▶ While awaiting sample return missions from Mars, our only way to study martian rocks in the laboratory is with meteorites. Although Tissint meteorite (909 g sample - NHMV-N9388) was recovered shortly after its fall on 18 July 2011, it was already contaminated with terrestrial elements.

Europe needs facility to handle extra-terrestrial space material

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Exploring our solar system has been keeping humankind busy for more than 100 years - from the theoretical work of 'The Exploration of Cosmic Space by Means of Reaction Devices' by Konstantin Tsiolkovsky in 1903 to the launch of the first artificial satellite Sputnik 1 in 1957 to the recent sample return mission OSIRIS-REx launched in 2016. Although orbiters and landers are equipped with ever more accurate instruments and with increased capacities to study planets, moons, asteroids and comets, analyses are still somewhat limited in comparison to what can be done in laboratories on Earth. Here, Aurore Hutzler and Ludovic Ferrière argue the case for Europe to develop its own curation facility so it can be more involved in future sample return missions.

The typical constraints of spaceflight mean that the mass, the volume, the power supply and the data feed of pieces of equipment must be kept as low as possible. Some analytical instruments routinely used in research laboratories on Earth - such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS) - cannot be used in space because it involves preparing a liquid solution out of the sample.

Even if instruments on spacecraft have allowed significant advances in a number of different fields, to obtain high-precision analyses, it is necessary to bring samples back to Earth. Sample return

Sample return missions have enabled extraordinary discoveries

missions have enabled extraordinary discoveries that fundamentally improved our understanding of the Moon with the Apollo missions and their 382 kg of lunar rocks; of comets with the Stardust mission; and of asteroids with the Hayabusa mission.

Until now, sample return missions have been led mostly by NASA in the US, by Roscosmos in Russia and by JAXA in Japan. Europe is a main actor in space exploration but has lacked the goal of claiming part of the samples brought back by these missions.

One possible explanation is that there is currently no dedicated curation facility for pristine extra-terrestrial samples on European territory, similar to those at NASA's Johnson Space Center, Houston, or at JAXA, Sagamihara, Japan.

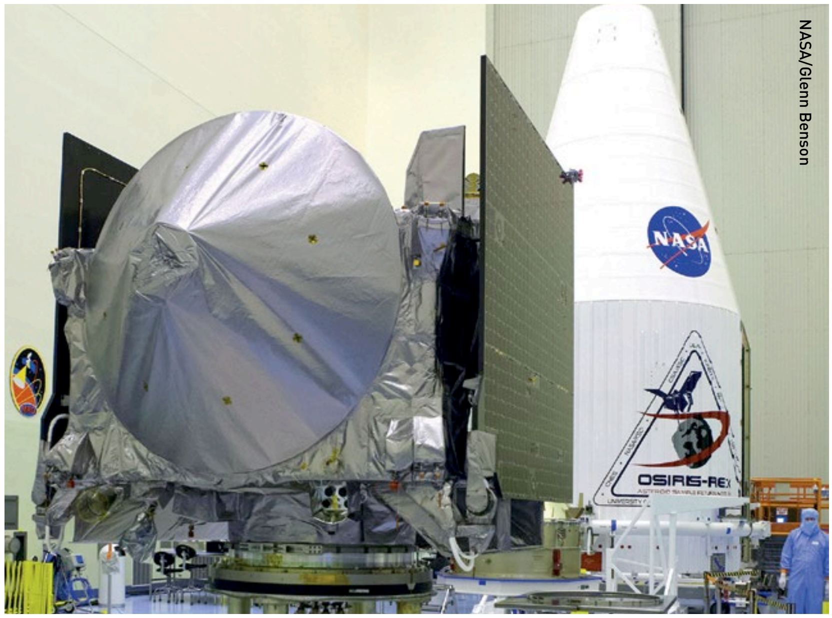
Unrestricted or restricted samples

The two facilities cited above have been designed to keep the samples protected against a range of contaminants which may affect the scientific analysis of returned samples. The main requirements rely on technologies routinely used in cleanroom environments (i.e., by keeping the rooms under positive pressure, with a range of High Efficiency Particulate Air (HEPA) and Ultra-Low Penetration Air (ULPA) filters to scrub the air of any particles) and on the rigorous selection of materials allowed to be in contact with the samples.

Samples are typically kept under an inert atmosphere, usually dry nitrogen gas. However, all the samples which have been returned to Earth so far are from celestial bodies known to be devoid of any potential present or past form of life.

The Committee on Space Research (COSPAR) [1] defines five planetary protection categories with subcategories dependent on the target of the mission and the type of mission (fly-by, orbiter or lander). Category I missions do not have planetary protection requirements, e.g., for missions to undifferentiated, metamorphosed asteroids or Io.

Category V missions include the most stringent planetary protection requirements. All missions which will return extra-terrestrial samples to Earth for further analysis belong to category V. Dependent on the origin of the extra-terrestrial material, a category V mission can be an unrestricted Earth return mission (e.g., in the case of samples from the Moon) or restricted Earth return mission (e.g., in the case of samples from Mars or Europa).



NASA/Glenn Benson

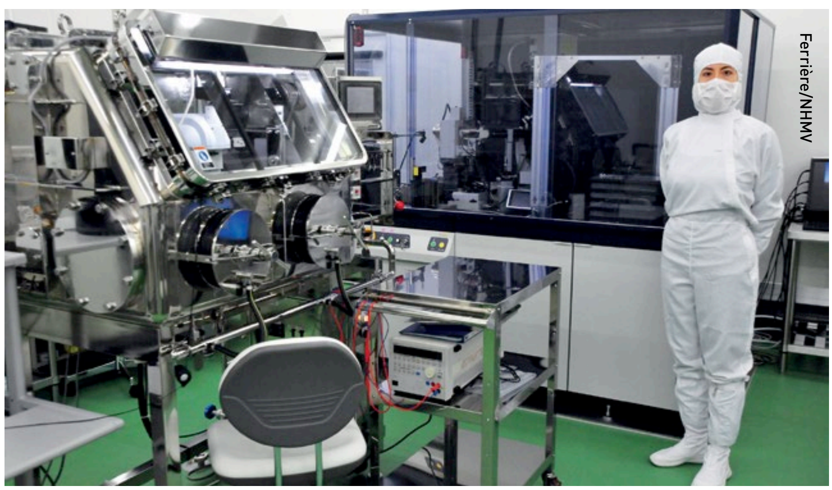
▲ NASA's OSIRIS-REx spacecraft during its preparation for encapsulation in its payload fairing prior to launch in September 2016. It is the first US mission to sample an asteroid, retrieve at least two ounces of surface material and return it to Earth for study.

▼ Aurore Hutzler in front of an X-ray diffractometer inside JAXA's Hayabusa-returned sample curation facility in Japan. The lab coat (a class 1,000 gown) is specifically designed to reduce contamination from workers.

There are no special requirements for sample containment for unrestricted missions. However, for restricted missions, where there is thought to be a chance of life, the requirements include absolute prohibition of destructive impact upon return, containment of all returned hardware which directly contacted the target body, and containment of any unsterilized sample returned to Earth.

Considering the Mars sample return missions planned for the future, it is imperative to start now to plan a facility able to receive and host these potentially biohazardous samples, especially knowing that the design, construction and certification of such a facility can take a decade to be up and running [2].

Study and long-term curation of extra-terrestrial samples, either unrestricted or restricted, require the samples to be protected


Ferrière/NHMV

There is currently no dedicated curation facility for pristine extra-terrestrial samples on European territory

▼ Ludovic Ferrière in front of a positive pressure glovebox, containing lunar rock samples at the Johnson Space Center's Lunar Curation Laboratory. The glovebox is filled with nitrogen to minimise the samples' alteration.

▼ Bottom: Overview of Johnson Space Center's Lunar Curation Laboratory, equipped with gloveboxes dedicated to Apollo sample return missions. Note the windows at the end of the room, separating the high cleanliness part of the facility from a monitor room.

against a range of contaminants which may affect the scientific analysis to be conducted. For restricted mission samples, in addition, containment is required to prevent the release of any biohazards in the environment until they can either be proven to be devoid of any life-forms or be effectively sterilised to destroy any life-forms [3, 4]. The co-requirements for a combined high containment and ultraclean facility are unique and will lead to the development of a highly specialised and unique facility that will require the development of novel scientific and engineering techniques.

The objective of the EURO-CARES (European Curation of Astromaterials Returned from Exploration of Space) - a three-year project funded by the European Commission's Horizon 2020 research programme from January 2015 to December 2017 - was to create a roadmap for the implementation of a European Extra-terrestrial Sample Curation Facility (ESCF) to involve Europe more in sample return missions.

The EURO-CARES consortium is composed of planetary science researchers and curators, biosafety specialists, and engineers, from all parts of Europe (www.euro-cares.eu).

There have been a few previous studies on curation facilities, which have typically been either country-specific or mission/target specific [5]. EURO-CARES proposes to move onwards from these specific studies to look at what would need to be done to create a European facility that would be suitable for the curation of samples from all possible return missions likely over the next few decades to the Moon, asteroids and Mars.

The project considers all different aspects, starting with the landing of the Earth Return Capsule (ERC). A team is focused on how to bring the ERC to the curation facility, then the process of receiving and opening the different layers to access the samples. All activities related to curation are roadmapped in the framework of EURO-CARES.

Curation or science?

The term 'curation' covers all activities related to organising and maintaining a collection of artifacts, art pieces or scientific samples. Although a number of curatorial centres and institutions may have dedicated scientific laboratories, one of the main purposes of curation is to make precious samples available to science for several generations.

In the case of a curation facility for mission returned samples, the frontier between what is pure curation and what is science can sometimes be blurred. The EURO-CARES team defined that the ESCF has two main goals: first, conducting basic analyses to characterise the samples and associated hardware, then curating *sensu stricto*, i.e., storing, handling and managing the samples as a valuable scientific resource for generations of researchers to study.

The first step is the phase of Sample Early Characterisation (SEC), which aims at characterising the samples with non-destructive methods, to set the basics for high-quality research to be conducted afterwards (i.e., outside of the facility, in state-of-the-art, dedicated laboratories). The next step is the Preliminary Examination (PE) phase, in which further analyses are conducted on the samples. Depending on the nature of the samples, this phase can be done inside or outside of the ESCF.

It is planned to keep the curation facility as light as possible in term of instrumentation, and to disseminate unrestricted samples to external laboratories (and even restricted samples in specific specific sealed containers with semi-transparent windows allowing different analyses to be conducted). However, it is clear that in the case of restricted samples, it will be necessary to keep the research under containment. Some part of the sample will need to be devoted to Life Detection (LD) and Biohazard Assessment Protocols (BAP) [4], with analyses from non-destructive, to destructive, to microbiology cultures and to potentially animal tissue testing.

Flexible facility

Flexibility is seen as one of the most important concepts to be considered for such a project to allow for future developments of scientific analytical capabilities and this was developed at several scales in the framework of EURO-CARES, with the requirement of future extensions and potential growth.

Through a collaboration with the Vienna University of Technology (2016) [6], and with the Canadian branch of Merrick and Company (2017) [7], functional layouts and global designs were produced. The flexibility requirement was developed at three scales, from the room scale (some rooms should allow for restructuring or a change of the activity to be conducted inside), to the laboratory scale (a curation laboratory might be expanded for new missions, or an office building might accommodate more staff), to the ESCF scale (it is very unlikely that all different parts of the ESCF will be built at the same time from the beginning).

On top of the flexibility, architectural layouts were taken into account along with other important aspects, such as opportunities to encourage meetings and communication between personnel to increase working efficiency and cooperation, and favour the health and well-being of staff by providing a pleasant work environment.

The EURO-CARES team presented the case for an ESCF at a workshop in Florence, Italy, in July 2017. The last steps of the project will then be to wrap feedback from all different communities (architects, geologists, microbiologists, engineers, etc.) knowing that to be truly successful in such a project all different expertises and opinions should come together. ■

▲ NASA's Stardust was the first spacecraft to return cometary samples. In 2004, the Stardust spacecraft made a close flyby of comet Wild-2, collecting comet and interstellar dust, returning samples to Earth in a capsule two years later.

References

1 1COSPAR (2002). COSPAR Planetary Protection Policy. 4 p.

2 Space Studies Board (2002). The quarantine and certification of Martian samples. Committee on Planetary and Lunar Exploration (chaired by J. Wood), National Research Council, National Academy Press, Washington D.C. ISBN-13: 978-0309075718.

3 Ammann W., Barros J., Bennett A., Bridges J., Fragola J., Kerrest A., Raoul H., Rettberg P., Rummel J., Salminen M., Stackelbrandt E., Swings J.P., Walter N. (2012). Mars Sample Return backward contamination - Strategic Advice and requirements, ESF-ESSC Study Group on Mars Sample Return Requirements, Printing: Ireg - Strasbourg, July 2012, ISBN: 978-2-918428-67-1.

4 Rummel J.D., Race M.S., DeVinenzi D.L., Schad P.J., Stabekis P.D., Viso M., and Acevedo S.E. (2002). A draft test protocol for detecting possible biohazards in Martian samples returned to Earth. NASA/CP-2002-211842.

5 Beaty D.W., Allen C.C., Bass D.S., Buxbaum K.L., Campbell J.K., Lindstrom D.J., Miller S.L., and Papanastassiou D.A. (2009). Planning considerations for a Mars Sample Receiving Facility: summary and interpretation of three design studies. Astrobiology 9(8), 745-758.

6 Häuplik-Meusburger S. and Lu S.-H. (Eds.) (2016). European Extra-terrestrial Sample Curation Facility - Design Studio SS2016. Vienna University of Technology, Department for Building Construction and Design - HB2, 121 pages [https://issuu.com/hochbau2/docs/book_institute_hb2].

7 Hutzler A. et al. (2017). D3.4: Final Design of the Facilities and Infrastructure, Deliverable of the EURO-CARES project.

About the authors

Aurore Hutzler, a geologist with a focus on geochemistry, has a doctorate in Planetary Science. Her research on cosmochemistry of meteorites led her to work on more pristine extra-terrestrial samples from sample return missions. She is currently a full-time post-doctoral researcher for the EURO-CARES project at the Natural History Museum Vienna, Austria.

Ludovic Ferrière, a doctor in geology, is chief curator of rock collections and co-curator of the meteorite collection at the Natural History Museum Vienna. He is also a researcher and has confirmed, together with different colleagues, three of the currently 189 recognised meteorite impact craters on Earth.

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