Compositional Dependencies of Lunar High-Energy Epithermal Neutrons. David J. Lawrence[1], Vince R. Eke[2], Richard C. Elphic[3], William C. Feldman[4], Herbert O. Funsten[5], Thomas H. Prettyman[4], Luis F. A. Teodoro[6]; [1]Johns Hopkins University Applied Physics Laboratory (11100 Johns Hopkins Drive, Laurel, MD, 20723; David.J.Lawrence@jhuapl.edu); [2]Durham University, Durham UK; [3]NASA Ames Research Center, Moffett Field, CA 94035; [4]Planetary Science Institute, Tucson, AZ 85719; [5]Los Alamos National Laboratory, Los Alamos, NM 87545; [6]BAER, NASA Ames Research Center, Moffett Field, CA 94035.

Introduction: The presence of enhanced hydrogen (H) abundances at the lunar poles is a topic of intense interest for both the scientific and space exploration communities. The Clementine and Lunar Prospector (LP) spacecraft provided initial indications [1] and quantitative assessments [2,3] of the hydrogen enhancements located at the lunar poles. Recent measurements from the Lunar Crater Observation and Sensing Satellite (LCROSS), Lunar Reconnaissance Orbiter (LRO), and Chandrayaan-1 spacecraft [4,5,6,7] are providing further information about the nature, abundance, and spatial extent of lunar polar volatiles. In particular, data from the Lunar Exploration Neutron Detector (LEND) has been used to make assessments of lunar polar H with a claimed spatial resolution substantially better than that of the LP neutron measurements [7,8]. Based on a study of high-energy epithermal (HEE) neutrons (E_n > 1 keV), which likely constitute a background in the LEND collimated data, we suggest that the claim of high-spatial resolution neutron measurements is premature. We suggest further work should be carried out to understand better the quantitative contribution of this background to the LEND collimated neutron data.

Relation of High-Energy Epithermal Neutrons to LEND Measurements: LEND uses the technique of orbital neutron spectroscopy to detect and quantify planetary surface H concentrations. Orbital neutron detectors are typically omnidirectional with an intrinsic spatial resolution equal to its spatial footprint of 1 – 1.5 times the spacecraft altitude. LEND is designed to achieve improved spatial resolution by placing a neutron absorbing collimator in front of standard ^{3}He neutron sensors. If enough wide-angle neutrons are blocked by the collimator, then the narrow field-of-view (FOV) neutrons provide measurements with enhanced spatial resolution [8].

Based on standard neutron transport physics, any neutron collimator is transparent to neutrons with sufficiently high energy. For this discussion, epithermal neutrons can be divided into two subsets: HEE and low-energy epithermal (LEE) neutrons. HEE neutrons are defined as neutrons with an energy $E > E_{trans}$, the energy above which the LEND collimator is transparent to neutrons. LEE neutrons are defined as those neutrons with $E < E_{trans}$ and are collimated by more than a factor of 1/*e*. The LEND ^{3}He sensors provide no information about a neutron's incident angle or energy and only indicate a neutron detection, so HEE neutrons are indistinguishable from LEE neutrons in the LEND sensors. Therefore, HEE neutrons constitute an uncollimated background that requires subtraction and/or correction. The spatial character and magnitude of this background is driven by the energy- and angle-dependent sensor response, the relative FOV ratio between the HEE and LEE neutrons, and E_{trans}.

E_{trans} values for LEND have not been published. We have consequently estimated E_{trans} using published instrument specifications [8] and the particle transport code MCNPX (e.g., [3]). We find E_{trans} to be in the range of 1 – 10 keV. Accurate, quantitative assessments of the other factors, which mostly affect the magnitude of the HEE background, require a neutron transport model of the LEND instrument and LRO spacecraft and is beyond the scope of this study. Qualitative information about the HEE neutron background can be obtained by studying its dependence on lunar surface composition. Some estimates of the magnitude of the HEE background can be obtained by investigating measured LEND data.

Compositional Dependencies of HEE Neutrons. LEE neutrons, which dominate collimated LEND data and previous uncollimated Lunar Prospector (LP) data [3,9], show a strong anticorrelation with neutron absorbing elements Fe, Ti, Gd, and Sm for equatorial, non-H bearing soils. This anticorrelation is seen both in measured data [9] and models [3], and is illustrated in Figure 1. In contrast, HEE neutrons show a positive correlation with the soil's average atomic mass (Figure 2) in a manner similar to that of fast neutrons [10,11] (atomic mass is highly correlated with Fe content in lunar soils). Figure 2 shows 10% count rate variation from mare to highlands soils in a ^{3}He neutron sensor. For polar soils enriched with H, HEE neutrons behave almost identically to that of LEE neutrons (Figure 3). Thus, the uncollimated HEE neutron background should correlate with fast neutrons in equatorial, non-polar regions, and correlate with LP epithermal neutrons in polar regions.

Observations with LEND Data. Figure 4 shows a summed count rate map of all LEND collimated sensors with data taken from the NASA Planetary Data System (PDS). Enhancements in the nearside mare are highly correlated with LP measurements of fast neutrons [9,10,11], which suggests that background HEE neutrons are responsible for this spatial variation. The mare/highlands count rate decrease is ~0.3 cps (4.93-4.63). If this count rate difference represents the ~10% change from a HEE background, then the implied HEE neutron count rate is in the range of 3 cps (i.e., 3 = 0.3/0.1), and would therefore be a significant background compared to the LEND count rate of 5 cps [7].

The polar regions show count rate decreases that are correlated with LP epithermal neutrons [2,3]. It is this count-rate decrease that indicates the presence of enhanced, polar-H abundances. From the discussion of HEE compositional dependencies, and from the observation that there appears to be a significant HEE background in the equatorial LEND data, the polar regions may also have a significant, uncollimated HEE background that varies with polar H content. It is therefore important that this uncollimated, H-dependent background be fully characterized and removed from the H-dependent collimated foreground signal.

Conclusions. Characterizing and quantifying the HEE background requires detailed modeling and documentation of the LEND energy and angle response. Independent analyses of Earth-to-Moon cruise data as well as global elliptical orbit data, which have large altitude variations, should also provide considerable insight because each of the signal components (FOV foreground and various backgrounds) depend differently on spacecraft altitude. Such altitude dependencies should be identifiable within these data, which can enable the magnitude of each component to be quantified.

References: [1] Nozette et al., *Science*, 274, 1495, 1996; [2] Feldman et al., *JGR*, 105, 4175, 2000; [3] Lawrence et al., *JGR*, 111, 10.1029/2005JE002637, 2006; [4] Colaprete et al., *Science*, 330, 462, 2010; [5] Spudis et al., *GRL*, L06204, 2010; [6] Gladstone et al., *Science*, 330, 472, 2010; [7] Mitrofanov et al., *Science*, 330, 483, 2010; [8] Mitrofanov et al., *Space Science Review*, 10.1007/s11214-009-9608-4, 2009; [9] Maurice et al., *JGR*, 109, 10.1029/2003JE002208, 2004; [10] Maurice et al., *JGR*, 105, 20365, 2000; [11] Gasnault et al., *GRL*, 28, 3797, 2001.

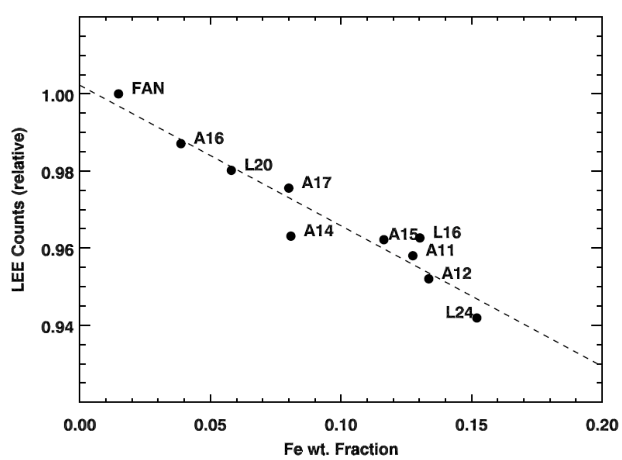

Figure 1. Modeled LEE epithermal neutron count rate versus Fe content for various returned lunar soils (adapted from [3]). Relative count rates are calculated for the LP ^{3}He neutron sensors. The count rates are anticorrelated with Fe content. The anticorrelation is confirmed with LP orbital data [3,9].

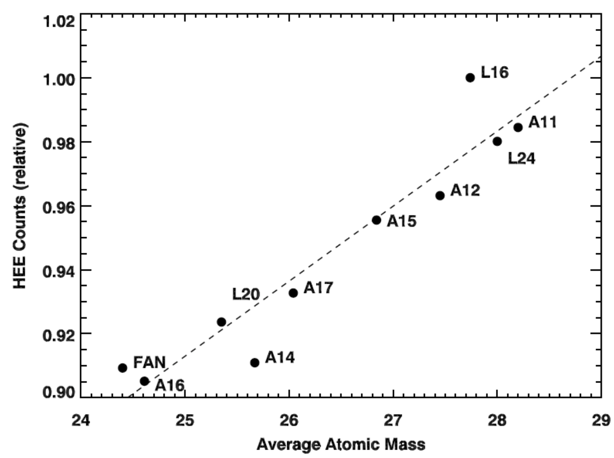

Figure 2. Modeled HEE (E_n > 1 keV) epithermal neutron count rate versus average atomic mass for returned lunar soils. Relative count rates are calculated for the LP ^{3}He neutron sensors. In contrast to LEE neutrons, HEE neutrons show a positive correlation that is similar to the behavior of fast neutrons.

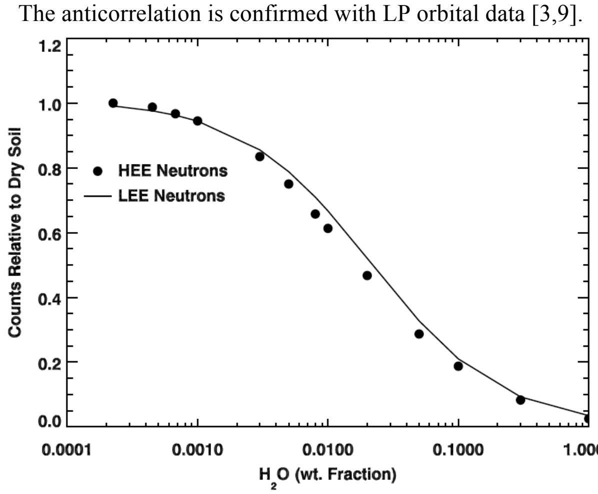

Figure 3. Modeled epithermal neutron count rate ratio (dry/wet) versus water equivalent hydrogen content for lunar ferroan anorthosite soils. HEE neutrons from ^{3}He sensors are circles. LP LEE-dominated neutrons are the solid line from fit of [3].

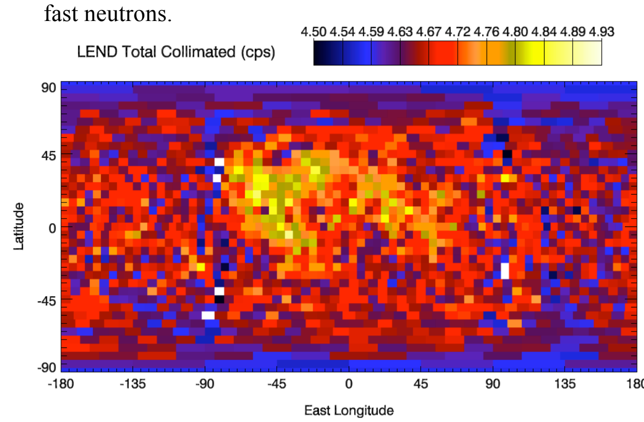

Figure 4. Map of LEND collimated neutron count rate, summed for all LEND sensors and given in units of counts per second on pixels of ~150km x 150 km.