THE CAESAR NEW FRONTIERS MISSION: 5. CONTAMINATION, RECOVERY AND CURATION.

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Introduction: The Comet Astrobiology Exploration Sample Return (CAESAR) mission will acquire and return to Earth for laboratory analysis a minimum of 80 g of surface material from the nucleus of comet 67P/Churyumov-Gerasimenko (67P). CAESAR will characterize the surface region sampled, preserve the collected sample in a pristine state, and return evolved volatiles by capturing them in a separate gas reservoir.

Comet sample analyses in laboratories on Earth can provide unparalleled knowledge about presolar history through the initial stages of planet formation to the origin of life. CAESAR's sample analysis objectives address questions regarding the nature of Solar System starting materials and how these fundamental components came together to form planets and give rise to life. Returned samples are unique in providing material for generations of scientific discovery in laboratories around the world.

To achieve the CAESAR mission goals, the condition of the sample must be preserved and documented through collection, recovery, and curation within the resources of the NASA New Frontiers 4 program. We have taken our experiences from OSIRIS-REx, Hayabusa, Genesis, Stardust, and Apollo, and applied them to the unique sample returned from a comet surface.

Contamination Control and Knowledge: CAESAR takes the strategies successfully executed on OSIRIS-REx and applies them to the cometary environment [1]. Like OSIRIS-REx, collection of a pristine sample is a Level 1 requirement, with a series of graceful descopes at the ready for cost and schedule containment. The Level 1 requirement is supported by Level 2 requirements for both maintaining the cleanliness of the sample and documenting the nature of contamination even if it is present below requirements. Like OSIRIS-REx the critical surfaces are maintained at IEST-STD-CC1246E Level 100 A/2 with special attention to C, K, Ni, Sn, Nd, Pb and with the addition of Mn. OSIRIS-REx was the first mission to limit the amino acid abundance to 180 ng/cm^2 amino acids on critical surfaces (Table 1) and CAESAR will maintain the same requirement and procedures.

Unlike OSIRIS-REx, the cleanliness requirements for a cometary sample include volatile compounds. The cometary sample requires limits on NH_3, CO_2, Xe, H_2O, and O_2 contamination collected by the gas containment system (GCS) through recovery and curation. Likewise, witness materials are designed to collect and preserve volatile contaminants as well as particulate and non-volatile residue. There are also *in situ* sample pressure and temperature monitors to record the state and integrity of the sample, in the simplest, most cost effective manner.

Materials restrictions are expanded to include polyoxymethylene-based polymerics and incorporate OSIRIS-REx lessons-learned. Like OSIRIS-REx, which archived over 400 items, materials of potential concern, especially those present on critical hardware, will be archived for analysts to examine in parallel with the sample.

CAESAR retains the same contamination control and knowledge management structure, and is on track to fully benefit from the lessons of OSIRIS-REx to preserve both the sample and the mission cost.

Table 1. The amino acid load at component encapsulation of the three OSIRIS-REx critical sampling surfaces and the total of all stable primary-amine amino acids after a total of 310 days of clean-room exposure.

Location	Amino Acid (ng/cm^2)
OSIRIS-REx Sampler Head	0.96
SRC	13.1
Sampler Launch Container	2.32
Environment (310 days total)	21.3

Recovery Strategy: CAESAR's sample return capsule (SRC) will land at 9:14 AM on November 20, 2038, at the Utah Test and Training Range (UTTR). This is the same range where NASA's only other unmanned sample return missions have been recovered (Genesis, Stardust and soon OSIRIS-REx). CAESAR will leverage recovery operations and procedures from these previous missions capitalizing on lessons learned in order to cut down on the time to secure the samples into cold, clean storage.

Like Genesis, Stardust, and OSIRIS-REx, CAESAR will use military tracking assets at Hill Air Force Base to locate the SRC quickly. SRC recovery aids (radio beacon, LED and strobe lights) add further robustness to ensure efficient recovery.

CAESAR's nominal recovery operations include two helicopters staged just outside of the landing ellipse prior to landing. The primary helicopter locates the SRC from the air while the secondary helicopter sets down to assess SRC health/safety and attach it to the primary helicopter's long line. The primary helicopter then lifts the SRC and ferries it as an external load to a mobile cold storage unit staged in the Utah range.

Recovery operations also include two four-wheel-track-drive off-road vehicles to transport the recovery crew and cold storage container to the SRC landing site if weather precludes nominal flight recovery operations.

SRC processing will not be required for CAESAR at UTTR, unlike Genesis and Stardust. Stardust and Genesis both required installation of a mobile clean room at UTTR. OSIRIS-REx plans include a mobile clean room as well. The mobile clean room has previously served two purposes: 1) SRC processing which has included removal of pyrotechnic devices and heat shield as well as purging of the sample canister, and 2) providing a temporary curation clean room in the event of an anomaly (invaluable for Genesis). CAESAR does not require a clean room on site at UTTR for two reasons. First, unlike Stardust and Genesis that vented to the atmosphere, the CAESAR sample containers are hermetically sealed. Second, CAESAR's SRC design (Hayabusa heritage) differs from the Stardust and Genesis SRC by jettisoning the front heat shield and drogue parachute before touching down, and the main parachute immediately after. This allows the recovery team to deliver the entire CAESAR payload directly into a sealed cold shipping container purged with curation-grade nitrogen gas (GN2) from the UTTR field all the way to the sample curation facility at NASA's Johnson Space Center (JSC) in Houston, Texas. The continuous GN2 purge will protect the samples in the event of a malfunction of the knife edge seal.

After delivery to cold storage, the recovery schedule is less critical. Subsequent SRC transport plans from UTTR to JSC will follow the examples of Genesis, Stardust and OSIRIS-REx.

Sample Curation: The overarching objectives of CAESAR curation are to preserve and protect the returned 67P samples and space exposed hardware to maximize the science return. CAESAR curation builds on decades of curation experience at JSC. Apollo, Genesis, Stardust, and Hayabusa showed the importance and challenge of avoiding sample contamination and alteration. The key lesson from these previous missions is that sample protection begins with mission design and continues through curation. To this end, CAESAR sample scientists have been integrated with mission engineering from the outset to identify requirements on contamination and sample environmental controls.

Volatile and solid samples are segregated in flight into separate containers, and returned cold to avoid alteration and isotopic fractionation. The CAESAR SRC maintains H_2O in the GCS in a frozen state through atmospheric entry and recovery to prevent isotopic exchange and reactions among the volatiles.

By necessity, CAESAR's protocols to prevent sample alteration go well beyond previous sample return missions. Comet solids will most likely consist of an assemblage of highly unequilibrated components from the early solar nebula, and must be kept cold and dry to avoid reactions between grains and with any adventitious moisture. Amorphous silicates in cometary interplanetary dust particles (IDPs) alter to hydrated silicates in hours in room temperature water [2]. Even brief exposure of the sample to liquid water could confound attempts to determine if aqueous activity occurred in 67P.

In addition to leveraging JSC's curation experience, the CAESAR curation plan also factors in lessons learned from cold curation experts at the University of Alberta who are currently curating Tagish Lake meteorite samples cold [3], as well as space suit designers from JSC's human exploration office.

CAESAR's sample recovery, storage, handling procedures and facilities will be designed to protect the samples from contamination, temperature excursions, and moisture that could induce alteration in the sample. The facilities will enable the careful documentation and processing of the sample to enable world-class science while preserving most (≥75%) for future research.

The CAESAR Science Team will perform sample analyses to achieve the science investigation goals and objectives of the mission during preliminary examination, but it is the proper curation of the sample that allows for those investigations to continue for decades after sample return.

Summary: CAESAR will return the first sample from a comet nucleus. The payload has been designed to maximize the scientific value of the sample, including both its non-volatile and volatile components. Most of the sample (≥75%) will be set aside for analysis by generations of scientists using cutting-edge tools and methods, providing an enduring scientific treasure.

References: [1] Dworkin et al. (2017) *Space Sci Rev* 214: 19. [2] K. Nakamura-Messenger, S.J. Clemett, S. Messenger, L.P. Keller, Experimental aqueous alteration of cometary dust, Meteoritics & Planetary Science. 46 (2011) 843–856. [3] Herd et al. (2016) Cold curation of pristine astromaterials: Insights from the Tagish Lake meteorite. *Meteorit. Planet. Sci.* 51(3):499-519.