NEUTRON MEASUREMENTS AT THE LUNAR SURFACE (NMLS), AN EIGHT DAY MISSION TO LACUS MORTIS ON ASTROBOTIC MISSION ONE.

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Introduction: Neutron Measurements at the Lunar Surface (NMLS) is a project to deliver an instrument payload that is manifested on the Commercial Lunar Payload Services (CLPS) Astrobotic's Peregrine Mission One (M1). Astrobotic Mission One is planning to land in the Lacus Mortis basaltic plain (44ºN, 25ºE), just north of Mare Serenitatis and will be the farthest north landing site ever explored on the Moon, in 2021. The NMLS project is funded by NASA's Lunar Discovery and Exploration Program (LDEP). Astrobotic will fly up to fourteen NASA payloads to the lunar surface in addition to other payload customers. The NMLS instrument is a re-design of the MSFC Fast Neutron Spectrometer (FNS) currently operating on the International Space Station (for additional information,https://www.nasa.gov/mission_pages/station/research/experiments/explorer/Investigation.html?#id=1841). The design of the NMLS instrument enables integration into the Peregrine lander, operation on the lunar surface, and measurement of thermal and epithermal neutron count rates using composite scintillator detectors. The primary science objectives for NMLS are to provide ground truth of mapped neutron data from the Lunar Reconnaissance Orbiter and Lunar Prospector missions. Neutrons are generated when galactic cosmic rays (GCR) collide with the lunar regolith and provide valuable elemental composition information about the near surface (< 1 m). The NMLS instrument is a low mass (~4 kg), low power (~5 W), low volume (~20 x 17 cm), and low data (~10 bps) passive radiation monitoring instrument with a high science return.

NMLS Mission Objectives: The objective of the NMLS project is to determine the amount of neutron radiation at the surface of the Moon by measuring the thermal and epithermal count rates. It is important to understand the amount of neutron radiation at the lunar surface because it is a hazard to humans [1], and also to understand the Moon's near surface composition in terms of elemental abundances [2], and hydrogen content [3]. Measurements of neutron radiation on the Moon's surface have previously been made from the lunar surface at Apollo 17 [4], and from orbiters including the Lunar Prospector Neutron Spectrometer [5] and Lunar Reconnaissance Orbiter (LRO) Lunar Exploration Neutron Detector (LEND) [6]. Neutron measurements made at the lunar surface will improve the detail and reliability of the data gathered during orbital missions providing ground truth, and depending on availability at the landing site, could also help identify hydrogen, rare earth elements (REE), and help differentiate between mafic and anorthositic chemistry, all of which contribute to a fundamental understanding the Moon's geology and the processes that continue to shape it today [7]. These measurements may also help better understand the temporal variation of hydrogen throughout the lunar day [8].

Neutron Moderation Theory. Protons emitted from the Sun and 'cosmic-rays' (the nuclei of elements like hydrogen, helium, carbon and iron from sources in the Milky Way Galaxy such as supernovae), strike the lunar surface initiating nuclear reactions and generating fast neutrons. These fast neutrons lose energy through collisions, exchanging kinetic energy with target atoms. They may escape the surface as a less-energetic 'epithermal' neutron or continue to scatter until reaching thermal equilibrium with the surrounding medium. Thermal and epithermal neutrons are the result of these collisions and moderation, or slowing, of the fast neutrons [9, 10]. These slower-moving neutrons, known as 'thermal' neutrons, have energies less than ~0.4 eV, while having started out with energies on the order of one to hundreds of MeV. The amount of energy lost by the neutron per collision is driven by the relative size of the colliding nucleus. The presence of hydrogen, therefore, greatly increases the conversion of fast neutrons to thermal neutrons since collisions with the roughly equal-weight hydrogen is most effective at slowing them down. By analogy, consider a ping pong ball (the neutron) scattering persistently around a room full of bowling balls (atoms of regolith), but rapidly settling when encountering a bin of other ping pong balls (hydrogen atoms).

Neutron measurements at the lunar surface could support the development of future habitation of the lunar surface. Hydrogen or water on the lunar surface can support in-situ resource utilization (ISRU), such as the production of propellants or life support replenishment. The amount of thermal neutrons is also a very sensitive indicator of the presence of neutron-absorbing elements such as iron, titanium, gadolinium, and samarium. The ISRU community is very interested in titanium and iron alloys that might be present on the Moon and which could be used for additive manufacturing of parts or components on-site at a lunar surface habitat. Gadolinium and samarium are indicators of the possible locations for other rare earth elements. These elements are a critical ingredient in many high-tech applications such as computers and smartphones and are part of the focus of the "*Subcommittee on Critical and Strategic Mineral Supply Chains of the Committee on Environment, Natural Resources, and Sustainability of the National Science and Technology Council*" [11].

Measurement Technique: The neutron detectors to be used in this project combines two types of scintillators. Approximately 480 120-micron, ^{6}Li-doped glass fiber scintillators are embedded within a 1-inch cube scintillator made of plastic. The characteristic light pulse from the glass scintillator has a longer decay time than that from the plastic scintillator and indicates that a thermal neutron passed through the glass. Pulse shape discrimination allows the instrument to trigger on thermal and epithermal neutrons while rejecting other types of radiation, primarily gamma-rays and charged particles. Two identical detectors are present in the unit. One detector is surrounded by cadmium and measures only the epithermal neutron flux. The other detector is surrounded by tin and measures the thermal plus epithermal neutron flux. Neutron energy discrimination can then be performed by subtraction of the two signals. The rate difference between the two detectors yields the thermal flux. Tin is used since its attenuation will be nearly identical to cadmium for radiation other than thermal neutrons. We estimate a count rate on the order of 0.1 Hz on the lunar surface. Therefore, we expect the intended mission duration of eight days to be sufficient measuring time to determine the amount of thermal neutrons at the landing site and advance the science and exploration objectives.

Figure 1. NMLS engineering model is shown below, without the top and front plates, showing twin scintillator detectors, electronics, and harnesses enclosed in an alodined alumnimum casing. The engineering model is functional, and has undergone calibration testing.

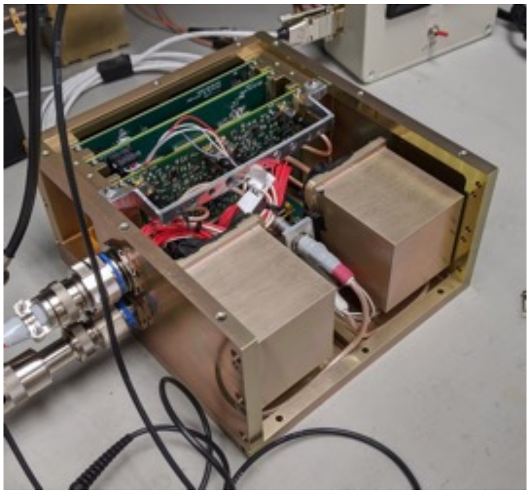
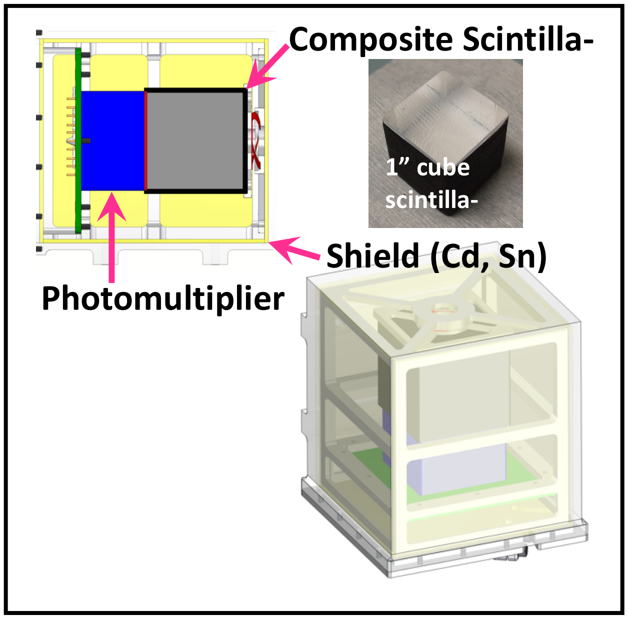


Figure 2. Schemtatic of scintillator assembly is displayed in a cut-through and isometric projections. The three key components are highlighted: the 1" cube composite scintillator wrapped in black tape, mated to a photomultiplier tube, wrapped by either a cadmium or tin shielding for measurements within the thermal and epithermal energy bands.



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