THE CAESAR NEW FRONTIERS MISSION: 4. SAMPLE ACQUISITION AND PRESERVATION.

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Introduction: CAESAR will collect at least 80 g of surface sample from the smooth terrain on the nu- cleus of comet 67P/Churyumov-Gerasimenko (hereaf- ter 67P), and return it to Earth. The system protects both volatile and non-volatile components from contamination or alteration that would hamper their scientific analysis [1,2].

Sample Acquisition and Sample Containment Systems (SAS/SCS): The SAS is mounted on a two-degree-of-freedom compliant end joint that allows it to conform to surface slopes up to ±15° when contacting the comet surface. The SAS includes a set of spring-loaded "ripper tines" which help to break up particles held together by cohesion. A pneumatic system mounted on the Touch-and-Go (TAG) robotic arm provides high purity nitrogen gas to a series of pneumatic nozzles within the SAS sampling cone. These nozzles are located within a set of four sampling chambers, which act to funnel cometary particles into a centralized sample container. Once the SAS makes contact with the surface, gas nozzles near the outer perimeter of the sampling chambers agitate particles and direct them inward, towards the inner gold-plated sample container. Another nozzle located closer to the throat of the funnel is used to open a flexible Kapton flap, allowing the sample to flow into the sample container. These flaps close once the gas flow stops, entrapping particles within the sample container. We demonstrated the performance of the SAS in both vacuum and zero gravity at the NASA Glenn Zero Gravity Research Facility, routinely collecting over 300 g of autoclaved aerated concrete "Aircrete", which has a density similar to the bulk density of comet 67P [3].

Once TAG is complete, verification of sample acquisition is performed using the CANCAM camera, which has a direct view into the sample container through a sapphire window, using LEDs to illuminate the interior. In addition to a visual confirmation, the sample mass is confirmed by swinging the TAG Arm and using a load cell on the end of the forearm to measure the increased mass due to the collected sample.

After sample verification is complete, the SAS sample cone is jettisoned using a decoupling mechanism (Figure 1). This event exposes the sample container, which is then inserted into the Sample Containment System (SCS) using a series of TAG Arm articulations. The sample container is passively locked into the SCS, then decoupled from the TAG Arm. With the sample container housed within the SCS, the SCS lid is closed and sealed with a knife-edge and copper ring. The SCS provides a hermetic seal to stringent leak rate requirements. The SCS interfaces directly to the Gas Containment System (GCS), a gas reservoir into which volatiles will be separated and isolated.

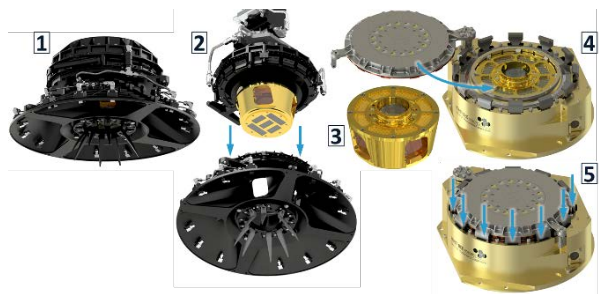

Figure 1. SAS (1), Jettison Sample Cone (2), Gold-Plated Sample Container (3), SCS Open (4), SCS Preloaded and Sealed (5).

Gas Containment System (GCS): The requirement to store the sample under conditions that prevent alteration, yet still achieve the science associated with comet volatiles, leads to the need for the GCS. Comet solids must be kept cold and dry to avoid aqueous and gas-solid reactions. Even brief exposure to liquid water or brines could confound attempts to determine if aqueous activity occurred on 67P. CAESAR preserves much of the science of a cryogenic sample return by retaining volatiles in a dedicated reservoir securely separated from the residual solid sample.

After sealing the SCS, the sample is warmed to temperatures similar to those experienced at 67P perihelion. The sublimated volatiles are then passively cryopumped into a separate radiator-cooled GCS gas reservoir (Figure 2). Once sample outgassing is complete, valves are actuated to seal the GCS and vent the SCS to space.

Based on brassboard ice transfer experiments inside a thermal vacuum chamber, >99.99% of sublimated H_2O can be captured inside a GCS cooled to less than -60ºC while maintaining water pressure well below its triple point (4.5 Torr), preventing liquid formation. Other comet species such as CH_3OH and H_2CO have similar volatilities to H_2O, and should also condense. More volatile species (*e.g.*, noble gases, CO_2, CO, O_2, HCN, NH_3, CH_4) will not solidify in the SCS or GCS. The GCS gas reservoir is sized to max- imize its volume (5 L) relative to the SCS headspace (~1 L), to trap the largest possible fraction (~83%) of the non-condensable gas species. Preflight calibration of the SCS-to-GCS volume ratio enables recovery of the original fraction of gas abundances.

Our baseline SCS temperature for gas transfer is -30°C, where prevention of aqueous alteration of the most reactive amorphous silicate minerals (based on measured forsterite powder gas-solid hydration reaction rates [4]) requires completion of transfer in ≤100 days. During the transfer, the partial pressure of water vapor is measured in a gas cell between the SCS and GCS using two redundant thermopile detectors with 2.7 μm and 6.5 μm H_2O absorption filters, each paired with IR sources. During return cruise, the spacecraft continuously monitors the temperature and pressure of the SCS and GCS. With the aid of flight-qualified phase-change materials, the Sample Return Capsule (SRC) keeps both systems below 0°C throughout en- try, descent, landing, and recovery. Careful control of volatile transfer and subsequent low-temperature storage prevent chemical reactions and isotopic exchange among the volatiles.

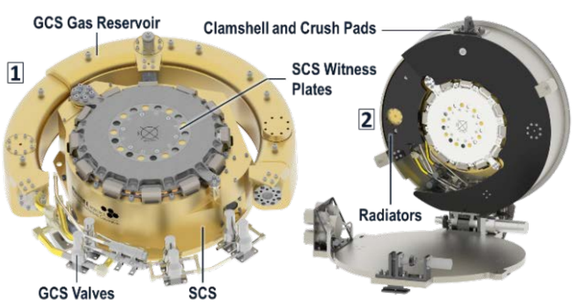

Figure 2. SCS and GCS (1), SCS and GCS mounted in a clamshell mechanism (2).

Sample Return Capsule (SRC): The JAXA-provided SRC is designed to accommodate storage of the SCS and GCS, mitigate environments associated with EDL, assure a soft landing at the UTTR (< 8 m s^{-1}), and help keep the GCS at a temperature below 0ºC for ≥4 hr after touchdown.

The CAESAR SRC is a scaled up version of the Hayabusa SRC, and remains within the proven Hayabusa reentry heating envelope [5]. The Hayabusa SRC can survive aerodynamic heating conditions at reentry speeds up to 12 km s^{-1}. The front heat shield is jettisoned during entry to prevent excessive heating of the payload due to heat soak back.

The shape of the CAESAR SRC is similar to that of Hayabusa, with a 45° sphere-cone reentry capsule. The same ablator material used for Hayabusa is also used for the CAESAR SRC because the reentry speeds are identical. A two-stage parachute system is adopted for the CAESAR SRC to decelerate the SRC efficiently.

For CAESAR, the GCS radiator mounted inside the SRC needs to be exposed to space to maintain the low sample temperatures during the inbound cruise. Several days before Earth return, the reentry preparation sequence begins (Figure 3). Before reentry, the GCS lid shuts, and the SRC closes by driving the back-shell/payload into the front heatshield with a linear actuator.

On the day of reentry, the spacecraft releases the SRC using a spin-separation mechanism. After the 4-hr solo flight, the SRC reenters the Earth’s atmosphere. The SRC uses a two-stage subsonic parachute system that keeps deployment shocks below 10 g. After the drogue chute deployment, the front heat shield is jettisoned to avoid heat soak back and minimize sample heating. Finally, the main chute deploys at an altitude of 3.1 km and the SRC lands at a velocity of 7.5 m s^{-1}.

The CAESAR design and systems maintain the SCS and GCS below 0ºC throughout entry, descent, landing and recovery under worst-case landing site temperature and recovery conditions, fulfilling all mis- sion requirements to preserve the returned comet solids and volatiles.

Figure 3. SRC preparation sequence just before reentry.

References: [1] Lauretta, D. S. et al. *LPSC XLIX*. [2] Nakamura-Messenger, K. et al. *LPSC XLIX*. [3] Pätzold, M. et al. (2016) *Nature, 530, 63-65.* [4] Yamamoto, D. and Tachibana, S. (2016) *LPSC XLVII*, Abstract #1733. [5] Inatani, Y. and Ishii, N. (2003) *ISAS Report SP*, March 2003, No. 17, pp. 1-15.