Determining the Magnitude of Neutron and Galactic Cosmic Ray (GCR) Fluxes at the Moon using the Lunar Exploration Neutron Detector (LEND) during the Historic Space-Age Era of High GCR Flux

G. Chin[2], R. Sagdeev[1], G.M. Milikh[1], D. Usikov[1], J.J. Su[1], W. Boynton[3], D. Golovin[4], K. Harshman[3], M. Litvak[4], I.G. Mitrofanov[4], T. McClanahan[2], T. Livengood[5], L.G. Evans[6], A. Sanin[4], and R. Starr[7]

[1] Department of Physics, University of Maryland, College Park, Maryland, USA(rsagdeev@gmail.com), [2] NASA Goddard Space Flight Center, Greenbelt, Maryland, USA, [3]University of Arizona, Tucson, Arizona, USA, [4]Institute for Space Research (IKI), Moscow, Russia, [5] CRESST/UMD/GSFC, Greenbelt, Maryland, USA, [6] Computer Science Corporation, Lanham-Seabrook, Maryland, USA, [7] Catholic University of America, Washington, DC, USA.

Historic Space-Age Era of High Galactic Cosmic Ray Flux: The Lunar Reconnaissance Orbiter (LRO) was launched June 18, 2009 during an historic space-age era of minimum solar activity [1]. The lack of solar sunspot activity signaled a complex set of heliospheric phenomena [2,3,4] that also gave rise to a period of unprecedentedly high Galactic Cosmic Ray (GCR) flux [5]. These events coincided with the primary mission of the Lunar Exploration Neutron Detector (LEND, [6]), onboard LRO in a nominal 50-km circular orbit of the Moon [7].

LEND measures the leakage flux of thermal, epithermal, and fast neutrons [6] that escape from the lunar surface. Neutrons are produced within the top 1-2 meters of the regolith by spallation from the GCR flux. The energy spectrum and flux of the emergent neutron population is highly dependent on the incident flux of the GCR due to its influence on the depth of neutron production and total number of neutron-producing events.

Methods to calculate the emergent neutron albedo population using Monte Carlo techniques [8] rely on an estimate of the GCR flux and spectra calibrated at differing periods of solar activity [9,10,11]. Estimating the actual GCR flux at the Moon during the LEND's initial period of operation requires a correction using a model-dependent heliospheric transport modulation parameter [12] to adjust the GCR flux appropriate to this unique solar cycle. These corrections have inherent uncertainties depending on model details [13]. Precisely determining the absolute neutron and GCR fluxes is especially important in understanding the emergent lunar neutrons measured by LEND and subsequently in estimating the hydrogen/water content in the lunar regolith [6].

Simultaneous measurements of the LEND detectors determine the absolute GCR and neutron flux levels: LEND is constructed with a set of neutron detectors to meet differing purposes [6]. Specifically there are two sets of detector systems that measure the flux of epithermal neutrons: a) the uncollimated Sensor for Epi-Thermal Neutrons (SETN) and b) the Collimated Sensor for Epi-Thermal Neutrons (CSETN).

LEND SETN and CSETN observations form a complementary set of simultaneous measurements that determine the absolute scale of emergent lunar neutron flux in an unambiguous fashion and without the need for correcting to differing solar-cycle conditions. LEND measurements are combined with a detailed understanding of the sources of instrumental background, and the performance of CSETN and SETN. This comparison allows us to calculate a constant scale factor that determines the absolute flux of neutrons at the Moon and then subsequently to deduce the proper scale of the GCR flux model without correction by use of the heliospheric modulation potential for this unique solar cycle minimum.

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