LUNAH-MAP MINIATURE NEUTRON SPECTROMETER RESPONSE OVER NEUTRON SUPPRESSED REGIONS S. West[1], C. Hardgrove[1], R. Starr[2], E. B. Johnson[3], J. Christian[3], A. Genova[4], A. Colaprete[4] and D. Nelson[5]; [1]Arizona State University, Tempe, AZ (stwest@asu.edu); [2]Catholic University of America, Washington, D.C.; [3]Radiation Monitoring Devices, Watertown, MA; [4]NASA Ames Research Center, Moffett Field, CA; [5]KinetX, Simi Valley, CA.

Introduction: The Lunar Polar Hydrogen Mapper (LunaH-Map) is a 6U CubeSat mission that will launch as a secondary payload on the Space Launch System (SLS) Exploration Mission 1 (EM-1) in late 2018. LunaH-Map will use a low-thrust propulsion system to maneuver into an eccentric orbit with perilune at a low altitude over the south pole. LunaH-Map will carry a miniaturized neutron spectrometer (Mini-NS) to measure the spatial extent and distribution of hydrogen enrichments within permanently shadowed regions. The Mini-NS instrument employs an uncollimated detector system using two 2×2 arrays of an elpasolite scintillator, Cs_2LiYCl_6:Ce, that is sensitive to both gamma-rays and neutrons [1,2]. The total detector area of the Mini-NS is ~200 cm^2. A thin cadmium shield limits the Mini-NS sensitivity to only epithermal neutrons (>0.4 eV).

The development of the LunaH-Map spacecraft requires a fast-paced schedule, with concurrent development of the instrument and flight systems. Accordingly, a full description of the instrument characterization, performance, and calibration will not be presented until the Mini-NS design has progressed beyond a critical design review. In the interim, a tool was needed to quickly assess trajectories prepared by the mission design team. Here we present the preliminary results of anticipated spatial sensitivities to hydrogen based on the current LunaH-Map science orbit and Mini-NS design.

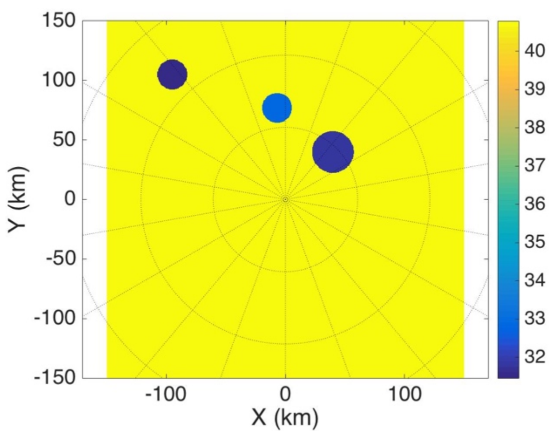

Figure 1: The 600×600 pixel basemap for Mini-NS dataset simulation represents a simplified geometry of south pole craters Haworth, Shoemaker, and Cabeus and uses 7.5×7.5 km pixels to represent a 150×150 km area.

Dataset Simulation: The LunaH-Map Mini-NS dataset is simulated by stepping through the current spacecraft science orbit using a fixed integration time of 1 second (equal to a down-track distance of approximately 2 km at perilune). JPL's SPICE toolkit [3] for MATLAB is used to extract spacecraft lunar latitude and longitude from an SPK file provided by the mission design team. A basemap is created to represent a simplified geometry of hydrogen enriched regions in the craters Haworth, Shoemaker, and Cabeus (Figure 1). Initial dimensions and hydrogen abundance of the basemap regions were chosen to be approximately consistent with the neutron suppressed regions (NSRs) detected by the Lunar Reconnaissance Orbiter (LRO) Lunar Exploration Neutron Detector (LEND) [4]. The "dry" count rate of 40.8 counts/sec (cps) was derived from a MCNP6 simulation using a model of the Mini-NS instrument. The resulting basemap of epithermal neutron count rates shown in Figure **1** is derived from the relationship between count rate and hydrogen abundance taken from Prettyman et al. [5] and shown in Figure **2**.

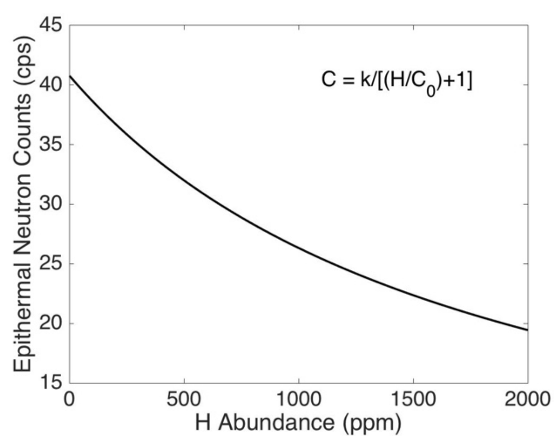

Figure 2: Experimentally determined relationship between epithermal count rate and hydrogen abundance. Here, k (fit constant) is taken to be 1820 µg/g and C_0 ("dry" epithermal count rate) is taken as 40.8 cps.

In this work, neutron flux is assumed to be constant with altitude but will be adjusted in future analyses. Total counts at each time step are simulated by applying Poisson noise to the seeded epithermal count rate from the base map and multiplying by the instrument integration time (1 second). The output of the simulation routine is a series of total epithermal neutron counts for each second of the LunaH-Map science phase where the spacecraft is poleward of 70 degrees.

Mapping Routine: Maps are created from the time series data using only spacecraft position information as an additional input. A 7.5×7.5 km mapping grid is used to represent the same 150×150 km area. At each time series data point, the total counts recorded are assigned to the grid square containing the sub-satellite point.

Results: The current LunaH-Map science orbit provides 141 science passes over the south pole in approximately 30 days. Figure 3 shows the resulting count rate map.

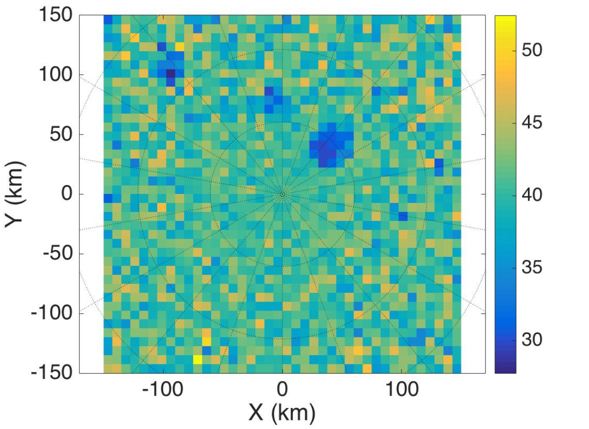

Figure 3: The count rate map shows lower count rates corresponding to the enriched regions in Figure 1.

To evaluate the spatial sensitivity of the LunaH-Map Mini-NS, measured count rates were compared for different combinations of hydrogen abundance and spatial extent in the craters Haworth, Shoemaker, and Cabeus. The product of enriched area (km^2) and hydrogen abundance (ppm) was kept constant for all test points. Sensitivity will be latitude dependent because the geometry of the science orbit provides greater coverage (more integration time) closer to the pole. The test points are shown in Table 1 with results in Figure 4. Error bars shown represent the error in total counts (both "dry" and enriched) propagated through to hydrogen abundance.

Discussion: As mapping grid pixel size is increased (e.g. 15×15 km v. 7.5×7.5 km pixel), the total binned counts in each pixel increase, thereby decreasing statistical uncertainty. In this preliminary work, our results indicate that the LunaH-Map Mini-NS is capable of detecting hydrogen enrichments consistent with LEND NSRs. In our analyses, we also include smaller neutron suppression regions than those observed by LEND, with these regions containing even greater hydrogen abundances, to determine sensitivities to more localized hydrogen enrichments. For example, within Haworth, LunaH-Map can detect 490±130 ppm water equivalent hydrogen (WEH) over a 490 km^2 area or 1200±230 ppm WEH over a 177 km^2 area. Further development of mapping routines and characterization of the Mini-NS instrument response function will enable higher fidelity simulation of science results.

Table 1: Enriched areas and corresponding hydrogen abundance for spatial sensitivity study

Haworth		Shoemaker		Cabeus	
Area (km^2)	WEH (ppm)	Area (km^2)	WEH (ppm)	Area (km^2)	WEH (ppm)
490.9	440	962.1	510	490.9	540
314.2	690	706.9	700	314.2	840
176.7	1220	490.9	1000	176.7	1500

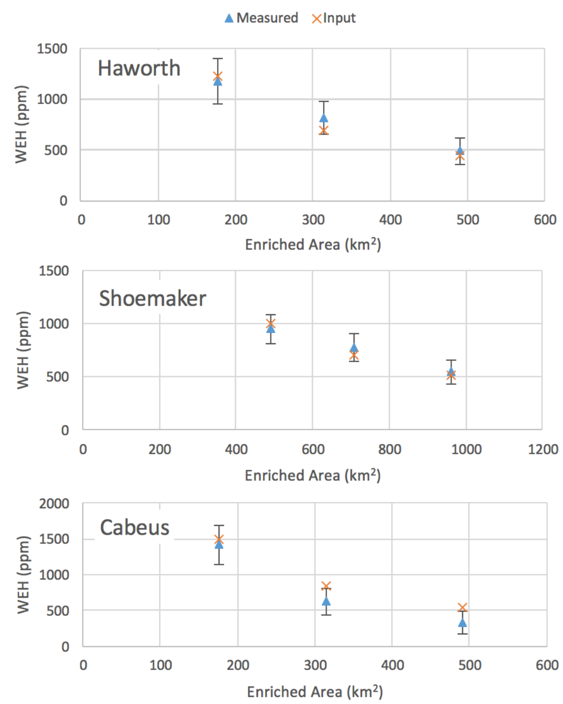

Figure 4: LunaH-Map Mini-NS performance over south pole NSRs

More precise hydrogen measurements may be obtained by extending the science phase beyond the 30 days simulated. Since LunaH-Map's science orbit is currently "quasi-frozen" (minimal apsidal precession), science phase extension to 2-4 months may be possible with minimal propellant expenditure. Future simulations will take this into account as the mission design continues to mature.

References: [1] Glodo, J. et al. (2007) IEEE Nuclear Sci. Symposium Conf. pp. 959-962. [2] Johnson, E. et al. (2013) INMM Annual Meeting. [3] Acton, C.H., (1996) *PSS*, pp. 65-70. [4] Sanin, A.B. et al. (2017) *Icarus* 283, pp. 20-30. [5] Prettyman, T.H. et al. (2012) *Science* 338, pp. 242-246.