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Development for the estimation of fast neutron flux leakage from the Moon based on the data observed by Kaguya Gamma-Ray

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A gamma-ray spectrometer onboard Kaguya (KGRS) measured lunar gamma rays from 200 keV to 13 MeV [1]. The observed spectra include many gamma ray peaks which are mainly induced by neutron interactions with lunar materials such as neutron capture and nonelastic scattering except for naturally radioisotopes. Therefore, neutron fluxes on the Moon are quite important to derive each concentration of lunar elements from the observed gamma ray data.

Since KGRS did not accompany with a neutron spectrometer, the neutron flux during the observation period have to be estimated from other related data. One of possibilities is the use of gamma ray lines emitted from detector materials themselves. Because the detector of KGRS consists of a large germanium (Ge) crystal surrounded a massive BGO scintillator [1], gamma ray lines of Ge are emitted by neutron capture and inelastic scattering inside the Ge detector and detected by the detector itself. While the shape of gamma ray peak is the same as other peaks of lunar gamma rays in the case of Ge(n,g) reaction, that becomes irregularly shaped peak called " sawtooth" peak in the case of Ge(n,ng) reaction. The net counts in these peaks directly reflect lunar neutron fluxes; the former is of thermal neutrons and the latter is of fast neutrons. Especially, the latter case allows us easily to assign the peaks of Ge relating to lunar fast neutron. Based on the data obtained by KGRS, six large sawtooth peaks are appeared in the energy spectrum; whose peak energies are 1039.3 keV from 70Ge(n,ng), 692 keV and 834,8 keV from 72 Ge(n,ng), 596.1 keV and 1205.2 keV from 74Ge(n,ng), and 562,9 keV from 76Ge(n,ng) as referring to nuclear data of ENSDF [2]. Since many ordinary peaks of lunar gamma rays and background gamma rays from satellite body and gamma rays from Ge detector by (n,g) reaction are on the sawtooth peaks. Therefore, net counts of sawtooth peak have to be estimate by peak fitting method in order to remove these interfering peaks.

The sawtooth peaks are produced when the energy from the deexcitation of an excited level is summed with some of the recoil energy of Ge nucleus introduced by interactions of fast neutrons with that Ge nucleus in the detector [3]. Therefore, the sawtooth peak has a high-energy tale depending on the recoil energy distribution. For the Ge detector, the tail shape may only depend on atomic mass of Ge because of completely same source spectrum of fast neutrons.

The fitting function for the ordinary peak is Gaussian with exponentially low energy tail used by GRS/Mars Odyssey [4]. For sawtooth peaks, we modified this function that has quasi-exponentially high energy tail as similar to the function of low energy tail. Fitting parameters for high-energy tail are junction energy between Gaussian and quasi-exponential tail, and power of exponential type function for quasi-exponential tail which is permitted to vary between 1 (exponential tail) and 2 (Gaussian tail). As a result of peak fitting, we were able to confirm that this function well reconstructs sawtooth peaks.

The sawtooth peaks in an energy spectrum are produced by interactions of the same source spectrum of fast neutrons with the Ge detector. That is, the ratios of peak area of a sawtooth to the others depend on just their production rates of gamma ray lines of Ge. This situation means that the ratios in one lunar region must be the same to those in another lunar regions. Therefore, we can check the presented analysis method for fast neutrons by comparisons of the ratios between different lunar regions. We will verify and discuss whether the method of sawtooth fitting is applicable to estimate fast neutron flux by comparison of the ratios between different regions.

1. N.Hasebe et al. 2009, J. Phys. Soc, Jpn., Suppl. A78, 18.
2. ENSDF Database is available http://ie.lbl.gov/databases/ensdfserve.html.
3. P.Englert et al., 1987, J. Radio. Nucl. Chem. 112, 11.
4. L.G.Evans et al., 2007, JGR 111,E03S04.

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