LUNAR EXPLORATION NEUTRON DETECTOR (LEND) FOR NASA LUNAR RECONNAISSANCE ORBITER: SEARCHING FOR THE WATER ICE

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Introduction: The Lunar Exploration Neutron Detector (LEND) instrument on board the Lunar Reconnaissance Orbiter (LRO) spacecraft will measure both the neutron emission (albedo) from the lunar surface and the local neutron background in orbit [1]. The objectives of the LEND science investigation is to determine with high spatial resolution possible presence of water ice on the Moon and to map global distribution of hydrogen in the regolith. The measurement of the neutron lunar albedo will also help determine the surface neutron radiation environment, which is of great importance for the planning and operation of future human lunar missions.

Scientific background: There are three large planets in the Solar system which emit gamma-rays and neutrons from surfaces: the Moon, Mars and Mercury. This nuclear emission is produced by bombardment of galactic cosmic rays and, episodically, by solar energetic particles. High energy protons and nuclei of cosmic rays collide with nuclei in the soil within a depth of first meters and produce secondary neutrons with energy about 10 – 20 MeV. Neutrons diffuse in the subsurface colliding with soil nuclei until they leak from the surface, or are absorbed due to capture reaction, or decay due to finite life time. The neutron emission detecteble by onorbit observations is associated with the first option only.

Neutrons lose energy with collisions; the moderation of escaped neutrons is greater for those particles which have a greater number of interactions. The energy spectrum of emitted neutrons has a thermal component (corresponding to particles which have been thermalized before escaping), and a power-law tail from epithermal energies up to original energy (representing particles which escaped before thermalization) [2]. The energy spectrum of leaking neutrons depends on the composition of the soil, and mostly, on the content of hydrogen, because H nuclei are the best neutron moderators. Even a fraction of hydrogen as small as 100 ppm is known to produce a measurable change of epithermal neutron albedo from the surface of a planet with thin or no atmosphere.

Lunar orbital observations by Neutron Spectrometer on Lunar Prospector [3] have shown that the lunar maps of neutron emission provide evidence of high content of hydrogen (or water ice deposits) at polar regions of this body.

Here we present the LEND instrument, which is the large orbital neutron telescope for orbital mapping of the Moon's neutron albedo. The LEND is a collimated neutron detector system with a 10 km (FWHM) diameter field of view foot print for the nominal 50 km orbital altitude. LEND is the Russian contributed instrument for NASA's Lunar Reconnaissance Orbiter [4], and its investigation team includes scientists from leading research centers for nuclear and planetary science both from Russia and from the United States.

Instrument design: The nadir pointing Moon viewing part of the LEND system is a collimated instrument that consist of four high pressure ^{3}He proportional counters with a Cadmium (Cd) foil covers (sensors CSETN 1-4 on Fig.1). They surround a stilbene (organic crystal scintillator) based sensor (SHEN) of collimated high energy neutrons. An active anti-coincidence shield allows the SHEN electronics to reject cosmic rays and other background signals.

The Module of Collimation (MC) is constructed from polyethylene and Boron-10 (^{10}B) powder. Off angle neutrons are moderated by the polyethylene and then captured by the ^{10}B nucleis. The physical design is such that the collimator defines for sensors CSETN 1-4 a surface foot print of 10 km (FWHM) for a spacecraft mapping orbit of 50 km.

To characterize the neutron environment at the spacecraft in orbit, the LEND carries four additional ^{3}He detectors external to the collimator. They are identified in Fig. 1 as SETN (sensor of epi-thermal neutrons) and STN 1 – 3 (sensors of thermal neutrons). SETN is Cd shielded to reject all neutrons with energy below 0.4 eV. STN 1 and SETN measures the local omni-directional background of thermal and epithermal neutrons, which is contributed by the surface emission of the Moon and by secondary neutrons from the spacecraft. They are positioned near the top of collimation module on sides +Y and –Y and have the largest possible views of the lunar surface. The other two sensors of thermal neutrons, STN 2 and STN 3, are positioned on sides +X and –X at the middle of the collimator body (Fig. 1). These two sensors constitute the Doppler filter detector [5]. Data from all four external omni-directional sensors STN 1 – 3 and SETN measures the thermal and epithermal neutrons from the Moon and the local spacecraft background. Global maps of neutron radiation environment with spatial resolution of 70 – 100 km will be produced from these data.

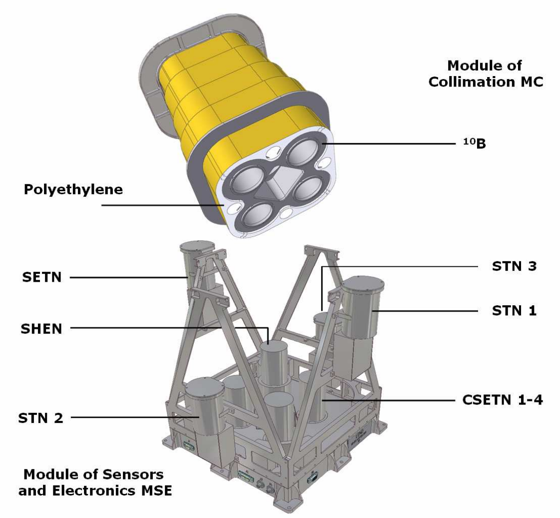

Fig. 1. The LEND instrument. Nine neutron sensors are shown: 2 open filed sensors of thermal (STN 1) and epithermal neutrons (SETN), 2 sensors of Doppler filter for thermal neutrons (STN 2 and STN 3), 4 collimated sensors (CSETN 1-4) of epithermal neutrons and one collimated sensor of high energy neutrons (SHEN). Simple stricture of neutron collimatin module (MC) is shown also.

Expected Results: LEND will perform global mapping of the entire Moon with the same field of view (FOV). At moderate latitudes and at the equator the integrated exposure time for corresponding surface elements is rather small in comparison with the poles, because only a fraction of crossing orbits will contribute to observation time. However, counting statistics for particular spatial elements could be increased by increasing the surface area. Some surface features of hydrogen enhancement with large contrast may be imaged with the spatial resolution of the instrument FOV, but for most number of regions at moderate latitudes the data will be combined into pixels as large as about 20 – 30 km.

The major targets of LEND observations are the permanently shadowed craters distributed around the poles. Created comprehensive numerical models of the onorbit flux of lunar albedo neutrons, of the collimated properties of the MC module and of the detector efficiency, allowed to estimate detection limit (3 sigma) of about 83 ppm for Hydrogen for an area with a radius of 5 km on a pole, assuming 1 year of mapping from 50 km ideal polar orbit. This detection limit reduces for larger regions, and increases for regions further from the poles. Also we have calculated detection limits of hydrogen for cold traps inside known craters (se Fig.2) taking into account the presently available data for landscape around them from Clementine [6] and for the predictable LRO orbit. These limits show that LEND has sufficiently high sensitivity for detection of enhanced hydrogen (or deposits of water ice) at these spots (see Table 1).

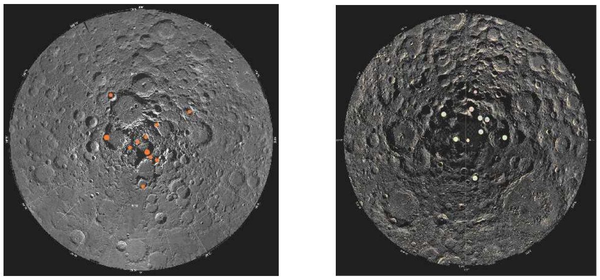

Fig. 2. Cold traps in the northern (left) and southern (right) hemisphere of Moon.

Table 1. Results of numerical simulation of LEND detection limit concerning search for Hydrogen content inside cold traps.

LEND candidate targets of cold traps with possible water ice deposits (coordinates and surface area are indicated)	LEND Hydrogen detection limit level (in ppm)	LEND sensitivity of water ice deposits (in wt %)
No.1: (89.9° S; 111.1°E) 380 km^2	31	0.03
No.2: (88.5° S; 220.0°E) 400 km^2	76	0.07
No.3: (87.6° S; 38.0°E) 580 km^2	80	0.07
No.4: (88.6° N; 32.0°E) 170 km^2	114	0.10
No.5: (89.2° N; 122.5°E) 110 km^2	122	0.11
No.6: (89.0° N; 291.2°E) 148 km^2	136	0.13
No.7: (88.4° S; 260.2°E) 145 km^2	141	0.13
No.8: (86.8°S; 75.8°E) 257 km^2	152	0.14

References: [1] Mitrofanov I. et al. (2008) Astrobiology 8, Issue 4, 793-804. [2] Drake D.M. et al. (1988) JGR 93, 6353-6368. [3] Feldman W.C. et al. (1998) Science 281, 1496-1500. [4] Chin G. et al. (2007) Space Sci. Rev., 129, 4, 391-419. [5] Feldman W. and Drake D. (1986) Nucl. Instrum. Methods Phys. Res., Sect. A, A245, 182. [6] Rosiek M. and Aeschliman R. (2001) LPS XXXII, Abstract #1943.