

Lunar Exploration Analysis Group
Volatile Viability Measurement Special Action Team (VVM-SAT)
Final Report

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Motivation

A series of robotic exploration missions to the lunar poles is intended to make measurements sufficient to understand the physical state, abundance, and economic viability of the volatile resources presumed to be present there. It is a broad, well-founded community consensus that these measurements are the necessary first steps towards not only understanding the volatile history of the Earth-Moon system, but fully incorporating the Moon into America’s economic sphere. Furthermore, both the 2018 LEAG/SRR report and the LEAG Commercial Advisory Board findings specifically called for the establishment of a LEAG Special Action Team (SAT) to assess which near-term measurements can be made on the Moon to establish the commercial viability of lunar polar resources. LEAG and the Human Exploration and Operations Mission Directorate therefore convened a LEAG SAT (hereafter, the Volatile Viability Measurement Special Action Team, or VVM-SAT) to address this clear community need.

Charter

The VVM-SAT will consider what measurements are required to answer key science (SCEM/ASM-SAT and Decadal) and Exploration (SKG Theme 1) questions. To ensure a feasible scope to this activity, VVMSAT will consider the likely near-term opportunities for acquiring such measurements. This therefore includes small landers as well as modest-sized (< 300 Kg) rover platforms. The plan is to consider both remote sensing data, as well as direct measurements of the lunar regolith, and any volatiles contained within it. We will therefore also ask the team to consider the value of acquiring data from the subsurface. LEAG will draw upon the full collected expertise of the United States lunar exploration community to ensure that the membership of VVMSAT inclusively blends the full diversity of the US lunar exploration community. Ultimately, the outcomes of this SAT will be used to prepare a standalone report, as well as update the HEO Strategic Knowledge Gaps for Lunar Exploration (specifically, Theme 1, “Understand the Lunar Resource Potential”).

Membership

- Barbara Cohen (GSFC), chair
- Amy McAdam (GSFC) – mass spectroscopy / analysis
- Paul Lucey (U Hawaii) - remote sensing
- Heather Franz (GSFC) - stable isotopes
- Tony Colaprete (Ames) - remote measurements

- Addie Dove (UCF) - regolith properties
- Jess Barnes (JSC, remote) – volatile origins
- Observing: James Carpenter (ESA/PROSPECT)
- Ex Officio: Ben Bussey (NASA HQ), Sam Lawrence (LEAG Chair)

Process

The LEAG VVM-SAT held a single in-person meeting for a half-day on Nov 16, 2019, immediately following the LEAG meeting in Columbia, MD. Thereafter, email and a collaborative Google Doc were used to conduct assignments and updates.

The committee began by reviewing volatiles-relevant goals from previous reports and briefings, including

- The Scientific Context for the Exploration of the Moon (SCEM) 2007
<https://www.nap.edu/catalog/11954/the-scientific-context-for-exploration-of-the-moon>
- LEAG Volatiles Strategic Action Team (VSAT) 2014
https://www.lpi.usra.edu/leag/reports/vsat_report_123114x.pdf
- LEAG Advancing Science on the Moon (ASM-SAT) 2017
<https://www.lpi.usra.edu/leag/reports/ASM-SAT-Report-final.pdf>

The committee decided, for expediency, to adopt the goals defined by the ASM-SAT, which were derived from the SCEM report but updated with more recent assessments, particularly in the area of volatiles. The committee broke each goal down into individual measurements that would address the larger goal and defined how well each measurement would need to be made to “take the next significant step” in our scientific understanding. This qualitative assessment is not necessarily the definitive measurement that needs to be made to close a goal, but rather the smallest useful step in making progress toward it. For each measurement, the committee provided a non-exhaustive list of candidate instrument types that might be able to make the desired measurement.

The committee completed the exercise for scientific goals. The committee was able, in the time allotted, to map measurements and instruments to the scientific goals of potential robotic missions, and in subsequent emails, to determine the fidelity that would be required to make Decadal-level progress on them. During the in-person meeting, the committee also discussed the exploration-related goals for this SAT but determined that the current goals for exploration, consider what measurements are required to answer key science (SCEM/ASM-SAT and Decadal) and Exploration (SKG Theme 1) questions. The time allotted for the SAT was insufficient to update the HEO Strategic Knowledge Gaps for Lunar Exploration as intended. The VVM-SAT therefore recommended a follow-up activity focused on defining the measurements required for exploration-related goals. [editor’s note: this follow-up activity is being conducted in 2019, L-WIMS]

Outcomes and Discussion

See accompanying Excel file VVM-SAT.xlsx

Tab 1: Science Goals, Objectives, and Measurements

Science Goal: Science Goals keyed to the ASM-SAT report

Science Objective: A non-exhaustive list of information that would address the science goal. Not all objectives need to be accomplished simultaneously to address the Goal.

Measurement: The specific measurement to be made, and if possible, definition of the precision, frequency, or other information about how well the measurement needs to be made to make the next step in understanding the Goal. Multiple measurements are frequently beneficial, either in time or across the surface.

Techniques: A non-exhaustive list to illustrate the ways the measurements may be made planetary exploration.

Comments/additional information: Additional rationale or caveats for the measurements.

Tab 2: Techniques.

All of the techniques from Tab 1 are listed here, along with their utility to directly make or support observations related to lunar volatiles, example flight heritage, and methods. See additional discussion in instruments, below.

Implementation. The committee concluded that significant, meaningful progress may be made against high-priority lunar science goals by deploying flight-heritage instruments on the lunar surface. Because the field of volatiles on the Moon is rapidly emerging, and our current knowledge so scarce, there exist many Objectives within each science Goal that can be addressed in different ways, starting with small, stationary campaigns, expanding to mobility options and extending through long-lived monitoring campaigns across the lunar surface.

Instrumentation. The instrument types are illustrative only, drawing on the committee's knowledge of currently available, largely flight-heritage instruments. It is entirely possible, if not probable, that other instruments could make similar measurements in any category. However, it would be incumbent on the instrument provider to make the case that their instrument, as configured and flown, would be able to achieve the desired measurement in terms of precision, level of detection, etc. The DALI, NPLP, LSITP, and PRISM programs are all of utility in advancing and flying instruments that can help achieve these new measurements.

Exploration. Oftentimes, the measurement requirements (precision, time series, location, etc.) required to address a scientific question may seem to be more demanding than that required for exploration objectives. For example, determining the isotopic ratios of subsurface water in order to determine the source of the water may seem like a complex measurement of purely scientific interest. However, it is usually the case that science and exploration work hand-in-glove; in this example, isotopic measurements are used to determine the source of the volatiles, thereby enabling deduction of likely contaminants, timescale for replenishment, and expectation of spatial distribution, which are all useful for utilization campaigns. Though the committee did not have the ability to fully explore exploration needs, a committee set up to focus on these needs would be of great value - in particular, measurements needed to plan and execute meaningful *in situ* resource utilization to enable sustainability and economic onramps.

[Appendix 1: Excel file VVM-SAT.xlsx](#)