National Aeronautics and Space Administration

VOLATILES INVESTIGATING POLAR EXPLORATION ROVER

PROPOSAL INFORMATION PACKAGE

VIPER

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CONTENTS

DOCUMENT OVERVIEW

This Proposal Information Package (PIP) document supports the NASA Research Announcement for the VIPER (Volatiles Investigating Polar Exploration Rover) Co-Investigators. This PIP includes an overview of the VIPER Project and foundational knowledge about the mission science, phases, instruments, and operations for proposers to consider.

1. VIPER MISSION OVERVIEW

VIPER is a lunar volatiles detection and measurement mission that will be launched as a payload on the CLPS (Commercial Lunar Payload Services) provided Astrobotic's Griffin lander to the lunar south polar region. VIPER includes a suite of rover-mounted instruments that will conduct science and map volatiles (especially hydrogen-bearing volatiles). The VIPER rover is also designed to excavate volatiles such as hydrogen, oxygen, and water from the Moon.

After landing the VIPER rover will travel to investigate a range of Ice Stability Regions (ISRs) across scales from 100s of meters to kilometers and conduct surface and subsurface assessment of lunar water and other volatiles. The VIPER science mission team will use the instrument data to characterize the nature of the volatiles in the area and to extrapolate these data to create global lunar water resource maps. The expected lunar surface mission duration is up to four lunar days, with active surface operations during the periods when both Sun exposure and direct to Earth (DTE) communication conditions overlap. When comm and Sun are not both available, VIPER will go into 'Safe Haven operations' and maintain survival temperatures until Sun and comm return. The rover is controlled in near-real time and science decisions are made both tactically (short-term) and strategically (longer-term) to achieve the mission science success criteria and objectives.

1.1. HERITAGE, SIGNIFICANCE AND IMPACT OF THE VIPER MISSION

While the existence of lunar volatiles has been known since the Apollo era, only more recently (the last 10-20 years) has the extent and form of these volatiles been better understood. It now appears that economically significant amounts of water ice may exist at the poles of the Moon, however, the distribution of this water is still not sufficiently characterized or understood in a manner that would enable their evaluation as an economically viable resource. The water ice (and other potential volatiles), also termed the "ore body", needs to be understood at the scales of 10s to 100s of meters to evaluate localization, extraction and processing techniques. VIPER builds on the findings of the Lunar CRater Observation and Sensing Satellite (LCROSS), Lunar Reconnaissance Orbiter (LRO) and Chandryaan-1 missions that proved the existence of water on the Moon by taking the next step to understand and evaluate the water as a potential resource. In addition, VIPER will address key science objectives (Table 1-1) from the Planetary Science Decadal Survey (2011), The Science Context for Exploration of the Moon (SCEM, 2007), and Advancing Science of the Moon (ASM, 2018).

The mission objectives for VIPER align with the National Research Council's (NRC) stepping stone approach to Mars with feed-forward technology development. VIPER is an early expedition in the proving ground that will help NASA and its partners better understand the quality and quantity of water and other volatiles on the Moon that could support human explorers on the lunar surface, orbiting above in cislunar space, or on their way to destinations such as Mars and the outer Solar System worlds. The technologies and operational capabilities that VIPER validates will also have direct extensibility toward how we may someday harvest resources on Mars, asteroids, or other planetary bodies.

Table 1-1. VIPER addresses key Agency science and exploration objectives

Visions and Voyages Planetary Decadal (2013)	*Understand the origin and diversity of terrestrial planets* Characterize Planetary Surfaces to Understand How They Are Modified by Geologic Processes Develop an inventory and isotopic composition of lunar polar volatile deposits to understand their emplacement and origin, modeling conditions and processes.
	Understand how the evolution of terrestrial planets enables and limits the origin and evolution of life Understand the Composition and Distribution of Volatile Chemical Compounds Determine the state, extent, and chemical and isotopic compositions of surface volatiles, particularly in the polar regions on the Moon.
Scientific Context Exploration of Moon (SCEM) (2007)	*Determine the compositional state (elemental, isotopic, mineralogic) and compositional distribution (lateral and depth) of the volatile component in lunar polar regions. (Goal 4a)*
	Determine the source(s) for lunar polar volatiles (Goal 4b)
	Understand the transport, retention, alteration, and loss processes that operate on volatile materials at permamently shaded lunar regions (Goal 4c).
	Understand the physical properties of the extremely cold (and possibly volatile rich) polar regolith (Goal 4d)
Advancing Science of the Moon (LEAG Community Report)	*The lunar poles are special environments that may bear witness to the volatile flux over the latter part of solar system history (Concept 4)*
	Lunar Volatile Cycle (New Concept)
NASA's Strategic Knowledge Gaps (SKG) (2016)	*Understanding the Lunar Resource Potential (Theme 1)* D.3 Geotechnical characteristics of cold traps D.4: Physiography and accessibility of cold traps D.6 Composition, Form, and Distribution of Polar Volatiles D.7. Temporal Variability and Movement Dynamics of Surface-Correlated OH and H2O deposits towards PSR retention
	Understand How to Work and Live on the Lunar Surface (Theme 3) A.1 Technologies for excavation of lunar resources C.2 Lunar surface trafficability - in situ measurements D.2 Regolith adhesion to human systems and associated mechanical degradation
VIPER Mission Objectives	Characterize the distribution and physical state of lunar polar water and other volatiles in lunar cold traps and regolith to understand their origin
	Provide the data necessary for NASA to evaluate the potential return of In-Situ Resource Utilization (ISRU) from the lunar polar regions

2. VIPER SCIENCE OVERVIEW: OBJECTIVES AND BACKGOUND

VIPER has two primary objectives:

1. Characterize the distribution and physical state of lunar polar water and other volatiles in lunar cold traps and regolith to understand their origin.

2. Provide the data necessary for NASA to evaluate the potential return of In-Situ Resource Utilization (ISRU) from the lunar polar regions.

To evaluate the potential return of ISRU, the distribution and physical state of the water must be better understood. Currently, several data sets indicate buried hydration (e.g., neutron spectrometer observations) and surface abundances (often referred to as "frosts"). However, these observations are ambiguous with respect to physical state and vertical distribution. Lateral and vertical observations of the water (and other volatiles) are required to assess volatiles abundance and form.

Ongoing ISRU architecture studies have proposed a critical cutoff of water ice ISRU at around 5-10 wt% and a desire to understand down to concentrations of 2 wt%. Other volatiles are expected and may be important as either resources or hazards, including H_2, H_2S, NH_3, CO_2 and CO. These should be identified if present at concentrations greater than 5%, as these currently have less importance within an ISRU architecture and greater overall uncertainty in the presence and distribution.

The high rate of small impacts that excavate to one meter or less means vertical mixing is expected to be greatest in the top ~meter of regolith. Micrometeorite gardening is expected to desiccate the top 10-20 cm of regolith. Global hydrogen maps made from neutron observations provide data down to about one meter into the lunar subsurface. Converting these neutron data into water concentration (water equivalent hydrogen or WEH) depends on the vertical distribution of water in the top meter of regolith. Understanding this vertical distribution of water will reduce uncertainty in water resource maps, as well as ensuring the water ice is characterized to a depth where the amount of ground material removal may be acceptable to economic mining models.

Ice Stability Regions (ISRs) are areas in which it is expected that between the surface and one-meter depth, the thermal environment would support water ice being stable for geologic periods of time (defined as a loss of 1 mm/m^2 per Gy). In these regions, water ice may exist and be extractable.

- "Surficial" means surface temperatures are sufficiently cold for ice to be stable at the surface (such as in Permanently Shadowed Regions (PSRs));
- "Shallow" means ice could be stable between 0-50 cm deep;
- "Deep" means ice could be stable between 50-100 cm deep;
- "Dry" means ice should not be stable anywhere from the surface down to 100 cm.

ISRs are defined from models of the thermal environments, both at the surface and subsurface. Surface temperature predictions in these models are validated with orbital observations of surface temperatures. Characterizing the volatiles, including the distribution and form, in each of these types of ISRs will provide a necessary link between surface ground truth and orbital data sets.

In order to extrapolate beyond sample points and build resource favorability maps, including developing and testing resource distribution models, key geological contextual parameters must be measured along with the volatile concentrations. Some of these parameters are expected to have critical implications for retention (e.g., surface and subsurface temperatures), while others may allow for important spatial proxies that can be mapped at regional and global scales (e.g., surface mineralogy). Finally, in order to assess the accessibility of any volatile resource, bulk mechanical properties must be understood, including soil load bearing strength and angle of repose.

The VIPER Level 1 mission requirements are listed in Table 2-1. Key VIPER Level 2 Measurement Requirements are shown in Table 2-2.

Table 2-1: VIPER Level 1 Science Mission Requirements

	Science Requirement
1.1	VIPER shall operate on the surface at a lunar polar region to measure the physical state and abundance of hydrogen-bearing volatiles, including H_2O when present at concentrations >2 wt%, H_2, H_2S, NH_3, and other non-hydrogen-bearing volatiles including CO_2 and CO when present at concentrations >5 wt%, and the lateral distribution of these volatiles at the decimeter scale.
1.2	VIPER shall operate at a lunar polar region to measure the subsurface extent of hydrogen bearing volatiles as a function of depth at the decimeter scale down to a depth of 80 cm with a Water Equivalent Hydrogen concentration detection limit of 0.5 wt%.
1.3	VIPER shall characterize the volatiles in the four types of Ice Stability Regions (ISRs), as predicted by current ISR orbital data models, including Surficial, Shallow, Deep and Dry regions.
1.4	VIPER shall characterize the geologic context of the ice stability regions by measuring surface and subsurface temperatures, identifying surface mineralogical features consistent with mafic minerals and hydrous mineral phases present at >5 wt%, and determining the bulk mechanical characteristics of the lunar regolith.

Table 2-2: VIPER Level 2 Science Measurement Requirements

	Science Requirement
L2-SPL-1	The Science Payload shall identify the presence of volatiles species on the lunar surface and in the subsurface up to a 100 cm depth.
L2-SPL-2	The Science Payload shall identify, by direct measurement, the presence of hydrogen-bearing volatiles, including H_2O when present at concentrations >2 wt%, H_2, H_2S, NH_3, and other non-hydrogen-bearing volatiles including CO_2 and CO when present at concentrations >5 wt% on the lunar surface and in exposed subsurface regolith
L2-SPL-3	The Science Payload shall identify the physical state of water on the lunar surface and exposed subsurface regolith.
L2-SPL-4	The Science Payload shall measure water ice on the surface or in subsurface material at a concentration as low as 0.5 wt%.
L2-SPL-5	The Science Payload shall measure the Water Equivalent Hydrogen down to at least 80cm with a horizontal spatial resolution of no greater than 5 m.
L2-SPL-6	The Science Payload shall determine subsurface temperatures at excavation sites.
L2-SPL-7	The Science Payload shall measure isotope ratios for D/H, and O18/O16.
L2-SPL-8	The Science Payload shall identify mineralogical features consistent with mafic minerals and hydrous mineral phases present at >5 wt% in the lunar regolith.
L2-SPL-10	The Science Payload shall determine the lunar surface temperature below the Rover.
L2-SPL-11	The Science Payload shall expose regolith samples from any depth between 0-cm and 100-cm.
L2-SPL-12	The Science Payload shall extract a regolith sample that is representative of a 4-cm subsurface minimum interval.
L2-SPL-23	The Science Payload shall measure water on the lunar surface at a scale of less than 10cm
L2-SPL-24	The Science Payload shall measure water on the lunar surface with a horizontal spatial resolution of no greater than 5-m when water concentrations are greater than 2wt%.

3. VIPER ROVER AND PAYLOAD

The VIPER payload suite of instruments will be integrated with the rover platform to form the surface segment. The surface segment will be integrated with the system provided by the lunar landed service partner, Astrobotic, which will be responsible for all activities necessary to deliver VIPER to the pre-selected landing site and time.

3.1 VIPER ROVER

The rover (Figure 3-1) hosts the science payloads, providing structure, power, thermal management, mobility, navigation, and communications services. The rover is being developed by NASA with principal participation by NASA-JSC and NASA-ARC.

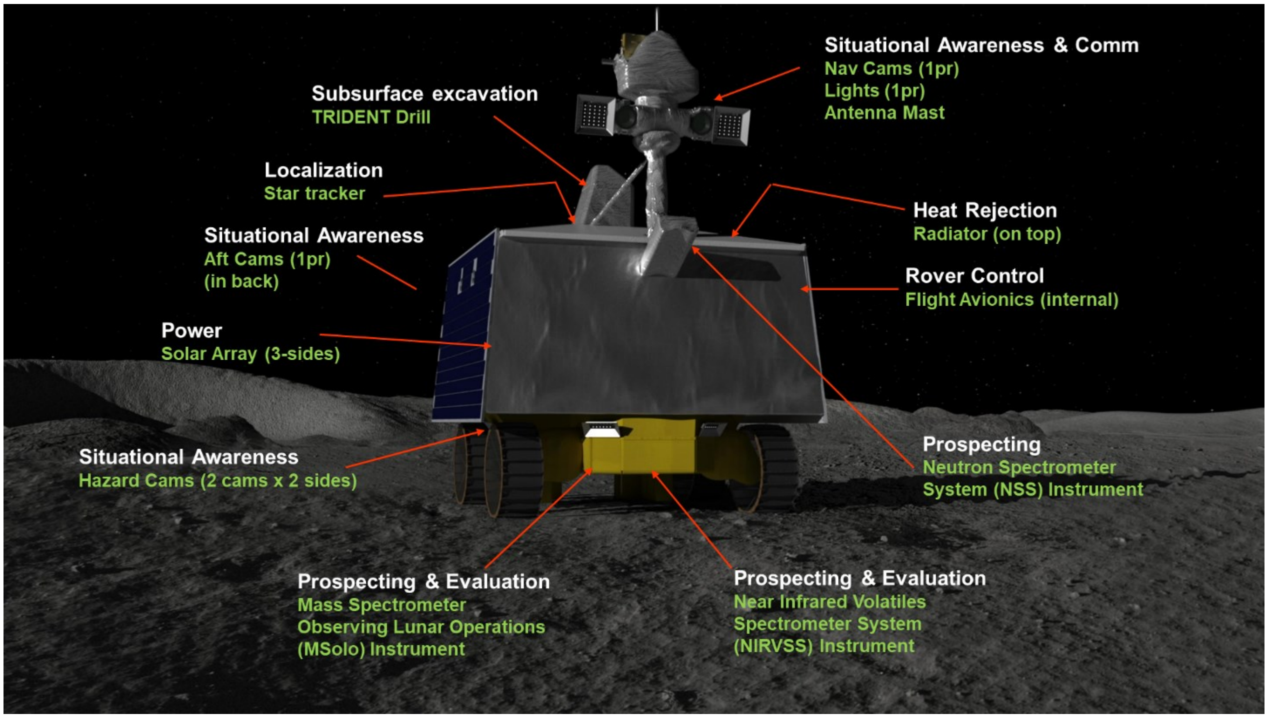

Figure 3-1. VIPER and its navigation, prospecting, surface and subsurface assay science instruments.

The rover is a solar powered vehicle, consisting of a battery and three approximate 1 m^2 solar arrays (one each on the port, starboard, and aft surfaces), generating 410 (TBR) W of total power.

The rover is powered-off during launch and ascent and powers on using its own power after launch vehicle separation, to enable operation of its survival heaters. After a brief period of time, rover power transitions from rover to lander. The lander continues to power the rover until lunar surface touchdown. During the lunar transfer phase, the surface segment performs initial checkout and calibration activities, communicating with the ground via a communications link provided by the lander. Early on during the lunar transfer phase the rover establishes communication with the ground via both its omnidirectional and high gain antennas to verify its communications subsystem is functioning properly. During this checkout, the rover's high gain antenna relies upon the lander for pointing as its pan/tilt gimbal is locked-out to minimize loads during descent and landing. Upon landing on the lunar surface, the rover transitions to its own power, establishes a direct-to-Earth (DTE) communications link via its high gain antenna and completes other post-landing surface segment checkout activities. After completion of the post landing checkout activities, the surface segment egresses from the lander to begin surface operations. During surface operations, the rover follows a specific surface traverse plan, primarily by teleoperation via waypoint commands set several meters ahead of the vehicle. During the active traverse, the rover operates with constant DTE communications while in the Sun and in shadows (for short periods of time). After the rover loses direct line-of-site with the Earth and does not have DTE communications, it has periods in the sunlight, where is charges its battery and thermally conditions the surface segment system, followed by minimal periods of no sunlight, about 48-96 hours. During periods of no sunlight, the surface segment hibernates, operating survival heaters to keep the surface segment's systems above survival temperatures.

3.1.1 VIPER NAVIGATION SYSTEM

The rover navigation subsystem help enable Mission Operations to observe the lunar environment, determine its absolute and relative positions (i.e., localize), and avoid hazards and obstacles. It accomplishes these tasks using cameras, lights, a star tracker, wheel and suspension encoders and an inertial measurement unit (IMU).

A pair of navigation cameras (NavCam) are mounted on a pan/tilt gimbal on the mast to provide a 360 degree view of the mid- to far-field environment surrounding the rover. Images from these cameras provide the primary feedback to ground operators for driving. These navigation cameras consist of two monochrome imagers in a stereo mount. Their Field of View (FOV) is 70 degree Horizontal with 2048 x 2048 resolution elements with a IFOV of about 0.5 cm at 10 meters distance.

Four monochrome hazard cameras (HazCam) are located around the chassis to provide a 360 degree view of the near-field environment for hazard identification, hazard avoidance, and fault management. One can be found in each of the four wheel wells providing an inside wheel view useful for gauging wheel sinkage.

In addition, a fixed stereo pair of rear facing monochrome cameras (AftCam) fill in the large navigation-camera blind spot caused by the solar arrays and radiator. The hazard and rear-facing cameras have 110 degree Horizontal FOV with 2048 x 2048 resolution with an IFOV of about 1 cm at 10 meters.

All cameras will be operated with a narrow bandpass filter that corresponds to imaging illumination lamps. The illumination lamps include a long range (spot) luminaries positioned at the same height as the camera, outboard of each NavCam (~500W total when imaging), and a six short range (flood) luminaries positioned around the chassis of the rover providing 360 degree of coverage (~60W each).

Both the IMU and star tracker provide data for localization, attitude, and body rate (rate of change in role, pitch and yaw) information to the rover’s navigation algorithms. The star tracker faces zenith for sun avoidance, while the IMU is placed near the rover’s center of mass.

3.2 SCIENCE PAYLOAD

3.2.1 NEUTRON SPECTROMETER SYSTEM (NSS)

The Neutron Spectrometer System (NSS) will be used to “prospect” for the presence of hydrogen rich materials while roving, mapping the distribution of these materials to assist in excavation site selection and better understand the morphology of the resource. The NSS instrument consists of the Sensor Module and Data Processing Module. The Data Processing Module contains support electronics and interfaces with the Rover for commands, data processing, and power. The Sensor Module contains the detectors and is to be positioned on the front of the rover in order to have an unobstructed view of the lunar surface. The sensors consist of helium-3 filled tubes with one coated such that it is sensitive to epithermal neutrons, while the other uncoated tube is sensitive to thermal and epithermal neutrons. The tubes are sized to achieve a detection sensitivity of 0.5% (wt) at 3-sigma while roving at 10 cm/s.

3.2.2 NEAR-INFRARED VOLATILES SPECTROMETER SYSTEM (NIRVSS)

Operating during roving or drilling operations, the Near InfraRed Volatiles Spectrometer System (NIRVSS) instrument will be used to look for near-real-time changes in the properties of the materials exposed. Using different wavelengths of light to illuminate the surface, NIRVSS will also be used to provide an additional means of surveying the surface and immediate excavation site for water and other volatiles, providing surface and regolith mineral context.

The NIRVSS instrument consists of a Spectrometer, Bracket Assembly, and Fiber Cables. The Bracket Assembly (BA) is positioned strategically on the rover with the ability to view below the rover and measure the cutting pile material as it comes up to the surface from down to 1 meter depth. The Fiber Cables connect the Bracket Assembly to the Spectrometer allowing the data to be evaluated on the ground. The BA includes the aperture for the spectrometer, spectrometer lamp, Longwave Calibration Sensor (LCS), a four-channel thermal radiometer, and the Ames Imaging Module (AIM), a Complementary Metal–Oxide–Semiconductor (CMOS)camera with LED illumination.

The NIRVSS spectrometer is a dual-channel near infrared (NIR) spectrometer with the two channels defined as the Shortwave (SW) and Longwave (LW) channels. The SW channel operates over a range of 1300-2400 nm with a spectral resolution of approximately 10-20 nm. The LW channel operates over a range of 2200-4000 nm with spectral resolution of approximately 20-40 nm. The spectrometer channels are fed by a fiber optic bundle that runs to the Bracket Assembly where it is interfaced to a single lens system that provides input to the spectrometer. A tungsten filament lamp with cut-on filter (>1100 nm), located on the BA, is used to illuminate the spectrometer FOV at the surface.

LCS consists of four thermopiles with filters at 10, 14, 18, and 6-25 microns. These sensors are sampled at several gains each once per second continuously while roving and drilling.

The AIM is an unfiltered 4 mega-pixel CMOS imager. Seven sets of LEDs are used to provide illumination for imaging. The LED colors include 348, 410, 540, 640, 740, 905 and 940 nm.

3.2.3 THE REGOLITH AND ICE DRILL EXPLORATION OF NEW TERRAIN (TRIDENT)

The Regolith and Ice Drill Exploration of New Terrain (TRIDENT) system includes the hardware to physically excavate/extract regolith at 10 cm increments from the lunar surface to a depth of 1 meter and deliver the samples to the surface. Per an auger/percussion within the TRIDENT subsystem, sample excavation will be done in such a way to minimize the disturbance to volatiles as much as practical. In addition, the excavation device will be instrumented to measure forces and displacements to determine critical bulk properties of the regolith. TRIDENT drill bit also includes two temperature sensors imbedded in the drill string at the drill bit tip and approximately 20 cm up from the drill bit tip. These temperature sensors are used to measure subsurface temperatures. A heater imbedded within the drill bit at about 20 cm can be used to warm the drill (e.g., to perform thermal conductance experiments).

3.2.4 MASS SPECTROMETER OBSERVING LUNAR OBSERVATIONS (MSOLO)

Mass Spectrometer Observing Lunar Observations (MSolo) is a modified, commercial off-the-shelf (COTS) quadrupole mass spectrometer from INFICON. MSolo utilizes a 100 amu INFICON Transpector

MPH in a crossbeam configuration. The electronics and structural chassis have been modified for spaceflight, and an Instrument Interface Unit has been added to provide standard spacecraft interfaces between the COTS instrument and the rover power and communication systems. A Dust Cover mechanism is incorporated to protect the instrument until after lunar landing and checkout are completed. A Calibration Gas System with a known gas mixture allows for periodic calibration.

The MSolo instrument analyzes volatiles released from the lunar regolith during lunar traverses as well as subsurface regolith extraction via the TRIDENT payload. MSolo will measure constituents below atomic number 100 (including H_2, He, CO, CO_2, CH_4, N_2, NH_3, H_2S, SO_2, etc.), and estimate water (H_2O) abundance. MSolo has the capability for isotope detection, specifically it is able to determine the difference between protosolar (~20 ppm) and cometary (>200 ppm) D/H values. Initial characterization measurements with the MSolo-VIPER configuration, the instrument peak widths were decreased to improve peak separation and minimize abundance sensitivity. Initial measurements are reproducible with a relative standard deviation (RSD) between 1-3%. With an RSD of 1-3%, the predicted performance is 95% confidence (2 sigma) in measuring differences greater than ~15 ppm.

4. VIPER MISSION PHASES OVERVIEW

The VIPER mission profile consists of the three major phases, including Lunar Transit/Orbit, Landing and Egress, and Traverse (Figure 4-1). Following mission completion there is a six-month closeout period during which primary instrument and rover imaging data is prepared for archiving to the Planetary Data System (PDS). Currently a second delivery of derived products is being considered for delivery after an additional six months.

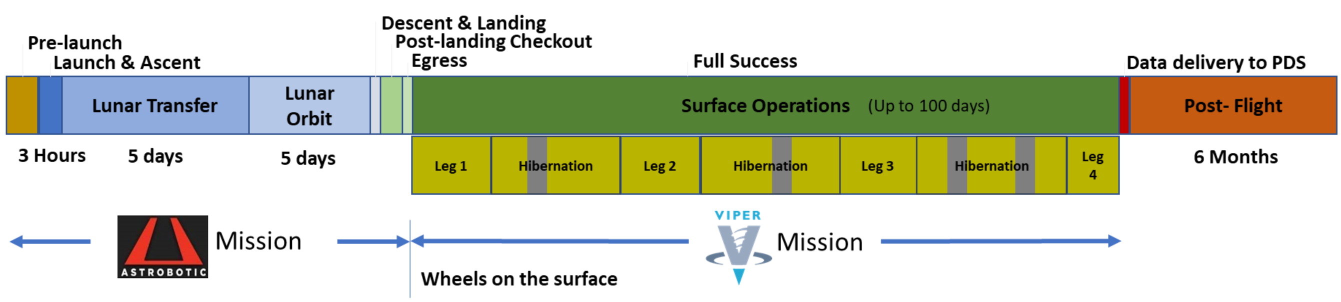

Figure 4-1 VIPER Mission Phases

4.1 LUNAR TRANSIT/ORBIT

Lunar transfer and orbit are part of the Astrobotic delivery service. During this period the landed system will undergo checkouts and health and status monitoring. The NSS instrument will operate away from the Earth, at least at a Moon-radii from the Moon and in lunar orbit to acquire calibration data. MSolo and NIRVSS will undergo checkouts and bakeouts to minimize contamination and facilitate outgassing.

4.2 LANDING AND EGRESS

After landing each instrument will undergo checkout to verify operation status. NIRVSS will perform a radiometric calibration of its spectrometer using a reflectance target affixed to the rover/lander interface assembly. This calibration target remains behind with the lander. After its checkout MSolo will also perform a calibration. It is the goal to egress from the lander with six hours after landing. After egress the TRIDENT will calibrate its system by deploying the drill footpad and applying sufficient force to the footpad to allow for drilling. No drilling will be performed.

4.3 SURFACE OPERATIONS

Surface operations activities and associated traverse planning activities are organized into two categories which include those at a Science Station and those while traversing between Science Stations. In-between Science Stations all instruments will remain on, however, the goal is to get from one Science Station to another, or to an area of safety (in terms of Sun and comm, referred to as a Safe Heaven) as efficiently as possible (e.g., power, time). An illustration of Surface Operations is shown in Figure 4-2. Further details about the measurement requirements for traverse planning and sizes of Science Stations are in Section 5.

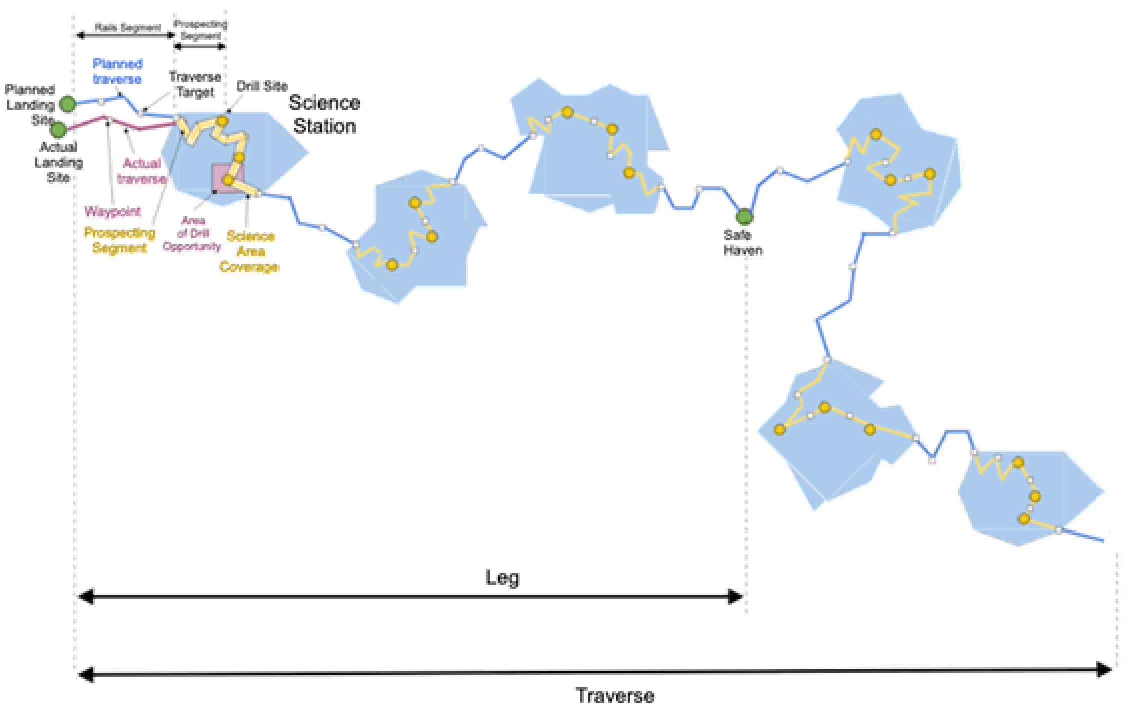

Figure 4-2 Overview of VIPER Science Operations activities.

4.3.1 ON-RAILS TRAVERSING

The in-between Science Station traverse segments are referred to as being “on rails”. While “on rails” instruments are not required to meet Level 2 measurement requirements (Table 2-2) and the rover speed is allowed to exceed the science acquisition speed of 10 cm/s.

4.3.2 SCIENCE STATION ACTIVITIES

A Science Station is a designated 3800 m^2 area that will include one or more ISR types (except in the case of a PSR) and specific measurement activities are carried out. Each Science Station will be dominated by a particular predicted Ice Stability Region (ISR) (i.e., Dry, Shallow, Deep, Surface). "Dominated" is defined here to be that a particular ISR comprises of at least 66% (1σ) of the total sampled area. For example, a "Shallow ISR Science Station" would have its planned boundaries around an area that is dominated (see additional definition below) by Shallow ISR. Currently ISRs are derived from thermal modeling (Paige et al, 2010) using a 1-meter Digital Elevation Model (DEM). However, the exact extent/boundaries of any ISR may be modified as new data is obtained by VIPER or other sources. Typically, because net sunlight tends to decrease as one moves towards a PSR, these Science Stations will be localized near PSRs. Within a Science Station traverse, science operations are organized into two prime activities: Prospecting (Mapping) and Subsurface Assay (SA). Each are summarized below.

4.3.2.1 PROSPECTING

- While roving at speeds no greater than 10 cm/s, near continuous observations from NSS provides bulk hydrogen down to 1 m, and NIRVSS and MSolo measure surface hydration, volatile composition and minerology.
- Key areas for subsurface evaluation activities are identified.
- The environment (e.g., temperatures, geomorphology, and minerology) is characterized.
- Drill site selection is pre-planned. However, the final drill site selection at a given science station is evaluated in real-time and may be changed based on prospecting observations.

4.3.2.2 DRILLING/SUBSURFACE ASSAY

- Drilling to a specified depth, up to 1 meter, each 10-cm segment is exposed for examination by NIRVSS and MSolo.
- For traverse planning purposes the full 1 meter drill depth is assumed, however, it is possible that this drill depth could be changed (e.g., drilling only to 50 cm).
- Volatile content with depth is identified and 'Water Equivalent Hydrogen'(WEH) models (predicted by neutron counts from NSS) are constrained by measuring vertical extent of ice and any dry overburden.
- The third drill site in each Science Station is evaluated and anticipated to be changed, based on prospecting data and data obtained in the first two drill sites.
- To infer subsurface temperatures, the drill string will preload against the borehole floor, placing its temperature sensor in contact with the regolith. A nominal 30 minute pause will be included in the SA activity, with the assumed depth of this pause to be at 100 cm. Due to resource constraints, this is not enough time to allow for the drill string to reach thermal equilibrium with the regolith, and therefore thermal modeling and correlation with laboratory testing will be used to infer regolith subsurface temperature.

4.3.3 SAFE HAVEN OPERATIONS

At the end of each lunar day the Earth will set below the horizon and communication with the rover will not be possible, and thus the rover cannot maintain itself unless it is positioned in sunlit areas. During these

Loss of Signal (LOS) periods the rover will position itself in an area of persistent sunlight, or Safe Havens. At Safe Havens the rover will configure itself for a low-power state, shutting down all non-essential subsystems including the payload. This configuration allows for survival during periods of extended (<70 hours) of shadow. This configuration is entered prior to Earth setting. Once Earth rises again and communications are regained the rover will prepare itself (e.g., warm critical systems and payload) for the next portion of the planned traverse.

4.4 DECOMMISSIONING & CLOSEOUT

The end of the mission occurs when shadow periods at the Safe Havens are longer than what the rover can survive. The final disposition of the rover, for example driving deep into a PSR or parking at a Safe Haven will be defined at around the time of the mission Critical Design Review (CDR).

4.5 MISSION SCIENCE PHASES

The VIPER mission surface operations are conceptualized as two science-driven Phases that will each be in service of meeting mission success criteria:

- Phase I ("Early"): meeting Science Objectives, Science Requirements, and Minimum Mission Success criteria.
- Phase II ("Late"): will commence when the total set of minimum traverse measurements (Level 1 Full Success) are met. However, Phase II science operations activities are contiguous and also concurrent to Phase I, given that Phase II strategic planning will begin prior to the completion of Phase I. During Phase II, the VIPER Science Team (VST) may introduce and recommend mission activities that test relevant theories of water emplacement and retention and/or test predictive capabilities of developed Resource Maps and Models. Phase II Science Operations details will be scoped after CDR.

Descriptions of VIPER science team roles during these phases are further described in Section 6.

5 TRAVERSE PLANNING PROCESS

5.1 TRAVERSE REQUIREMENTS

There are five primary science driven VIPER traverse planning requirements described within this section. These requirements are separate and in addition to any measurement requirements called out within the VIPER Level 2 Science Requirements (Table 2-2).

1. Determine water distribution and form across four defined ISRs (see Section 2 for definition) with an uncertainty of <50%
    a. Areal measurement density of >10% (floor) to 15% (goal) for an equivalent area of at least 3800 m^2.
    b. Total drive distance in ISR ≥224 m (floor) to 335 m (goal) assuming a 1.7 m sampling area.
2. To account for possible scales of variability, must measure at scales of <5 meters and as large as 1000 m.
3. Minimum of two additional ISR repeat measurements separated by at least 100 meters.
4. Minimum of three subsurface characterizations in each ISR separated by 10s of meters.

5. Subsurface measurements must sample across depths from 10 cm to 80 cm with a sampling interval of at least 8 cm.

Rover navigation camera imagery is not specified here, however, this imagery is necessary to provide geologic context, help in identifying drilling locations and rover localization, and help with quantifying geotechnical properties of the lunar regolith.

Traverse planning within a Science station will maintain a goal of measuring across spatial scales between 10-100 meters in both x and y (to insure adequate sampling across possible physical length scales). Also, spatial data interpolation methods benefit greatly from tracks extending in both x and y (as opposed to longer mono-directional tracks). Integrated area mapping of any ISR type does not need to be contiguous in time or space. That is, total area mapping coverage can be accumulated for any ISR type over multiple subsequent mapping activities in individual ISRs. Area mapping density within a PSR is only valid (i.e., count toward the 10% minimum area density) while the traverse is more than 30 meters from the predicted PSR boundary. This is to avoid possible miss-classification of a PSR boundary due to uncertainties in DEMs (currently LOLA 20 meter DEM is used for PSR planning).

Three 1-meter drill tie points are required at each ISR except for PSRs:

- These drill sites are initially pre-planned; however, the third drill site may be relocated.
- Subsurface sampling intervals are in 10 cm increments, or “bites”. After each bite a pause of at least 5 minutes will occur to allow for observation of the cuttings pile.
- Due to thermal/power constraints it is required to plan only one 1-meter subsurface assay in a PSR. However, multiple shallow subsurface assays should be allowed as long as they fit within the allocated time/power planning for a PSR. These shallow subsurface assays include assays down to 60 cm (just beyond the “Shallow/Deep ISR” boundary) and down to 40 cm (below the seasonal thermal skin depth).
- At least one subsurface assay must include a subsurface temperature measurement, which includes a nominal “pause” duration of at least 30 minutes (typically planned as part of the first drilling activity).

5.2 TRAVERSE PLANNING PHILOSOPHY

Ultimately two products are to be generated with traverse observations: (1) Resource Maps and (2) Resource Models. A Resource Map is defined here to be a map of water abundance (total yield for a specified volume of material) that is based entirely on observational data and interpolation or other data modeling techniques. These maps can be made at any scale but will have the highest confidence in areas with the highest observation densities. A Resource Model utilizes all data sets and applies physical models of distributions, based on theories of emplacement and spatial, physical or chemical modification, to provide additional predictive capability beyond interpolation and spatial/environmental proxies.

Initial traverse planning should work to meet observation density requirements at each of the ISRs (and ISR duplicate visits) with little consideration to testing water emplacement or retention/redistribution theories. Traversing should focus on total coverage across an ISR, noting trends in physical length scales and correlation between instrument data sets (e.g., surface hydration and subsurface hydration, hydration with surface temperature, etc.). When the total set of minimum traverse measurements are met then traverse planning may introduce activities that test relevant theories of water emplacement and retention and/or test predictive capabilities of developed Resource Maps / Models. In so doing these plans may not necessarily meet all observation density goals, but rather work toward alternate goals, for example, mapping radially from craters of varying ages, or multiple shallow subsurface assays into micro PSR to test more recent volatile accumulation.

5.3 LANDING AND TRAVERSE STUDY SITES

Several regions near the south pole have been used as study sites for evaluating the lander and rover design and to develop traverse planning tools and data sets. Figure 5-1 shows the three primary study sites that have been evaluated in detail. In each of these areas high resolution shape-from-shading Digital Elevation Models (DEMs) have been produced. These DEMs are then used to calculate critical data products, including Sun and Direct to Earth (DTE) communication availability vs. time, surface and subsurface temperatures vs. time, and slopes. In addition to these data products, map layers indicating hazards (e.g., craters) and logically combined mission constraint layers (e.g., Sun AND communication AND slopes that meet design constraints) are used for traverse planning.

Key to the selection of these study sites are the presence of areas with shadow durations less than 70 hours (required rover design duration to survive without Sun in a hibernation mode). These areas are referred to as "Safe Havens" (yellow pixels in Figure 5-1). Traverses are planned such that the rover returns to a Safe Haven for hibernation (minimum power mode to maintain rover system temperatures during shadow period). It should be noted that while the longest shadow periods are no more than 70 hours, during this same period Earth will be set and the rover will be without communication, that is in a Loss of Signal (LOS) period, for up to 18 days. During the LOS period the rover will be in its hibernation state at a Safe Haven.

Figure 5-2 shows a notional traverse at the Nobile study site. The total number of ISRs and drilling activities are summarized in Table 5-1. This is a notional traverse used to evaluate rover design and for mission planning development. Along this drawn traverse are circles that represent Science Stations. Within each Science Station the traverse is planned to meet both the minimum success criteria for traverse coverage (i.e. 10% area coverage) and three Subsurface Assays Within this notional traverse, full mission success is achieved in the second lunar day. At other sites (i.e., Haworth and Shoemaker), traverses typically meet full mission success in the third or fourth lunar day. The current schedule requires the "flight" site and traverse be identified two months prior to the mission Critical Design Review (CDR). Landing site and traverse contingencies are developed following CDR.

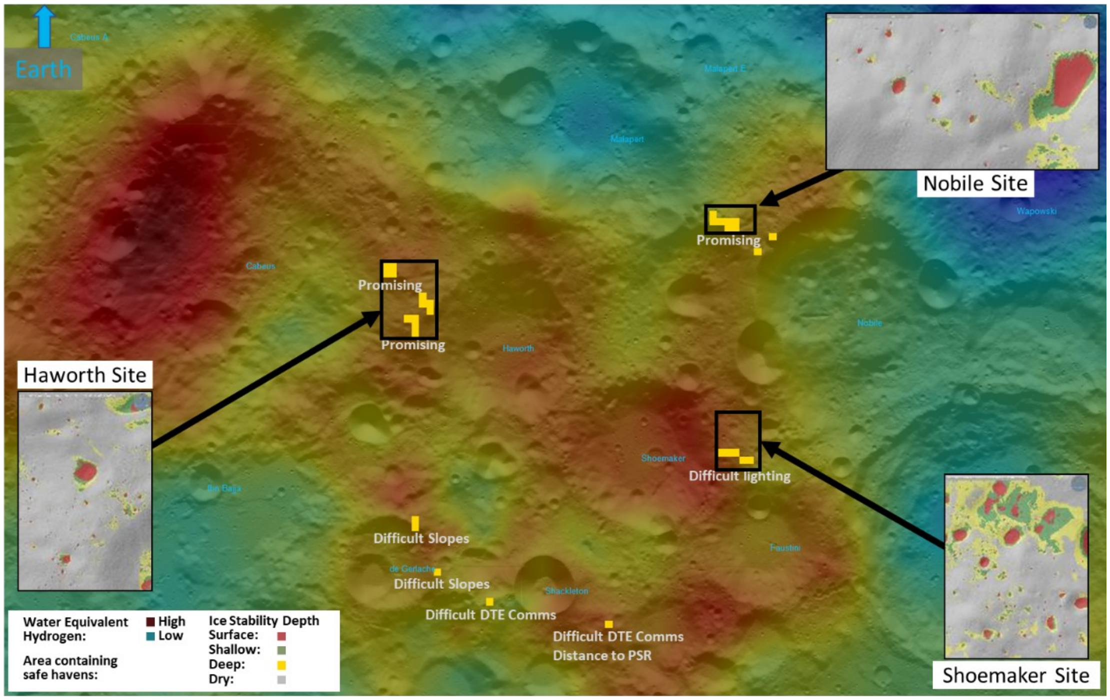

Figure 5-1 VIPER south pole landing/traverse sites under study

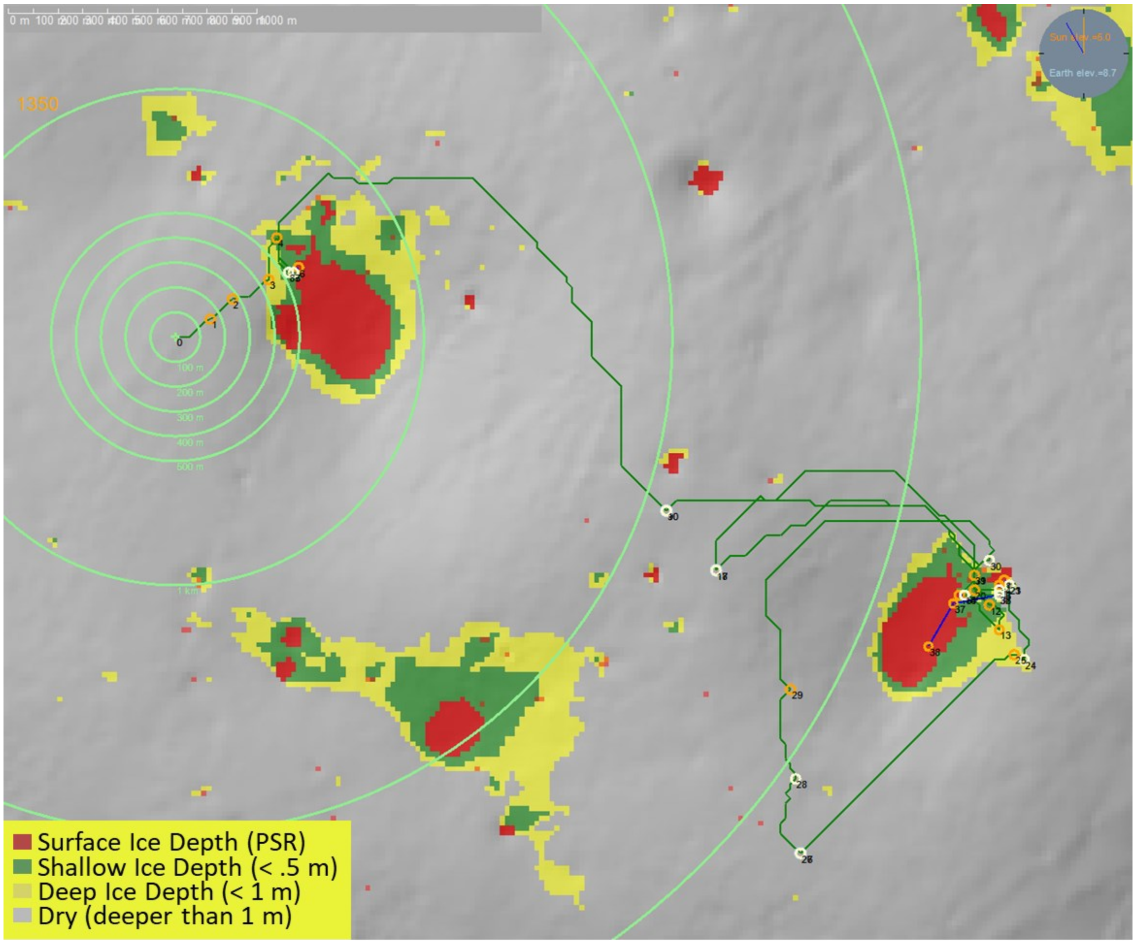

Figure 5-2 Notional traverse at the Nobile study region. The landing site is at the center of the smaller light green circles at the upper left of the image (each of these light green circles are 100 meters apart). The colored areas indicate ISR types (see key).

Table 5-1 Summary of ISR numbers/area and other characteristics of the traverse shown in Figure 5-2.

Parameter	**Quantity**
Duration	91 days
Length	13.25 km
# of PSRs	2 (4 entries)
# of Shallow ISR Science Stations	6
# of Deep ISR Science Stations	3
# of Dry ISR Science Stations	2
# of Subsurface Assays (to 1 meter)	35
Total area mapped (m2):	
Dry	765
Deep	1241
Shallow	2295
PSR	765

6. VIPER SCIENCE OPERATIONS AND ORGANIZATIONAL ARCHITECTURE OVERVIEW

6.1 SCIENCE OPERATIONS DURING SURFACE OPERATION

VIPER Science Operations will be centered around providing timely, mission enhancing input throughout Surface Operations. The Mission Science Center (MSC) organizational architecture (including roles and responsibilities), VIPER Science Team (VST) data synthesis, analysis and decisioning work processes, and timelines (e.g., tactical and strategic) to support VST decisioning cadence is described below.

6.2 VIPER SCIENCE TEAM ORGANIZATIONAL ARCHITECTURE

The VIPER Science Team (VST) will be located across mission workspaces at NASA-ARC and remote to NASA-ARC. The VST organization is shown in Figure 6-1. In addition to science management, data management, traverse planning and science operations, there are four science themes that have been defined. These science themes help to organize science and analysis activities, especially during mission operations when science theme leads will be charged with providing tactical and strategic input into traverse planning and activities. Each VST member will have a defined role and specific science operations protocols for participating in tactical and strategic/long-term planning decision-making throughout Surface Operations.

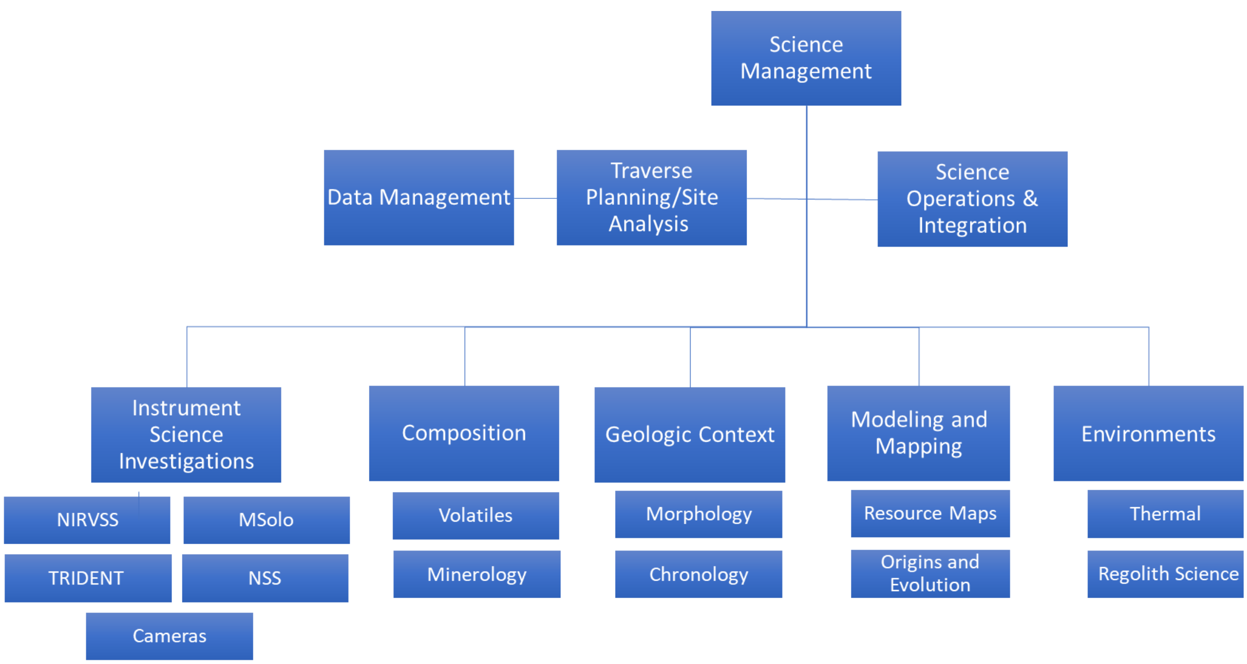

Figure 6-1 VIPER Science Team Organization, including the Science Themes of Composition, Geologic Context, Modeling and Mapping & Environments.

6.3 VIPER SCIENCE TEAM

VIPER's science investigations in Table 1-2 will be accomplished by the VIPER Science Team (VST). The current Science Team membership (excluding Project Science Support roles) is listed along with their roles in Table 6-1. Instrument team members who provide science support that is specific to that instrument are shown in Table 6-2.

Table 6-1. VIPER Science Team

Investigator	Institution	Role
Anthony Colaprete	ARC	Project Scientist
Darlene Lim	ARC	Dep. Proj Sci., Science Operations, Planning & Integration Lead
Kimberly Ennico-Smith	ARC	Dep. Proj. Sci., Data Products, DAWG Lead, Science EPO Lead
Ross Beyer	ARC/SETI	Map Cartographer Lead, Site Analysis, Geologic Context
Jennifer Heldmann	ARC	Science Mission Planning, Mission Science Center Displays and Tools Lead
Matt Siegler	PSI	Thermal Science Lead, Site Analysis, Science Mission Planning
Eldar Noe Dobrea	ARC/PSI	Surface Spectroscopy/Composition, Data Products, Dep DAWG Lead
Josh Coyan	USGS	Economic Resource Mapping, Geo Stats Science Lead
Julie Kleinhenz	JSC	ISRU Requirement Infusion and Application, Mission Planning
Caleb Fassett	MSFC	Site Analysis, Geologic context

Table 6-2. VIPER Instrument Science Teams

Investigator	Institution	Role
Rick Elphic	ARC	NSS PI
David Lawrence	APL	NSS Instrument Scientist; Develop models of neutron count rates for various WEH abundances and layering scenarios.
Patrick N. Peplowski	APL	NSS Instrument Scientist; Simulations and measurements to develop an instrument response model.
Jack Thomas Wilson	APL	NSS Instrument Scientist; Developing a data processing pipeline to de-noise the time series data and reconstruct the spatial distribution of WEH around the rover's path.
Janine Captain	KSC	MSolo PI
Roberto Aguilar Ayala	UCF/KSC	MSolo Instrument Scientist; Coordination of instrument operation based on science objectives and mission activities
Kenneth Wright	INFICON Inc.	MSolo Instrument Scientist; Responsible with MSolo team for instrument ops and data interpretation based on science objectives.
Anthony Colaprete	ARC	NIRVSS PI
Ted L. Roush	ARC	NIRVSS Instrument Scientist; compositional, morphological, and thermophysical measurements near, and in, permanently shadowed regions on the lunar surface.

Amanda Marie Cook	ARC	NIRVSS Instrument Scientist; Integration & Test Lead for NIRVSS Instrument, Operations Lead for NIRVSS Instrument
Vandana Jha	ARC	NIRVSS Instrument Scientist; Integration & Test, calibration, and operations support.
Kris Zacny	Honeybee Robotics	TRIDENT PI

6.4 PHASE I SURFACE OPS: SCIENCE TEAM OPERATIONAL ACTIVITIES

This section provides operational details on the science activities that will be conducted in support of VIPER Surface Operations. These tasks will be linked to the horizontal and vertical mission and VST-specific timelines. Broadly, the VST will utilize the science-relevant instrument and rover (e.g., imaging) capabilities in support of real-time science operations. Prior to launch, traverses will be planned, with all science stations and activities identified and scheduled. However, traverse paths and the third drill site in each science station may be modified based on rover/payload performance and/or observations to date. These changes can originate from the Mission Systems Planners, for example, due to performance updates on rover speed, or from the MSC. The MSC will work with the Mission Planners to develop changes in plans which are then proposed to Mission Science for approval.

While the rover is 'on rails' or within a science station and 'prospecting', the NSS, NIRVSS, MSolo, and the rover navigation (Navcam, Hazcam imaging, and positioning systems) instrument payload systems will be active and transmitting data products (though at different rates depending on the instrument and operational mode).

6.4.1 VST ACTIVITIES AND REAL-TIME PROCESSING FOR PLANNING SUPPORT

NSS: The NSS data products will be used to convert neutron data into water concentration (water equivalent hydrogen (WEH)), which depends on the vertical distribution of water in the top 1 m of regolith, and particularly in the top 0.5 m. NSS measures thermal and epithermal neutrons, and these measurements can be transformed into simple depth profile models. Ultimately, the profiles are ground-truthed at a specific location by near-surface assay drill activities.

NIRVSS: NIRVSS data products will be used to characterize the surface hydration (including surface water and hydroxyl), surface temperatures, mineralogy and fine scale geomorphology. NIRVSS will compute in real-time various spectral properties relevant to surface composition, including water ice band depths. While 'on rails', imaging (monochromatic) and spectra/temp data will be continuously collected by NIRVSS, with no additional imaging being provided at the traverse waypoints. While 'prospecting', NIRVSS will continue to collect imaging and spectra/temp data (as during 'on rails' driving), however during 'prospecting' mode, at least three additional images (at four different colors) will be collected at each waypoint (assumes a 4 m drive segment). In prospecting mode, NIRVSS relies on a maximum drive rate of no more than 10 cm/s, in order to meet spatial coverage requirements with sufficient spectral SNR.

Temperature variations will be largely determined by lunar topography; thus, temperature variations will likely be significant down to scales of <5 m. The correlation between accurately localized surface temperatures and topography will be a priority analysis in order to update thermal models. The NIRVSS radiometer will report a brightness temperature, derived from radiometer counts and laboratory calibration, for all four channels once per second.

MSolo: The MSolo instrument will provide 1-100 AMU measurements of the (released) volatile content from the regolith surface. These measurements will assist with the characterization (compositional) and quantification (concentration) of regolith water content based on MSolo signal intensities. MSolo captures data through continuous scans. Each data set is tagged with a time stamp that can be used to plot the intensity against time. From these scans, the ion current values for each mass trace can be plotted as a function of time as long as the method retains the same peaks within range.

While ‘on rails’ and while ‘prospecting’, MSolo will be continuously scanning at 1 point per AMU resolution, and conducting a full 1-100 AMU scan every 4 sec. This scan rate is faster than the rover will be traversing whether ‘on rails’ or ‘prospecting’. This scan rate is variable (for example, the rate can be reduced to 7 kbps if necessary, depending on downlink rates). Upon landing, MSolo will be able to begin generating mass spectra, there is a chance that initial results will detect material outgassing from the rover and the surrounding area, as initial concentrations of propellant and or any contaminants will more than likely be at their highest during early stages of the mission.

MSolo data immediately available and plotted real time is the signal intensity. Additional data reduction is required to convert the intensity into a quantitative water value. Should the scan sensitivity be increased to a higher resolution, then the longer it will take to integrate data and generate associated plots. These higher resolution scans oversample the mass spectrum with 10-25 points per AMU and allow for calibration of the spectral position during the mission.

TRIDENT: The TRIDENT drill will provide significant science data that can be used as stand-alone information, and to constrain or supplement information from other instruments. Both of these data applications will be in service of meeting mission success thresholds and enabling the science team to meet their highest-level objective of characterizing ISR types through ground-truthed data, and thus significantly reducing uncertainty related to modeled ISR determinations. Specifically, the TRIDENT will enable the science team to constrain their ISR characterizations through a) Derived data products that will help to constrain the VST’s science assessment of dominant ISR type: Subsurface Thermal Data, Unconfined Compressive Strength (UCS), Water weight %, Thermal Conductivity; as well as through b) Direct data sources from NIRVSS and MSolo measurements of the TRIDENT cuttings pile.

The TRIDENT drill will use a bite sampling approach to preserve layer stratigraphy during drilling, minimize necessary power while drilling, and allow the subsurface to return to its ambient temperature between two consecutive bites. The drill is retracted after each bite is completed to fully clean off the auger drill string. A passive brush mounted alongside the auger will move the cuttings from the drill string down a chute where a cuttings cone will form. As such, the most recently drilled material will be deposited on top of the cone surface, covering the previous bite worth of material. Each bite nominally proceeds 10 cm further than the previous bite.

The TRIDENT drill can be commanded to take smaller "bites" in a suspected shallow ISR if higher resolution sampling is desired by the Science Team. TRIDENT will have the capability to vary key drilling parameters prior to, and during, drilling operations, to allow for efficient drilling. These parameters include, but are not limited to auger speed, percussive frequency (including turning percussion off completely), weight on bit (WOB), rate of penetration (ROP), drill depth, and "bite" size (up to 10 cm).

Geostatistics: The MSC will be performing tactical geostatistical modeling during Surface Operations Phases I (Early) and II (Late) to provide guidance and science-based fine-tuning for path plan optimization in service of reaching mission objectives.

The following geostatistical tasks will be conducted during roving, drilling surface operations phases, and likely continue into the Safe Haven Operations stage, where the application of these analytical methods will take on more strategic planning elements:

1) Trend analysis
Trend analysis will be used to examine if any geospatial trends exist within each of the NSS, NIRVSS and MSolo instrument datasets. This task is estimated to take less than 1 minute per dataset if the data arrives to Geostatistics Lead in the correct format.

2) Simple Linear Regression analysis
Simple linear regression analysis will be used to examine relationships between NSS, NIRVSS, and MSolo datasets. Other relationships and correlations will be explored through simple linear regression as data is provided (e.g., slope, soil color, roughness/level of soil deflation, particle size from camera).

3) Ordinary Kriging and Empirical Bayesian Kriging (EBK)
Ordinary kriging and empirical Bayesian kriging (EBK), using NIRVSS spectral wavelength data, will predict ice burial depths, temperatures, and mineralogy in the area surrounding the data collection paths. Ordinary kriging methods examine each data point and its relationship to all other data points in the vicinity, weights are calculated using variogram analysis, taking into account distance between points, redundancy of measurements, and continuity of data. The weights are applied to existing measurements to estimate the value at locations not measured. EBK methods use expected maximum likelihood, a variogram-based assessment, to predict the values between measurements and produce a metric that our local area predictions are accurate. Fundamentally, these methods will enable the VST to assess how well we were capturing reality.

4) Sequential Gaussian Simulation
Sequential Gaussian Simulation (SGS) is a procedure that uses the kriging mean and variance to generate a Gaussian field. It uses input data and simulated data when computing a value at an unsimulated grid cell. SGS repeats this process for all grid cells producing a realization. Subsequently, multiple (usually 100) equiprobable realizations are produced. This provides a probability distribution that not only represents the natural variability in the deposit but captures the uncertainty. In this way a 10, 50, and 90 percent probability

that there is ice can be reported. In addition to providing a probability distribution, the 100 equiprobable simulated realizations may be aggregated to produce a map of the expected value, similar to the kriged solution. Simulation can provide a more robust answer than kriging, which may provide over and under estimation due to smoothing.

7. VIPER DATA PRODUCTS

VIPER Data products will be archived in the Planetary Data System (PDS) for use by the scientific community. Data from MSolo, NIRVSS, TRIDENT and NSS will be archived at the Geoscience node at Washington University in St. Louis. Data from the rover cameras will be archived at the Imaging node at JPL. Trajectory and rover localization data will be archived at the NAIF node at JPL. At present the VIPER project plans to produce a single PDS data delivery of standard science data products within six months after the end of mission. A second PDS delivery of updated data products plus higher science products (e.g. maps) is planned six months following. A list of archive products as they are currently known is listed in Table 7-1.

Table 7-1 VIPER standard data products

Instrument	**Raw**	**Partially Processed**	**Calibrated**	**Derived**
MSolo	Time-stamped intensity (Amps) per channel		Time-stamped intensity separated by AMU	Geospatially mapped ppm per species; isotope ratios
NIRVSS: AIM	Time-stamped images with raw counts			False color and color- slope images
NIRVSS: SPEC	Time-stamped spectra with volts per channel		Time-stamped spectra, wavelength calibrated and in radiance units (W/m^2 um sr)	Geospatially mapped band depths
NIRVSS: LCS	Time-stamped volts per channel		Time-stamped temperatures per channel	Geospatially mapped surface temperature
NSS	Time-stamped counts per channel		Time-stamped neutron flux (n/cm^2/sec) per channel	Geospatially mapped WEH maps

TRIDENT	Time-stamped raw counts	Rotation speed (rpm) Rate of penetration (m/s) Time-stamped torque (Nm) Time-stamped temperature (K)	Specific Energy (kWhr/m^3)	Material strength (MPa) and temperature per depth Surface bearing capacity (kPa) Thermal gradient (K/m)
Rover Imagery	Time-stamped images with raw pixel values and imaging parameters	High Dynamic Range Bracket (consisting of multiple images of the same scene under varying exposure)	Radiometrically calibrated images giving luminous exposure from the scene (e.g. Lux) Depth/Disparity Image (giving the range of each pixel in a stereo image pair - meters)	3D point cloud (one stereo pair) 3D panoramas (6+ stereo pairs stitched from a single location DEMs created from multiple point clouds projected onto a planar surface Hazard Maps created from DEMs and slopes, surface normal, etc.

Appendix A – Acronyms

AIM	Ames Imaging Module
AMU	Atomic Mass Unit
APL	Applied Physics Laboratory
ARC	Ames Research Center
BA	Bracket Assembly
CDR	Critical Design Review
CLPS	Commercial Lunar Payload Services
CMOS	Complementary Metal–Oxide–Semiconductor

COTS	Commercial Off the Shelf
DAWG	Data Analysis Working Group
DEM	Digital Elevation Model
DEM	Digital Elevation Model
Direct To Earth	DTE
EBK	Empirical Bayesian Kriging
FOV	Field of View
IMU	Inertial Measurement Unit
ISR	Ice Stability Region
ISRU	In-Situ Resource Utilization
JPL	Jet Propulsion Lab
JSC	Johnson Space Center
KSC	Kennedy Space Center
LCROSS	Lunar CRater Observation and Sensing Satellite
LCS	Longwave Calibration Sensor
LED	Light Emitting Diode
LOS	Loss of Signal
LRO	Lunar Reconnaissance Orbiter
LW	Longwave
MSC	Mission Science Center
MSFC	Marshall Space Flight Center
MSOLO	Mass Spectrometer Observing Lunar Observations
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
NIR	Near Infra-Red
NIRVSS	Near InfraRed Volatiles Spectrometer System
NRC	National Research Council

NSS	Neutron Spectrometer System
PDS	Planetary Data System
PIP	Proposal Information Package
PSI	Planetary Science Institute
PSR	Permanently Shadowed Region
ROP	Rate of penetration
RSD	Relative Standard Deviation
SA	Subsurface Assay
SCEM	Science Context for Exploration of the Moon
SETI	Search for Extraterrestrial Intelligence
SGS	Sequential Gaussian Simulation
SW	Shortwave
TBR	To Be Resolved
TRIDENT	The Regolith and Ice Drill Exploration of New Terrain
UCF	University of Central Florida
UCS	Unconfined Compression Strength
USGS	US Geological Survey
VIPER	Volatiles Investigating Polar Exploration Rover
VST	VIPER Science Team
WEH	Water Equivalent Hydrogen
WOB	Weight on bit