Lunar Surface Missions for Resource Reconnaissance: NASA's PRIME-1 and VIPER . J.E. Kleinhenz[1], J.W. Quinn[1], A. Coleprete[1], J.E. Captain[1], K. Ennico-Smith[1], D.S.S. Lim[1], R. Aguilar-Ayala[1], Hancock, M.L[1], K.A. Zacny[2], P.C. Chu[2] , and V.R.Vendiola[2], [1]NASA (21000 Brookpark Rd. Cleveland, OH, Julie.E.Kleinhenz@nasa.gov), [2]Honeybee Robotics (2408 Lincoln Ave Altadena, CA 91001 kazacny@honeybeerobotics.com).

Introduction: In 2019 NASA announced it would return to the Moon where it would seek to establish a sustainable lunar presence [1]. In Situ Resource Utilization (ISRU) is a critical part of the infrastructure needed to sustain and grow human surface exploration. NASA further codified its ISRU intentions with the release of the Moon to Mars objectives in 2022 [2], which calls out specific infrastructure goals, and in the release of the Architecture Definition Document in 2023 [3]. While there are a variety of resources that are of interest, including oxygen from regolith minerals, water is a game changing resource for in-situ consumable and propellant production. NASA's intention of targeting of the lunar polar region for Artemis is, in part due to the potential of water resources there.

While water has been identified in the lunar polar regions [4], there is limited information regarding the form, abundance, and extent of the resource, particularly at scales and resolution that are relevant to surface exploration. Establishing ISRU infrastructure requires locating, and understanding the characteristics of, a water reserve [5,6] and developing a set of missions to make this possible [7].

NASA has established two missions as the first steps in these resource reconnaissance efforts. The first is the Polar Resources Ice Mining Experiment-1 (PRIME-1), a stationary lander which is scheduled to land in late 2024. This will be followed by the Volatiles Investigating Polar Exploration Rover (VIPER). Both missions include versions of The Regolith and Ice Drill for Exploring New Terrain (TRIDENT) and Mass Spectrometer observing lunar operations (MSolo). TRIDENT is a 1-meter rotary-percussive drill capable of bringing lunar regolith samples from depth to the surface for volatile analysis. MSolo is a modified, commercial-off-the-shelf (COTS) mass spectrometer capable of qualifying and quantifying atomic species in the 1-100 amu range, including isotopic differentiation.

VIPER includes a wider suite of instruments in addition to versions of the PRIME-1 suite. However, the fundamental drilling procedure is consistent. The drill will proceed to the maximum 1 m depth in incremental 'bites'. The drill retracts to the surface after each bite and deposits regolith retrieved from depth onto the surface. MSolo monitors the cuttings pile for the sublimating volatiles (including water) resulting from the regolith exposure. Visible images of the cuttings pile during both missions will provide information regarding the regolith sample size (e.g., pile volume), angle of repose, and any pile dynamics (e.g., hole collapse, etc.) that may occur during operations.

Both PRIME-1 and VIPER are intended to operate in near real-time with streaming data and commanding, allowing for adjustments to the operational cycles based on the engineering and science data received. Baseline timing of the drilling con-ops are based on thermal vacuum chamber testing [8].

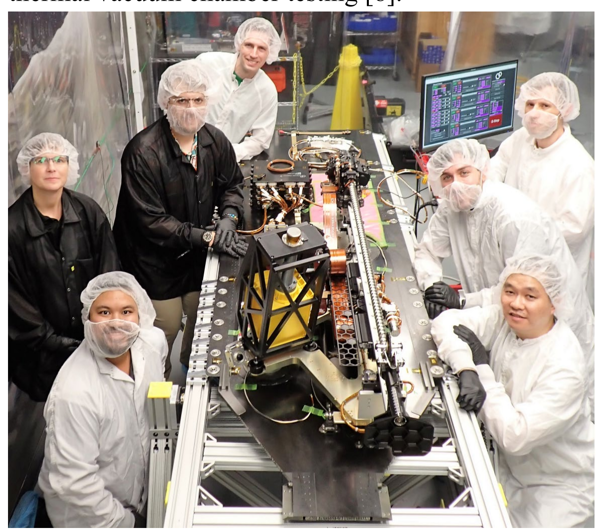

Fig. 1 The TRIDENT flight drill installed horizontally on the IM-2 Nova-C lander panel with a MSolo model temporarily installed for alignment.

In addition to the volatile information from MSolo, a temperature sensor within the TRIDENT drill bit will supply subsurface temperature information as permitted during drilling operations. Once the drill reaches its full 1 m depth, the bit will be lowered back downhole for a 'cold soak' to get better predictions of subsurface temperature.

PRIME-1: PRIME-1 is the suite of two instruments, TRIDENT and MSolo, operating off the stationary Nova-C "IM-2" lander from Intuitive Machines (IM), which has been contracted via the NASA Commercial Lunar Payload Services (CLPS) acquisition process. A camera, supplied by IM, will image the cuttings pile during deposition and periodically between bites.

Because only one drill hole will be achieved during PRIME-1, the con-ops allows flexibility within the 72 hour allotted PRIME-1 operations time. Nominally, the timeline allows for up to 15 drill bites at 7 cm depth each. Between bites, MSolo has opportunities built into the timeline to assess the signal response (volatile sublimation (peak signal) as well as dissipation (signal decay)), adjust parameters, and perform calibrations.

PRIME-1 is scheduled to land at the Shackleton connecting ridge at the lunar south pole in late 2024. The target site was chosen based on its potential to host volatiles (ice stability maps), and lander constraints including sun, earth visibility, and mild slopes. The TRIDENT drill is installed on IM-2 lander panel, Fig. 1, which will be mounted vertically to the side of the lander once IM-2 Nova-C is assembled. MSolo is complete, in storage, and will be mounted just prior to launch to minimize contamination potential.

Fig. 2: The TRIDENT drill integration onto the VIPER rover assembly. NASA/Bill Stafford

VIPER: VIPER's suite of instruments includes versions of the PRIME-1 suite, TRIDENT and MSolo, along with the Neutron Spectrometer System (NSS), and the Near Infrared Volatiles Spectrometer System (NIRVSS). A visible camera suite also provides science and navigation information. All the instruments are mounted to the rover which is to drive up to 20 km during a mission of over 90 earth days.

All but TRIDENT operate continuously during driving to obtain data over a variety of ice stability regions (ISRs). VIPER must survey each of the 4 ISR types by driving 223-335m within each designated ISR 'science station' area. Additionally, VIPER must revisit at least 2 ISR types. A minimum of three drill holes, separated by 10s of meters, is planned for each ISR, except for permanently shadowed areas where one drill site is planned [9].

VIPER is scheduled to land on Mons Mouton near the Nobile crater at the lunar south pole. The rover and instruments are being integrated and tested (Fig. 2). As of March 2024 the rover is over 80% complete.

Summary: PRIME-1 is scheduled to be the first drilling operation on the lunar south pole. As such, it is structured to focus on developing and testing the operations and science approach of the drilling process and be an anchor data set for volatiles and sublimation models for the moon within a single ISR type. The mission is expected to provide informative details regarding energy usage, timelines to reach targeted depth, volatile sublimation timelines and molecular definition.

VIPER will apply this data in its drilling approach but offers a larger data set; drilling is only one of VIPER's reconnaissance capabilities. The mobility of VIPER will allow for wide spatial coverage over numerous ISR types. The broad instrument suite data can inform a wide variety of lunar science objectives as well as the data needed to develop geostatistical models and maps needed for resource mapping.

Both missions will obtain geotechnical information during the drill process, both from the drill engineering parameters, but also imaging the soil interaction (cuttings pile, drill footpad, etc.)

Reconnaissance going forward: PRIME-1 and VIPER are only the first steps to locating a lunar water reserve. These missions both fall into the Type 1 category in [5] where the goal is to gain the information needed to develop the geostatistical models to map resource favorability. Further exploration is needed to understand the lunar water resources with enough confidence to emplace hardware and develop an infrastructure [7].

References:

[1] NASA'S Plan For Sustained Lunar Exploration and Development. (2020). [2] NASA Moon to Mars Objectives (2022) [3] NASA. ESDMD-001 Revision A. [4] Colaprete, A. et. al., Science 330, 463, 2010, DOI: 10.1126/ science.1186986 [5] Kleinhenz, J., et. al., 2020. NASA TM-2025008626 [6] Keszthelyi, L.P., et al. USGS Circular 1507. [7] Neal. C. R., et. al. 2024. Acta Astronautica, V.214, pg 737. [8] Kleinhenz, J. et al. 2018 ASCE Earth & Space Conference. Pg 454-466. [9] Ennico-Smith, K., et. al. 2022. Space Resources Roundtable 2022.