Hydrogen on the Moon: A Summary of Lunar Prospector Neutron Measurements of Lunar Hydrogen Concentrations. David J. Lawrence[1], [1]Johns Hopkins University Applied Physics Laboratory (11100 Johns Hopkins Drive, Laurel, MD 20723; David.J.Lawrence@jhuapl.edu).

Introduction: Planetary neutrons are created from nuclear spallation reactions when high-energy galactic cosmic rays (GCR) hit planetary surfaces. These high-energy (E_n=MeV) neutrons undergo scattering and absorption reactions through which the concentrations of various elements (H, Fe, Ti, Gd, Sm) can be inferred [1,2,3,4,5]. In the presence of hydrogen (H), which has the same mass as neutrons, neutrons lose their energy very efficiently because of the large scattering cross section of H and their closely equal mass. While epithermal neutrons (0.4<E_n<500keV) are somewhat sensitive to neutron absorbing elements (Fe, Ti, Gd, Sm)[6,7] they are most dominantly sensitive to H concentrations [7].

The Lunar Prospector Neutron Spectrometer (LP-NS) was the first successful use of planetary neutron spectroscopy. Global measurements were carried out over 18 months in two mission phases [6]. The first phase lasted 12 months and collected data from a 100 km altitude polar orbit; the second phase lasted six months and collected data from a 30 km altitude polar orbit. Because the LP-NS is an omni-directional detector, the spatial resolution of the measurements is ~1 – 1.5 times the mean altitude above the surface [6].

Initial LP Measurements: In the studies of Feldman et al. [1,2,3], clear evidence was given for enhanced H at the lunar poles based on decreases of epithermal neutrons in the vicinity of permanent shaded craters. When averaged over the entire LP-NS field of view, the measured H was found to be 100 – 150 ppm H, compared to ~50 ppm H observed at more equatorial latitudes due to solar wind implanted H. If it is assumed that the H signal only comes from permanently shaded regions (PSR), it was inferred that the average H concentration within PSRs is 1.5±0.8 wt.% water equivalent hydrogen (WEH). Due to the broad spatial resolution, it is not possible to isolate H signals from any PSR.

Follow On Studies Using LP-NS Data: More recent studies of LP data have focused on various aspects of lunar H concentrations that can be inferred from LP neutron data. Lawrence et al. [7] carried out detailed neutron transport modeling to conclude that H is the most likely cause of the polar epithermal neutron decreases as opposed to other elements such as Si or Ca, as was suggested by Hodges [8]. [7] also used combined thermal and epithermal neutron data to conclude that the polar H enhancements were likely covered by 10s of centimeters of dry lunar soil.

A series of studies have been completed that utilize spatial deconvolution techniques as constrained by other measurables (e.g., shade, temperature) to improve our spatial distribution knowledge of polar H concentrations [9,10,11]. These studies conclude that LP data require most of the H to be concentrated in PSRs at up to 1 wt.% WEH. Higher H concentrations in small locations (<few km^2) are also consistent with these analyses. These abundances are greater than the highest solar wind H abundance in returned lunar samples, and may indicate ice between regolith grains. Finally, as prompted by recent detections of surficial lunar volatiles in non-polar regions (e.g., Goldschmidt crater)[12], it has been determined that spatially coincident detections of surficial H with LP-NS data cannot yet be ruled out [13]. New neutron models and analyses are needed to better understand the surficial form of water that may be detectable with LP data.

Future Directions for LP-NS Studies: Even 10+ years after acquisition, the LP-NS dataset remains a valuable and unique resource of information due to its high statistical precision, good spatial resolution, and analysis maturity [6]. A variety of future studies can be carried out with LP-NS data. First, new spatial deconvolution studies using updated lighting and temperature constraints from the Kaguya and LRO missions are already in progress [14]. Second, further modeling and correlation studies with M3 spectral data need to be carried out to understand the extent to which LP-NS data can constrain surficial H concentrations. Finally, non-polar H concentrations are not fully understood with current analyses of LP epithermal neutron data [15]. New data from LRO (Diviner and LEND) should be combined with LP epithermal neutron data to better understand global H concentrations.

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