Lessons from Apollo for Volatile Detection and Mass Spectrometry in the Age of ISRU. E. L. Patrick and the ENABLE Team, Southwest Research Institute®, San Antonio, Texas, 78238 (epatrick@swri.edu)

Introduction: As we begin tooling up for lunar ISRU under the banners of multiple international space programs, it is useful to review the detections of volatiles made during previous missions. These can provide some constraints and context for the coming armada of spacecraft tasked with the prospecting and processing of volatiles at the lunar surface as we develop the *in situ* diagnostic tools that will probe the lunar surface.

Lunar surface pressure at low latitudes during local Midnight is fifteen orders of magnitude below that of terrestrial sea level. To place that order-of-magnitude difference in perspective, that's the same difference between the length of four school buses parked bumper-to-bumper (40 m) and the distance to Alpha Centauri ($4x10^{16}$ m). Rather than fielding pressure gauges that extend to the 15th decimal place, the laboratory space environment investigator overcomes such a span using multiple gauges overlapping specific pressure ranges. These might include, for example, a Pirani gauge ($1x10^5$ to 0.1 Pa) and an ion gauge (1 to $2x10^{-8}$ Pa).

The Apollo Era: Though in situ detections of the concentration and composition of both native and contaminant volatiles have been limited, each Apollo mission played a role in telling that story. Here we present examples of these data from two Apollo missions.

Apollo 11. Examples of findings by Apollo involving volatiles include the temperature-programmed desorption (TPD) work of Gibson & Johnson[1] on lunar **Apollo 11** sample 10086. The high temperature at the lunar surface during local Noon is ~120 ^oC, yet once returned to a terrestrial lab, 10086 began evolving N_2 immediately upon heating above room temperature[1]. What is the trapping mechanism for such an inert gas? Did it result from decomposition of a combustion by-product in the spacecraft engine plume? How long can such a volatile remain trapped in the lunar surface?

Apollo 12. **Apollo 12** deployed the Cold Cathode Gauge Experiment (CCGE). The first pressure gauge at the lunar surface, the CCGE produced evidence of landing site contamination, detected the pressure wave from depressurization ("DEPRESS") of the cabin atmosphere of the Lunar Module (LM), and detected the pressure signature evolving from an astronaut's life support system[2][3]. A "trench" sample (120) taken from over 150 m away from the LM did not produce a signature for N_2 below ~120 ^oC[1]. The Suprathermal Ion Detector Experiment (SIDE), also deployed during Apollo 12, detected the impact signature of the **Apollo 13** Saturn IV-B upper stage, as well as the flyover of the **Apollo 14** Ascent Module at a range of 19 km[4].

Mass Spectrometry with ENABLE: Mass spectrometry (MS) has provided *in situ* analytical chemistry in a planetary science heritage covering nearly half a century[5][6][7][8]. MS provides *in situ* analysis at pressures spanning orders of magnitude within the instrument itself (10^{-2} to $5x10^{-12}$ Pa) and are characteristic of those observed at the lunar surface.

Starting with a successful design for a commercial-off-the-shelf (COTS) quadrupole mass spectrometer (QMS) with integral Pirani and ion gauges, we are utilizing a field-programmable gate array (FPGA) in a development program known as **Environmental Analysis of the Bounded Lunar Exosphere (ENABLE)** to produce a prototype software-defined mass spectrometer (SDMS) for lunar surface operations aboard multiple deployment platforms.

Combined with the broad range in pressure measurement capability (Pirani + ion gauge) provided by the COTS instrument, the ENABLE instrument suite will span the entire pressure range from 1 atm to $1x10^{-15}$ atm ($1x10^{-10}$ Pa). Consequently, ENABLE will not only conduct MS within the extreme high vacuum (XHV) conditions existing at the lunar surface, but will also record pressure data during the high pressure impulses anticipated from distant spacecraft engine plumes or nearby ISRU processes.

We will provide context in our review of the Apollo gas detections and some interpretation useful for ISRU and future mission scenarios. We also update the community on the current status of our ENABLE mass spectrometer development effort, as well as elaborate on mission scenarios appropriate for deploying such *in situ* analytical chemistry diagnostics aboard multiple instrument platforms.

Acknowledgments: The ENABLE Team includes Co-Investigators Don George, Ph.D. (Instrument Scientist), Michael Poston, Ph.D. (Science), Ryan Blase, Ph.D. (Calibration), Carlos Urdiales (Electronics), and Diane Squire (Software), and electronics leads Robert Bolanos (RF), Sam Blackshear (Digital) and Steve Solis (FPGA). ENABLE is funded by the NASA ROSES DALI Program (80NSSC21K0744).

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