PLANNING FOR THE PRESERVATION AND CURATION OF ARTEMIS RETURNED SAMPLES.

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Introduction: In 2019, the Vice President stated in Space Policy Directive-1 that “the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations.” He also stated that the U.S plans “to return American astronauts to the Moon within the next five years.” The Artemis Program plans to return new geologic samples from the lunar south pole, a previously unsampled environment. In particular, sample preservation during collection and return is necessary for: understanding the history of volatiles in the Solar System and the evolution of the Earth-Moon system, fully constraining the hazards of the lunar polar environment for astronauts, and providing the necessary data for constraining the abundance and distribution of resources for in-situ resource utilization (ISRU). Here we summarize the efforts of the Astromaterials Acquisition and Curation Office (hereafter referred to as the Curation Office) at the Johnson Space Center (JSC) to ensure the success of Artemis sample return (per NASA Policy Directive (NPD) 7100.10E).

Mission Context. The lunar south pole presents unique challenges to surface operations and sample preservation, collection, transportation, characterization, and long-term storage. As a result, the current Artemis architecture includes a complex sequence of steps for sample return from the lunar south polar region. After the initial samples are collected, they will be transferred to the Human Landing System (HLS) until the crew departs from the lunar surface. The samples will be transferred from HLS to Gateway where they will be stored for a to-be-determined amount of time. The samples will then be transferred to Orion for return to Earth. After Earth return, the samples will be recovered and rapidly transported to the curation facility at JSC.

During the Apollo Program, astronauts grappled with the vacuum, radiation, and dust-rich environment of the sunlit lunar equatorial/mid-latitudes [e.g., 1]. Artemis crew will not just grapple with those conditions, but also larger temperature swings, low/oblique lighting conditions, the extreme cold of permanently shadowed regions (PSRs), and the unique chemical hazards posed by volatiles within those PSRs [2-4].

Challenges and Strategies for Sample Return. Successful sample return means preserving the sample from collection to analysis on Earth with little to no alteration in the chemical or physical makeup of the sample. This is particularly difficult for volatile-rich samples, which contain compounds that are highly reactive, have low sublimation temperatures, and are mixed with silicates (lunar highlands regolith).

Sample Preservation. Apollo-era intimate hardware was primarily constructed from Teflon (PTFE and FEP), stainless steel (300-series), and aluminum (6061-grade) [5]. However, the additional requirements for preserving volatiles potentially alter the requisite materials needed for sample containment. In particular, metals are particularly sensitive to highly reactive species like H_2S, necessitating a reevaluation of acceptable metal components/hardware.

Temperatures higher than those in the PSR where samples are collected could alter the volatiles within those samples. In particular, species like methane, H_2S, ammonia, etc. with low condensation temperatures will be especially sensitive to temperature changes due to their reactivities and likelihood of phase change. If these compounds react with each other, the lunar soil, or the sample container(s) to form new compounds, the true chemical makeup of volatiles on the Moon may not be decipherable from the returned samples even with high-precision analytical techniques. Therefore, temperature storage constraints for lunar polar samples need to be determined.

Contamination control (CC) is needed to prevent contamination from both particulates (e.g. from the vehicle, space suit, and/or crew) and volatile element contamination. CC can take the form of limiting waste dumping, atmospheric (suit/vehicle) leakage, propellants, etc. in proximity to PSRs, thereby reducing the effect of crew operations on condensed materials in PSRs. The impact of CC on scientific analyses should be determined for the various sources of contamination (e.g., chemical reactions, effects on isotopic characterization, etc.). Contamination knowledge (CK) in the form of inorganic, organic, particulate, and microbial characterization of tools, containers, the vehicle, and suits should be implemented prior to, during, and after flight. CK can take the form of witness plates or coupons, in-situ swabbing (for biological samples), and the characterization and curation of flight spares. These materials would become part of the Artemis sample curation collection as they are produced and used throughout the Artemis missions.

Sample Collection. Science requirements will determine the minimum quantity of sample needed for lunar polar sample studies, along with the types of samples needed (soils, clasts, volatile-bearing, etc.). These requirements will translate into engineering requirements for sample tools, containers, and in-flight operations. In many cases, lessons learned from Apollo [5] will feed forward to sample tool design and define the new capabilities needed for Artemis.

Sample Transportation. PSR samples will need to be actively cooled during the transit from the Moon to the curation facility on Earth. PSR samples are likely to represent a smaller proportion of returned sample mass than sunlit samples. Therefore, the mass storage requirements for a freezer will be less than the total needed for all returned samples. A cold/cryogenic freezer will maximize volatile preservation during transport on Orion/HLS and during storage periods on Gateway.

Sample Characterization. After sample return, the curatorial preliminary examination (PE) process is typically performed to develop an initial assessment of the returned samples. PE includes, but is not limited to: photographing the samples, cataloging individual clasts/particles, measuring their masses, performing an initial assessment of their composition, and distributing information on the samples to the scientific community. To date, the PE process has only been conducted on astromaterials that are in the solid phase at room temperature and atmospheric pressure. For volatile-bearing samples, the PE process will need to be adapted for either nondestructive assessment of condensed phase compositions, or gas-phase compositional analyses [6]. Due to the low expected mass of volatiles in the lunar polar samples, nondestructive PE techniques are preferred to minimize consumption of precious sample. Potential volatile PE methods include cavity ringdown spectroscopy, FTIR, and possibly GC-MS (if rapid, high-precision analyses are prioritized over sample retention). Regardless of the PE technique(s) used, significant adaptations to the standard curatorial PE process will need to be implemented to allow for sample access, transport, storage, and characterization without altering the sample composition or isotopic abundances therein.

Long-Term Storage. The Curation Office has successfully preserved the Apollo lunar samples for over fifty years; the same long-term mindset is applied to all curation collections, including Artemis. To preserve a volatile-bearing sample for the long term may require separating reactive species from susceptible ones, storing for the long-term at cryogenic temperatures, and/or developing new sample handling and allocation techniques. Long-term storage combines the requirements of all of the previous constraints – materials, temperature, atmospheric compatibility, preventing loss of volatiles due to glovebox/containment leakage, and so on.

Ongoing Efforts. The primary question regarding lunar polar sample return is the necessary temperature at which the samples need to be stored in order to preserve their chemical and physical makeup. This question has implications for sample storage container requirements, freezer and cold stowage capabilities on HLS, Gateway, and Orion, and the associated mass, power, volume, and operational impacts. To address this question, we are conducting storage testing of a lunar volatile-rich simulant. This testing involves storing the samples at a range of temperatures, from room temperature (25°C) down to cryogenic (-196°C) to assess the impact of storage temperature on sample composition and physical state. A baseline simulant sample will also be stored under lunar conditions in a specially developed environmental chamber built for that purpose. Initial testing will be limited to two weeks in duration to mimic the duration of in-flight activities, from sample collection to transport to lunar orbit, Earth orbit, and Earth surface. Samples will be characterized for gas-phase compositional variations and solid-phase alteration (compositional and physical) throughout the test cycle. The entire test will be conducted multiple times to account for variations in the volatile-rich simulant starting composition. After temperature storage tests are complete, materials compatibility testing will be conducted in 2020 and beyond to determine the compatibility of various metals and plastics with volatile-rich analog materials and the cold conditions in which they will be stored.

Contamination requirements are in the process of being established by the scientific community. These requirements will dictate sample handling and materials constraints. Preparatory work for sample processing and preliminary examination under cold and cryogenic conditions is also in progress. Throughout all of these efforts, the Curation Office is interfacing with NASA engineering and mission operations teams to ensure all sample intimate hardware successfully preserves the scientific integrity of the samples, allowing the analytical goals of the scientific community to be met.

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