TRIDENT Drill for VIPER and PRIME1 Missions to the Moon. K. Zacny[1], P. Chu[1], V. Vendiola[1], E. P. Seto[1], J. Quinn[2], A. Eichenbaum[2], J. Captain[2], J. Kleinhenz[3], A. Colaprete[4], R. Elphic[4] and TRIDENT/VIPER team, [1]Honeybee Robotics, Altadena, CA, KAZacny@HoneybeeRobotics.com, [2]NASA Kennedy Space Center, FL, [3]NASA Johnson Space Center, TX, [4]NASA Ames Research Center, CA

Introduction: The Regolith and Ice Drill for Exploration of New Terrains (TRIDENT) is an ice mining drill under development for two exploration/ISRU missions to the Moon: Volatiles Investigating Polar Exploration Rover (VIPER) – see Figure 1, and PRIME1 (Polar Resources Ice Mining Experiment) – see Figure 2 [1]. PRIME1 is scheduled to fly to the Moon in 2022 while VIPER is targeting 2023 launch year. Both missions are targeting South Pole's volatile rich deposits.

The primary goal of TRIDENT is to deliver volatile-rich samples from up 1 m depth to the lunar surface [2]. Once on surface, the material would be analyzed by Mass Spectrometer Observing Lunar Operations (MSolo) and the Near InfraRed Volatiles. Spectrometer System (NIRVSS) to determine volatile composition and mineralogy of the material. MSolo will fly on both missions while NIRVSS will fly on VIPER, only.

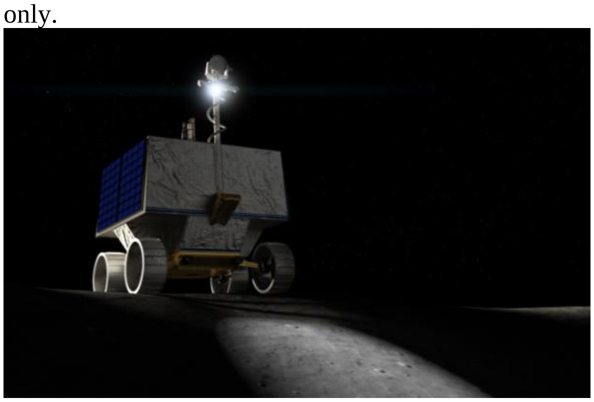

Figure 1. VIPER mission. TRIDENT is placed in vertical position in the middle of the rover.

Figure 2. PRIME1 mission. TRIDENT is vertically mounted on the right hand side of the Intuitive Machines (IM) lander.

TRIDENT is a rotary-percussive drill which enables it to cut into icy material that could be as hard as rock. The drill consists of several major subsystems: rotary-percussive drill head for providing percussion and rotation to the drill string, deployment stage for deploying the drill to the ground, feed stage for advancing the drill string 1 m into subsurface, drill string for drilling and sampling, brushing station for depositing material onto the surface (Figure 3).

Percussive energy is set to 2 J/blow and maximum frequency is 972 blow per minute. The rotation speed is 120 revolutions per minute and the stall torque is 16 Nm. The mass of the drill is 20 kg without harness and the mass of avionics 5.4 kg. The stowed volume of the drill is 20.6 cm x 33.3 cm x 168 cm.

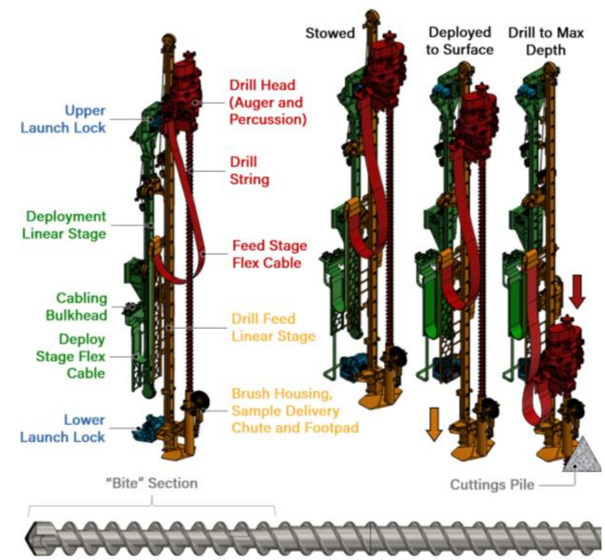

Figure 3. TRIDENT subsystems. The sampling auger is pictured at the bottom.

To reduce thermal risks, risk of getting stuck, reduce drilling power, and provide stratigraphic information, the drill will capture samples in so-called 10 cm bites (Figure 4). That is the drill will drill 10 cm at a time and bring up 10 cm worth of material to the surface. For this reason, the auger is split into two sections (Figure 3 and Figure 4). The lower section has flutes designed for sample retention: the flutes are deep and have low pitch. The upper section is designed for efficient conveyance of material to the surface: the flutes are shallow and the pitch is steep. This combination allows efficient sampling but inefficient conveyance – the drill should not be used to drill to 1 m depth in a single run as this will lead to increase in drilling power and ultimately heat input into formation.

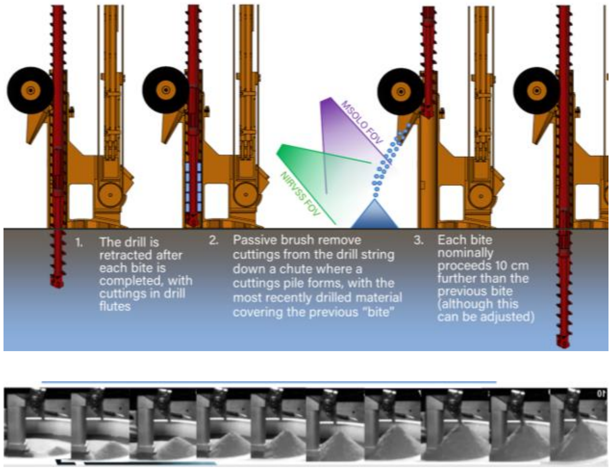

Figure 4. Bite sampling approach. Shown below are cuttings cones every 10 cm bite.

In addition to being tool for providing samples, TRIDENT is also an instrument. TRIDENT drilling power and penetration rate is used to determine regolith strength. Measuring the strength in combination with input from MSolo, NIRVSS and Neutron Spectrometer System (NSS), will enable determination of the physical state of ice – whether it's mixed with regolith or cemented with regolith grains. The former will lead to low drilling power and the latter to high drilling power – while the water-ice concentration could be the same.

TRIDENT's integrated 40 Watt heater and RTD temperature sensors will measure downhole temperature and could provide thermal conductivity. These two measurements, temperature and thermal conductivity, are needed to determine heat flow properties of the Moon. The first RTD is located in the drill bit and the second RTD is co-located with the heater, some 20 cm above the bit.

TRIDENT will also be able to provide bearing capacity of the top lunar surface from measuring of the sinkage of its footpad into the surface, as well as angle of repose from measuring the angle of the cuttings pile.

It needs to be emphasized that drilling in 10 cm bites enables more accurate measurement of subsurface temperature and material strength. Every time the drill is lowered into the borehole, it will be pre-loaded onto the bottom of the borehole and cold soaked without drilling (i.e. no heat input). This cold soaking with be used to extrapolate the subsurface temperature. In addition, when the drilling starts, the drilling power will be initially attributed to penetrating/breaking the icy-formation. As the drill continuous drilling deeper, the power would start increasing due to the cuttings removal (i.e. auger) contribution to the total power budget (the drill can only measure the total drilling power – contribution of drilling and cuttings removal). As such knowing the initial drilling power and the power once the drill penetrated 10 cm will allow determination of the auger-contribution to the total power budget.

TRIDENT's downhole heater and temperature sensors pave the way for more advanced downhole technologies that could be developed for future missions. For example, neutron spectrometer and near infrared spectrometer could be integrated into the auger. This advancement would change the paradigm of planetary exploration: instead of bringing a sample to an instrument we would be bringing an instrument to a sample.

TRIDENT drill has undergone several end to end tests at NASA Glenn Research Center (**Figure 5**). These tests were conducted with NIRVSS and MSolo instruments and in the NU-LHT-3M lunar soil simulant doped with various water-ice concentrations. In all cases, the vacuum was maintained in the 10^-5 torr range (or lower) while the temperature of the chamber and the sample was mainatined at around 100K or higher.

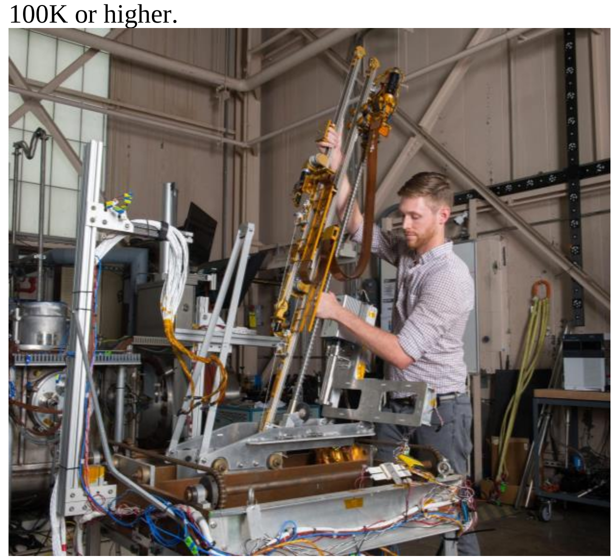

Figure 5. TRIDENR drill undergoing TVAC tests at NASA GRC.

The drill has passed Crititcal Desig Review (CDR) in 2020 and is currently being assembled. The flight drill is scheduled to be delivered to NASA in March of 2022.

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References: [1] Colaprete et al., (2020), LPSC, [2] Zacny et al., (2018), LPSC, [3] Paulsen et al., (2018), Aerospace Mechanisms Symposium.