Maximizing scientific opportunities through the careful selection, collection, storage, curation, and analysis of samples from the Artemis program.

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Introduction: Our understanding of the Moon and its early history has been revolutionized through the study of samples collected by astronauts during the Apollo missions. The lunar crust records and preserves an archive of planetary history that is unparalleled in the solar system. Over the last half century, the Apollo samples have given us a glimpse into the early history and broad-scale petrogenesis of the Earth-Moon system, planetary formation, evolutionary processes, and the history of formation of our solar system [e.g., 1-3]. Many of these key discoveries have been made only in the last decade due to advances in existing technology or the invention of new technology, and because the Apollo samples have been curated in a pristine manner and continually made available to the international scientific community. Future generations of scientists will use the new samples returned from unexplored terrain(s) by the Artemis missions, in concert with continued studies of the Apollo collection (and even lunar meteorites) to extract startling surprises and make profound discoveries about the Moon and the solar system [4]. The long-lasting legacy of sample return from the Moon is a key component of a holistic way of studying our solar system through time.

The Apollo program utilized a myriad of sample collection tools including hammers, scoops, tongs, rakes, drills, drive tubes, etc. Apollo-era sampling tools and sample containers, storage, and curation tools were made almost entirely of Teflon, aluminum, and stainless steel. Overall, those materials were well-suited to the study of lunar materials [5]. As Artemis engineers set about designing new lightweight and high-tech tools, we recommend consideration of the following points about contamination knowledge and minimization activities for fundamental topics in lunar and planetary science:

Contamination Knowledge and Other Considerations for Artemis Samples: Contamination knowledge (CK) is the information gained from studying the collected/curated reference materials and witness plates in conjunction with returned sample analysis [6]. Establishing a robust CK for Artemis is of paramount importance to prevent science loss due to contamination of returned samples during sample collection, return, storage, and curatorial processing. Below are several important topics that should be considered as part of the Artemis mission preparations:

(1) **Tools and experimental abrasion considerations:** Artemis tools should be tested against different targets (rocks, soils) so that loss and transfer of material to and from tools is accounted for. A series of modelling and experimental trials should be performed that can verify contamination performance for different analytical techniques. Tools should be tested using well characterized analogs of rocks and soil expected at the Artemis landing site(s). The chemistry and isotopic composition of such analog materials should be determined using a range of analytical techniques to quantify contamination potential. The Apollo-era tools should be used as witnesses of contamination during lunar sampling, e.g., Pb contamination was an issue during Apollo [7] and there is potential for metal transfer [5]. Furthermore, chemical and isotopic determination of any potential tool coatings and tool materials will be critically important to understand contamination risk to returned samples.

(2) **Volatile loss considerations:** The extraction of polar-like regolith using different techniques needs to be assessed to prevent science loss (e.g., ice sublimation, fractionating D/H ratios, breakdown of organic molecules, etc.). Further, it is important to assess how various storage containers/boxes will allow preservation of volatiles, ices, organics, and gases, as well as the effect that the preservation of volatiles has on the ability of the samples to be used for other geologic analyses. It may be important to conduct *in situ* measurements on the surface (e.g., porosity, temperature, volatile phases of and within lunar material) to understand the degree of modification of the sample once it is collected, stored, and curated. Maintaining sample integrity (the original state) from collection through transportation and storage to analysis is critical to maximize the scientific return of these precious samples. Without this protection, sample properties and compositions could change, ultimately influencing the interpretation and understanding of a given sample and, by extension, the Moon. This is especially critical for the sampling, transportation, storage, and analysis of volatile-rich samples, particularly those sourced from permanently shadowed regions (PSRs) [8]. Systems capable of maintaining samples under lunar cryogenic conditions will be of value not only to lunar sample return but also to Mars, comets, and potentially the ocean- and ice-world satellites of the outer planets.

(3) **Organic considerations:** Analysis of witness plate materials and spacecraft components (including sealants, fuels, bags, suits, etc.) is critical to evaluate potential organic contamination [9]. Equally important is to evaluate how tools and sample bags change under different sterilization methods and/or radiation environments and their effects on sample contamination. Assessing the contamination from landing equipment and descent engine exhaust is critical for understanding and interpreting endogenic vs. exogenic organic/volatile-bearing samples. This would also be relevant to the collection of material from the lunar exosphere.

(4) **Curation and allocation considerations:** NASA has more than fifty years of experience in curating, processing, and distributing astromaterials, as well as providing fair and open access to these samples to the international science community. A similarly fair, open, and impartial sample request and allocation system, to which all other NASA sample collections adhere to, is recommended for the Artemis samples, and could follow the well-established CAPTEM model and NASA sample loan scheme. In addition, the Apollo program anticipated the advancement of analytical techniques and prepared for this by sealing a subset of lunar samples for future investigations under a variety of conditions [see 10]. Recently, the ANGSA program has begun to fulfill that task [11]. Artemis may consider doing something similar.

(5) **Astronaut training considerations:** Astronauts need to be well trained in geology and are integrated into the science mission planning teams so that they understand the rationale for geology stops, sampling requirements, and traverse plans. This will enable the astronauts to intelligently explore, recognize, and sample essential and unique elements of a field site thoroughly and efficiently, and to identify serendipitous sampling opportunities [12].

(6) **Understanding other community needs**: Beyond fundamental science interests, consideration should be given to applied exploration science communities, e.g., for in-situ resource utilization (ISRU) and bioscience and human health issues with regards to needs for sample collection, storage and curation. Further, education and outreach play an integral part by informing and educating the public about the Moon, the space environment on the Moon, and the Artemis missions and for inspiring the next generation of diverse lunar scientists. Thus, it is essential to understand the future needs for lunar samples of these institutions and communities.

These considerations (1-6) led to the formulation of a set of findings for Artemis sample collection, storage, and curation. These findings map to strategic science questions and goals that Artemis sample-returns could address, and permit establishment of the limits, compositions, and thresholds for elements and isotopes of interest to science priorities for the Moon (see part of the table below; the full, detailed table can be found here and here [13]).

Peak Priorities 1-4 (as identified in NRC (2007);	Method(s) needed to address the concept	Analyses/ Instrumentation	Elements needed/of interest	ppt-level	ppb-level	ppm-level	wt%-level
1a. Test the cataclysm hypothesis by determining the spacing in time of the lunar basins.	Isotope age dating (bulk sample, in situ on targeted mineral phases)	TIMS, MC-ICP-MS, SIMS, LA-ICP-MS, NI-NGMS	Ar, Ne, Xe, Pb, U, Sr, Nd, Ti, Ni, Co, He, Pu, Zn, Ga, Ne, Rb, HSEs, Trace elements, stable and radiogenic isotopes	Noble gases	Pb, Nd, Ar, U, Zn	Co, Ni, Sr, Rb	K, Ti
1b. Anchor the early Earth-Moon impact flux curve by determining the age of the oldest lunar basin (South Pole-Aitken Basin).	Highly siderophile element analysis to determine impactor types	TIMS					
1c. Establish a precise absolute chronology.	Geologic context of samples (petrology); Noble gas and cosmogenic radionuclides	EPMA, SEM, Spectroscopy, LA-ICP-MS, NGMS, Accelerator mass spectrometry					

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