ENABLING EXPLORATION: ROBOTIC SITE SURVEYS AND PROSPECTING FOR HYDROGEN. R. C. Elphic[1], L. Kobayashi[2], M. Allan[2], M. Bualat[2], M. Deans[2], T. Fong[2], S. Lee[2], V. To[2], and H. Utz[2], [1]Space Science and Applications, Los Alamos National Laboratory, Los Alamos, NM 87545, relphic@lanl.gov, [2]Intelligent Robotics Group, NASA Ames Research Center, Moffett Field, CA 94035 .

Introduction: One of the central challenges for lunar exploration is to mature and validate the system-level concepts of in-situ resource utilization (ISRU) and surface operations including mapping, surveying and prospecting. In particular, identifying and quantifying the distribution of polar volatiles (especially buried water ice in permanently shadowed craters) is essential for determining to what extent ISRU will play a role in lunar exploration. Although remote sensing (e.g., using the numerous sensors carried by LRO) can provide much information, prospecting for subsurface resources can only be performed directly on the surface. In particular, mapping the lateral and vertical distribution of hydrogenous resources on sub-meter scales requires surface activity.

Background: For the past two years, the Intelligent Robotics Group (IRG) at NASA Ames Research Center has been developing a multi-robot system for performing systematic site surveys [1,2]. During July 2007, IRG used this system to survey multiple sites in Haughton Crater (Devon Island, Canada), including a roughly 700 m x 700 m region called "Drill Hill". Two NASA Ames K10 rovers were equipped with the JPL CRUX ground penetrating radar (to map subsurface layers) and an Optech 3D scanning laser (to map surface topography).

In August 2007, we integrated the HYDRA neutron spectrometer, developed by Los Alamos National Laboratory, with a K10 rover. HYDRA is a small neutron spectrometer designed for lander or rover-based detection of surface and near-subsurface hydrates. HYDRA makes use of technology derived from the LANL sensors carried by Lunar Prospector and has been matured to nearly TRL 6. It is ideal for rover-based operations, being low mass (0.5 kg), low power (1.8 W) and compact (18x12x6 cm). We will report on prospecting tests conducted at NASA Ames in September, 2007. **Figure 1** shows the HYDRA neutron spectrometer mounted on a fixture at the front-end of the K10-black rover. The sensors are located some 15 cm above the ground.

Test Objectives: The purpose of the rover test is to demonstrate the utility of HYDRA in prospecting for near-surface hydrogenous deposits, such as might be found in permanently shadowed polar craters on the Moon. But by measuring both thermal and epithermal neutrons, it is possible to extend this capability to deposit characterization. In particular, the two energy ranges make it possible to estimate both burial depth and abundance at depth below a dry surface regolith layer. This has been demonstrated in previous testing at much smaller scales [3]. The spatial extent of a given deposit is provided using the rover's mobility, by mapping the neutron response with position.

Fig. 1. The K10-black rover, with the HYDRA neutron spectrometer mounted at the front (outlined in red). Power, command, and telemetry is provided by the rover. The inset shows a close-up of HYDRA.

Test Setup: A relatively level test site, approximately 40m x 40m in extent, will serve as a proxy for the lunar surface. It is devoid of vegetation and has no buried utilities or other hydrogenous materials. The soil itself contains some clay, so some water of hydration will be present even where there are no deposits. Within the test area, several holes will be excavated and one of two materials will be emplaced at various depths. For some holes, 10-cm thick stacks of polyethylene serve as proxies for 100-wt% ice deposits, as shown in **Figure 2**. At other holes, 15-cm thick stacks of gypsum board serve as proxies for either hydrous minerals or interstitial (pore) ice having 21 wt% water-equivalent hydrogen.

On the lunar surface, cosmic rays constantly impinge on the regolith and create a steady state population of fast neutrons within the soil. But for terrestrial testing, a neutron source is needed to interrogate the

Fig. 2. Emplacement of polyethylene slabs as proxies for water ice. The measured neutron response to a buried deposit depends on burial depth, total hydrogen content, and composition of the overburden.

subsurface. The rover will carry a Californium-252 neutron source mounted next to the HYDRA sensors. The activity of this source is approximately $2x10^6$ n/sec, with a mean neutron energy of ~2 MeV. Fast neutrons from this source penetrate the soil and interact with the materials found there. Deposits with high abundances of hydrogen preferentially moderate (slow down) and thermalize the fast neutrons. Some of these moderated and thermalized neutrons leak out of the subsurface and are detected by the HYDRA sensors. The leakage flux of thermal and epithermal neutrons depends on the burial depth, the net hydrogen content of the buried deposit, and the composition of the overburden.

The prospecting test will be carried out in a single-blind mode. The rover will execute a planned set of traverses, each providing a transect across the test area. Traverse planners will not have knowledge of the deposit locations. Consequently deposit discovery and characterization will only take place if the rover "stumbles upon" a neutron hot spot.

Expected Results: Tests carried out previously on the CRUX project have shown that it is possible to detect buried deposits, and even to characterize their spatial extent, burial depth and the deposit's water-equivalent hydrogen abundance. We expect similar results here, but from a far more realistic roving scenario. Phase 1 will involve executing the transects with 1-meter spacing. The nominal driving speed is planned to be 10 cm/sec, but it is likely that sufficient signal-to-noise can be achieved with 20 cm/sec.

Figure 3 shows the calculated maps obtained from 100-wt% and 21 wt% H_2O deposits at various burial depths, for a subset of the planned test area. Each deposit is 1-m by 1-m in size, and the rover traverse speed is 20 cm/sec. Suitable Poisson statistics are included in the calculation, to give a sense of the effects of noise. All deposits should be clearly detected based on this calculation.

We will compare the test results to the simulated results, and explore the ramifications for robotic surface exploration at the lunar poles.

References: [1] Fong, T. et al. (2007) *LPS XXXVIII,* Abstract 1487, Houston, TX. [2] Fong, T. et al. (2006), AIAA-2006-7425, *AIAA Space 2006*, San Jose, CA. [3] Elphic R. C. et al. (2007) *Astrobiology, in press*.

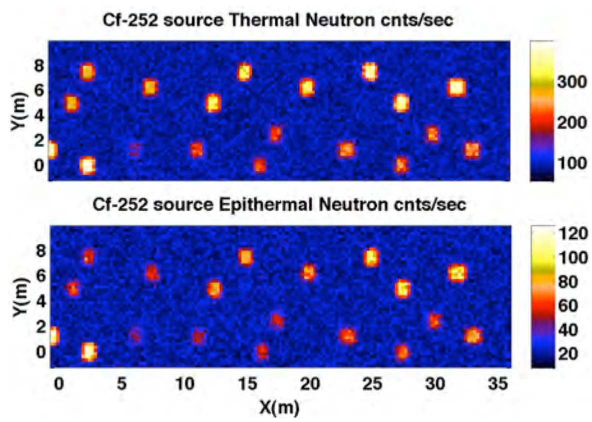

Fig. 3. (Top) Thermal neutron count rate for 100-wt% and 21 wt% H_2O-equivalent deposits, each 1-m by 1-m, buried at 30, 15 and 5 cm depths. (Bottom) Epithermal neutron count rate for the same deposits.