**THE LUNAR GEOCHEMICAL ANALYSIS BY A GAMMA-RAY SPECTROMETER FOR NEXT LUNAR EXPLORATIONS.** S. Kobayashi[1], T. Mitani[1], T. Takashima[1], Y. Karouji[2], N. Hasebe[2], [1]Japan Aerospace Exploration Agency, Kanagawa, Japan (e-mail: shingo@planeta.sci.isas.jaxa.jp), [2]Research Institute for Sci. and Eng., Waseda Univ., Tokyo, Japan

**Introduction:** The elemental composition of the lunar surface has been measured by several gamma-ray spectrometers (GRS) onboard lunar orbiters [1-4]. One of the most important discoveries accomplished by GRSs is the dichotomic distribution of K, Th and U on the global lunar surface. GRSs have found that K, Th and U are considerably concentrated in Procellarum, Imbrium and Fra Mauro region (Procellarum KREEP Terrain, PKT [5]) as shown in Fig. 1. The most important question, however, is whether the bulk of the underlying crust in PKT also contains much of K and Th or not [5,6]. The total abundance of K, Th and U in bulk PKT is a key parameter to understand several important lunar issues: the bulk composition of refractory elements [5], the thermal history of the Moon and the nearside unique volcanic activity [7], the origin of the PKT itself [6] and the issues related to Imbrium basin (the effect of Th-rich Imbrium ejecta on the lunar farside [8] and the unusual viscous relaxation of Imbrium basin [9]). Therefore, the concentration of K, Th and U in bulk PKT is closely related to the origin and evolution of the Moon. There are several methods to investigate the deep in PKT by geophysical techniques (ex. thermal flowmeters and seismometers etc.). On the other hand, we can also access the deep crustal materials by exploring a central peak of a crater and this geochemical method is complementary to the geophysical ones. Here, we consider the feasibility of a mission to explore the central peaks by a gamma-ray spectrometer in order to obtain information on the deep crustal materials.

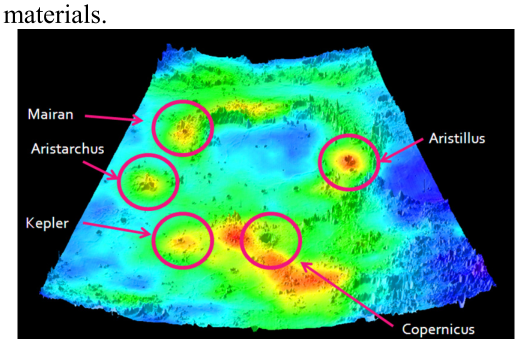


Fig. 1 Th distribution around PKT measured by Kaguya gamma-ray spectrometer.

**PKT:** The Th distribution in PKT has been obtained by several gamma-ray spectrometers and is shown in Fig. 1. Kepler, Aristarchus, Mairan and Aristillus crater have high-Th characteristics, while Copernicus shows a lower Th abundance. The exact Th abundance inside a crater, however, is unknown. Because of the limitation of spatial resolution of a gamma-ray remote sensing (>~50 km), it is impossible to distinguish a crater into its floor, the central peak and the ejecta. Thus it is important for a next mission to measure Th abundances of them separately in order to know the stratigraphy of the PKT. According to an estimation, the average Th abundance of the bulk PKT is 4-7 ppm, which is assumed as a mixture of Apollo 15 KREEP basalt (Th ~ 12 ppm) and Ferroan anorthosite (Th < 1 ppm) [6]. Thus, the gamma-ray spectrometer for the exploration of a crater in PKT is necessary to quantify the Th abundance of rocks and regolith at least in this range from 0 to 12 ppm.

**Candidates of the gamma-ray spectrometer for the exploration of a crater:** There are two options to explore a crater in PKT by a gamma-ray spectrometer. The first is to improve the spatial resolution of the gamma-ray remote-sensing method. Some preliminary studies to improve the spatial resolution of a GRS has been continued (e.g. [10]), but a GRS with a high spatial resolution is not ready for a practical use. The second is to carry out a landing mission (e.g. Japanese SELENE-2 landing mission). In both cases, the candidates of the gamma-ray spectrometer would be $LaBr_3$ [11], CdTe, CdZnTe and Ge [12], because of the good energy resolutions. Here we investigate the performance of $LaBr_3$ as the gamma-ray spectrometer for the exploration of a crater.

**Performances of $LaBr_3$:** The $LaBr_3$ scintillator has a good energy resolution (2.8%@662 keV [11]) and a wide operation temperature. One concern is the relatively high background due to $^{138}La$ and $^{227}Ac$ which is incorporated in the detector itself and there is a possibility that the background could degrade the sensitivity of the GRS. We have perfumed the measurement of the internal background of $LaBr_3$ (See Fig. 2). The background level is about 100 times as high as that of NaI (Tl), which was used as the gamma-ray detector onboard Apollo [1]. The background spectrum of $LaBr_3$ has a strong peak at around 1468 keV whose peak becomes a major interference in the measurement of the K peak at 1461 keV. The Th peak at 2615 keV is also moderately interfered by the internal background. The solution for this problem is to measure precisely the internal background before the launch.

In order to investigate the influence of the internal background, the sensitivity of a $LaBr_3$ detector (1200g) is estimated based on [13] (Fig. 3), assuming that a lunar orbiter (or a lunar rover) carries the $LaBr_3$ detector and analyzes the chemical abundance of a lunar regolith under the orbiter (or the rover). As the ambiguity of the internal background is dependent of the observation time taken for the background measurement at a ground test ($t_{obs}$), the observation time for a lunar sample analysis also depends on it. The result shows that the detection limit of Th with the gamma-ray spectrometer is 0.1 ~ 0.2 ppm in the case of $t_{obs}$ = 10 days. Hence, the influence of the internal background can be minimized if the internal background is precisely measured before the launch.

The analysis times required to measure the several samples are calculated based on [13] and shown in Table I. The results show that Th abundance compatible to the average bulk PKT material can be measured by dozens of minutes with 10% accuracy. For a remote sensing mission by a gamma-ray detector with an improved spatial resolution, the performance become a trade-off between the analysis time and the spatial resolution, hence a further study for the spatial resolution of the detector is necessary. For a rover mission, the

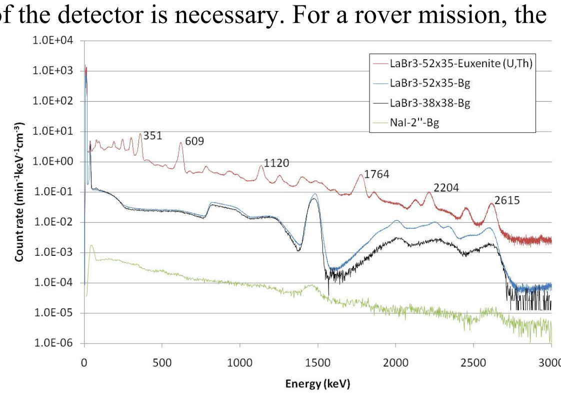


Fig. 2 The internal background of scintillators: blue line, $LaBr_3$ (ϕ52mm×35mm); black line, $LaBr_3$ (ϕ38mm×38mm); light green line, NaI(Tl) (ϕ51mm×51mm). Red line is the spectrum of gamma rays from Euxenite (U, Th).

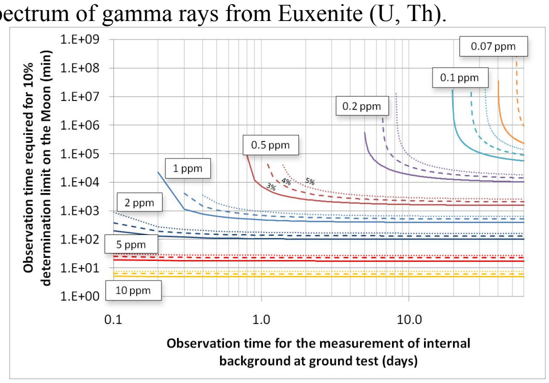


Fig. 3 The relationship between the analysis time required to determine the Th abundance in the lunar regolith (0.07 ~ 10 ppm) and the observation time for the measurement of the internal background at a ground test ($t_{obs}$). Solid line shows the case that the energy resolution of $LaBr_3$ detector is 3%; dashed line 4%; dotted line 5%.

Table I The observation time required to determine K and Th abundances with 10% accuracy by a $LaBr_3$ gamma-ray spectrometer (1200g, $t_{obs}$ = 15 days).

| Sample | K | Th |
|---|---|---|
| SaU169 [14] | 8 min (4500 ppm) | 0.8 min (32.7 ppm) |
| KREEP basalt [15] | 7 min (4970 ppm) | 5 min (11.8 ppm) |
| Average PKT [6] | (N/A) | 12 ~ 34 min (4 ~7 ppm) |
| A16 regolith [16] | 196 min (934 ppm) | 132 min (2.0 ppm) |
| Dhofar489 [17] | 2.7 days (300 ppm) | unmeasuralble (0.063 ppm) |

$LaBr_3$ detector has a sufficient sensitivity to analyze rocks and regolith, because it can complete an analysis at least within a few hours.

**Summary :** The abundance of K, Th and U in bulk PKT is a key to understand the origin and the evolution of the Moon. The detection limit of a $LaBr_3$ gamma-ray detector (1200 g) is estimated to be about ~ 0.2 ppm for Th though it is necessary to verify it experimentally hereafter. The $LaBr_3$ detector has a sufficient sensitivity for the exploration of the central peak and the floor of a crater in PKT.

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