PREPARING FOR LUNAR VOLATILE-RICH CRYOGENIC SAMPLE RETURN AND ANALYSIS. C. A. Hibbitts, C. Drabenstadt, K. Stockstill-Cahill, Johns Hopkins Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel, Md 20723. Karl.hibbitts@jhuapl.edu

Introduction: On the lunar surface, there is solar wind -derived water (both OH and H_2O), lunar cometary water in the lunar surface [1-6], as well as water in returned samples including apatite [e.g.,7, 8], in impact-derived and volcanic glasses [9, 10], in melt inclusions [11], and in vesicles in the space-weathered rims on grains exposed to solar wind and micrometeoroids [e.g.12,13,14,15]. We need to understand the origin and evolution of these various types of water to develop a model of where water resources are likely to be and where they are unlikely to be. This is where science can significantly help exploration. As part of this discovery process, scientists will need to conduct analyses that can only be done using Earth-based tools. Thus, potentially volatile rich samples will need to be brought back to Earth; the Artemis mission will be bringing back these types of samples. The challenge we are addressing is how to handle and transport these samples once they are brought back to Earth so that sufficient (but not all) science will be preserved to adequately understand lunar volatiles for development of these predictive models.

Some of this water may prove to have accumulated into deposits of reserves, and all of it will be scientificly intriguing. Thus, in order to understand both the resource potential (and challenges) as well as science implications, these types of volatile bearing materials will need to be sampled, transported, curated, and transferred to investigation facilities under cryogenic temperature and pressure conditions that preserve the volatiles to the extent needed while minimizing contamination by telluric gases. We have been developing an approach for the cryogenic transfer between NASA JSC curation and investigators' laboratories of volatile rich lunar samples to enable these types of investigations of returned samples.

Discussion: Different volatiles are lost or preserved at different temperature regimes [17]. Depending on the nature of the volatile in question, different temperature regimes can be appropriate. While ambient temperature only preserves implanted volatiles and extreme cryogenic temperatures can preserve hypervolatiles, intermediate temperatures (i.e., ~ 153 to 193K) preserve valuable science as well. Ion and electron probe surface analysis techniques, while possible at cryogenic temperatures [18], can fully accomplish their science goals at intermediate temperatures that will keep volatiles inside grains stable from diffusing on experimental timescales [17]. However, understanding the ices will require preserving the sample at liquid nitrogen temperatures.

Sample transfer. Artemis IV astronauts and possibly robotic explorers will collect samples from the surface of lunar PSRs in the hunt for volatiles. Transported in sealed (and in later missions, also frozen) containers they will be brought back to Earth and stored at NASA JSC cold curation facility. From there they will be sent around the nation to be analyzed by different institutions in an attmpt to fully understand both their scientific and resource potential.

In support of the Earth-based analyses efforts, we have developed an initial sample design concept for preserving the samples while being transferred from curation to investigation facilities, and which simplifies sample handling within a facility including the transfer of the sample cryogenic. The sample transfer container is optimized for maintaining sample physical and thermal integrity, being unreactive to any released volatiles, and simple to manipulate when cryogenic.

The design supports the expected workflow and is driven by the need to maintain sample integrity during sample transfer interfaces, which is when sample integrity is most likely to be compromised: 1. Sample preparation at cold curation, 2. Extracting the sample at investigor's institution, 3. Preparing sample for analysis, and 4. Inserting sample into and extracting from an analysis system. This last step, colloquially referred to as 'the final three feet', can require a separate handling approach, but also one that has benefitted from significant commercial development.

The current (i.e. preliminary) capabilities for the sample holder attributes have been derived from efforts by the SSERVI RASSLE and CLEVER teams and from the LEAG/ExMAG SAT on Artemis Samples: Cold Curation and Volatile Samples. They are:

1. Provide a simple, easy to use, effective, and 'universal' cryogenic sample transfer device for shipping samples between NASA JSC Curation and laboratories and between laboratories.
2. Minimize the retrofit requirements on laboratories while meeting (but not exceeding) the storage attributes of Curation.
3. Be able to collect (gaseous sampling) and monitor the volatiles or at least analyze the composition of the 'headspace' in the sample holder after transport.
4. Monitor vibe/shock sample experiences during transport.
5. Maintain chain of custody.
6. Use sample holder material that will not react with corrosive gases.

7. Address the charging and electrostatics of small grains.
8. Be able to visually inspect and conduct spectral measurements of the sample without removing it from the transfer device.

We will present an update the development of this sample transfer device, and will look forward to discussing desired capabilities and potentially other applictions for maintaining the integrity of cryogenic volatile rich lunar samples.

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References: [1] Colaprete et al., 2010; [2] Pieters et al. 2009; [3] Sunshine et al. 2009; [4] Klima et al. 2013; [5] Hendrix et al., 2012; [6] Honniball et al. 2021; [7] McCubbin et al. 2010; [8] Barnes et al. 2014, [9] Saal et al. 2008; [10] Liu et al. 2012; [11] Hauri et al. 2011; [12] Burgess et al. 2022; [13] Greer et al. 2020; [14] Cymes et al. 2022; [15] Kling et al. 2024; [16] Artemis III SDT, 2020; [17] Shearer et al., 2024; [18] Meibom et al, 2023.