TESTING OF LUNAR DUST DISSOLUTION IN AQUEOUS ENVIRONMENTS. R. L. Kerschmann1, D. J. Loftus1, D. Damby2, K. Scheiderich2, D. Winterhalter3, 1 NASA Ames Research Center, Division of Space Biosciences, Moffett Field, CA 94035, USA, rkerschmann@gmail.com, 2 United States Geological Survey, 345 Middlefield Rd. Menlo Park, CA 94025, USA, 3 Jet Propulsion Laboratory, California Institute of Technology, NASA/Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, M/S 183-300, Pasadena, CA 91109-8099, USA.

Introduction: The impact of lunar dust on lunar exploration has been extensively studied in the post-Apollo era. However, a topic that has been insufficiently examined is the behavior or lunar dust in water-based solutions, which has important implications for crew health and engineered exploration systems.

While some primordial water is preserved in lunar volcanic particles and in mare basalts [1], it is widely accepted that the moon is dry, except for some ice likely present in the permanently shadowed craters at the poles [2]. However, due to human exploration, water will be everywhere on future missions. It will be transported to the moon along with other mission assets in critical vehicle and habitat life support systems [3], and it will be extracted in quantity through ISRU processing of lunar minerals [4]. And, it will exist within the bodies of the lunar crews, since humans are composed of approximately 70% water [5].

Water and dust will inevitably mix on the moon, especially during long-term stays, and some important aspects of this interaction have not been examined.

Once lunar dust comes into contact with water or water-based solutions, there is good evidence that the dust particles will dissolve and release their constituent chemicals. Lunar dust is dominated by impact-generated glass, and it has been established that terrestrial glasses, both artificial and natural, will dissolve slowly in water [6]. Glass-containing lunar dust simulants have also been shown to dissolve [7]. Since lunar dust, in situ, is exposed to intense radiation on the moon, and particle radiation can disrupt the structure of mineral particles, it is possible that lunar dust is more susceptible to dissolution than terrestrial dusts that are not exposed to radiation. Further, there is experimental evidence that native lunar dust suspended in water gives off metals and other elements for at least months, which suggests that the dust particles gradually dissolve [8].

During the initial Apollo 11 quarantine period, freshly returned lunar dust was injected into tissues of mice and later examined when the animals died naturally in about two years. It was seen in these animals that some particles persisted, but further examination to document the extent of dissolution or the physical and chemical nature of the surviving particles was not performed [9, 10].

Chemicals given off by lunar dust could be concentrated or chemically altered during recycling or other mission processing systems, which could present hazards to the crew and their equipment.

Lunar mission design teams will need a full accounting of what elements are released from lunar dust in water, what the concentrations are, and at what rates these materials enter into solution. It is theorized that due to the high surface area and surface chemical reactivity, when lunar dust is first introduced into water there will be a short-lived release of highly concentrated elements, dominated by iron, that might damage equipment components or be a threat to crew health. This initial release is likely followed by a prolonged release over months of many elements contained in the particles, possibly culminating in the total dissolution of some of the particles.

However, no standardized laboratory method currently exists for measuring the water-based dissolution of celestial dusts or for determination of the detailed time-course of release of all factors, particularly metals. Neither has the microscopic effect of lunar dust dissolution on grain morphology been observed in any detail.

We propose that analytical systems be identified, and that standard operating procedures be developed and documented for carrying out lunar dust dissolution studies in a uniform and reproducible way.

Testing will be initiated on available lunar dust simulants [11], and also on terrestrial control dusts that have been well-studied in the context of occupational health [12]. In addition, powdered geochemical standard reference materials (SRMs) provided by the USGS can be used to validate quality control for new methodologies and for instrument calibration and internal quality checks. BHVO-2 (Hawaiian basalt) and BCR-2 (Columbia River basalt) are both powdered volcanic rock standards that have been extensively characterized for mineralogy and geochemistry. As they are freely available in large quantities, they can be used to trial the methodologies developed herein.

Once the test parameters have been established, the system will be validated and studies can commence on curated Apollo lunar dust samples provided by NASA through the Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM, https://www.lpi.usra.edu/captem/).

Several other control materials, including known water-soluble toxic terrestrial dusts, will be tested in parallel to the lunar dust. These will include for example CuO and ZnO [13].
The analytical design makes no assumption about how dust is separated from rough lunar regolith, except that any such separation process must strive to thereafter preserve the dust in as near-native condition as possible, without exposure to water.

In a terrestrial lab, this can be accomplished by cyclone separation process [14]. On future missions to the moon, separation could be performed at the lunar site of collection by mechanical sieving or other means, allowing for bulk quantities of materials in the dust size-range to be returned to Earth for analysis.

This proposal assumes that all water extraction procedures and leachate analysis will be performed in terrestrial laboratories. Bench-top dust leaching methods and hardware will be selected and validated to expose lunar dust to aqueous solutions over time spans ranging from minutes to months, along with suitable controls.

It is the opinion of these authors that a fixed volume tube-based system (batch extraction) with standard rocker platform or other motorized agitation will be the most manageable process for the wide range of time-spans contemplated for the project. At predetermined time points, aliquots will be removed, centrifuged for 10 minutes, and filtered through a 0.2 μm filter in preparation for chemical analysis of the solution. If the volume of water is large compared to the volume of dust, equilibrium is not likely to be reached for most of the contemplated analytes. Such methods have been described for studying the water-based release (extraction) from terrestrial dusts, including volcanic particulates [15] and atmospheric pollutants [16].

Water used in these studies will be purified to 18 mega ohm purity by sub-boiling distillation in a quartz system, and will be obtained from the USGS. Batches of this water will be qualified as study-grade by independent testing before use in the dissolution study.

The pH of the water or other aqueous dissolution medium will be adjusted to span the pH range likely seen in potential lunar water purification systems, ISRU extraction systems, or in the human body. Human relevant pH, pertinent to the lungs, will range from near neutral (airways) to pH 4.0 (phagolysosomes). For the gastrointestinal system, pH ranging from 1.5-8.0 will be relevant.

All dry specimen processing will be conducted under purified and dried nitrogen gas to minimize contamination of the lunar dust samples, and handled with adherence to CAPTEM standards.

The proposed project will be structured in two phases: design and construction of the experimental apparatus for lunar dust exposure to aqueous solutions, with validation of accuracy, precision, interfering substances, analytical range and other conventional laboratory validation factors. Once it is proven that the design can generate reproducible and accurate data, the laboratory will be considered validated for the second phase of the procedure, testing of native lunar materials.

Once the dissolution technique is performed and leachates are collected, we propose to use the most sensitive and accurate commercially available water purity analytical systems currently employed for geological and public health applications. The principal instrument that will be used is Inductively-Coupled Plasma Mass Spectrometry (Nexion 300Q Perkin-Elmer, USGS). This platform is capable of measuring with high accuracy nearly all the elements in the periodic table to the parts per billion, and for some analytes, to the parts per trillion level.

Any dust that remains at a final sample time-point will be dried, weighed, and examined by electron microscopy and bulk-analyzed through standard mineralogical methods to complement the dissolution data.

The proposed work will have broad applicability to human exploration on the moon and other planetary bodies. The data collected on lunar dust dissolution will be shared via an on-line database. The results of this study will influence the design of engineered, human safety and health systems, and will establish standards for analysis of lunar dust samples returned from future manned and robotic missions.

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References