Hayabusa2 curation: from concept, design, development, to operations

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Introduction: JAXA conducted and is conducting sample return missions, such as Hayabusa and Hayabusa2, to bring back samples of extraterrestrial materials from asteroids (S-type asteroid Itokawa and C-type asteroid Ryugu, respectively). The returned materials are scientific valuable samples that can provide scientific knowledge about the origin and evolution of the Solar System [1]. Prior to sample return, meteorites were the only accessible extraterrestrial samples to unravel the history of the Solar System. However, meteorites have to be strong enough to fly through the Earth's atmosphere to fall, and, after dropped on the ground, they are contaminated by terrestrial atmosphere, water and materials, changing their properties. On the other hand, sample return missions allow to store the sample in a sealed container and protect them from terrestrial contamination and from heat and shock during re-entry to the Earth. Returned samples are very valuable scientifically, and it is extremely important to handle them without compromising their scientific characteristics.

Scientific requirement: The curation center that handles returned samples has the following scientific requirements to maintain the high scientific value of the returned samples: 1) Do not expose the sample to the Earth's atmosphere; 2) Do not lose the sample; 3) Do not destroy the sample except for when needed. The first requirement is to prevent the samples from being reacted with terrestrial materials to be altered. If the terrestrial compounds are mixed into the sample, the reliability of the analytical results is not ensured. The second requirement should of course be met considering the cost, time, and human resources to get samples back from space. The third requirement is not strict, but refers only to preliminary examination of the samples. The preliminary examination team at the curation center performs first description of the returned samples before detailed initial analysis by the project-lead analysis team. The destructive analysis of the sample should not be performed in the preliminary examination at the curation center in order to enable the initial analysis team to perform a comprehensive analysis that combines the morphological observation of the sample and the destructive chemical analysis.

Role: The curation center is responsible for the receipt and preliminary analysis (we call it “initial description”) of returned samples while satisfying the above requirements as well as the long-term storage and scientific investigation of the samples after the initial description. Examples of the initial description include size and shape description by optical observation, sample mass measurements, non-destructive spectroscopic observations for chemical and mineralogical analysis. In the case of Hayabusa, the total amount of sample brought back from Itokawa was small (i.e., about 1 mg) and spectroscopic observation was difficult. To compare with the data of the X-ray fluorescence spectrometer on-board the Hayabusa spacecraft, elemental analysis was also carried out by SEM/EDS during the initial description stage [2]. All these preliminary analyses have the important role to provide a scientific link between the sample brought back and the target body. Normally, the returned samples are stored in a special storage container, and it is necessary to take out the sample from the container by a special procedure. After the initial description, except for a part of the sample stored separately for future use, around half of samples is distributed for detailed analysis, for example the initial analysis and the AO (Announcement of Opportunity) research, which is open to the science community. The sample distribution also requires curational work, such as taking out and storing the samples in a distribution/transport container and tracking the analysis records.

Design: In consideration of the above roles, JAXA has designed clean rooms and clean chamber dedicated to each sample return mission (Hayabusa and Hayabusa2). The primary reason for this is to avoid mixing of samples from different targets but it is also because the method of taking out the samples from the container and the planned analyses for the initial description were different for the two missions. The facility design for the curation center initiated about 5 years before the sample returned to Earth. This is because it was expected to need one year for designing, two years for manufacturing, one year for confirming functions after manufacturing, and one year for rehearsal of the operation for receiving the returned sample. At the design stage, the specification study team from the JAXA curation members, the design team of the spacecraft sampler, and sample scientists from the research community played a central role in establishing the required specifications. After that, the manufacturer was selected by bidding after receiving the specification approval from the curation steering committee and the Hayabusa/Hayabusa2 project team.

Specifications for Clean room: The specifications of the clean room at the JAXA Curation Center are basically the same for Hayabusa and Hayabusa2. The cleanliness of the clean room where the clean chamber is installed is Class 1000 (US federal standard), equivalent to Class 6 in ISO 14644-1 standard. The floor has a grating structure, and the return airflow travels from the bottom of the grating through the back of the wall to the ceiling and circulates from the ceiling using a ULPA filter to remove dust in the air. The clean room is maintained at a pressure higher than the outside to prevent outside contamination. The positive pressure control is performed with the adjacent downstream room, and the shortage is taken in from the outside air through a filter by approximately 10% of the circulating air volume. Temperature and humidity are controlled and maintained at 24±2 °C and at 50±10% RH, respectively. The humidity is maintained at a high value to suppress the generation of static electricity. The supply pipes for exhaust gas, purified gas, cooling water, compressed air, etc. are connected to the clean chamber through a grating floor. Equipment that degrades the environments (for example, rough grinding pumps) are installed in isolated areas outside the clean room.

Specifications for Clean chamber: The clean chamber of the JAXA curation center is designed to perform all the operations on samples in a vacuum or pure nitrogen gas environment, i.e., sample extraction from the sample storage container, initial description of the samples, and distribution and storage of the samples. In particular, because the structure of the sample storage container of Hayabusa and Hayabusa2 is complex to store and deliver the samples safely, the clean chambers for both missions are required to have the interface to the sample container opening mechanism. Electrolytic polishing was applied to the inner surface of the chambers for quick cleaning recovery and to avoid contamination to the samples as much as possible. Several types of clean chambers are prepared for the purpose of work after opening the sample storage container, and they are connected to each other through gate valves. In principle, the sample container opening work is performed in a vacuum environment, but the sample removal, initial description, and distribution work have been performed through gloves in a high-purity nitrogen environment. Viton gloves were initially used to minimize organic contamination, but due to the difficulty in obtaining them because of the discontinuation of production, mainly Viton coated butyl gloves have recently been used. Materials used for the jigs used in the clean chamber and materials of the chamber itself were chosen to avoid materials other than those used in the sampling device of the spacecraft as much as possible in order to control the contamination. In particular, the containers to store the samples are basically made of synthetic quartz glass or sapphire, and in some cases stainless steel, aluminum, or Teflon are permitted to use. The use of copper- or gold- plated sample holders for certain analyses such as SEM/EDS is also allowed.

Operations and development: The curation center has been operated by the Astromaterials Science Research Group (ASRG) of ISAS, which is responsible for curational work (receipt, description, utilization, and storage) on extraterrastrial returned samples and for facility maintenance [3]. Hayabusa 2 samples were returned in December 2020. After opening the sample storage container in a vacuum environment, most of the curation work has been performed by using gloves in a nitrogen environment. The Hayabusa2 science team required the ASRG to pick up a small fraction of samples to store in a vacuum environment for future analytical studies without ever being exposed to nitrogen gas. Therefore, at the JAXA Curation Center, the clean chamber of Hayabusa2 has the new function of observing the inside of the sample storage container and taking out a part of the sample in a vacuum environment. Two millimeter-sized particles were successfully picked up and are now stored in the vacuum environment.

A total of 5.4 g of Ryugu samples were collected from the chambers A and C of the sample container, which were used for the sample collection at the first and second touchdown sites. The maximum particle size of the sample is about 1 cm, and hundreds of samples with a particle size of 1 mm or more have been confirmed. In the curation center, we plan to store each particle in an individual container as much as possible, acquire initial description data for individual particles to list in the sample catalog. The ASRG has independently-developed handling tools and sample containers to improve work efficiency while minimizing contamination. We believe that these developments will also help us receive and curate future returned samples. The ASRG also study Ryugu samples along with the project-lead initial analysis, which will also provide new insights into the origin and evolution of the Solar System.

References

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