SENSITIVITY OF NEUTRON MEASUREMENTS TO THE THICKNESS AND ABUNDANCE OF SURFICAL LUNAR WATER. D. J. Lawrence[1] , W. C. Feldman[2], R. C. Ephic[3], S. Maurice[4], D. M. Hurley[1], and R. S. Miller[5], [1]Johns Hopkins University Applied Physics Laboratory (11100 Johns Hopkins Drive, Laurel MD, 20723; David.J.Lawrence@jhuapl.edu), [2]Planetary Science Institute, Tucson, AZ; [3]NASA Ames Research Center, Moffett Field, CA; [4]CESR, Toulouse, France; [5]University of Alabama-Huntsville, Huntsville, AL.

Introduction: The possibility that water might be present on the Moon has been investigated over the past 40 years with both theoretical studies [1,2] as well as a variety of space-based measurements [3,4]. Most of these studies have focused on the presence of water and/or hydrogen in permanently shaded regions (PSR) at the lunar poles. It has further been assumed that water could not be present to any significant extent in lunar sunlit regions due to its inherent instability on the hot lunar surface. Thus, recently released results that show extensive water on the lunar surface as detected by near infrared (NIR) data has surprised the planetary science community [5,6,7]. These data show that OH/H_2O is extensively spread across the lunar surface, may be present to a depth of a few mm, and has an abundance of ~700 ppm H_2O. The exact depth and abundance values, however, are highly uncertain. In addition, data from the Chandraayan-1 M[3] instrument shows an enhancement of an OH/H_2O signature at Goldschmidt crater, which is located in the northern, lunar nearside. Goldschmidt crater also shows an enhancement of epithermal neutrons, which according to convention methods of interpreting neutron data, indicates very low H abundances within the top 30 cm.

This study has a two-fold purpose: 1) Investigate the sensitivity limits of neutron data – both in terms of layer thickness and H abundance – for detecting the type of surfical water measured by the NIR data. 2) Use this information to investigate Lunar Prospector (LP) neutron data, particularly at Goldschmidt crater, for signs of surfical water.

Neutron Transport Models: In previous studies that have modeled the response of thermal and epithermal neutrons to hydrogen, it was assumed that the H was either in a single layer or in two layers where a desiccated layer overlaid a H-rich layer. The case of an H-rich layer on top of a dry layer has not been modeled. Here, we model the case of an H-rich layer overlying a dry layer using the particle transport code MCNPX as described in [8]. For a set of models using a ferroan anorthosite composition (FAN), the top thickness layer is varied from 0.05 – 100 cm and the H abundance within the FAN is varied from 10^{-6} – 10^{-2} wt. frac. H. The modeled neutron flux is shown in Fig. 1 for three top layer thicknesses. For layers thinner than 0.5 cm, the H-rich layer is seen to have no effect on the neutron flux. The H-rich layer starts to clearly affect the neutrons for a thickness of 3 cm with an increase in thermal neutrons that leak over to the epithermal range, and a slight decrease in high energy epithermals. At 100 cm, the top layer shows the same behavior as a single, H-rich layer with a large decrease in epithermal neutron flux for increasing H abundance.

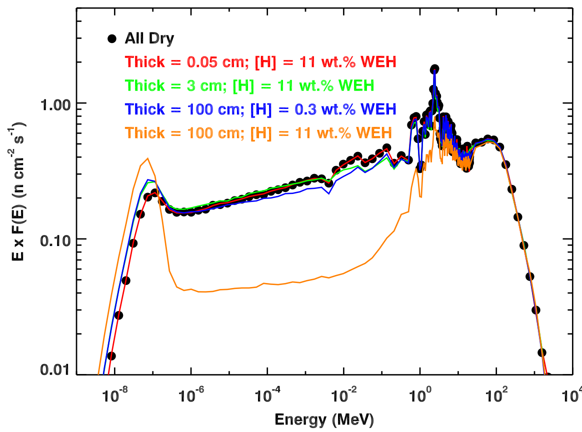

Fig. 1. Neutron flux (F) times energy (E) as a function of energy for various top layer thicknesses and H abundances.

The neutron fluxes have been converted to thermal and epithermal neutron counting rate ratios (Fig. 2) for LP-type ^{3}He neutron detectors [9]. These ratios show that for layers thinner than 0.3 – 0.8 cm, neither thermal or epithermal neutrons are sensitive to any amount of H up to 10 wt.% water equivalent hydrogen (WEH). For thicknesses between 1 and 30 cm, the epithermals show a relative increase in counts, which is contrary to their behavior for a single layer or a dry over wet layer scenario. Thermal neutrons show a monotonic count rate increase for this range of thicknesses and H-abundances.

Lunar Prospector Neutron Data: Here we focus on Goldschmidt crater, which was identified by [5] as having an enhancement of surfical OH/H_2O as well as a relative maximum of epithermal neutrons of ~3%. We also note that Goldschmidt crater also shows a relative maximum in thermal neutron counts of ~19% compared to the surrounding region. Based on a single layer model, the relative enhancement in epithermal neutron counts indicates a relative minimum in H abundance. However, with the new modeling results described above, an initial interpretation could be suggested that the neutron data show evidence of an H-rich top layer having loose constraints of 1 – 30 cm in thickness and 0.1 – 10 wt.% WEH, where the larger H abundances correspond to thinner layers.

However, before reaching such an unexpected conclusion, other explanations for the thermal and epithermal data should be investigated. It is well known that both thermal and epithermal neutrons are affected by the presence or absence of elements with large neutron capture cross sections such as Fe, Ti, Gd, and Sm [10,11]. Fig. 3 shows plots of thermal and epithermal neutrons versus scaled Fe and Th abundances in the Goldschmidt region, where Fe and Th are scaled to their maximum values. Here, Th is used as a proxy for the incompatible rare earth elements Gd and Sm. The black data points show the global trends and the red data points show trends in the Goldschmidt crater region. As seen, there is a strong correlation between both neutron energies and the combined Fe and Th abundances, which indicate that neutron capture effects are the dominant factor driving the neutron measurements in the Goldschmidt region. In contrast, the orange data points show data poleward of 80º, where the previously identified polar H deposits show no correlation Fe or Th abundances. In particular, Goldschmidt crater has large neutron counts mostly due to a relative lack of Fe, Gd, and Sm content as demonstrated in elemental maps (not shown). We further note that in a general survey of sunlit regions polar of 60º, the Goldschmidt region stands out by having this simple correlation of Fe, Th, epithermal, and thermal neutron measurements.

Two implications of this result are: 1) Neutron data do not show strong evidence for a H signature at Goldschmidt crater; and 2) Based on the new neutron transport models described above, the thickness of the H-rich material detected by the NIR spectral data is less than 0.5 cm.

References: [1] Watson K. et al., (1961) JGR, 66, 3033; [2] Arnold J. (1979) JGR, 84, 5659; [3] Nozette S. et al. (1996) Science 274, 1495; [4] Feldman W. C. et al. (1998) Science 289, 1489; [5] Pieters C. M. (2009) Science 326, 568; [6] Clark R.N. (2009) Science 326, 531; [7] Sunshine J.M. et al. (2009) Science 326, 565; [8] Lawrence D.J. et al. (2006) JGR 111, 2005JE002637; [9] Lawrence D.J. et al. (2009) Icarus, submitted; [10] Elphic R.C. et al. (2000) JGR 205, 20333; [11] Maurice S. et al. (2004) JGR 109, 2003JE002208.

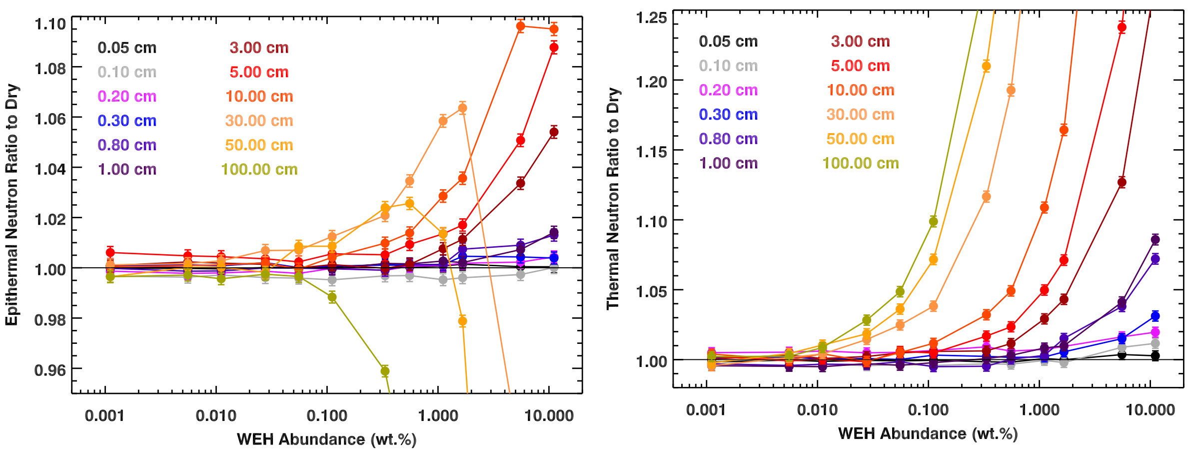

Fig. 2. Epithermal (left) and thermal (right) neutron count rate ratios for various top layer thicknesses and H abundances.

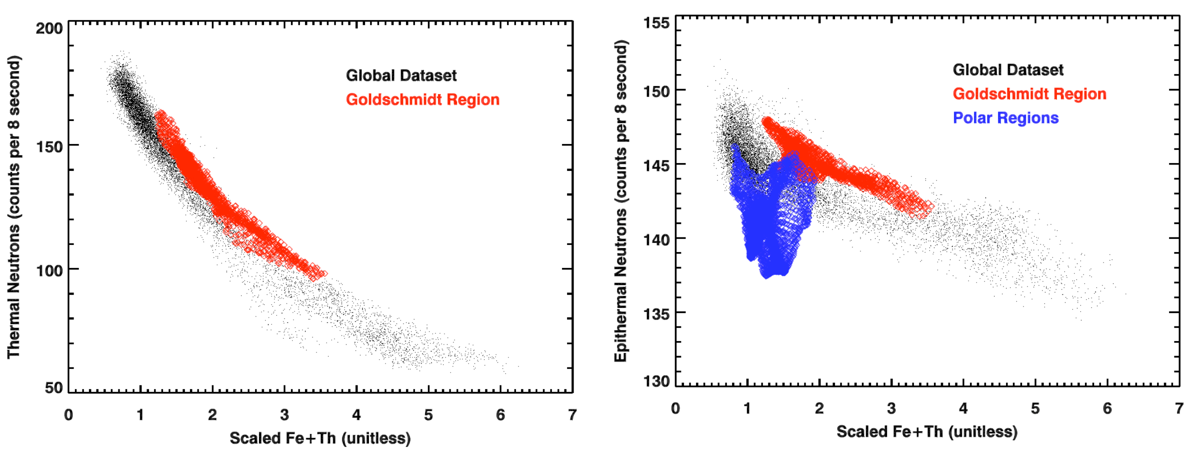

Fig. 3. (Left) Thermal neutrons versus scaled Fe+Th abundances for the entire moon (black) and Goldschmidt region (red). (Right) Epithermal neutrons versus scaled Fe+Th abundances for the entire moon (black), the Goldschmidt region (red) and regions poleward of 80º (orange).