ARTEMIS CURATION: PREPARING FOR SAMPLE RETURN FROM THE LUNAR SOUTH POLE.

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Introduction: Space Policy Directive-1 mandates 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.” These efforts, under the umbrella of the Artemis Program, include such historic goals as the flight of the first woman to the Moon and the exploration of the lunar south-polar region.

Among the top priorities of the Artemis Program is the return of a suite of geologic samples, providing new and significant opportunities for progressing lunar science and human exploration. In particular, successful sample 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) to ensure the success of Artemis sample return (per NASA Policy Directive (NPD) 7100.10E).

Science Goals and Objectives. The Artemis Science Definition Team (SDT) Report [1] outlines the major science objectives and their prioritization for Artemis III, the first landed mission of the Artemis Program. These objectives are broadly categorized into: Understanding planetary processes; Understanding the character and origin of lunar polar volatiles; Interpreting the impact history of the Earth-Moon system; Revealing the record of the ancient Sun and our astronomical environment; Observing the universe and the local space environment from a unique location; Conducting experimental science in the lunar environment; and Investigating and mitigating exploration risks. The SDT report also recommends science investigations to meet these objectives; many of these investigations require the return and detailed study of lunar polar samples. Therefore, to successfully meet the science objectives of the Artemis Program, it is critical to maximize the preservation of the samples through all stages of each mission and to ensure robust curation of the samples after Earth return.

New Challenges. The lunar south pole presents unique challenges to surface operations and sample preservation, collection, transportation, characterization, and long-term storage. Thus, the current Artemis architecture includes a complex sequence of steps for sample return from the lunar south pole. 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., 2]. Artemis crew will not just contend 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 [3-5].

Sample Preservation. Apollo-era intimate hardware was primarily constructed from Teflon (PTFE and FEP), stainless steel (300-series), and aluminum (6061-grade) [6]. However, the additional requirements for preserving volatiles potentially alters the requisite materials needed for sample containment. Specifically, 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 volatile materials. 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. Scientific analyses in support of the Artemis science investigations constrain the minimum quantity of material to be collected on the Moon, along with the types of samples needed (soils, clasts, volatile-bearing, etc.). These constraints are listed in Section 6.1 of the Artemis SDT Report as a notional science program, and will translate into engineering requirements for sample tools, containers, and in-flight operations. In many cases, lessons learned from Apollo [6] will feed forward to sample tool design and define the new capabilities needed for Artemis.

Sample Transportation. To maximize their preservation, PSR samples should be actively cooled during the transit from the Moon to the curation facility on Earth. Since PSR samples might represent a smaller proportion of returned sample mass than sunlit samples, 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. Rock samples will likely have a low volatile content, however, they should be characterized in-situ prior to storage in the crew cabin to ensure sample preservation and crew safety.

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 [7]. 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 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. Contamination requirements are in the process of being developed based on the science objectives outlined by the SDT. These requirements will dictate sample handling and materials constraints. Materials compatibility testing will be conducted in 2021 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. Temperature storage testing of volatile analog materials is also planned; this testing will determine thermal requirements for flight and long-term curation. Preparatory work for sample processing and preliminary examination under cold and cryogenic conditions is also in progress. The Apollo Next Generation Sample Analysis (ANGSA) Program is providing significant experience in executing cold sample processing of lunar materials. 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, enabling the success of the Artemis sample science.

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