CONDUCTING SUBSURFACE SURVEYS WITH A CREW ROVER TO ADDRESS BOTH SCIENTIFIC AND ISRU OBJECTIVES. David A. Kring[1,2] and Essam Heggy[3,4], [1]Center for Lunar Science and Exploration, Lunar and Planetary Institute, Universities Space Research Association, 3600 Bay Area Blvd., Houston TX 77058 USA (kring@lpi.usra.edu), [2]NASA Solar System Exploration Research Virtual Institute, [3]University of Southern California, Viterbi School of Engineering, Los Angeles CA 90089 USA, [4]Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109 USA.

Introduction: If one or more reusable crew rovers are deployed on the lunar surface, then they may be available for tele-robotic operations between crew visits. Potentially, a crew rover with a ground penetrating radar (GPR) and neutron spectrometer system (NSS) can be used to conduct a subsurface survey for ices and other targets of interest [1,2].

A National Research Council report [3], *The Scientific Context for Exploration of the Moon*, outlined several investigations related to polar volatiles: a study of polar volatile compositions and sources; their transport, retention, alteration, and loss processes in permanently shadowed regions (PSRs); their host regolith physical properties; and a measure of the ancient solar environment as derived from implanted volatiles. Volatile species are also being targeted for *in situ* resource utilization (ISRU) that supports long-term exploration of the lunar surface and other deep space destinations.

Those studies require a survey over broad geographic regions. For example, to address transport, deposition, and retention processes one would ideally survey from relatively warm temperatures to relatively cold temperatures; i.e., along thermal gradients that can be examined in light of physical models of transport, deposition, and retention processes.

Thus, a mobile analytical platform, like the crew rover, is needed to survey for subsurface volatiles to resolve the science issues identified by the NRC [3]. That same mobile assessment is needed to prospect for locations with the greatest ISRU potential. As noted elsewhere [4,5], the ISRU potential may vary from the relatively warm edge of a PSR to its coldest core.

Instrumentation: Two GPR instruments have been previously incorporated into terrestrial prototypes of crew rovers. The first GPR was incorporated into an unpressurized crew vehicle (UPR) called Chariot [6]. The instrument operated at a frequency of 400 MHz. The instrument was used in a 2008 lunar mission simulation at Moses Lake, Washington. It detected water in the subsurface which was verified by test conductors once crew had completed the traverse.

A second GPR was installed on a prototype small pressurized rover (SPR) for crew, called the Lunar Electric Rover [7]. The GPR was installed beneath the aft deck of the vehicle (**Fig. 1**) and operated at a frequency of 400 MHz. This instrument was deployed during a 14-day lunar mission simulation, surviving operating conditions over harsh terrain.

Figure 1. A ground penetrating radar (GPR) was installed beneath the aft deck of the Lunar Electric Rover, a terrestrial prototype of a Space Exploration Vehicle. The instrument was a technology demonstration component of a 14-day-long lunar mission simulation at Black Point, San Francisco Volcanic Field, northern Arizona.

A NSS was not incorporated into either of those vehicles, but an engineering model has been utilized in terrestrial field tests [8,9], installed on smaller robotic rovers, and can be configured for a large crew vehicle. Importantly, *in situ* NSS data can provide ground truth for orbital measurements of neutron absorption and inferred hydrogen abundances within ~1 m of the surface. The instrument is designed to detect low (≥0.5 wt%) abundances of water-equivalent hydrogen while roving in the polar regions. Once survey results have been established in representative locations, they can be used to interpret orbital measurements over a much broader region.

The two instruments complement each other. While the NSS provides a measure of H near the surface and a link to regional distributions determined from orbit, the GPR provides a picture of the distribution of any ice deposits as a function of depth below that ~1 m horizon. Together they provide a test of the calculated resource potential [5] of ices in the south polar region.

Previous lunar surface studies suggest survey traverses are tractable in Cabeus and Amundsen craters (e.g., **Fig. 2**) [10,2], two locations where model calculations [11,12] and observations [13,14] suggest volatiles may exist. Locations elsewhere in the south polar regions should also be tractable, as long as slopes are similar.

Because a survey may be conducted tele-robotically when a crew is not available for EVA, the vehicle could be augmented with a robotic arm with trenching, scooping, and grappling capability for *in situ* examination of regolith and sample recovery.

Potential Mass of the Investigation: The GPR is a low mass, low power, and low data rate instrument that can be accommodated within a rover, as previously demonstrated with terrestrial prototypes. Likewise, the NSS data rate is sufficiently low that it can be accommodated on a much smaller robotic vehicle (VIPER) and, thus, is compatible with a more capable crew vehicle.

Estimates of the Cost to Develop and Operate the Investigation: Costs include the development of terrestrial prototype instruments suitable for installation on the next-generation crew rover; tests of an integrated system in a tele-robotic configuration in a benign terrain, such as land at the Johnson Space Center; a simulation of tele-robotic and crewed missions in a lunar analogue terrain, such as the San Francisco Volcanic Field of northern Arizona; production of flight instruments; pre-launch tests of hardware; integration of instruments into flight versions of the crew rover; and flight operations of the instruments, both during crew landings and between crew landings.

Amount of Crew Interaction Needed: In a tele-robotic mode between crew landings, the instruments can be configured to send data to a science operations center on Earth. This remote application of the instrumentation would produce the bulk of the data volume. However, the instruments can also be configured to provide astronauts with real-time output in a SPR cabin that can be used to modify traverse plans.

Requirements for Landing Site(s): The radar can be used in terrains across the entire lunar surface, as it can image regolith with and without volatiles. The former has been demonstrated by the Yutu rover, which imaged regolith down to depths of 20 m using a frequency of 40 and 450 MHz [15].

A radar unit and neutron spectrometer system are ideally suited for lunar terrains that may host subsurface deposits. In this case, landing sites would be in polar regions, typically poleward of 85°, where model calculations and/or orbital observations suggest subsurface ice deposits may exist.

Because a subsurface survey requires mobility, terrain slopes must be suitable for both landing and traverses. A recommended requirement to traverse 25° slopes emerged from the Apollo program [16] and remains a useful benchmark. The chassis of the UPR Chariot was designed to accommodate up to 15° slopes in terrestrial analogue terrains [6]. After a cabin was added to that chassis to produce a SPR, the LER climbed 18 to 20° slopes on cinder-covered volcanic vents. That implies a 25° slope may be possible on the Moon [17]. While slopes >25° exist in the south polar region and will, in some locations, be barriers to trafficability, shallower slopes also exist (**Fig. 2**) in areas that can provide access to PSRs with potential subsurface ice.

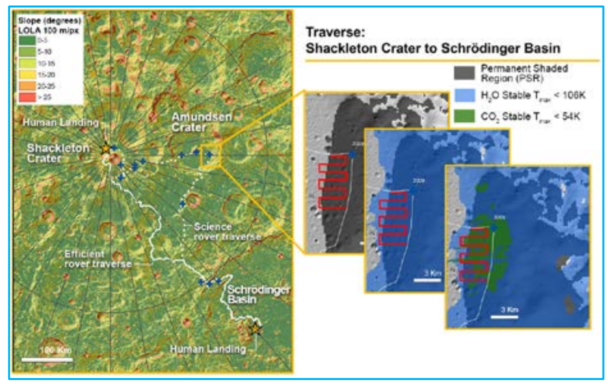

Figure 2. In a tele-operated traverse of the crew rovers between two landing sites (Shackleton impact crater and Schrödinger impact basin), the rovers can take a longer route to conduct subsurface surveys of potential ice deposits that model calculations suggest exist. The three insets illustrate the location of a PSR, where water ice may be stable, and where dry ice may be stable on the floor of Amundsen crater. A survey path (red-line) in and out of the region allows the rover to repeatedly access solar power while providing a regional analysis of potential ISRU targets. After [10,1,2].

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