ENERGY AND ANGULAR SPECTRA OF ALBEDO PROTONS AND NEUTRONS EMITTED FROM HYDRATED LAYERS OF LUNAR REGOLITH.  L.W. Townsend¹, F. Zaman¹, N.A. Schwadron², J.K. Wilson³, H.E. Spence², A.W. Case³, J.C. Kasper³, J.E. Mazur⁴, and M.D. Looper⁴, ¹Department of Nuclear Engineering, The University of Tennessee, Knoxville, TN, USA (first author email address: ltownsen@tennessee.edu), ²EOS Space Science Center, University of New Hampshire, Durham, NH, USA, ³University of Michigan, Ann Arbor, MI, USA, ⁴The Aerospace Corporation, El Segundo, CA, USA.

Introduction. Nuclear interactions of galactic cosmic rays (GCR) with lunar regolith have produced albedo protons detected by the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) instrument onboard the Lunar Reconnaissance Orbiter (LRO) spacecraft [1]. These albedo protons are mainly composed of secondary protons produced by fragmentation/spallation reactions of the incident cosmic ray spectrum, and incident protons themselves scattered by the regolith components. Data analyses by the CRaTER team have indicated that there is an approximate 40% increase in proton flux when observing the lunar limb rather than the nadir [2]. Also, the presence of diurnal variations in albedo proton yields is under investigation.

Modeling of Albedo Yields. In an effort to further understand the measured albedo proton yield variations, we have modeled the energy and angular yields of protons and neutrons emitted from the lunar surface as a function of hydration layer thickness in the lunar regolith using the MCNP (Monte Carlo Neutral Particle) computer code developed at Los Alamos National Laboratory [3]. Estimated yields of albedo protons and neutrons as a function of energy and angle for protons at 100, 300, 500, 750 and 1000 MeV incident energies striking the lunar surface at angles of 5 and 90 degrees above the surface are reported. The lunar surface was assumed to contain thin layers of hydration of varying thicknesses between 1 and 10 cm. Calculations were also performed for a complete, isotropic GCR proton spectrum incident on these same thicknesses of hydrated regolith. For this full spectrum, energy and angular spectra of albedo protons and neutrons were also estimated.

Energy and Angular Spectra Characteristics. As expected, yields of albedo protons increase with increasing depth of the hydrated layer at high energies, but not so at energies around 100 MeV. Yields of albedo neutrons, on the other hand, increase with angle relative to the surface, and are peaked at 90 degrees. Yields of albedo neutrons also increase with incident proton energy at all angles, which is to be expected since the number of neutrons produced in each spallation reaction is known to increase with incident proton energy. Neutron yields for all proton energies are also higher for thinner hydration layers, which indicate that thicker layers tend to attenuate the neutrons through nuclear collisions with the added hydrogen content. Some of this attenuation of neutrons contributes to increased proton yields as the hydration layer thickens.

For an isotropic distribution of incident GCR protons (full GCR spectrum), The calculations indicate that the albedo proton yields are broadly-peaked around 15 degrees from the horizontal, independent of hydrated layer thickness (comparing 1 cm to 10 cm thicknesses). The peak proton yields around 15 degrees are also a factor of two larger than the yields at angles larger than 70 degrees, which tends to explain the observed increased proton yields when observing the lunar limb.