Status and Performance of the Gamma-Ray Spectrometer on the KAGUYA (SELENE)

Masanori Kobayashi[1], Nobuyuki Hasebe[2], Eido Shibamura[3], Takashi Miyachi[2], Takeshi Takashima[4], Osamu Okudaira[2], Naoyuki Yamashita[2], Shingo Kobayashi[2], Makoto Hareyama[2], Yuzuru Karouji[2], Mitsuru Ebihara[5], Tomoko Arai[6], Takamitsu Sugihara[7], Hiroshi Takeda[8], Kazuya Iwabuchi[2], Kanako Hayatsu[2], Shinpei Nemoto[2], Takeshi Hihara[5], Satoru Nakazawa[4], Hisashi Otake[4], Claude d'Uston[9], Sylvestre Maurice[9], Olivier Gasnault[9], Benedicte Diez[9], and Robert C. Reedy[10], [1]Nippon Medical School (m-kobayashi@nms.ac.jp), [2]Research Institute for Science and Engineering, Waseda University, [3]College of Health Science, Saitama Prefectural University, [4]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, [5]Dep. of Chemistry, Tokyo Metropolitan Univ., [6]National Institute of Polar Research, [7]Japan Agency for Marine-Earth Science and Technology, [8]Research Institute, Chiba Institute of Technology, [9]Centre d'Etude Spatiale des Rayonnements, CNRS, [10]Planetary Science Institute.

Introduction: The KAGUYA main orbiter carries a gamma-ray spectrometer (GRS) that has a large volume germanium semiconductor detector of 252 cc as the main detector and bismuth-germanate (BGO) and plastic scintillators as active shieldings [1] [2]. With the highest energy resolution, the KAGUYA GRS will provide the concentrations of the major elements of the material of the lunar surface, O, Mg, Al, Si, Ti, Ca, Fe, the natural radioactive elements K, Th, and U, and also will possibly detect the existence of water, in which one is very interested from the viewpoint of future lunar utilization.

In this presentation, the status and performance of the KAGUYA GRS observations in the primary mission and early extended mission are given.

Performance of the KAGUYA GRS in orbit:

Cryostat Performance. From a viewpoint of the stability of the signal gain, the temperatures of the detectors and the electronics are preferred to be stable. The sensor subsystem GRD of GRS on the nadir side panel, however, is susceptible to periodic heat input by lunar albedo. So far the checkout operation the housekeeping data of the GRS showed the stability of the temperature of the sensor subsystem.

The heat input to the GRD changes when the β angle relative to the Sun changes, and the Ge detector temperature changes. The cryocooler is not automatically controlled to stabilize Ge temperature. Therefore the cryocooler voltage was sometimes changed by manual operation so that the temperature of the Ge detector was kept in the range from 75 K to 80 K.

There was a temperature change of about 5 K in Ge detector temperature and first stage electronics, but there was no change in the conversion equation from a channel to energy through all of the observation period.

Spectroscopic measurement. The GRS started its regular observation on December 14, 2007. Fig. 1 shows energy spectra of gamma rays with the energies from 200 keV to 12 MeV obtained by the Ge detector of the KAGUYA GRS in lunar orbit with or without anti-coincidence. The upper spectrum (live time was 1.5 hours) was obtained with no operation of anti-coincidence, although some background gamma rays, especially from the spacecraft body, are absorbed by the thick BGO scintillator. The lower spectrum (live time was 682 hours) was obtained from the Ge using the anti-coincidence system. From the comparison of these spectra, a remarkable reduction of the gamma-ray continuum was made by the anti-coincidence operation due to Compton suppression. Many more peaks of gamma-ray lines, especially weaker ones, will be seen in the anti-coincidence spectrum of gamma rays. The level of background continuum in the energy range above 2 MeV is decreased by a factor of 5 to 20. Because the signal-to-noise ratio is higher in the lower spectrum, it becomes clear that the anti-coincidence operation is very effective for improving the detection and measurement of peaks.

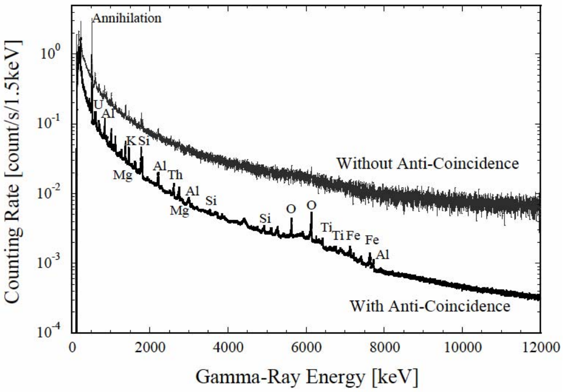

Fig. 1. Energy spectra of gamma rays observed by the Kaguya GRS with and without anti-coincidence. The upper spectrum was obtained in accumulation time of 1.5 hours without anti-coincidence, the lower one was in 682 hours with anti-coincidence.

Observation status in the primary and extended mission: The regular observation of the Moon by the KAGUYA GRS began on December 14, 2007. The high voltage (HV) applied to the Ge detector at first was 3.1 kV. After an eclipse of the Moon in February, 2008, the noise in the signal of the Ge detector became serious. The GRS stopped its observation, and the investigation of the cause was conducted for four months. The GRS resumed its observation in July, 2008, with the HV value of the Ge detector set to 2.5 kV. Because the channel-to-energy conversion equations of the GRS data are almost same and the detection efficiency does not have the significant difference between 2.5 kV and 3.1 kV, there spectra can be merged.

Besides an observation stop by the serious noise as mentioned above, the GRS stopped its observation due to eclipses of the moon or the maintenace of the spacecraft or special operations of the GRS (see the next section). But for the other periods the GRS has continually observed lunar gamma rays as shown in Fig. 2.

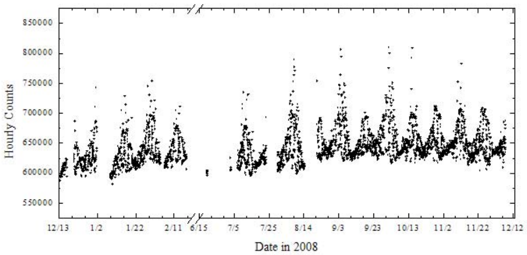

Fig. 2. Hourly counting rates of gamma rays (0.2 - 12 MeV) measured by the GRS in the primary mission and early extended mission.

The cryocooler of the GRS was stopped at every satellite maneuver in which the telemetry from the KAGUYA was limited until August, 2008. On this account, radiation damage occurred, and the energy resolution had been getting worse from the beginning of the primary mission. The cryocooler has kept the Ge detector to be colder than 80 K since September, 2008 except the Ge detector annealing (see below).

The details about the analysis of observation data please see Yamashita et al. [3] and Reedy et al. [4].

Special Operation of the KAGUYA GRS:

Background measurements. The measurement of the background (BG) gamma rays is required for the quantitative evaluation of the lunar surface material. Two times background gamma ray measurement was performed while the spacecraft was pointed away from the Moon for a number of orbits. In these BG measurement operations, the GRS sensor head mounting surface sees only deep space, and the spacecraft body is between the Ge detector and the Moon.

In the first BG measurement implemented in July, 2008, we found that gamma rays from K, U, Ti, Al and Mg contained in the spacecraft body and the instrument was emitted at significant strength. In particular the contribution of BG gamma rays from Al is significant because most structure of the spacecraft and the instruments are made of Al. In the second BG measurement in December, 2008, we took sufficient time to acquire BG data so that we are able to identify the 1368.6 keV gamma ray from lunar surface even in the area where the strength of the 1368.6 keV gamma ray is the weakest. Accumulation time of BG data is about 37,000 seconds in total.

Annealing Ge detector. Because the cryocooler was stopped frequently until August, 2008, serious deterioration of the energy resolution of the Ge detector was seen. It was necessary to anneal the Ge detector at a high temperature to remove the deterioration of the energy resolution by the radiation damage in the Ge detector [5].

In an annealing operation, conducted in December, 2008, the Ge detector was maintained in each of 20 degrees Celsius and 50 degrees Celsius for 24 hours to degas the gas that was stuck to the Ge detector. Afterwards the Ge detector was maintained at 80 degrees Celsius for 48 hours, and high temperature annealing was conducted.

After the end of the annealing, the performance of the Ge detector was checked with HV=2.5 kV. It was found that the tails of peaks became small by comparing with the tails before annealing [4]. The evaluation of detailed energy resolution was conducted after having accumulated enough statistics. The energy resolution seems to have been improved to the one at the beginning of the primary mission.

References: [1] Hasebe, N., et al. (2008) *Earth, Planets and Space*, *60*, 299-312. [2] Kobayashi, M. et al. (2005) *Nucl. Instrum. and Meth.*, A548, 401-410. [3] Yamashita, N. et al. (2009) *LPSC XXXX,* this issue. [4] Reedy R. C. et al. (2009) *LPSC XXXX,* this issue. [5] Brückner J. et al. (1991) *IEEE Trans. Nucl. Sci., 38*, 209-217.