# COLD AND CRYOGENIC CURATION OF LUNAR VOLATILE SAMPLES RETURNED TO EARTH.

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**Introduction:** The study of volatile compounds and volatile elements, such as H, He, C, N, O, $H_2O$, $CH_4$, $SO_2$, CO, $CO_2$, $NH_3$, HCN, etc., are commonly used for constraining evolutionary processes on planets, satellites, and asteroids, as well as formulating models of solar system formation. For Lunar science, the recent evidence of regolith and rocks containing small amounts of $OH^-$ and/or $H_2O$ has renewed scientific interest into the study of lunar volatiles [1, 2]. Future lunar sample return missions will include the study of volatiles as a high priority.

Comet particles from the Stardust mission, asteroid particles from Hayabusa, meteorites, and subsurface lunar samples all occupied subfreezing environments prior to collection. Valuable geochemical information on volatiles is often lost when these samples are allowed to reach ambient temperatures on Earth. The ability to store, document, subdivide, and transport extraterrestrial geologic samples while maintaining below freezing or cryogenic temperatures is required for the complete scientific study of such samples, as well as future samples from a wide range of solar system bodies.

**Lunar Temperatures:** Recent Lunar Reconnaissance Orbiter (LRO) Diviner radiometer observations have shown that cold traps in the polar regions of the moon have temperatures as low as 38 K [3]. Diviner data also estimates that the lunar surface (in the top 2 cm), daytime temperatures range from about 180 to 300 K and 60 to 120 K in semi-shaded areas [3]. Nighttime observations show an estimated temperature range from 38 to 90 K, where 38 K is in permanently shadowed craters [3]. Therefore, volatiles in regolith samples that would be collected and returned to Earth might need to be maintained at extremely low temperatures to fully preserve their scientific integrity.

**Curation at 250 K:** Subsurface lunar regolith samples collected and preserved at 250 K could contain ice and solar wind derived volatiles. Returning such samples from the lunar surface could require having the sample return capsule outfitted with several sample containers situated inside a freezer that would survive a reentry. Curation at 250 K on Earth could require that the samples be handled inside an insulated glovebox with an inert gas environment. An alternative option would be a glovebox placed inside a walk-in freezer [4]. Storage of the samples would be in commercial freezers with redundant systems.

**Curation at 40 K:** Samples from extremely cold environments, including the lunar polar cold traps, could require curation at temperatures as low as 40 K. For cryogenic samples returning to Earth, a combination of passive cooling during cruise and active cooling during and after reentry might be required. Once on Earth, the sample return container could be placed into a helium shroud cryopump vacuum chamber. Cryocontainment would be maintained through delivery to a cryogenic chamber in the curation facility. This 40 K thermal vacuum chamber would include cameras and robotic manipulators for preliminary examination, subdivision of samples, and specialized sample allocation containers for shipment to laboratories. Cryogenic curation is feasible with current technologies developed for the superconductor industry. However, significant research and development costs would be required to tailor these technologies to the task of sample return and long term curation of lunar volatile samples at 40 K.

**Future Cold / Cryo Curation:** With over four decades of scientific investigation, the Apollo sample collection has given the science community the ability to study lunar materials with highly precise measurements made in multiple laboratories. High-resolution studies of lunar volatiles will require a sample return mission where cold or cryogenic curation preserves the scientific integrity of these fragile samples.

**References:** [1] Pieters, C.M. et al. (2009) Science, 326(5952): 568-572. [2] Anand, M. (2011) Earth, Moon, and Planets, 107(1): 65-73. [3] Paige, D.A. et al. (2010) Science, 330(6003): 479-482. [4] Herd, C.D.K. et al. (2011) The Importance of Solar System Sample Return Missions to the Future of Planetary Science Workshop, Abstract# 5029.