LUNAR ADVANCED VACUUM APPARATUS (LAVA) E. Patrick[1], M. Necsoiu[1], D. Hooper[2], [1]Southwest Research Institute®, San Antonio, TX 78238, [2]WEX Foundation, San Antonio, TX 78205 (epatrick@swri.edu)

Background: Many laboratories study soils and their properties, and many laboratories are filled with ultra-high vacuum (UHV) systems, but there are few laboratories where investigators intentionally place "dirt" inside UHV systems. Ultra-clean UHV chambers are extremely sensitive to particle contaminants which can migrate to affect pumping, charged particle optics, ionization sources for gauges and mass spectrometers, as well as high voltage (HV) cables and electronics, some of which cannot be insulated in the breadboard prototype, engineering unit (EU) or flight unit (FU) configurations. Thus, typical vacuum systems for spaceflight instrumentation are wholly unsuitable for the introduction and containment of lunar regolith simulants or similar unconsolidated granular and powdery materials.

Our first experiments began with the SwRI internally-funded Polar Regolith Environment Molecular Impact Simulation Experiment (PREMISE) and followed by the NASA-funded Regolith Environment Volatile Impact Simulation Experiment (REVISE), Grant NNX-14AN53G. Both systems were specifically constructed so as to minimize chamber surface area with respect to the specific area of the sample being used (typically 10 g, with a surface area of approximately 6,000 cm^2).

To advance the simulation of bulk regolith at the lunar surface, it was necessary to construct a column of simulant material of sufficient volume (diameter and depth), not only to produce a satisfactory analog lunar surface condition, but to also allow permeation of that column for the characterization of mobility and bulk adsorption of gases. It is this gas behavior at the lunar surface which has implications for both the paleocosmic history of the Moon and for *in situ* resource utilization (ISRU) programs currently under development.

The discovery of significant inventories of volatiles at the lunar poles[1] has energized the concept of ISRU[2]. One of the hottest topics in planetary exploration today, ISRU has the potential to exploit local resources on planetary bodies for propellant, life support, or feedstock for construction materials[2] that would otherwise need to be brought from Earth, increasing mission costs and reducing mission payload for science discovery and exploration. Consequently, ISRU is an important science and engineering driver in a number of current and upcoming space missions.

In the case of the Moon, *in situ* analytical chemistry of its exosphere was first conducted at its surface in December 1972 by the Lunar Atmospheric Composition Experiment (LACE) deployed by the astronauts of Apollo 17[3]. Despite subsequent remote sensing observations by an armada of spacecraft, this four-decade lack of *in situ* lunar surface instrumentation contributes to a large strategic knowledge gap (SKG) regarding the Moon's surface behavior, particularly in lieu of its recently discovered inventory of important volatiles[1]. This knowledge gap increases the unknowns and risks associated with plans for a permanent human presence at the lunar surface, and also motivated development of our Lunar Advanced Vacuum Apparatus, or LAVA. "LAVA" is also a play on words, as the JSC-1A lunar soil simulant used in our chamber is processed from the volcanic ash of Merriam Crater, a cinder cone in the San Francisco Volcanic Field of Northern Arizona.

The Chamber: LAVA consists of a large, multi-ported 66-liter vacuum chamber fitted with feedthroughs, manifolds, instrumentation and tubing for the purpose of investigating how volatiles diffuse through bulk lunar regolith[4]. A schematic cross-section of LAVA in Fig. 1 also portrays its 50 cm column filled with simulant. Adjacent to the upper surface of the simulant column is a Spectralon® optical reference target (Fig. 2).

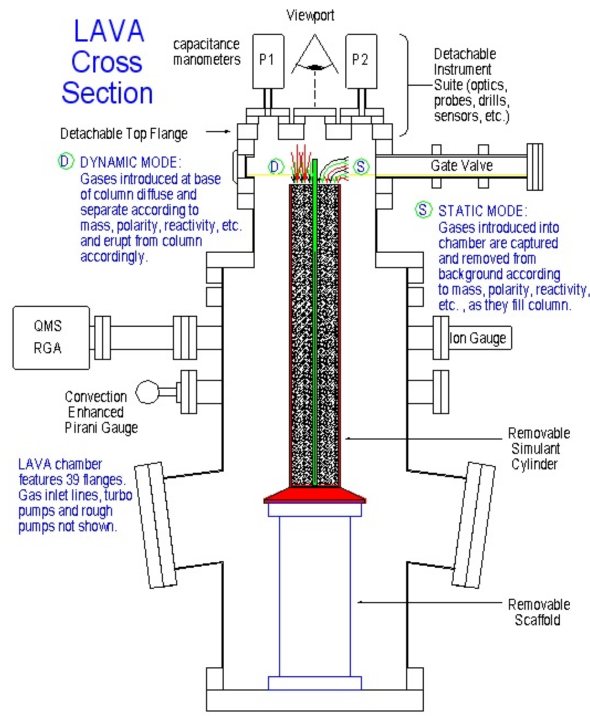

Figure 1. Cross section of the LAVA chamber. In dynamic mode, gases introduced to the base of the column diffuse to the surface at a rate in equilibrium with the chamber pumping speed. In static mode, the injected gas pressure drops as the gas is adsorbed until equilibrium is reached and active sites for gas-surface interaction are filled.

Objective 1: An important objective of this investigation is the simultaneous monitoring by both mass spectrometry and visual-infrared (VIR) spectroscopy of the simulated regolith during gas diffusion experiments, and how spectroscopic properties may change during and after extended gas exposure. **Objective 2:** Understand how weathering and processing of lunar simulants may, by analogy, have implications for the fidelity and weathering of curated lunar samples. **Objective 3:** Provide a state-of-the art space environment simulation system suited for the study of the surfaces of not only the Moon, but also those of asteroids, Mercury, and Mars. **Objective 4:** Provide groundbreaking results to present LAVA as a laboratory system to support future NASA missions to the regolith surfaces of primitive solar system bodies.

Figure 2. Top of the 50 cm JSC-1A simulant column with adjacent Spectralon® optical reference target for reflectance spectrometry.

Approach: Our previous investigations of the JSC-1A lunar soil simulant[5,6] revealed unexpected behavior in gas-surface interactions, including the retention of CO_2 and CO. LAVA investigations will include monitoring the gas diffusion behavior of JSC-1A lunar soil simulant and other pure and processed samples under UHV conditions, as well as using both mass spectrometry and optical spectroscopy techniques to simultaneously monitor simulated surface conditions of the Moon and other primitive solar system bodies (Fig.3).

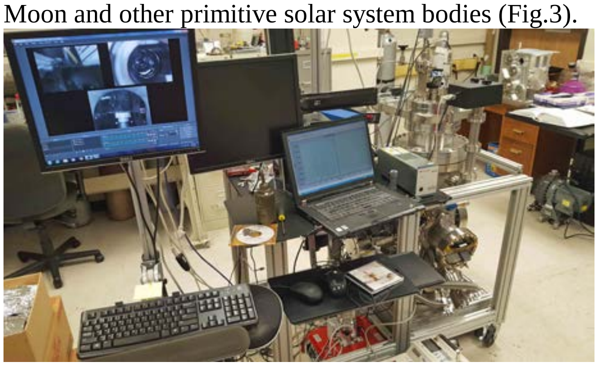

Figure 3. Data acquisition includes separate PCs and monitors for recording multiple camera views of simulant column (left) and mass spectra of the chamber interior (center).

Anticipated Benefits: A 10″ ConFlat® flange at the top of the chamber above the gate valve contains five (5) 2.75″ ConFlat® flanges for the installation and testing of mechanical and optical probes, or drilling systems. LAVA will provide empirical data for the capability of optical spectroscopic techniques to probe the surface conditions of primitive planetary bodies under conditions in which mass spectrometry at the surface of such bodies can detect gases and volatiles. Changes in optical properties brought about by exposure to various reactive volatiles known to be sequestered in lunar polar cold traps (H_2O, NH_3, O_2, etc.) will have implications for remote sensing observations by future robotic and human surface exploration. LAVA represents the first study by SwRI of gas permeation through bulk lunar simulant in a UHV environment and expands our capabilities for laboratory space environment simulation of the surfaces of primitive solar system bodies such as the Moon, Mars and asteroids.

Lunar Strategic Knowledge Gap (SKG): Gas behavior on the Moon was first observed by video recording of vernier engine plumes of Surveyor 5 impinging upon the lunar surface nearly two years prior to the Apollo 11 landing[7]. However, observation of gas escaping the lunar surface did not preclude the possibility that rocket exhaust could have become trapped long term in the exposed regolith. In fact, experiments on lunar samples taken from near the Apollo 11 Lunar Module (LM)[8,9] released N_2 that we have been unable to trap under laboratory conditions using the simulant JSC-1A[5,6] or lunar sample 10084.

Data from analytical instruments deployed during multiple lunar missions (Apollo[3], LCROSS[1], LADEE[10]), combined with recent laboratory results[5], suggest the regolith surface of the Moon can trap more volatiles in gas-surface interactions than is currently known or understood[6]. In an analogy borrowed from gas chromatography (GC), the lunar surface may behave as a giant 3-dimensional “chromatogram” separating gas atoms and molecules according to their mobility and gas-surface interaction as they ballistically “hop” across the lunar regolith.

Here we will present our latest LAVA results. Gases we will expose to materials under extremely low mass flow and UHV conditions will include He, Ne, Ar, Kr, Xe, CO, CO_2, O_2, N_2, CH_4 and NH_3.

References: [1]Gladstone, G. R., et al., *Science* 330, 472 (2010). [2]Sanders, G. & Larson, W., *JAE* 26, 5-17 (2013). [3]Hoffman J.H. et al. *A17 PSR*, 17-1(1973). [4]Necsoiu et al., *LPSC 49*, 2083 (2018). [5]Patrick et al. *Icarus* 255, 30-43 (2015). [6]Patrick et al., *LPSC 47*, 2649 (2016). [7]Christensen, E. M., et al., *JGR* 73, 7169-7192 (1968). [8]Gibson E. K. & Johnson S. M., *LPS II*, 1351-1364 (1971). [9]Henderson W. et al., *LPS II*, 1901-1912 (1971). [10]Hurley D.M. (2014) *LPSC 45*, 2160.

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