VIPER SCIENCE OPERATIONS: SCIENCE TRAVERSE PLANNING PERSPECTIVES, PROCESSES, AND TOOLS.

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Introduction: The NASA Volatiles Investigating Polar Exploration Rover (VIPER) launches in late 2024 towards a landing site on Mons Mouton in the Nobile region of the Lunar South Pole (LSP). As described in other LPSC presentations [1,2,3], the primary objective of the VIPER mission is to study the composition and distribution of hydrogen-bearing and other volatiles by way of a complementary suite of payloads that the rover will carry to the Moon: three "prospecting" instruments which operate continuously while roving - the Neutron Spectrometer System (NSS), the Near InfraRed Volatiles Spectrometer System (NIRVSS), and the Mass Spectrometer observing lunar operations (MSolo). A 1-meter auguring/percussive drill called the The Regolith and Ice Drill for Exploration of New Terrains (TRIDENT) is used to bring subsurface cuttings to the surface in 10-cm increments where they are interrogated by NIRVSS and MSolo. The Visible Imaging System is comprised of eight cameras (the NavCam stereo pair mounted on the mast gimbal, the AftCam stereo pair mounted on the aft panel, and four HazCams mounted in the wheel wells) that capture grayscale visible wavelength images of the lunar environment and the rover's upper deck. The VIPER mobility system is a four-wheel design that includes the following motorized modules: Suspension, Steering, and Drive/Propulsion. Wheel odometry and applied torque — combined with position data from rover imagery — can be used to compute assessments of 'slip and sinkage'. Slope estimates can be computed from stereo rover imagery, as well as pitch and roll data from the IMU (Inertial Measurement Unit) and Star Tracker telemetry.

Mission Traverse Planning: To plan for the exploration of the mission area, the VIPER Science and Mission Systems teams built traverses that contend with constraints dictated by variables such as Earth-LSP sun and communication dynamics, Safe Haven (where the rover will hibernate while out of Direct-to-Earth (DTE) communication because Earth drops below the local horizon for approximately half of each month) availability, trafficability (slope ≤ 15 degrees), and the details outlined in the VIPER Mission Measurement Plan [4]. The VIPER Mission Planning team has been using automated route planning approaches [2] that evaluate and eliminate landing site options, optimize mission productivity and minimize risks, and adhere to measurement plan science requirements. This process generates a set of mission traverse options inclusive of science stations, safe havens and the paths (location, direction and timing) that connect these areas. These are reviewed, analyzed, and approved in a series of iterative sessions involving stakeholders from Mission Systems Engineering, Project Science, Mission Systems, and Project Management. Once approved, these Mission traverses move into a Science Traverse review and planning process that leads to refined traverse paths and drill site locations within each of the vetted science stations.

Science Traverse Planning: A science station is an area (~3800 m2) designated in any one of the Ice Stability Regions (ISRs) in which specific measurement activities are carried out. Within each science station, operations focus on two activities: prospecting (mapping) and subsurface assay (drilling). The Science Traverse planning products are focused on optimizing science return from within these science stations and tracking return from the areas between science stations.

The Science Traverse planning activities occur in advance of landing (pre-mission) and while at the LSP. For both cases, the VIPER Science Operations & Integration (SciOps & Int) team [5] identified that a) to ensure that broader VIPER and lunar community science goals were addressed throughout our traverses and b) to enable scientific decision-making within the operational paradigm of the VIPER lunar rover mission requires a detailed articulation of the VIPER Science Team's (VST's) scientific objectives and the operationalization of these objectives through their association with specific data products, tasks, and decisional procedures. Defining and tracking scientific success metrics throughout surface operations enables the VST to have a quantified understanding of the mission's evolving accomplishments towards the stated scientific objectives during and after the mission. This abstract gives an overview of the methods and development activities towards defining, operationalizing, and tracking scientific objectives and goals throughout VIPER surface operations, and the defining of roles and responsibilities during the pre-launch and surface operations science traverse planning periods.

1) Pre-mission Science Traverse Planning: A) *Articulating Science Objectives:* The VST was organized into four VIPER Science Theme Groups (Compositions, Geological Context, Modeling and Mapping, Environments) and, additionally, into working groups that included representatives from each of these VIPER disciplines. Members of the SciOps & Int team organized and managed small-group conversations and synthesized content. These working groups were tasked with articulating science objectives that they and the wider

lunar science community want to address while exploring the mission area – these goals were described from broad to measurement-specific perspectives. The VST produced the VIPER Lunar Dynamic Science Table (LDST): a science traceability matrix that is applied dynamically and reactively towards both the planning for and the actual accrual of data and exploration findings. Lim et al [6] is a complementary abstract to this document that includes further details regarding the LDST. B*) Organizing and Visualizing Science Objectives into traverse components:* The VST created Science Objectives Tables associated with each Science Station that organized LDST objectives into traverse segments. This step ensured that each path portion within a Science Station was mapped to one or more LDST objectives. In parallel, the VST used a web-based data visualization platform developed by NASA called Open Mission Control Technologies (OMCT) and the associated Map Tool and supporting Map Server datasets to draw traverse paths and select drill site locations within the vetted Science Stations that would address the articulated science objectives. These Science Traverse plans were collaboratively reviewed in a sequence of meetings that began with small group meetings, continued through review sessions with Mission Planning and Instrument teams, and then finalized in a set of all-hands VST sessions where primary and back-up traverse plans were identified and agreed to by the VST. Each of these final sessions was led by the Project Scientist. The final Science Traverse products were then shared with stakeholders who were initially involved in the Mission Traverse Planning process. C) *Prioritizing Science Traverse plans:* Science Traverse paths were ranked using a leaderboard which allowed the VST to order the candidate path and drill site locations by priority informed by the LDST objectives each working group wanted to highlight and address while prospecting and drilling. While a single path plan was finalized for each Science Station, 1-3 additional options were archived on the leaderboard as back-up plans that would be invoked if needed once surface operations at the LSP commenced.

2) Surface Operations Science Traverse Planning: A critical function of the VST working in the Mission Science Center (MSC) and the Mission Operations Center (MOC) is to confirm or reselect the position of the third drill site, also known as Drill Site C, within each Science Station, during surface operations. The option to move one of three drill sites represents a balance between optimizing its location using nearby observations and providing the operations team with a clear and fixed schedule to work to. This decision must be made under time-pressure so that the third drilling operation can be completed before the fixed time for exiting the Science Station. As a group, in real-time, the VST must make decisions based on pre-planned science traverses (i.e. the priorities and backup plans created during the pre-mission period), the exploration findings to that moment on the LSP, the status of the mission in meeting full or minimum success criteria, and the forthcoming mission plans for the remainder of the mission. As with all exploration, it must be anticipated that new discoveries and scientific findings will occur during the mission and must be factored into decisions.

The VST in the MSC works in collaboration to make decisions and is supported by an MSC Lead, who is responsible for keeping work coordinated with activity objectives and time constraints. The VST in the MSC and MOC are in direct contact via the MSC Lead and a Science Lead who is seated in the MOC alongside a Real-Time Science (RTSci) Lead who is embedded in the VIPER Drive Team. During Surface Operations (which run 24/7 over the duration of the ~14-day period where sun and DTE communications are available prior to Safe Haven periods), VST in the MSC will conduct three shift handovers per Earthday. Tools are needed to support actively accruing, tracking, and documenting learnings, findings, and rationale for the priorities and decisions across shifts. SciOps & Int drew from tools such as Office products, Confluence, Jira, OMCT, as well drawing up VST-specific tools. The VIPER Tactical Science Tracker tool, referred to as the VIPER "Tracker" [6], was designed to track progress on the completion of science objectives during prospecting and drilling activities, which will be factored into the minute-scale decisions. The VST will invoke Standard Operating Procedures (SOPs) and Standard Analytical Methods (SAMs) designed and prepared in advance to support science-decisioning including confirming or reselecting Drill Site C. An image request form is used for communicating image settings and parameters among multiple workgroups. An active digital leaderboard will support group decisioning by giving a shared view on the VST's rank order of drill site locations and pathways to and from those locations during time-bound discussions on how to best optimize science return throughout the remainder of a Science Station and the mission itself. The VST is currently conducting Science Traverse Planning, and refining SOPs and SAMs through a series of Science and Integrated Mission System Simulations that will be active until T-6 months to launch.

References:

[1] A. Colaprete et al LPSC 2023 pg.2910, [2] M. Shirley et al LPSC 2022 pg.2874, [3] R. Beyer et al. LPSC 2023 pg. 2377 [4] A. Colaprete et al. LPSC 2021 pg.1523, [5] Z. Mirmalek et al. LPSC 2021 pg.1734 [6] D. Lim et al LPSC 2024.