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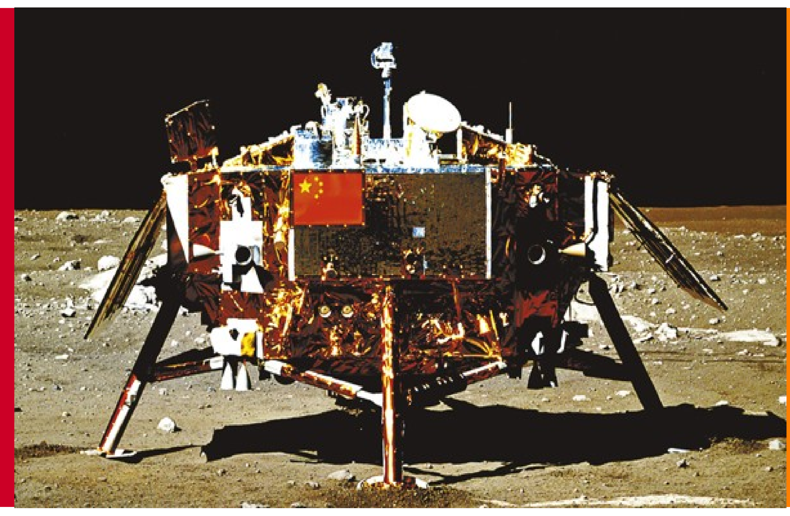

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The Lunar Lander Neutron & Dosimetry (LND) Experiment on Chang'E4

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1. Abstract

The Lunar Lander Neutrons & Dosimetry experiment (LND) is part of the payload of the next Chinese lunar mission, Chang'E 4, which will land on the far side of the Moon towards the end of 2018. The mission consists of a lander, a rover, and a communication relay. The LND instrument will be accommodated on the Chang'E 4 Lander and has ***two major science objectives:***
1) dosimetry for human exploration of the Moon and
2) contribute to heliospheric science as an additional measuring point.
To achieve the first objective, LND is designed to measure time series of dose rate and of linear energy transfer (LET) spectra in the complex radiation field of the lunar surface. For the second objective, LND is capable to measure particle fluxes and their temporal variations and thus will contribute to the understanding of particle propagation and transport in the heliosphere. Its stack of 10 silicon solid-state detectors (SSDs) allows to measure protons from 10-30 MeV, electrons from 60-500 keV, alpha particles from 10-20 MeV/n and heavy ions from 15-40 MeV/n. In addition, LND can measure fast neutrons in the energy range from 1-20 MeV and, using two Gd-sandwich detectors, measure fluxes of thermal neutrons, which are sensitive to subsurface water and important for understanding lunar surface mixing processes.

2. Instrument Concept

The zenith-pointing LND is mounted inside the payload compartment of the Chang'E 4 lander and consists of a thermally decoupled sensor head and an electronics box (see Figs. 1 and 2). The sensor head consists of a stack of 10 SSDs (Fig. 4) as well as two Printed Circuit Boards (PCBs). One PCB is used to pre-amplify the detector signals, the other PCB contains shaper circuits and the Analog to Digital Converters (ADCs). These digitized signals are sent from the sensor head to the electronics box which accumulates the data into histograms, count rates, PHA words, etc., packetizes them and sends them to the Instrument Control Unit (ICU). The latter serves as the electrical and data interface with the lander.

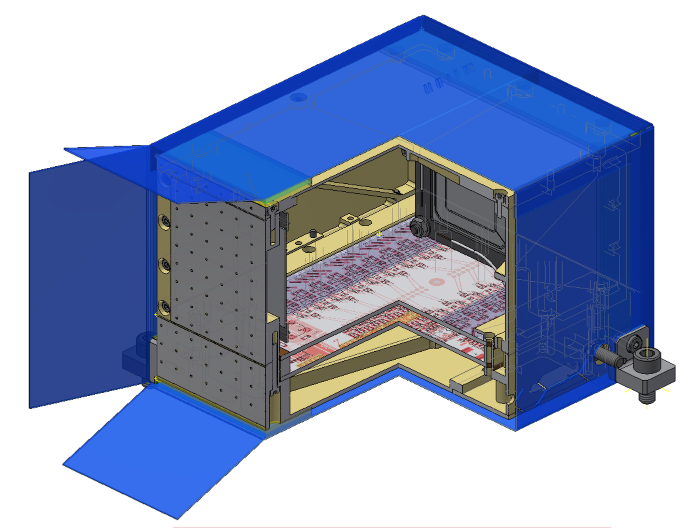


Fig 1: The sensor head of LND

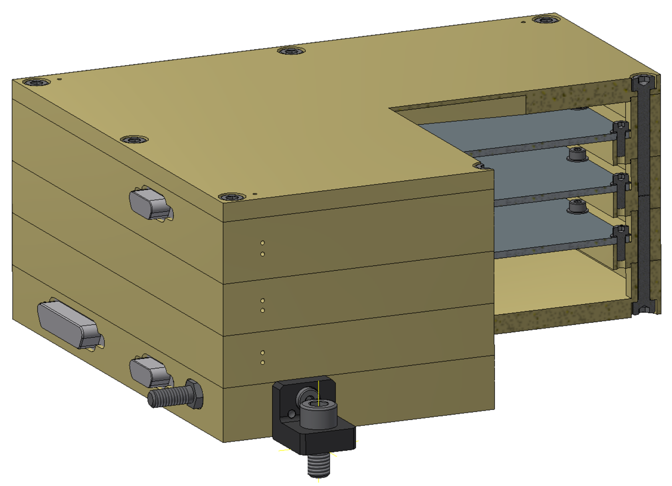


Fig 2: The electronics box of LND

3. Measuring fast neutrons

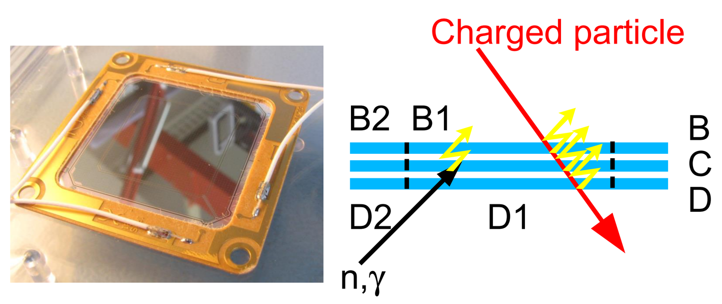


Fig 3: Measurement of fast neutrons

Fast neutrons are generated by the interaction of the galactic cosmic rays with the lunar regolith and are an important source of radiation dose reaching the interior of an astronaut's body. LND uses three segmented Si SSDs which are as closely packed as possible to detect fast neutrons. The innermost segment of the C detector in Fig. 3, C1, measures neutral radiation in anti-coincidence with all outer segments (B1&B2, D1&D2, C2). LND's response to neutral radiation (n, γ) is shown in Figs. 7 and 8.

4. The Sensor Head Design

LND is largely based on developments which were made for the Ionizing Radiation Sensor (IRAS) in an early phase of Exomars. As shown in Fig. 4, LND is basically a telescope consisting of ten segmented SSDs (A-J). Three detectors (B, C, and D) are packed as close together as possible to measure neutrons in the energy range 1-20 MeV (see section 3). The lower six detectors (E-J) are mounted in two different sandwich configurations. In one each sandwich clamps a very thin (~20 µm) Gd foil (shown in red) to detect thermal neutrons (see section 4). To discriminate thermal neutrons which are emitted from the lunar soil (and are thus sensitive to the subsurface proton (water) content), the GH sandwich is shielded from above by a thicker Gd foil which is encased in two thick Al sheets. The GH sandwich then measures thermal neutrons from below and the EF sandwich thermal neutrons from above. The lowermost sandwich is a copy of the IRAS BC-sandwich and serves as the final detector in the stack. The J detector serves as an anti-coincidence to discriminate stopping particles from penetrating ones.

The opening angle of the LND FOV is determined by the inner segments of detectors A and B and the outer segment of detector J as sketched in Fig. 4. Geometry factors for various detector combinations are given below.

Front detector	Rear detector	Geometry factor
A1	B1	0.4 cm² sr
A1&A2	I1&I2	1.13 cm² sr
B1&B2	I1&I2	12.9 cm² sr

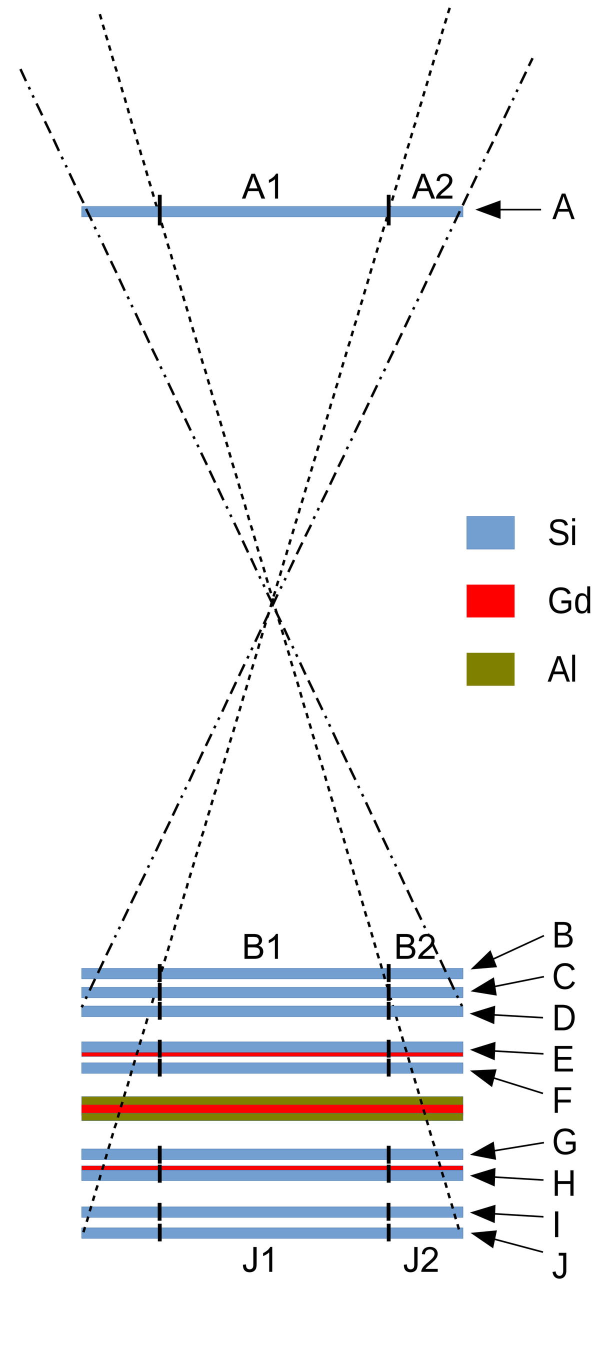


Fig 4: The particle telescope of LND

4. Measuring thermal neutrons using Gd converters

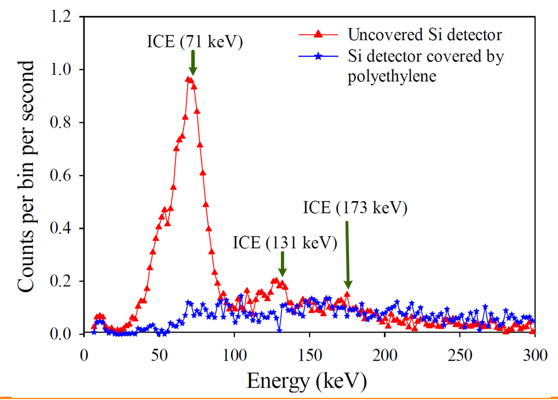
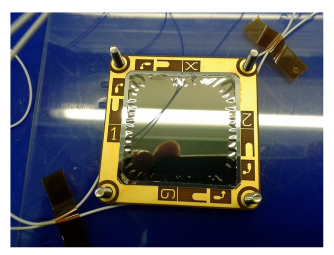


Fig 5: Spectrum of natural Gd conversion electrons (Kandlakunta, 2014)

Using Gd converter foils allows us to build LND in a very compact manner while still acquiring ample statistics of thermal neutrons.

Natural gadolinium (Gd) has a very large cross section for thermal neutrons (48'890 b). After neutron capture, the Gd nuclei have a large probability to decay via internal conversion emitting electrons with energies of 29, 72, 78, and 132 keV (Fig 5). LND uses a 20 µm thin natural Gd foil as a neutron converter. The electrons which escape from the foil can then be measured in the adjacent Si SSDs in anti-coincidence with the surrounding detectors.



LND will have to use a fairly thick (20 µm) foil. While our initial sputtering tests were successful, the sputtered Gd on the flight detectors showed bubbles (Fig. 6).

Fig 6: We encountered difficulties in sputtering Gd onto Si

5. Geant4 Simulations

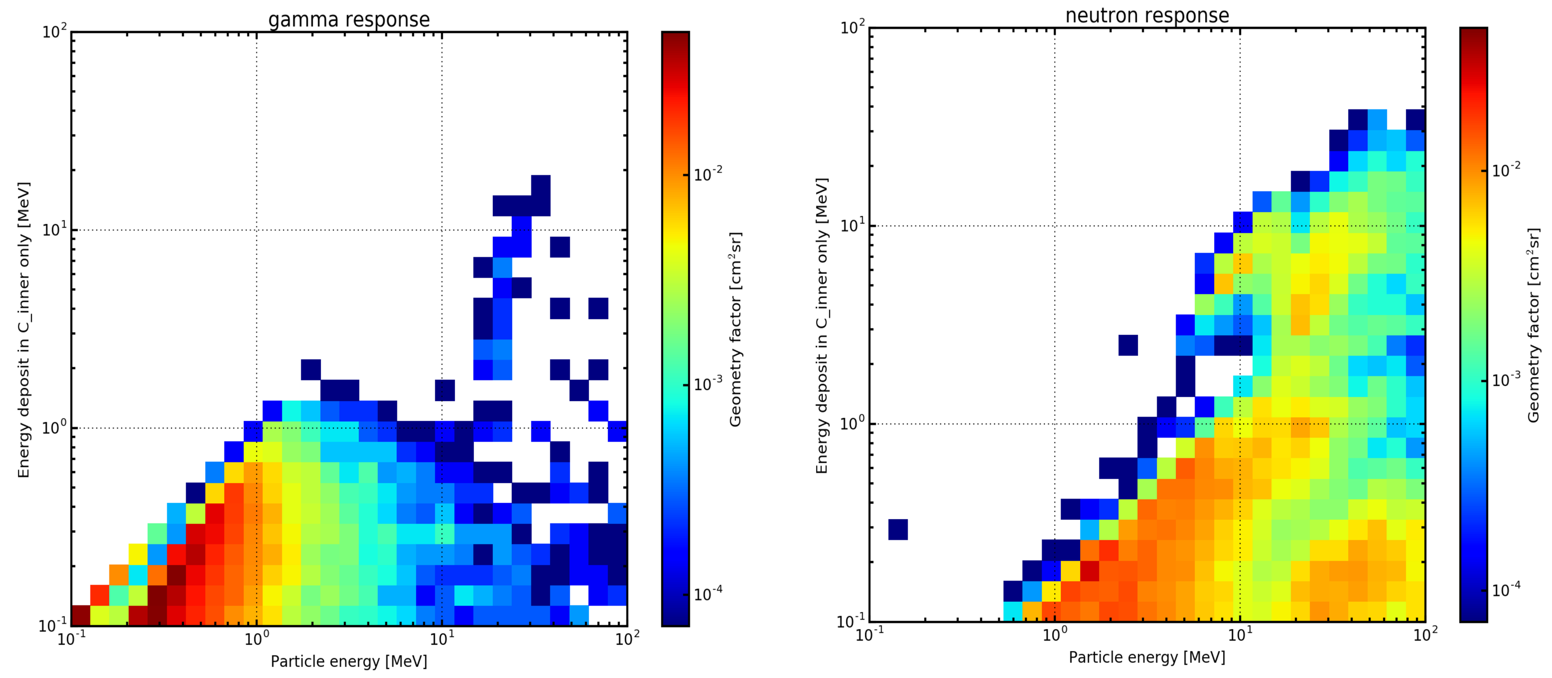


Fig. 7: Instrument response functions for gammas, and neutrons for the C inner detctor segment.

We used Geant4 to simulate the performance of LND. Fig. 7 shows the instrument response functions (IRFs) for the inner C segment (C1) for gamma and neutron particles. It is dominated by neutrons for energy deposits above 1 MeV.

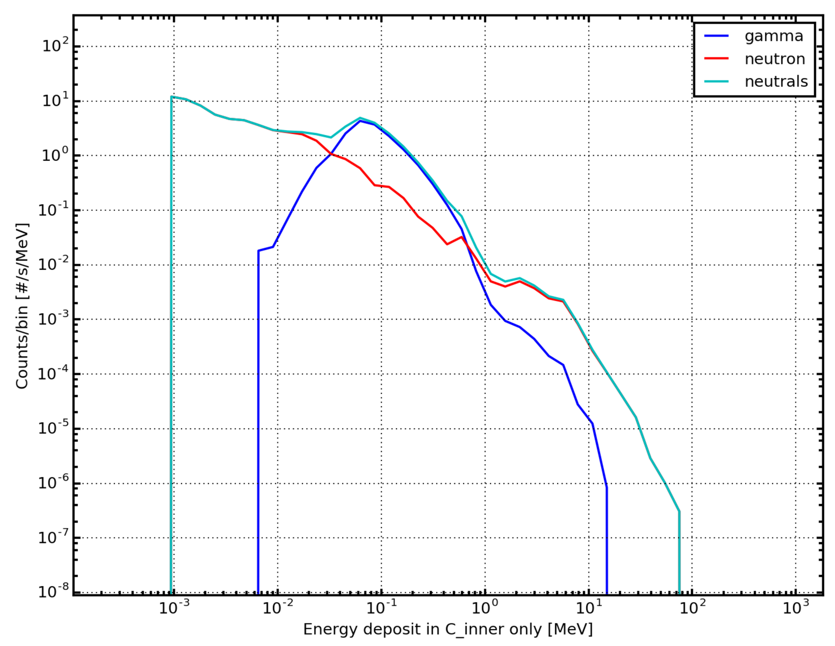


Fig 8: Expected spectrum energy deposits in C1 only

As discussed in section 3, LND measures fast neutrons by using an anti-coincidence of C1 with (B1&B2, D1&D2, and C2). Thus, if only the C1 segment was triggered, this was due to a neutron or gamma, because both of them only interact weakly with the Si-nuclei in the detector compared with charged particles, e.g., protons and electrons. The expected spectrum of neutral radiation energy deposits in C1 shown in Fig. 8 was obtained using a GEANT4-model of the lunar surface neutron and gamma spectra folded with the LND IRF. It is dominated by gammas at low energies. Above about 700 keV, neutrons start to dominate, e.g., at energies above 1 MeV, we expect only about 0.01 gamma, but ~0.03 neutron counts per second.

6. Data Products

No.	Measurement	Cadence
1	Dose rate in Si	1 minute
2	Neutral particle dose rate	1 minute
3	Housekeeping	1 minute
4	Pulse height analysis words	1 minute
5	Proton energy spectra up to around 20 MeV	5 minutes
6	Electron spectrum	5 minutes
7	Thermal neutron counts	5 minutes
8	Alpha-particle spectrum up to around 20 MeV/nuc	15 minutes
9	LET-spectra in the range 0.1-430 keV/µm	15 minutes
10	Fast neutrons in the range 1-20 MeV	15 minutes
11	^{3}He spectrum up to roughly 20 MeV/nuc	30 minutes
12	Composition of the radiation	30 minutes

The raw data of LND is processed by LND on board and telemetered to Earth via an Earth-Moon L2 relay satellite. LND data products and their cadences are given in the table to the left. LND provides measurements of interest for dosimetry, lunar regolith science, as well as heliophysics.
After receipt on ground, instrument response functions will be applied to the data, and visual inspections will be performed at CAU and NSSC. LND data will be made available to the scientific community via the usual channels.

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