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MARTIAN MOONS EXPLORATION (MMX) MISSION

SCIENCE REQUIREMENTS DOCUMENT FOR

NEUTRON AND GAMMA-RAY SPECTROMETER (NGRS)

REVISION AND HISTORY PAGE

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1. INTRODUCTION

1.1. Purpose and scope of this document

The purpose of this document is to describe scientific, performance, and technical requirements for the neutron and gamma-ray spectrometer (NGRS) of the Japan Aerospace Exploration Agency (JAXA) Martian Moons eXploration (MMX).

In case that raises issues in satisfying this document, coordinate with the MMX Project Team.

1.2. Outline of the MMX mission

Mars is the outermost planet among the rocky planets in the solar system. Phobos and Deimos are the two moons of Mars. Martian Moons eXploration (MMX) by Japan Aerospace Exploration Agency (JAXA) will make close-up remote sensing and in-situ observations of both moons, and return samples from Phobos.

With this MMX mission, we will give a boost to planetary science by adding new information on planetary formation and evolution processes in the part of the solar system linking its inner- and outer- part. The origin of Phobos and Deimos itself is a nice question to answer, but revealing the origin will enable us to step further forward to constrain the behavior of small bodies in the close proximity to the border between the inner- and outer-part of the solar system in it making. Small bodies in the internal boundary part of the early solar system are considered to have played a key role in providing habitability to the rocky planets. Focusing on the moons will also provide a vantage point from which new insight on how the Mars system, including its surface environment, involved in time.

There are two leading ideas for the origin of the two moons: captured asteroid or giant impact. While not a small amount of remote sensing data exist for Phobos, not enough has been gained to judge between the two ideas for its origin. It is likely that remote sensing data alone would not lead us to a definitive conclusion. Returning of samples which represents the original building blocks for detailed analysis to be performed on the ground is the way to give the end to the debate that would otherwise last forever. That is, a sample return mission to Phobos is what should be done to reveal its origin and to make substantial steps beyond. Our goal is to enhance our understanding of planetary formation processes at the outer-edge of the rocky planet region in our solar system.

A sample return mission requires more time and faces more technical challenges and risks. Yet, the merit brought-in due to outstandingly superior analytical capability provided by ground facilities, especially compared to the quality of data expected from instruments onboard a spacecraft, overrides the unfavorable aspects of a sample return mission. Indeed, remote sensing data becomes more valuable when credibility in their interpretation is supported by sample analysis results.

Sample return from Phobos would enable us to reveal its origin. Close-up observations of Deimos, and that with reference to the ground-truth results from Phobos, would enable us to give strong constraint to the idea for its origin. That is, the mission aims to deploy an integrated study on the origin of the two moons and to open a new window for our understanding of the formation processes in this critical part of the solar system. If the origin of Phobos is known to be captured primordial asteroid (D-type as has been inferred from visible-wavelength and the limited near-IR spectroscopic remote sensing data), detailed analysis of the samples allows us to study how the primordial materials, namely, water and organic compounds, are brought into the inner-part of the solar system from the outer-part across the border (so-called snow line). Sample analysis also allows us to unveil the migration history of the small body that behaved as a capsule which carried water and organic compounds into the inner-solar system. These studies will constrain the initial condition of the Martian surface environment and of rocky planets in the solar system. If the origin of Phobos turns out to be giant impact, samples will be composed of ancient Mars and impactor materials. In a sense, Mars sample return is realized. Their analysis will reveal the impact size and allow us to evaluate how the initial evolution of Mars surface environment was affected by the violent satellite formation process.

Due to its close orbit to Mars, Phobos would have been showered by debris generated by impact events on the surface of Mars. That is, we may find samples from ancient Mars surface among samples to be collected from Phobos (even if its origin does not turn out to be giant impact). The Mars samples may span over a wide range in time and may enable us to read-out the evolution history of Mars surface environment. The orbit of the Martian moons mission also provides an interesting vantage point allowing global perspective to inspect how water in the present Mars ground-air system is cycled, which would be a critical element in the mars climate system and its evolution. The mission orbit also provides occasions to male in-situ observations of particles to learn about atmospheric escape mechanisms of the present Mars, which helps us develop our idea for the huge loss of the atmosphere that happened in the past. That is, the mission is not only about the moons but also is our first approach to Mars itself, with the scientific focus on its surface environment transition.

2. SCIENTIFIC REQUIREMENTS OF THE MMX

2.1. Science goals of MMX

See MMX-Science Requirement Document (MMX-SciRD-ALL).

2.2. Model Payload of MMX Spacecraft

See MMX-Science Requirement Document (MMX-SciRD-ALL).

2.3. Mission objectives of NGRS onboard MMX

The NGRS is selected as the nominal payload on board the MMX spacecraft.

The NGRS is used to achieve mission-specified science objectives, in particular, Goals 1.1 and 1.2 in Section 2.1.

The NGRS is expected to identify elements within tens of centimeters of Phobos' surface by remotely detecting characteristic gamma-ray emissions and by characterizing the flux of thermal, epithermal, and fast neutrons.

The requirements for NGRS observations are described in the following subsections.

2.3.1. Elemental abundance of silicate portion of Phobos

The primary objective of NGRS is to determine the chemical composition of Phobos.

Long-duration exposure to solar wind and interplanetary dust particles (less than 1 micron) results in heavy weathering effects on Phobos' surface layers, the surface age of which is assumed to be 3.7–4.3 Ga (Schmedemann et al., 2014).

Surface alteration of regolith particles changes their spectral features from visible to near-infrared ranges. However, it does not change the elemental abundance of silicate minerals for particle sizes larger than 300 microns (Ramsley and Head, 2013).

Gamma-ray and neutron spectroscopy can measure the average composition of regolith material to 1 m depth to infer the major elemental abundance of Si, Fe, and possibly Ca, and to clarify whether Phobos material is primitive (e.g., C- or D-type asteroids) or differentiated (e.g., Mars's crust, SNC meteorites).

2.3.2. Detection of volatile elements from Phobos' interior

The neutron spectrometer of NGRS measures energy spectra derived from nuclear reactions occurring in the Phobos' surface material.

Because hydrogen's nuclear mass is nearly identical to its neutron mass, hydrogen down-scatters neutrons to lower energies much more effectively than any other element.

With an increase of hydrogen content (possibly from water ice), epithermal and fast neutron flux will decrease, and thermal neutrons will slightly increase.

The flux changes depending on the hydrogen abundance and depth distribution.

2.3.3. Support of landing site selection and benefit for returned sample analysis

From available spectral data by the Mars Express and Mars Reconnaissance Orbiter missions, it is known that Phobos has two distinct types of material: blue and red units (Fraeman et al., 2012).

Blue units are located inside the Stickney crater and its eastern region, and red units are widely distributed outside of that crater, in areas where the subsurface material would be exposed.

Although dependent on the observation altitude and accumulation time, NGRS data might distinguish compositional differences in red and blue units, and it would promote further our understanding of the homogeneity or heterogeneity of Phobos' surface.

Also, if the neutron spectrometer finds a regional concentration of hydrogen or other volatile elements, we could make a list of potential sampling sites.

Information related to volatile components on Phobos is very useful for curatorial analysis and interpretation of returned samples.

3. PERFORMANCE REQUIREMENTS OF THE NGRS INSTRUMENTS

This section describes the instrument specification of NGRS needed to meet the scientific requirements presented in Section 2. and applicable resources, which are provisional in the preliminary study. The details will be negotiated between the NGRS team selected through the AO procedure and the MMX Project Team.

3.1. Neutron spectrometer

The neutron spectrometer of NGRS will investigate whether water ice and related components exist.

To clarify whether Phobos is rich in volatile elements, hydrogen measurements are required for the neutron spectrometer.

Also, neutron flux data are highly correlated with cosmic ray protons, which are time-variable backgrounds induced by solar activity.

Therefore, the measured spectrum is essential for gamma-ray data analysis over a certain energy region.

To fulfill these objectives, the following capabilities are required:

<< Science requirements >>

- Hydrogen content to 20 % accuracy at a detection limit of 100 ppm
- Measurement of fast and thermal neutron fluxes sufficient for calibrating the gamma-ray spectra

<< Specification >>

- Thermal neutron : 0.01 eV–0.5 eV
- Epi-thermal neutron : 0.5 eV–0.5 MeV
- Fast neutron : 0.5 MeV–7 MeV

The specification of neutron spectrometer should quantitatively describe performance sufficient to meet the science requirements described in Section 2.3. , in these energy regimes.

3.2. Gamma-ray Spectrometer

The gamma-ray spectrometer of NGRS will investigate the primary elemental abundances of the silicate portion of Phobos.

To investigate the surmised capture or impact origins of Phobos, measurement of elemental concentration ratios, Si/Fe in particular, is required.

In addition, the Ca/Fe ratio, which is possibly dependent on both the accumulation time and Phobos' composition, should be determined. To fulfill these objectives, the following capabilities are expected:

<< Science requirements >>

・Si/Fe ratio to 20 % accuracy

・ Ca content to 20 % accuracy at a detection limit of 5wt%

・K content to 20 % accuracy at a detection limit of 300 ppm

The accuracy represents a statistical uncertainty in the process of data analysis

<< Specification >>

・Energy range : 200 keV–8 MeV

・Energy resolution : < 5.5 keV(FWHM)@1.332MeV

The specification of gamma-ray spectrometer should quantitatively describe performance sufficient to meet the science requirements described in Section 2.3. , in these energy regimes.

3.3. Resources of NGRS

Estimated upper limit of resources available including a margin for the NGRS instrument are as follows:

<< Maximum Possible Value >>

Instrument total mass	11 kg (including electronics and harness)
Instrument total power	22 W (nominal operation including cooler system)
Telemetry rate	330 bps (average in nominal operation)
Total amount of NGRS data	1.8 Giga bytes (3 years operation around Mars system)

See the policy of the design margin in the MMX-Instruments-Interface Requirements Document (MMX-I-IRD).

To reduce the NGRS instrument mass, power and its development time, an electronics package is expected to share functional elements common to the gamma-ray and neutron sensors.

Details of the electronic interface with the bus system of the MMX spacecraft are described in Section 4.

3.4. In-flight operation and calibration

A request for in-flight calibration during cruising toward Mars should be clarified by proposing teams.

In addition, any requests for specific operations, such as an active cooling for obtaining data with high energy resolution and a sensor annealing operation for recovery of deteriorated energy resolution loss due to radiation damage, should be clarified by proposing teams.

Details of the in-flight operation and calibration procedures will be negotiated after AO selection between all PI Instrument Teams and the MMX Project Team.

For both ground-calibration tests and in-flight data analysis, preparation of simulation code for nuclear reactions is the responsibility of the NGRS Instrument Team.

4. DESIGN REQUIREMENTS OF THE NGRS INSTRUMENTS

4.1. Engineering requirements

4.1.1. General

See MMX- Instrument Interface Requirement Document (MMX-I-IRD).

4.1.2. Mechanical interface

See the MMX-Instruments-Interface Requirements Document (MMX-I-IRD)

4.1.3. Thermal interface

See the MMX-Instruments-Interface Requirements Document (MMX-I-IRD)

4.1.4. Electrical interface

See the MMX-Instruments-Interface Requirements Document (MMX-I-IRD)

NOTE FOR NASA AO: See Section 3.3 of PIP/MMX-I-IRD for information on the power supply unit. For the NGRS, voltage conversion and stabilization into secondary power supply is performed by a secondary power supply converter inside NGRS.

NOTE FOR NASA AO: See Section 3.4 of PIP/MMX-I-IRD for information on the data handling electrical interface. For the NGRS, the plan is not to share any other common units. Command data will be distributed from SMU via SpaceWire interface, and telemetry data created by the instrument processor unit will be communicated to SMU and the common data storage via SpaceWire interface.

4.1.5. Telemetry and command interface

See the MMX-Instruments-Interface Requirements Document (MMX-I-IRD)

4.1.6. Software interface

See the MMX-Instruments-Interface Requirements Document (MMX-I-IRD)

4.1.7. Others

Detailed interface information is expected after selection. This will be provided as the Interface Configuration Document (ICD), which is the response to the updated MMX-I-IRD.

4.2. Ground segment and operation
See MMX- Instrument Interface Requirement Document (MMX-I-IRD).

4.3. Verification requirements
See MMX- Instrument Interface Requirement Document (MMX-I-IRD).

4.4. Product assurance requirements
See MMX- Instrument Interface Requirement Document (MMX-I-IRD).

4.5. Management requirements
See MMX- Instrument Interface Requirement Document (MMX-I-IRD).

5. DOCUMENTS

5.1. Applicable documents

(1) JAXA-RPR-MX16300

MMX Science Requirement Document for all instruments (MMX-SciRD-ALL)

(2) JAXA-RPR-MX16301

MMX Instrument Interface Requirement Document (MMX-I-IRD)

5.2. Reference documents

(1) JAXA-RPR-MX##### [to be issued]

MMX Interface Control Document (ICD)

6. ACRONYMS

JAXA	Japan Aerospace Exploration Agency
MMX	Martian Moons eXploration
NGRS	Neutron and Gamma-Ray Spectrometer