any orbit and attitude manoeuvres in order to remain above 3 km distance to the surface at any time, during four consecutive communication windows of 8 hours.
- <u>Safe position</u>: In the context of MarcoPolo-R, a safe position is an eclipse-free location where the spacecraft does not require any orbit and attitude manoeuvres during at least one week in order to remain at least 1 km distance away from the surface of the asteroid surface (and its secondary if applicable). Such a position can be either an asteroid-bound orbit or formation flying point or a heliocentric orbit, out of the asteroid influence (however close enough to allow return to asteroid in limited time and manoeuvre budget).
- <u>Failure</u>: The termination of the ability of an item to perform a required function (e.g. solar arrays not producing electric current following string failure, sampling mechanism stuck and not able to perform sampling).

14   LIST OF TBC AND TBD

14.1   List of TBC

To be written

<div align="center">Table 14-1: List of TBC</div>

14.2   List of TBD

To be written

<div align="center">Table 14-2: List of TBD</div>