

Lunar Exploration Neutron Detector for NASA Lunar Reconnaissance Orbiter

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Introduction: We would like to present here the **Lunar Exploration Neutron Detector (LEND)** instrument, which will accomplish the primary goals of lunar space exploration – to find the hydrogen and water resources on the Moon and to measure the radiation environment for future human missions.

The LEND instrument will operate onboard the NASA Lunar Reconnaissance Orbiter (LRO), which are in close relationship with the objectives of Lunar Exploration Program (LEP) (Figure 1).

Physical ground base of proposed investigations: Investigations by LEND are based on the detection of the Moon's neutron albedo, which is produced within a “neutron production level” of about 1 – 2 meters down to subsurface by the bombardment of galactic cosmic rays. Initial high-energy neutrons are moderated and absorbed by nuclei of the major soil-constituting elements. The leakage flux of neutrons has the components of thermal particles and power-low-like tail of epithermal and high-energy neutrons. Neutron emission is accompanied by emission of gamma rays from nuclei that were excited by neutrons. The energy spectrum of leaking neutrons depends on the composition of the soil, and mostly, on the content of hydrogen [1-3].

Concept of LEND measurements: The LEND instrument will contain nine sensors for measurements of thermal, epithermal and high-energy neutrons. The data from these sensors are necessary and sufficient to accomplish objectives of the LRO mission to the Moon (Figure 1.).

Numerical simulation of Lunar neutron albedo for determination of requirements for LEND: Figure 3 presents the expected effect of count rate decreases for epithermal neutrons at an altitude of 50 km

above the Moon in ^3He counter with diameter of 5 cm and pressure 20 atm. We may conclude that surface variations of hydrogen higher than 100 ppm on the “standard” background of soil with 50 ppm are detectable provided LEND may measure neutron variations with amplitude of 2 %.

Surface deposits of water ice also produce depression of flux of epithermal neutrons above it. Figure 4. presents the count rate of epithermal neutrons from lunar soil covered by a water ice layer with a different thickness. According to these numerical simulations, LEND will be able to detect water ice deposits with thickness larger than a few millimeters (Figure 4.).

Numerical models of shielding collimator for LEND: The target of the LEND investigation is to reach the spatial resolution of at least 5 km over the polar spots of the Moon for the level of contrast required to distinguish the pixels, corresponding to the soil with 100 ppm of H from the background of 50 ppm.

The ^3He counter is the best sensor for thermal and epithermal neutrons. LEND will contain shielding ^3He counters; Cd shield rejects thermal neutrons from the direct flux. The neutron collimator provides the instrument Field of View (θ_{FOV}): epithermal neutrons of direct flux inside FOV are recorded by the detector, and practically all neutrons outside FOV are absorbed by collimator.

The physics of LEND collimation points out that narrowness of field of view should be associated with rather strong absorption of neutrons from external directions. According to mapping condition, for $\theta_{\text{FOV}} \sim 0.1$ the collimation efficiency ξ should be $\ll 0.01$. We have studied different materials, which may provide

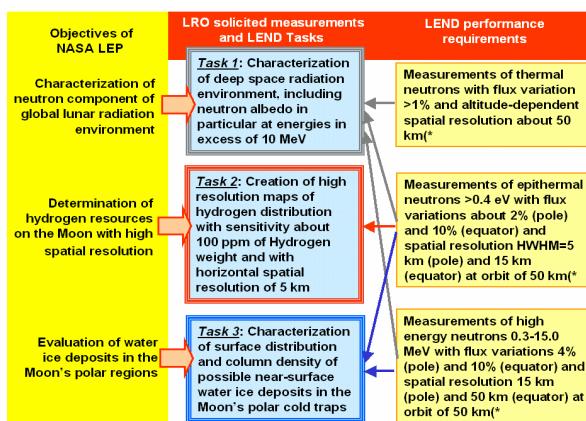


Figure 1. LEND traceability matrix: (*) spatial resolution corresponds to 50 km altitude.

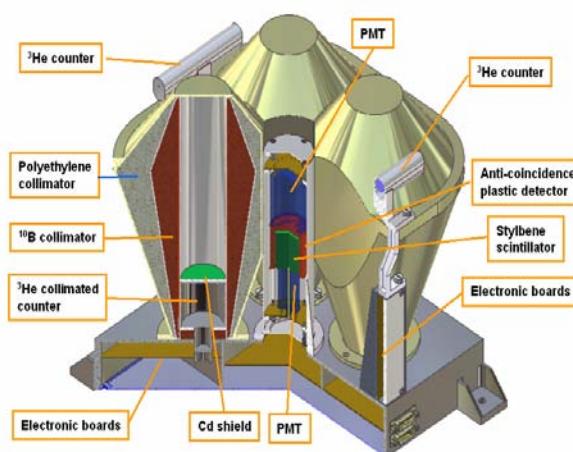


Figure 2. Cross-section of LEND

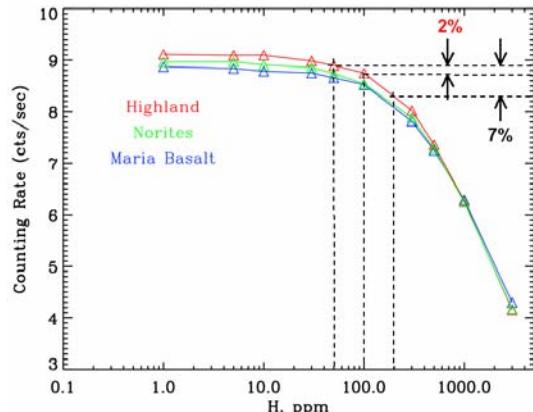


Figure 3. Decrease of count rate of epithermal neutrons in ${}^3\text{He}$ sensor at 50 km altitude above the Moon as function of content of hydrogen in the soil (ppm). Curves for three models of lunar soil are shown.

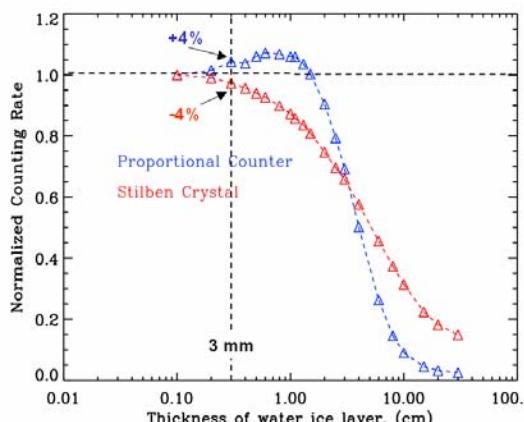


Figure 4. Dependence of count rate of epithermal neutrons in ${}^3\text{He}$ sensor and in stilbene scintillator at 50 km altitude above the Moon as function of thickness of water ice deposit.

high shielding efficiency. And found that a double-layered structure with an external layer of polyethylene and internal layer of boron ${}^{10}\text{B}$ may provide the necessary shielding of epithermal neutrons.

We performed numerical simulations of the neutron detector with one ${}^3\text{He}$ counter inside a collimator with different configuration of layers of polyethylene and ${}^{10}\text{B}$. The diameter of the collimator's central hole is 5 cm, and we have studied 5 options of collimators with different lengths h . We also estimated the efficiency of collimation and spatial resolution as HWHM for orbit altitudes of 50 km. We found that the best option for LEND performance requirements corresponds to the model of the collimated detector with a cylindrical counter with 20 atm pressure and collimator height 8 cm (Figure 5.). This best calculated model corresponds to opening angle $\theta_{\text{FOV}} = 5.6^\circ$ for FOV. The total mass of this detector is about 3.7 kg. For

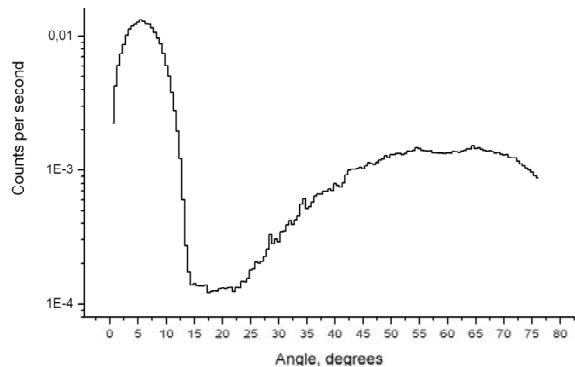


Figure 5. Calculated number of detected neutrons for different intervals of impact angles for collimated detector with $h=8\text{cm}$ cylindrical collimator.

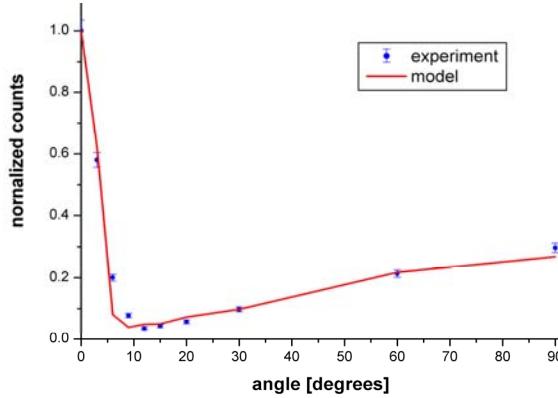


Figure 6. Collimation efficiency for different impact angles.

orbit with altitude of 50 km this HWHM corresponds to 5 km spatial resolution.

According to LEND performance requirements, the instrument will consist of four such detector. This up-scaling leads to about 4 times larger total mass of collimated module, about 15 kg.

Laboratory experiment of collimation concept:

A special laboratory test was performed at the Joint Institute for Nuclear Research (Dubna, Russia), which simulated the collimation efficiency of ${}^{10}\text{B}$ +polyethylene shielding. A one-dimensional collimated detector was tested with the leakage flux of neutrons from a thick polyethylene target. The neutrons were induced by a beam of mono-energetic neutrons at 200 keV. Dependence of count rate versus angle manifested the strong effect of collimation. Numerical simulations proved very good consistency between the observational data and calculations (Figure 6.). Therefore, we conclude that this laboratory test confirms the validity of our numerical model for LEND collimated sensors.

References: [1] Masarik J., Reedy R.C. (1996) *J.Geophys.Res.*, 101, 18891-18912. [2] Feldman W. C. et al. (1998) *Science*, 281, 1496– 1500. [3] Mitrofanov I. G. et al. (2004) *Solar System Research*, 38, 4, 253-257.