LOCAL SPOTS OF LUNAR WATER-ICE PERMAFROST IN SHADDOW AND IN SUNLIGHT, AS SEEN BY LEND/LRO.

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Introduction: The neutron telescope, LEND, was selected for NASA`s LRO mission for testing local spots of water-ice permafrost at lunar poles. This instrument maps epithermal neutron emission of lunar surface with high spatial resolution about 10 km from the orbit with altitude of 50 km [1, 2]. The epithermal neutrons are moderated in many collisions from original high energy neutrons with energy about 1 -20 MeV, which are produced by energetic particles of galactic cosmic rays. The leaking flux of epithermal neutrons depends on the content of hydrogen of the regolith, because more collisions with nuclei of hydrogen lead to faster moderation and thermalization of neutrons before leaking from subsurface. Observed suppression of emission of epithermal neutrons at some particular spot in comparison with the reference surface indicates enhanced content of hydrogen or water in the regolith.

Data analysis: To test for the presence of local suppression/excess spots, one should subtract the average count rate of the reference map smoothed with the scale of 230 km from count rate on the main map, and then test spatial distribution and amplitudes of residuals. If result of this test would be consistent with statistical fluctuation of counts, one should conclude that there are no local spots of water-ice permafrost as well as spots with chemical variations of the regolith which lead to variations of neutrons emission. On the other hand, the presence of such spots would be supported by experimental data provided statistical significant spots of neutron excess or suppression would be confidently detected on the surface of the Moon.

For selection of candidates for local spots with either negative (*Neutron Suppression Regions*, NSRs) or positive (*Neutron Excess Regions,* NERs) deviations over the testing map we use two thresholds ±0.0425 cps and ±0.085 cps for residuals with respect to the counting rate of the reference smoothed map at the same pixel. These thresholds correspond to 2.5% and 5% of the reference counts rate 1.7 cps, which is attributed for epithermal neutrons from lunar surface at the moderate latitudes [3]. The negative and positive thresholds determine the contours of potential candidates for NSRs and NERs, respectively. To test statistical confidence of each potential candidate spot, we sum up all counts of residuals of pixels inside the contour of a spot, and compare this value with the total statistical error estimated for initial counts of these pixels for the main map. We use 3standard deviation confidence selection criteria for candidate spots, which are used for further analysis of NSRs and NERs.

We decided to restrict this analysis of local candidate spots of NSRs or NERs by limiting their area to 2000 km^2, which corresponds to the spot's linear size about 40 – 50 km. Indeed, the reference map has a smoothing scale of about 230 km, so it does not contain variations with a moderate linear scale of about 100 km and less. On the other hand, these variations could be studied quite well by epithermal sensors with omni-directional field of view and large counting rate, and they are not proper observational targets for collimated sensors of LEND with narrow FOV.

So, we consider only candidate spots for NSRs and NERs, which are selected by thresholds criteria 2.5% and 5% , have confidence corresponding to 3σ or higher, and have the total area smaller than 2000 km^2.

Obtained results: Polar regions were tested above 70° at north and south by this method [4]. Twelve candidates were found including 8 NSRs and 4 NERs. These candidate were additionally validated by data from LOLA [5] and Diviner [6] instruments on LRO by testing the difference of solar irradiation and average surface temperature for areas inside and outside the candidate spots. It was found that 6 selected NSRs and 2 selected NERs are consistent with the phenomenological law "less/more heating – less/more neutrons", which prove that spots detected by LEND are real, because they are different from the surface at the nearest vicinity at the same latitude. This law could be related to the presence of hydrogen bearing volatiles in the regolith. When heating is small, regolith contains higher content of volatiles, and opposite – larger heating leads to less hydrogen in the subsurface.

The Shoemaker-Malapert territory is the most interesting case together with the crater of Cabeus of possible water-rich permafrost detected with LEND data (see also [7]). The NSRs at this territory S1 and S3 have the total area of about 5300 km^2 (Figures 1 and 2). S1 includes the the spot with the largest local suppression 12.2 ± 2.6% at the *Permanent Shadow Region* (PSR) at the floor of Shoemaker crater (Figure 1). It is interesting, that accuracy of neutron imaging by LEND telescope is high enough to resolve the boundary if the permanent optical shadow at this spot.

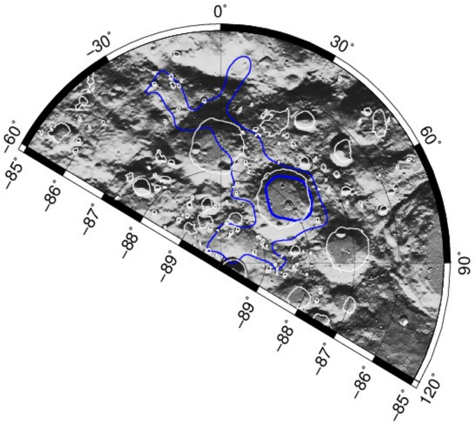

Figure 1. NSR S1 in Shoemaker with contours of suppression -2.5% (*thin blue*) and -5.5% (*thick blue*). White contours represent the boundaries of PSRs. PSR of Shoemaker is very well consistent with the contour of -5% suppression contour of NSR S1. Lunar landscape is shown in the Figures 1and 2 in accordance to LOLA altimetry and contours of PSRs are produced from this data also.

The contour of second NSR S3 at Shoemaker-Malapert territory has average neutron suppression even higher, 14.4 ± 4.1 %. The area of 650 km^2 includes part of Mountain Malapert with well-irradiared equator-facing spot together with large polefacing PSR (Figure 2). It is interesting, that average suppression of this spot with large fraction of sunlit surface is comparable with the suppression at Shoemaker, which is in the permanent shadow.

Conclusions: It is found that local NSRs is the real phenomenon at lunar poles [4, 8]. Comparison between selected NSRs and large PSRs lead to the conclusion that NSRs are not linked directly with PSRs, as has been commonly accepted before LEND investigation. One may conclude that favorable physical conditions for formation of NSRs at lunar poles are not directly related with the permanent shadow, but, on the other hand, the spot of permanent shadow could have larger suppression within the area of NSRs, which has been formed at this place.

The phenomenological law "more/less irradiation – more/less neutrons" leads to the hypothesis that irradiation and implantation of hydrogen from solar wind may work together, like chemical reactor, which produce water molecules during a sunlit time. We suggested to call this mechanism *Solar Water Chemical Reactor* (SWCR). A water molecule, which is produced at heated top layer from solar protons, could either diffuse down to cold subsurface for permanent trapping, or migrate out from the hot sunlit surface to cold shadow nearby for trapping there. The efficiency of SWCR depends on local landscape and on properties of the surface.

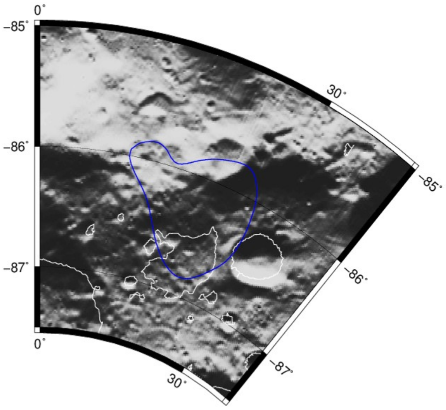

Figure 2. NSR S3 at south-east side of Malapert crater also has large fraction of the surface at PSR, and its another part is equator-looking slop of a rim.

There are two potential origins of lunar water, the *cometary water* delivered by comets and *solar water* produced by chemical reactions from protons of solar wind. In the first case water vapor from a comet would condense similarly at all cold traps of PSRs around the impact site. In this case one could expect that similar large PSRs should have similar deposits of water, and, *vise versa*, there should be no water deposits at sunlit surface outside the permanent shadow. Data presented above shows that it is not the case. This data is more favorable for the second choice, the *solar water* produced *in situ* from solar wind. In this case the difference between water-rich and water-poor PSRs could be explained by more or less favorable surface morphology for production of water at some local spots with SWCRs and for storage of water ice permafrost in the cold subsurface.

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