

Neutron Measurements of the Lunar Polar Hydrogen Deposits: How Present and Future Measurements Can Provide Understanding for Polar Volatiles. D. J. Lawrence, R. C. Elphic, W. C. Feldman, J. J. Hagerty, and T. H. Prettyman; Los Alamos National Laboratory (djlawrence@lanl.gov).

Introduction: A goal for both future exploration and science studies of the Moon is to better understand the abundance and spatial distribution of the polar hydrogen deposits. While there are clear exploration and resource utilization reasons for understanding the polar deposits, there are also scientifically compelling reasons to study and understand these regions. Here we will discuss some of these science goals as well as current information that is available about the polar deposits. In addition, we will discuss what new information can be obtained – both from orbital and landed platforms – to gain a better understanding of the nature of the polar deposits. Because of our familiarity with neutron spectroscopy, much of this discussion will be in the context of neutron measurements. However, a broad array of measurements are needed in order to fully understand the polar regions.

Science From Polar Hydrogen Deposits: While there is definitive evidence from orbital neutron data that there exist anomalously high hydrogen abundances at both lunar poles [1], there is considerable speculation regarding the source and molecular form of the hydrogen. It has been suggested in various studies [e.g., 2] that the observed hydrogen abundances can be explained as originating from solar wind implanted hydrogen in the lunar soil. In contrast, using knowledge of the polar cold trap temperatures, diffusion constants, and other information, it has been suggested that water is the likely form of the hydrogen [3]. Thus, one of the most fundamental science questions is to determine the form of the hydrogen and the dominant source and/or sources for the polar deposits.

If the sources are dominated by a cometary origin, then a number of other scientific questions emerge. For example, what other elements and molecular species are sequestered in the cold traps? If the deposits were laid down in episodic events, might the time of such events be detectable and characterized by identifiable stratigraphic horizons? If the polar deposits contain other elements having high abundances in comets (e.g., D, C, N, O, S, P), could there be prebiotic organic chemistry taking place at the lunar poles? [4]. In summary, the polar deposits provide the possibility of studying a time-integrated inventory of solar system volatiles.

Other planetary and lunar science questions relevant to the lunar poles include: 1) What are the accumulation and loss mechanisms acting on volatiles in the polar cold traps? How do these mechanisms compare to what occurs on other planetary bodies, for ex-

ample on the polar cold traps of Mercury? 2) What are the physical properties of lunar regolith when it is kept at a constant and very low (<50K) temperature? How are the properties of cold regolith modified when it may be cemented by frozen volatile elements?

Almost no information is available to answer any of these questions. Thus, new data from both orbital and landed platforms will be invaluable for providing answers to these questions. In addition, since a better understanding of lunar polar resources is critically needed for the lunar exploration program, the study of lunar polar deposits is highly synergistic for both exploration and scientific applications.

Neutron Measurements of Polar Deposits: In order to make progress in understanding the polar deposits, a broad program using a variety of measurements is needed. Such a program has already started with instruments on board the Lunar Reconnaissance Orbiter (LRO) and the LCROSS missions. These missions will measure polar temperatures, topography, lighting conditions, and hydrogen abundances (and possibly other volatiles). However, since a fundamental part of understanding the polar deposits is measuring the hydrogen distribution and composition, we focus here on ways to better understand hydrogen at the lunar poles.

While a variety of techniques have either been used or proposed for remotely identifying and measuring the hydrogen composition on planetary surfaces (e.g., neutron spectroscopy, gamma-ray spectroscopy, radar, infrared spectroscopy, laser induced breakdown spectroscopy), we consider that neutron spectroscopy is an ideal technique for lunar polar applications in permanent shadow. A primary reason is that neutron spectroscopy is extremely sensitive to small amounts of hydrogen (100 ppm H – few wt.% H₂O) that are expected to be found on the Moon. In contrast, other techniques such as gamma-ray spectroscopy and radar are better suited to measuring higher amounts of hydrogen.

Orbital Neutron Measurements: Measurements from the Lunar Prospector Neutron Spectrometer (LPNS) have provided the definitive evidence for the existence of anomalous hydrogen abundances at the lunar poles [3,5,6]. While there have been suggestions that the neutron signals may be caused by elements other than hydrogen [7], recent analyses have concluded that hydrogen is the most likely source of the neutron signals [1]. These studies also concluded that the meas-

ured hydrogen abundances for both poles, as averaged over the 45 km LP-NS footprint, is 100 – 150 ppm H.

Forward modeling and spatial deconvolution studies have been carried out in order to mitigate the effects of the broad LP-NS footprint. Based on this work [8], it can be shown that the LP data are consistent with higher abundances (a few wt.% H₂O) over small (<30 km diameter) regions. These studies rely upon other information such as the spatial distribution of permanent shade and the temperature within these regions, which currently have large uncertainties. Improved determinations of the locations and distribution of permanent shade will provide much better constraints on these forward modeling and deconvolution studies.

The LRO mission will attempt new measurements of hydrogen abundances at a better spatial resolution than the LP-NS data. These measurements are needed in order to associate the measured hydrogen abundances with specific landforms that will be identified with other methods (e.g., temperature, topography, morphology). The goal of the LRO/LEND instrument is therefore to measure and characterize the polar hydrogen deposits at spatial scales of 10 km and hydrogen sensitivities as low as 100 ppm H. If neutron measurements can be made to this fidelity, this would result in a significant improvement in understanding the polar hydrogen distribution. Despite the great utility of neutron spectroscopy, one of the challenges for the neutron technique is ensuring there exists a high enough neutron counting rate for statistically significant measurements. In order to achieve the needed factor of 4 – 6 improvement in spatial resolution over LP-NS, the LRO/LEND detector greatly restricts the detection solid angle. This results in an instrument geometric factor that is over two orders of magnitude smaller than the LP-NS. In the talk, we will discuss how this smaller geometric factor can affect the hydrogen sensitivity for a given spatial footprint.

Landed In Situ Measurements: To fully characterize the polar deposits for exploration and scientific purposes, landed missions in the permanently shaded regions are required. A variety of tools and instruments should be used to make various measurements. These include tools to excavate the soil (to remove a possible 5 – 20 cm thick desiccated layer, [1]) and drills and/or scoops to investigate stratigraphy. Such tools could also provide information about soil properties. Zeroth order measurements of elemental and isotopic composition will need to be made in order to understand the complete volatile inventory of the polar soils. Instruments for detecting organic molecules can be used for identifying possible pre-biotic compounds [4]. Preparation should also be made to account for

significant spatial inhomogenities of the hydrogen abundance. Since so little is known about the emplacement and retention processes of polar hydrogen, almost no information is available regarding scales of possible spatial inhomogenities. Therefore any landed mission (either stationary or mobile) should include the means to measure the macroscopic hydrogen content of lunar soils. As with the orbital case, such measurements can be made using neutron spectroscopy. In any realistic mission scenario, there is no need for an active neutron system since galactic cosmic rays produce an adequate neutron signal measured from the surface [9]. As a consequence, it is possible to build a very small, lightweight neutron detection package that can serve as a prospecting tool for most landed missions to the lunar polar regions. For example, Figure 1 shows a version of a thermal and epithermal neutron detector that has a mass of <500g that would easily fit within the envelope of a landed polar mission. Field tests for identifying the composition and depth dependence of frozen water have been carried out with this instrument [10].



Figure 1. Miniature neutron spectrometer; neutron sensors are in the sensor module (right). Associated electronics are in the data module (left). The mass of both modules combined is 484 g.

Summary: The lunar polar hydrogen deposits represent an exciting opportunity for carrying out new science and much work is already being done to better understand these regions. Since so little is currently known about the polar regions, almost all new data will provide a significant leap forward in new insight. Furthermore, since the polar regions present a potentially attractive source of lunar resources, information gained about these locations for science purposes will have direct relevance to NASA's exploration goals.

References: [1] Lawrence, D. J., et al., *JGR*, 111, 10.1029/2005JE002637, 2006. [2] Crider, D. H., and R. R. Vondrak, *JGR*, 105, #E11, 26773. [3] Feldman, W. C., et al., *JGR*, 106, #E10, 23231, 2001. [4] Lucey, P. G., *Proc. SPIE*, 4137, 84, 2000. [5] Feldman, W. C., et al., *Science*, 281, 1489, 1998. [6] Feldman, W. C., et al., *JGR*, 105, #E2, 4175, 2000. [7] Hodges, R. R., *JGR*, 107, #E12, 10.1029/2000JE001483, 2002. [8] Elphic, R. C., et al., *38th LPSC*, 2007. [9] Lawrence, D. J., et al., *6th Int. Conf. on Mars*, #3109, 2003. [10] Elphic, R. C., et al., *Space Resources Roundtable VIII*, 2006.