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MARCO POLO

SCIENCE REQUIREMENTS DOCUMENT (SCI-RD)

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CHANGE RECORD

issue	revision	date/*date*	reason for change/*raison du changement*	page(s)
1	-	29 Jan 2008	First complete issue	all
1	A	04 Feb 2008	Editorials	all
1	B	14 Feb 2008	Change dm to m in the resolution of IR for global characterisation	7
1	C	29 Apr 2008	Major update after CDF study, prepare for industrial ITT	All
`	D		Intermediate version	

issue	revision	date/*date*	reason for change/*raison du changement*	page(s)
1	E	12 Dec 2008	Added SA-045 on depth SA-050: Added "After collection, …" SA-120: Changed "should" to "shall" SA-130 and -140 addressing cross-contamination and cleanliness were added SC-010: Added "… and after", changed 20 um to 15 um SC-020: added "… at the sampling site…"; added "… before *and after*…" OR-010: rephrase to make clearer that it is *not required* to flyby the Moon, but rather the parenteses give an example. OR-020: Rephrased OR-040: added a requirement on being able to switch on instruments during any planetary flybys AS-020 – delete 'J1' AS-040: Deleted "…to allow searching for Inner Earth Objects." Updated the resolution requirement to allow the CUC to be body-mounted	
2	-	11 May 2009	Adapt document to current mission scenario	
2	A	14 May 2009	Relaxed SA-040	
2	B	20 May 2009	Modified wording of SA-040 (sample mass), deleted the goal Deleted SA-045 (sample depth), Reworded SA-060, in particular replaced 'pebbles' with 'fragments'	

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Scope

This document describes the detailed scientific requirements for the Marco Polo mission. These requirements are derived from discussions by the Science Study Team (SST) of the Marco Polo study and is based on the scientific objectives as described in the Marco Polo Proposal to ESA's Cosmic Vision programme (RD 01). The major part of the discussion took place at the 2nd SST meeting in Paris on 17 Dec 2007, with email updates and a final discussion on the 3rd SST meeting in Paris on 29 Jan 2008. After an ESA-internal study, the requirements were refined.

This updated document now serves as a starting point for the kick-off of the industrial study phase of the mission as part of the Cosmic Vision programme. It will be refined during the study and result in an Issue 2 at the end of the study.

This document serves as a starting point for the definition of the strawman payload in the Payload Definition Document (RD 02).

In case of the selection of this mission for implementation, another update of the document may be required to reflect updates in the scientific progress during the time of the study, resulting in an Issue 3.

1.2 Applicable Documents

AD 01 n/a

AD 02 Marco Polo Mission Requirements Document, SCI-PA/2008/001/Marco-Polo

1.3 Reference Documents

RD 01 Marco Polo – Near-Earth Object Sample Return Mission, Proposal to ESA's Cosmic Vision Programme, 20 Jun 2007

RD 02 Payload Definition Document, SCI-PA/2008/002/Marco-Polo

1.4 Acronyms

AD	Applicable Document
CDF	Concurrent Design Facility
ESA	European Space Agency
JAXA	Japanese Space Agency
NEO	Near-Earth Object
RD	Reference Document

SST Science Study Team

2 MISSION OBJECTIVES

The main objective of the Marco Polo mission is to return a sample from a Near-Earth Object (NEO) of primitive spectral type to the Earth. Scientific investigations will be included to make observations with the following priorities:

i. To enable the safe operation and manoeuvring of the spacecraft in close proximity to the NEO and safe collection of the sample(s).

ii. To place the samples in their global and local context.

iii. To provide complementary science results not achievable from the samples themselves.

The proposal lists the following top-level science topics where Marco Polo shall contribute to a better understanding:

(1) Origin of the solar system and planets

(2) Formation and evolution of NEOs

(3) Astrobiology

In the following text, 'shall' refers to a requirement which is a must for fulfilling the science goals. 'should' indicates that the science goals can be fulfilled without this requirement, but it would be beneficial to the mission science return to obtain this goal.

All requirements are numbered. The numbers are incremented initially in steps of 10 to allow inserting requirements at appropriate locations.

3 SCIENCE REQUIREMENTS

The main requirement is

To return a sample from a Near-Earth Object belonging to a primitive class to the Earth

which will allow the study of formation of the solar system and the planets, characterisation of a Near-Earth Object as a representative of a primitive solar system body, and contribute to the field of astrobiology.

In addition, scientific information shall be collected to provide the context of the sample.

In the following, we at first give requirements for the target selection and then the properties of the returned sample. After that, we distinguish between 'global characterisation', 'local characterisation', and 'sample context':

- 'Global characterisation' means to measure the properties of the whole NEO, on a global scale;
- 'Local characterisation' is the characterisation of up to 5 dedicated areas which are identified as potential sampling sites (see SR-10);

- 'Sample context' are measurements being performed at the actual sampling site.

Table 1 gives an overview of the required orders of resolution for the different scenarios.

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

	Spatial resolution for imaging in the visual	**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	hundred μm	-	-

3.1 Target selection

Requirements on the taxonomic class of the NEO are important to define the mission scenario. The following bullets summarize the required properties of the target. The current reference target is asteroid 1999 JU3. The list of the best four potential targets, for the given timeframe, is given in Appendix A, p. 12.

TS-10: Target type: The target shall be a Near-Earth Object of type C or D. Subtypes of C as well as B or T are acceptable. Note, however, that a scientific selection of the final target should take place at a later stage.

TS-20: Target size: There is no strong scientific requirement for a minimum target size. However, the target should be of a size such that:

i) It should have sufficient gravity to allow the determination of the gravity field to an accuracy good enough to provide some constraint to the internal structure (e.g. determine the J2 coefficient to 10 %).

ii) It is bright enough for fundamental properties (size, shape, albedo, rotation) to be estimated from ground-based observations.

As no precise numbers can currently be given for the above points, for the purpose of this study a minimum absolute visual magnitude of $H \leq 21$ mag shall be assumed, corresponding to a diameter $D \geq 340$ m for a representative primitive body assuming a visual geometric albedo of 0.06.

TS-30: To allow mapping the whole NEO in illumination in a reasonable amount of time, the maximum rotation period should not exceed 5 days.

TS-40: Minimum rotation period: The rotation period shall be greater than the limit for tidal disruption of non-cohesive bodies (~2.5 hours) to ensure the possibility of regolith for sample collection.

3.2 Sample requirements

To achieve the scientific goals of the mission, the following requirements shall be fulfilled by the sample:

SA-10: It shall be possible to characterize up to 5 potential sampling sites before the actual sampling. "Characterize" means:

(a) Determine the size distribution of the regolith down to scales in the order of a millimetre;

(b) Determine the rough mineralogical composition in the order of a decimetre;

(c) Determine the thermal skin depth indicative of regolith properties.

SA-020: It shall be possible to perform multiple sampling attempts (up to 3).

SA-030: Deleted.

SA-040: The sampling device shall have the capability to acquire a minimum mass of tens of grams and shall return them to Earth.

SA-045: Deleted

SA-050: After collection, the maximum temperature reached by the sample should not exceed +40 °C for long durations. For short durations of less than 1 minute, a temperature of up to +80 °C is acceptable.

SA-060: The sampling device shall have the capability to acquire a selection of cm-sized fragments, plus a large amount (ca. 10^4) of small (100s of μm-sized to mms-sized) particles.

SA-070: Highest priority for sampling shall be given to a target area which, from the global and local characterization of the NEO, appears to contain the most primitive material.

SA-080: Deleted

Contamination:

SA-090: During collection and storage (departure from NEO, cruise, Earth re-entry, ground retrieval and transfer to curation facilities) the sample shall be maintained free of organic and particulate contamination. The number of contaminating molecules deposited on the asteroid surface by the propulsion system shall be lower than 10^{+14} / cm^2 (goal 10^{+13} / cm^2).

SA-100: After being placed in the sample container, the sample shall not be contaminated by dust or liquid particles larger than 0.3 μm.

SA-110: Until the samples arrive in the curation facility, they shall be kept free of moisture from the atmosphere such that less than 0.1 ppm terrestrial water is present in the sample.

SA-120: The possible contaminants (e.g. propellant, S/C outgassing, etc.) shall be tracked in-situ (*e.g.* witness plates).

SA-130: Deleted.

SA-140: During the complete manufacturing process of the spacecraft, special procedures shall be in place to keep all parts of the spacecraft clean to a level to be specified.

3.3 Global characterisation requirements

'Global characterisation' means to measure the properties pertaining to the entire NEO. Section 3.4, lists requirements for the local characterisation, which is meant to study up to 5 potential sampling sites in detail high enough to decide that a sampling is useful. When the actual sample is taken, context measurements shall be performed, see Section 3.5.

In detail, the following requirements need to be fulfilled for the global characterisation:

GR-010: The complete surface of the NEO shall be imaged in at least 3 different colours, in the visible range with a spatial resolution of the order of decimetres, and with local solar elevation angle between 30 and 60° (Note: it is acknowledged that depending on the rotation axis of the asteroid there may be areas which cannot be imaged due to illumination constraints).

GR-020: The complete surface of the NEO shall be imaged in the visible and near-IR wavelength range from 0.4 to 3.3 μm to characterise the mineral properties of the surface with a spectral resolution of at least $\lambda/\Delta\lambda$ in the order of 200 and a spatial resolution of the order of meters to characterize the mineral properties of the surface (Note: it is acknowledged that depending on the rotation axis of the asteroid there may be areas which cannot be imaged due to illumination constraints).

GR-030: A shape model of the NEO shall be obtained with an accuracy of typically 1 m in height and spatial resolution with respect to the centre of mass, in both illuminated and unilluminated regions.

GR-035: The spatial resolution of the local topography (*i.e.* in relative coordinates) should be determined to an accuracy of the order of decimetres.

GR-040: The mass of the NEO shall be determined to an accuracy of about 1 % (may need to be rediscussed for small objects).

GR-050: The surface temperature of the complete NEO shall be derived to an accuracy of at least 5 K (goal 1 K) at a spatial resolution of the order of 10 m at a number (*tbc*) of rotational phases from which the thermal inertia can be determined to a precision of better than 10 % .

GR-060: The complete surface of the NEO shall be imaged in the mid-IR with a spatial resolution of the order of 10 m or better with a spectral resolution of at least $\lambda/\Delta\lambda$ in the order of 200 to determine the wavelength dependent emissivity, and hence identify mineral features in the range 8 – 16 μm (target 5 – 25 μm).

GR-070: The flux, speed, direction and mass of atomic/molecular particles escaping from the surface should be measured to detect products of solar wind sputtering or other active release processes. The energy range from 0.01 to 1 keV shall be covered with an energy resolution of about 25 % and an angular resolution of 5° x 5°; the particles with energies <0.01 keV shall be measured with $m/\Delta m$ of about 50.

3.4 Local characterisation requirements

'Local characterisation' is the characterisation of up to 5 dedicated areas which are identified as potential sampling sites (see SA-10). The following detailed requirements apply:

LR-010: An area of the size of the expected landing accuracy around the potential sampling sites shall be imaged in the visible in at least three colour filters, with a spatial resolution of the order of millimetres.

LR-015: An area of the size of the expected landing accuracy shall be imaged in the near-IR wavelength range to characterise the mineral properties of the surface with a spectral resolution of at least $\lambda/\Delta\lambda$ in the order of 200 and a spatial resolution of the order of decimetres to characterize the mineral properties of the surface.

LR-020: An area of the size of the expected landing accuracy around any of the potential sampling sites shall be imaged in the mid-IR with a spatial resolution of decimetres and a spectral resolution of at least $\lambda/\Delta\lambda$ in the order of 200 or better to determine the wavelength dependent emissivity, and hence identify mineral features in the range 8 – 16 μm (goal 5 – 25 μm).

LR-030: (As GR-070) The flux, speed, direction and mass of atomic/molecular particles escaping from the surface should be measured. The energy range from 0.01 to 1 keV shall be covered with an energy resolution of about 25 % and spatial resolution at surface about 10 m; the particles at energy <0.01 keV shall be measured with $m/\Delta m$ of about 50.

3.5 Sample context requirements

SC-010: The regolith size distribution of the actual sampling site shall be measured before and after sampling to sizes as small as 100 μm (goal: 15 μm) in an area about 5 times larger than the area sampled by the sampling device.

SC-020: Deleted.

SC-030: The bulk rock-forming elemental (Na, Mg, Al, Si, P, S, Cl, K, Mn, Fe, and Ni) composition of the sampling area should be determined with 10^{-2} amu resolution.

SC-040: An additional "local characterisation" shall be performed after the sample collection (*i.e.* fulfil LR-010 to LR-030 again).

SC-050: The images taken by the navigation camera (if any) during the descent should be made available to scientists upon request.

3.6 Other requirements

OR-010: It shall be possible to calibrate the colour response of the instruments, by providing a calibration target (if mission analysis foresees a lunar flyby allow imaging of Apollo 16 landing site).

OR-020: After sample collection, a device or method shall allow verification that a suitable sample has been collected, giving a rough estimate of the volume or mass of the sample.

OR-030: The sample(s) shall not be exposed to a shock load higher than 800 g.

OR-040: If the mission scenario foresees any planetary flyby, it shall be possible to switch on all payload for testing.

3.7 Additional NEO science requirements

These requirements describe the characterisation of the NEO as described in Section 2, bullet iii (thus 'category III') which offer additional NEO science. These have lower priority than the requirements given previously. It is acknowledged that with the current mission design (May 2009) points AS-010 and -030 are unlikely to happen.

AS-010: The inner structure of the NEO should be constrained, with the goal of doing this to a depth of about 100 m and a spatial resolution of about 10 m.

AS-020: The J2 terms of the gravitational field should be determined with an accuracy of 10 %.

AS-030: It should be possible to do near-surface investigations of several areas on the NEO (*e.g.* by hopping or hovering with a Lander).

AS-040: Complete images obtained with the Star Trackers should be made available to scientists upon request.

It is expected that in a future update of this document, more requirements will be added in this section.

3.8 Requirements to ground-based lab facilities

This section will give requirements to the ground-based laboratories and curation facilities. It will be filled in a future version of the document.

4 APPENDIX A – LIST OF POSSIBLE TARGETS

The current baseline target is 1999 JU3. To keep the history, the following table list the best four of the possible targets which were identified as good candidates for a Soyuz-launch during the CDF study. Either their size and rotation period is known, or it is possible to characterise them before the timeframe 2010/11. It should be understood that new objects may be discovered or existing objects could be characterized, leading to another (possibly better) target.

Table 2: List of possible targets.

Number	Prelim. Designation	Taxonomic type	Estimated diameter in km (*)	Rotation period in hours
162173	1999 JU3	Cg	0.92	7.7
162998	2001 SK162	T	1.52	68
65679	1989 UQ	C	0.76	7.73
	2001 SG286	D	0.35	Tbd

(*) calculated from Hv assuming an albedo of 0.06.