SIMULATING ACTIVE NEUTRON MEASUREMENTS IN LUNAR PITS. A. Berner1,2, C. Hardgrove1, P.J. Gasda3, K. Mesick2. 1Arizona State University (aberner1@asu.edu), 2Los Alamos National Laboratory.

Introduction: Pits and skylights on the lunar surface provide both a unique and important environment for future scientific exploration due to their geometries exposing the cross-sectional layers of the upper lunar crust [1,2]. Recently, the proposed mission Moon Diver has developed a framework to robotically explore lunar pits and perform experiments to investigate the geochemical composition of the layers exposed in the pit walls as the robot descends [3].

One method of investigating the geochemical composition of surrounding terrain, specifically the amount of hydrated material within minerals, amorphous phases and/or within ices (expressed as water-equivalent-hydrogen or ‘WEH’) and neutron absorption cross-section (Σp), is through active neutron interrogation. In addition, recent studies of the Dynamic Albedo of Neutrons (DAN) instrument response to high-relief topography on Mars have demonstrated there is a measurable effect of nearby topography and relief on neutron measurements [4,5]. Here we explore whether the unique geometries of lunar pits provide an environment where neutron interrogation can be used to investigate the geochemistry of the exposed crustal layers. Due to the lack of natural neutron generation through GCR interactions at depths greater than 5m [6], such measurements would need to be made with an onboard neutron source (thus, active neutron measurements). We present the results of simulations of active neutron measurements in lunar pit geometries and demonstrate the feasibility of performing such measurements. We also explore the potential to understand the geochemical composition of multiple nearby surfaces by comparing simulation results of different geometries.

Methods: Using the Monte Carlo N-particle transport code (MCNP6), we performed simulations of a point source (14.1 MeV) and point detector within two geometries: a full-cylinder and a half-cylinder of various diameters (20m, 10m, 5m) surrounded by lunar material, representing a lunar pit (Fig. 1). The source-detector pair were separated from each other by 4cm in the y-axis, and both were located 30cm away from the cylinder wall in the x-axis. The base composition of the lunar material is the Apollo 15 sample composition [7], and the hydration of the material was varied between 500ppm–1500ppm H in steps of 500ppm H. The depth of the (half-) cylinder was simulated as 30m and simulations of the point detector counts were performed at depths of 5m, 15m, and 25m.

Results and Discussion: Observability. To determine the observability of these simulations, we converted the MCNP6 output (particles/cm²) to simulated counts reflective of an instrument’s integration time by using DAN instrument parameters from [8]. We assume a 10-minute measurement, with the neutron source pulsing at 10 Hz and 10⁷ neutrons emitted per pulse. Neutron arrival time. For each cylinder geometry, we estimate the earliest time of arrival of thermal neutrons with energies of 0.3eV (consistent with Cd or Gd cutoff) returning from 5m away from the detector. We then compare these estimated earliest arrival times to results from the cylinder geometries and their counterpart half-cylinder geometries to understand the effect of the further surfaces on neutron counts.

Figure 1. Cross-section (X-Z) through the modeled pit and detector geometries. Pits are modeled as cylinders (left) and stars represent the relative locations and depths of source-detector pair in simulations. Half-cylinders (right) are used to assess the contribution of the near vs. far wall of the pit to neutron counts.

Figure 2. Simulated thermal neutron die-away curves for pits modeled as cylinders with diameters of 5m, 10m, and 20m. The detector is placed at 15m depth and the pit walls contain 500ppm H (10-min integration).
that measurements made in lunar pit geometries at the lowest sampled hydration (500ppm H) with 10-minute instrument integration times are statistically separable and interpretable based on observations made with DAN [8,9] (Fig. 2).

Figure 3. Simulated thermal neutron die-away curves for pits containing 500, 1000, and 1500 ppm H. The pit is modeled as a cylinder with a diameter of 20m and the detector is placed at 15m depth (10-min integration).

We find that within a 20m diameter pit, neutron measurements will be sensitive to the hydration of both the nearby and far walls. Variable hydration with depth will also produce distinctive neutron die-away curves (Fig. 3). Such curves from in-situ measurements could be used to derive geochemistry results of the nearest surface, as in [9, 10].

Neutron arrival time. In the smallest diameter simulations, we find that the later time bins of the full-cylinder die-away curves experience an increase in counts due to the later arrival time of neutrons returning from further surfaces (Fig. 4). In the full-cylinder, larger diameter pit simulations (10m and 20m), the broadening of the die-away curve is negligible, so we look at total counts in the later time bins. Here, “later time bins” are defined as the time bins spanning from ten bins after the primary curve peak out to 10,000µs. We compare the integrated counts of the full-cylinder and half-cylinder simulations and find that, at all depths, there is an increase in counts in the later time bins for the full-cylinder simulations (Fig. 5). As expected, there is a larger increase in counts at the 25m depth for both 10m and 20m diameters, which represents the contribution of neutrons returning from the floor. These results show that measurements taken in a full-cylinder geometry incorporate both the hydration of the near wall, as well as the hydration of the far wall.

This work demonstrates that active neutron measurements in lunar pit geometries have the potential to enable important geochemical investigations of the lunar crust at depth. At a minimum, these types of measurements are valuable in their ability to constrain the H content and ∑ of the wall nearest the detector. Additionally, these simulations suggest that die-away curves in such geometries hold information about surfaces beyond those nearest the detector.

Figure 4. Simulated thermal neutron die-away curves for 5m diameter full- and half-cylinder geometries at 15m depth at 500ppm H (10-min integration). The vertical dashed line represents the earliest estimated time 0.3eV neutrons begin to return from surfaces 5m away.

Figure 5. Total thermal neutron counts in later time bins for 10m diameter full- and half-cylinder simulations, with arrows representing the contribution of counts from the further walls. The difference between 10m diameter full- and half-cylinder total counts at 1000ppm H is greater than 316,000.

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