

CONTAMINATION CONTROL AND ASSESSMENT STRATEGY FOR MARTIAN MOONS EXPLORATION (MMX).

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Introduction: Martian Moons eXploration (MMX) is a sample return mission from the Martian moon Phobos. The MMX spacecraft is scheduled for launch in 2026 and return to Earth in 2031. The primary science objective of MMX is to reveal the origin of the Martian moons, thereby advancing the understanding of planetary system formation and material transport in the solar system, as well as to observe processes affecting the circumplanetary and surface environments of Mars [1,2]. The returned sample will be transported to the curation facility at ISAS/JAXA, and the subsequent curation and sample analysis activity will be conducted [3,4]. As a sample return mission, MMX requires strict contamination control to prevent the intrusion of terrestrial materials.

Sampling System: The MMX spacecraft is equipped with two sampling systems: a coring sampler (C-sampler) and a pneumatic sampler (P-sampler) and is designed to return more than 10 g of Phobos sample. The C-sampler is equipped with a coring mechanism and is capable of collecting subsurface samples from the depth of 2 cm to 7 cm. It is also equipped with a multi-degree-of-freedom manipulator, enabling sampling at targeted locations. The P-sampler, provided by NASA, is attached to one of the landing legs, with the sampling inlet located in the foot pad. Nitrogen gas is blown downward through the sampling inlet to collect surface materials from Phobos. These two complementary sampling systems provide broad scientific opportunities as well as important redundancy.

Contamination Control and Assessment: Contamination control and assessment activities are carried out by the MMX Sampler Science Team and the Curation Team. The fundamentals of contamination control to ensure the pristine quality of the returned samples are (1) minimizing the introduction of terrestrial contaminants, (2) performing contamination assessment, and (3) preserving contamination knowledge (CK) material coupons used in the spacecraft to enable the identification of contaminants found in the returned sample. In the MMX contamination control strategy, target materials for contamination control and their allowable contamination levels are defined based on the scientific objectives. The target materials include both organic molecules and inorganic elements. The allowable atmospheric leakage rate into the sample container is also defined. For organic materials, the target compounds include organic molecules found in carbonaceous chondrites, such as aliphatic and aromatic hydrocarbons, amino acids, and carboxylic acids. For inorganic elements, the targets include elements required to discriminate the origin of the Martian moons by major elements and nucleosynthetic isotope anomalies (e.g., Cr, Ti, and Mo), as well as important elements necessary for chronology (e.g., Hf, W, U, Pb, Rb, Sr, Sm, and Nd).

Contamination control activities begin at the design phase, and materials used in the sampling system are selected to prevent the introduction of contaminants. MMX is currently in a critical pre-launch phase known as ATLO (Assembly, Test, and Launch Operations). Prior to assembly, the sampling system underwent precision full-course cleaning [5]. This full-course cleaning consists of a stepwise ultrasonic cleaning protocol using multiple solvents with different polarities, followed by ultrapure water. During the ATLO phase, the sampling system is continuously maintained at positive pressure by purging pure nitrogen gas to prevent the intrusion of contaminants from the external environment. In parallel, the environment surrounding the sampling system is continuously monitored using a CK monitoring coupon set [6]. This set comprises multiple witness materials, including glass petri dishes, sapphire glass disks, and carbon adhesive tape, etc. In addition, comprehensive contamination assessments have been conducted for each cleanroom used during the assembly and testing of the sampling system. These assessments include microbial analyses. Contamination control activities will continue after the return and during analyses of the samples.

References: [1] Kuramoto, K. et al. (2022) *Earth, Planets, and Space* 74:12. [2] Usui, T. et al. (2020) *Space Science Review* 216:49. [3] Fujiya et al. (2021) *Earth, Planets, and Space* 73:120. [4] Fukai et al. (2024) *Meteoritics, Planetary Science* 59:321. [5] Yoshitake M. et al. (2021) *JAXA Research and Development Report*, JAXA-RR-20-004E, ISSN 2433–2216. [6] Sawada H. et al. (2017) *Space Science Reviews* 208, 81–106.