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Background deduction of the Chang'E-1 gamma-ray spectrometer data

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Abstract Gamma-ray spectrometer (GRS) is used to detect the elemental abundances and distributions on the lunar surface. To derive the elemental abundances, it is vital to acquire background gamma rays except lunar gamma rays. So GRS would observe background spectra in the course of earth-moon transfer on schedule. But in fact, GRS was not switched on in the course of flying toward the moon. After the CE-1 probe finished one-year mission, GRS carried out a test on background data on November 21−22, 2008. The authors did conduct research on the methods of background deduction using 2105 hours of usable gamma-ray spectra acquired at the 200-km orbital height by the GRS and more than 5 hours of gamma-ray spectra acquired in the GRS background test. The final research results showed that the method of deducting the background using the minimum counts in the CE-1 GRS pixels is optimal for the elements, U, K and Th. The method applies to such a case that the elemental abundances in the pixel with the minimum counting rate are 0 μg/g and the continuum background counts are constant over the Moon. Based on the method of background deduction, the full energy peak counts of U, K, and Th are calculated.

Key words Chang'E-1; gamma-ray spectrometer; lunar gamma ray; background deduction

1 Overview

Gamma-ray spectrometer (GRS) is one of the important payloads onboard the Chang'E-1 (CE-1) probe. GRS can be used to detect gamma rays given off by elements on the lunar surface. By data processing the elemental abundances and distributions of the lunar surface can be acquired. In addition to lunar gamma rays detected by GRS, which can be directly applied to the analysis of elemental abundances, GRS can detect gamma rays from other non-lunar sources. These non-lunar gamma rays are referred to as the background data with respect to the analysis of elemental abundances. So, only after the background data are deducted from the energy spectra detected by GRS can we acquire the lunar gamma-ray energy spectra, and further analyze the elemental abundances of the lunar surface. Therefore, as for the analysis of elemental abundances, background deduction is of great importance in GRS data processing. For this, in the CE-1 flight-controlling program it was scheduled to switch on GRS in the process of CE-1 flying toward the Moon so as to acquire background data. However, due to the alteration of later flight-controlling program, GRS was not switched on to conduct background detection in the process of CE-1 flying toward the Moon. This brought about great difficulties for GRS data processing. On the basis of the treatment and analysis of the GRS circumlunar data, this paper has put forward an effective method of background deduction that applies to such a case that the elemental abundances in the pixel with the minimum counting rate are 0 μg/g.

2 The sources of GRS background

This GRS background is very complex, and its main sources (Prettyman et al., 2006) include:

(1) Diffused gamma-ray background: in the universe there exists an almost isotropic gamma-ray background.

(2) The background resultant from interactions between cosmic rays and satellite body: the gamma-ray background was produced as a result of interactions between cosmic rays and satellite body, and the background flow is determined by cosmic ray flow, satellite mass, shape, material and GRS installation location.

(3) Radioactive isotopes produced by cosmic rays: the interactions between high-energy cosmic rays and the detector/its surrounding substances will produce radioactive disintegrated nuclides, and further emit gamma rays.

(4) The lunar continuum spectra: in addition to the characteristic gamma rays given off by elements on the lunar surface, there exists a continuum gamma-ray spectrum which is also a background.

(5) Compton scattering: in the gamma-ray spectral lines, it is not all the photons that will deposit their energy within the detector, and the Compton scattering will also be produced. As for spectral line detection, the Compton scattering is also a background.

In fact, the composition of the aforementioned background can be worked out by using the model (Seltzer, 1975), but, as the source intensity, and the transmission model and basic nuclear data suffer great uncertainties (Prettyman et al., 2006), so it is difficult to make use of a model to calculate the composition of the background mentioned above.

3 The method of background deduction

This paper deals with the method of background deduction based on the two types of data. One type of data refers to 5 hours and 38 minutes of gamma ray energy spectrum data acquired in the GRS background testing experiment and the other refers to 2105 hours of effective lunar gamma-ray spectral data detected by GRS in the circumlunar period.

3.1 Analysis of the data in the background testing experiment

In order to obtain the background data, in November 21, 2008 (Beijing Time) a background testing experiment with the time duration of 17 hours and 13 minutes was conducted after CE-1 finished its one-year mission. However, due to the fault of SRAM for GRS itself, only 5 hours and 38 minutes of observation data were acquired. As for these observation data, only the observation data obtained at the time when the Moon was outside the field of view of CE-1 GRS can be regarded as background observation data, i.e., the observation data acquired at the time when the GRS observation axis is located in the scope of the vertical of the tangent between GRS and lunar surface as is shown in the scope of θ of Fig. 1.

According to Fig. 1, the confirmed background observation time scope and the background spectrum accumulative time are listed in Table 1. It can be seen from Table 1, this background observation distributions involve five time periods, for each of which the background spectrum accumulative time is 1−3 minutes, and in the whole testing experiment, the background spectrum accumulative time is less than 12 minutes in total.

The background accumulative energy spectrum for series No. 2 time scope in Table 1 is shown in Fig. 2. It can be seen that in the background spectrum there exist O (6.129 MeV) and N (10.83 MeV) lines given off by satellite propulsion fuel excited by cosmic rays, as well as Mg (1.369 MeV) and Al (843.8 KeV and 2.754 MeV) lines released by the materials making up the satellite body excited by cosmic rays. After analyzing the background observation data for other time intervals as listed in Table 1, there have been found O, N, Mg and Al lines released by propulsion fuel and the materials making up the satellite body. So it is obvious that before background testing experiment, there must exist a large amount of background data of gamma rays given off by propulsion fuel and materials making up the satellite body under excitation of cosmic rays in the circumlunar spectra detected by GRS.

Table 1 The background observation time scope and background spectrum accumulative time

Series No.	Background observation time scope (Beijing Time)		Background observation accumulative time (second)
	Starting time	End time	
1	2008-11-21T18:35:10.000	2008-11-21T18:45:00.000	156
2	2008-11-21T20:35:00.000	2008-11-21T20:44:45.000	174
3	2008-11-22T02:08:10.000	2008-11-22T02:11:55.000	78
4	2008-11-22T04:04:50.000	2008-11-22T04:15:10.000	159
5	2008-11-22T06:05:30.000	2008-11-22T06:14:15.000	150
6	Total background observation accumulative time		717

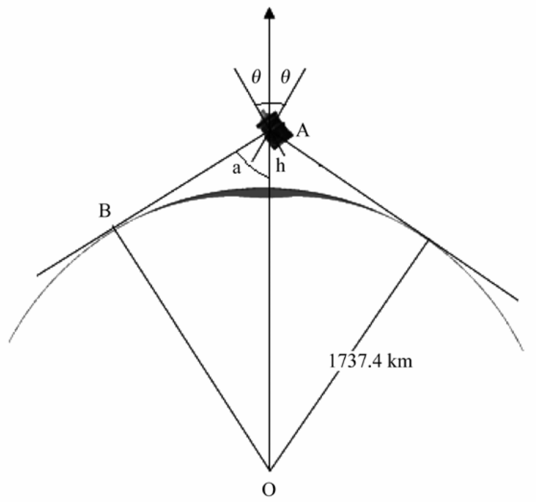

Fig. 1. Sketch of GRS background testing.

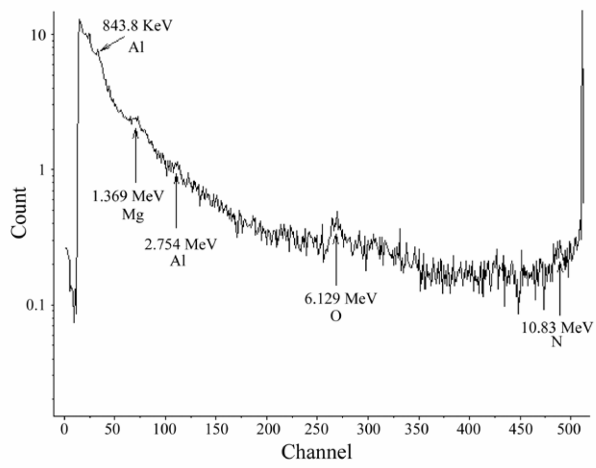

Fig. 2. GRS background accumulative spectrum for series No. 2 time interval in Table 1.

3.2 Analysis of GRS circumlunar data

At 03:58 on November 28, 2007, the GRS was switched on to acquire lunar gamma-ray spectra. Due to the SRAM failure, the GRS was switched off at 09:20 on July 25, 2008. During this period of time, the GRS acquired effective detection data for 1103 orbits, with the accumulative observation time reaching up to 2105 hours. Through the analysis of 2105-hours circumlunar exploration data obtained by the GRS, it was found that the global distribution of the total count of the time series corrected spectrum for each lunar coverage cycle of GRS possesses the significant regional distribution characteristics as shown in Fig. 3, namely the total count from the region of Oceanus Procellarum on the lunar surface is obviously higher than that in other locations. Through the analysis of the energy spectrum data from the regions with higher total count and those with lower total count, it was found that the significant difference lies in the pre-150-channels count, for example, as shown in Fig. 4. The energy scope covered by GRS prior to 150 channels mainly includes the characteristic gamma rays given off by U, K, Th, etc. It is known from the above that the total count of the region of Oceanus Procellarum as shown in Fig. 3 is obviously higher than that in other lunar regions. This is because the abundances of U, K and Th in the region of Oceanus Procellarum are relatively high, thus leading to far more characteristic gamma rays given off by those elements than in other lunar regions.

In this paper the spectral data acquired after correction of the GRS time series are accumulated according to 5°×5° pixel as the spectral data for the analysis of elemental contents. The global distribution of gamma-ray flow of the accumulative spectra also shows obvious regional distribution characteristics, as shown in Fig. 5. Accordingly, in terms of the analysis results mentioned above, it is shown that in the circumlunar spectra of GRS there exist characteristic gamma rays produced by the elements U, K, and Th. In the following we take the element K for example to indicate that the GRS has detected the characteristic gamma rays given off by K. Meanwhile, the method of background deduction is also introduced.

3.3 The method of background deduction

Through comparing the accumulative spectra from two regions, of which one is high in K contents and the other is low in K contents (lunar surface regions 1 and 2 in Fig. 6), it was found that:

(1) In the accumulative spectra for lunar surface regions 1 and 2 there do exist the characteristic peaks of Mg line (1.369 KeV) produced from satellite material as a result of excitation of cosmic rays; (2) in the accumulative spectrum for lunar surface region 2 the characteristic peak count of Mg line (1.369 KeV) is significantly higher than that of Mg line (1.369 KeV) for lunar surface region 1, as is shown in Fig. 7. It can be seen from the existence of K line (1.46 MeV) near Mg line (1.369 KeV) (Reedy, 1978) that in this characteristic peak there exist characteristic gamma rays produced by K line (1.46 MeV), i.e., K (1.46 MeV) line and Mg line (1.369 KeV) merge into one characteristic peak. In addition, as can be seen from Fig. 7, the combined peak of K line and Mg line for the known lunar surface region 2 is approximate to the upward-shifted combined peak for lunar surface region 1, showing no obvious increase in peak area. Therefore, the acquirement of the background through fitting method will lead to such a result that the all-around peak areas in the two regions are equivalent to each other. This is obviously in inconsistency with the fact that the two regions are significantly different in element contents.

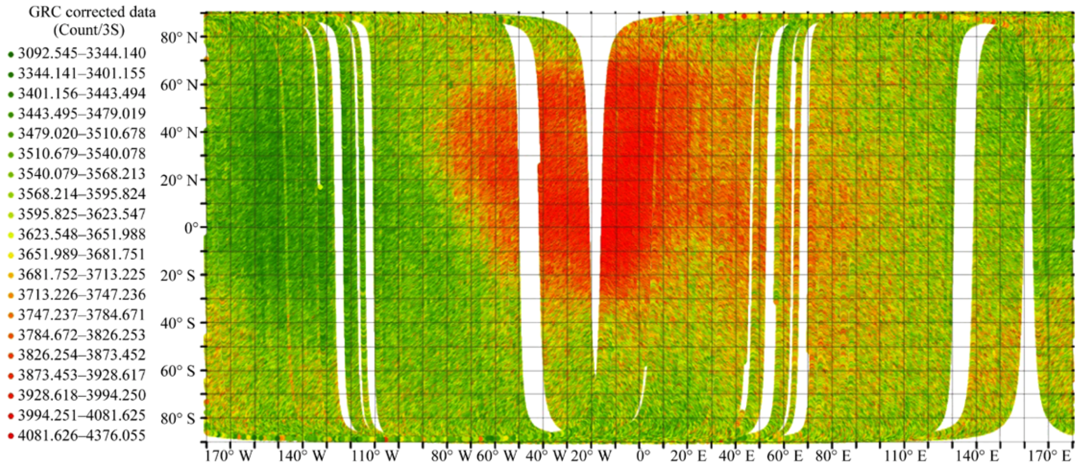

Fig. 3. The global distribution of the total count of the spectrum acquired at 18:15:05 on October 25, 2007 to 00:13:10 on January 08, 2008 (Beijing Time).

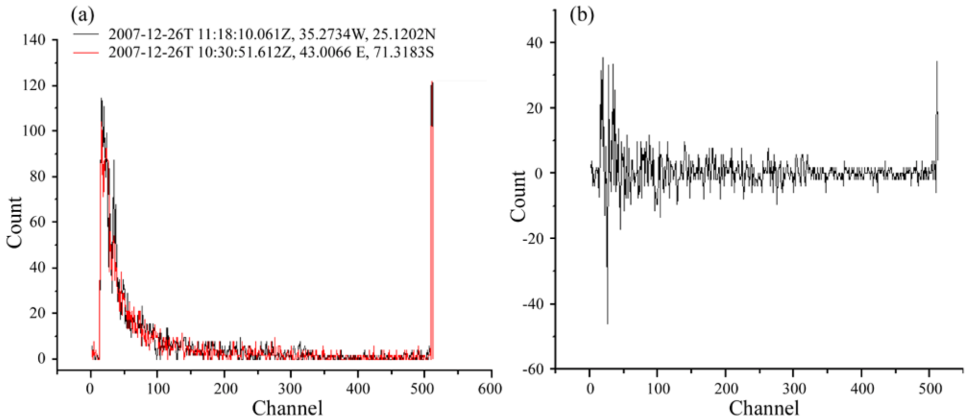

Fig. 4. (a) Two spectra with relatively high total count and relatively low total count; (b) one spectrum obtained after subduction of the two spectra.

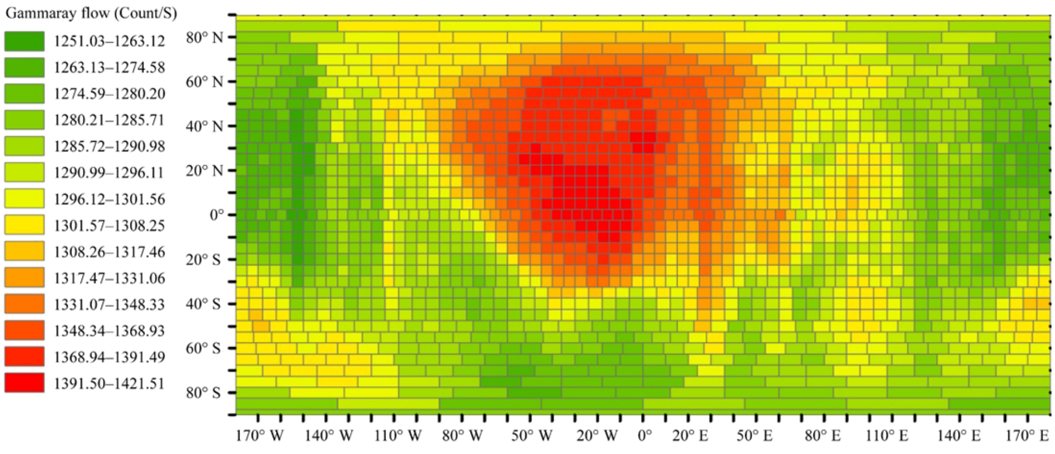

Fig. 5. Whole-lunar distribution of gamma-ray flow in 5°×5° pixel.

Based on the above analyses, this paper analyzes the global distribution of total count within the scope of K line-Mg line combined peak (as shown in Fig. 8), and it is found that this distribution is in accord with the rule of global distribution of the K abundance on the lunar surface (Prettyman et al., 2002). As the K abundance in some limited area of lunar surface are approximate to zero (Prettyman et al., 2002), therefore, based on the assumption that the lowest contents of the element K on the lunar surface are equal to zero, it is proposed that the lowest value of the total count within the scope of K line-Mg line combined peak is taken as the background data for the element K, i.e., the K abundance in the lunar surface region are zero and the characteristic gamma rays produced by K line (1.46 MeV) within the scope of the K line-Mg line combined peak in the accumulative spectra are equal to zero. Based on the fact that the lowest value of total count within the scope of K line-Mg line combined peak being taken as the background data for the element K, the global distribution of the characteristic peak area of the element K has been obtained, as is shown in Fig. 9.

According to the above method, this paper conducted the background deduction of the elements U and Th, and the global distributions of characteristic peak areas of the elements are shown in Fig. 10.

3.4 Analysis of the method of background deduction

According to the characteristics of GRS detection data, this paper puts forward the aforementioned method of background deduction with respect to the lunar surface elements whose abundances are approximate to zero. The characteristic peak areas of the elements U, K and Th were extracted. The concrete positions of the lowest values of total count in the scope of characteristic peaks taken in the background deduction for the three elements U, K and Th and comparisons of the lowest content values of the corresponding elements for Lunar Prospector (LP) are listed in Table 2 and shown in Fig. 11. It can be seen that the lowest content values of U, K and Th for CE-1 and LP are all located in the lunar highlands.

4 Conclusions

The sources of GRS background mainly include diffused gamma ray background, the background produced as a result of interactions between cosmic rays and satellite body, radioactive isotopes produced by cosmic rays, lunar gamma-ray continuum spectra and Compton scattering. It is hard to calculate GRS background composition with models. Therefore, in the flight-controlling program before CE-1 launch the GRS was planned to be switched on to acquire background data during the process of satellite flying toward the Moon. However, the change of flight-controlling program made the GRS having not been switched on for background detection. This paper mainly introduces the lunar gamma-ray spectrum data by making use of the GRS during its circumlunar flight, the background detection experimental data acquired by the GRS during its circumlunar flight, and research on the method of background deduction. In addition, it also puts forward the minimum counting method and introduces how to use this method of background deduction to extract effectively the characteristic peak areas of the elements U, K and Th.

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Table 2 The regions with the lowest element contents of U, K and Th for CE-1 and LP

Element	Region with the lowest total count in the scope of characteristic peak of CE-1 elements						Remark (the concrete position in Fig. 11)
	Pixel No.	Range of longitude and latitude				Corresponding LP element contents in this region (μg/g)	
		Minimum latitude	Maximum latitude	Minimum longitude	Maximum longitude		
U	789	-7.5	-2.5	-155	-150	0.25817	Purple-color region
K	789	-7.5	-2.5	-155	-150	319.63	Purple-color region
Th	717	-12.5	-7.5	-155	-150	0.26805	Green-color region
Element	Region with the lowest contents of LP elements						Remark (the concrete position in Fig. 11)
	Pixel No.	Range of longitude and latitude				Element content value (μg/g)	
		Minimum latitude	Maximum latitude	Minimum longitude	Maximum longitude		
U	790	-7.5	-2.5	-150	145	0	Purple-color region
K	87	-67.5	-62.5	-60	-50	0	Purple-color region
Th	163	-57.5	-52.5	-84	-76	0	Green-color region

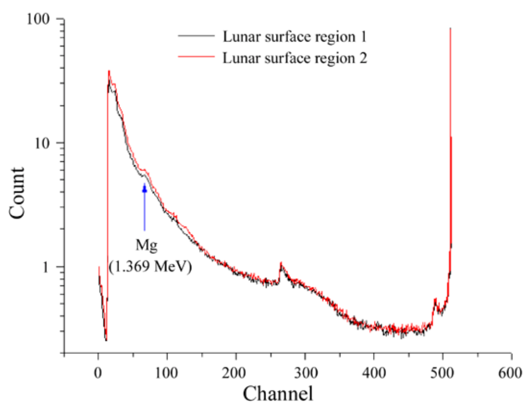

Fig. 6. Accumulative energy spectra of lunar surface regions 1 and 2.

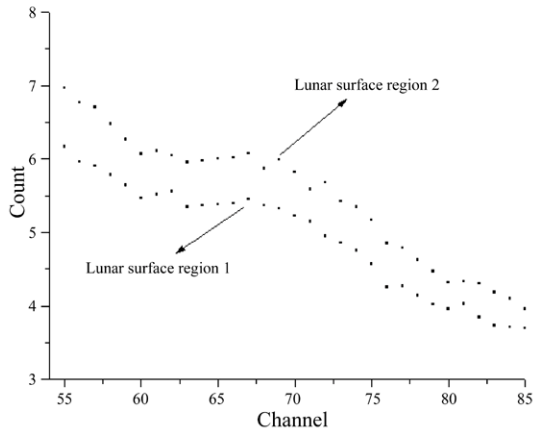

Fig. 7. Energy spectra in the 1.1−1.8 MeV energy scope in lunar surface regions 1 and 2.

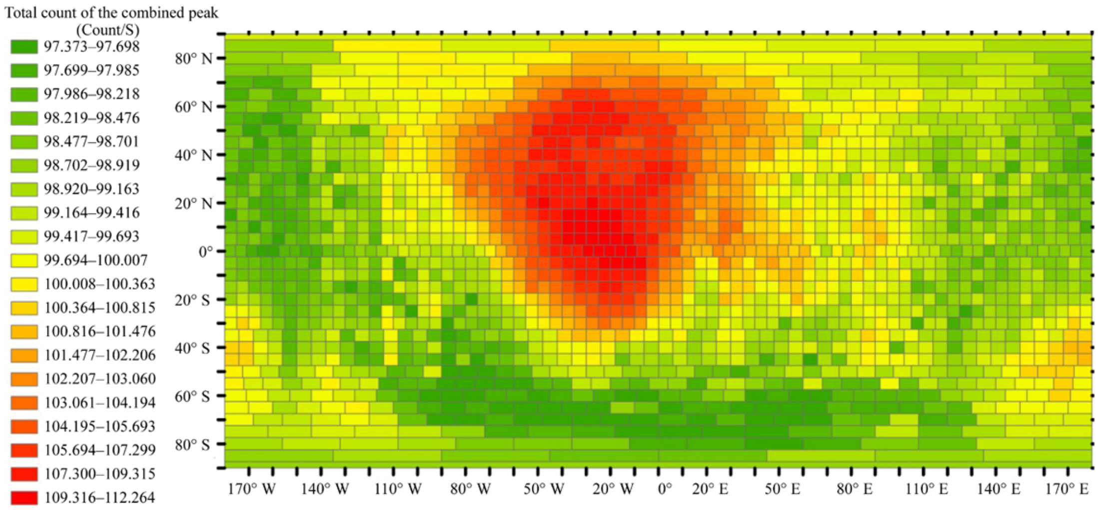

Fig. 8. The global distribution of total count in the scope of K line –Mg line combined peak.

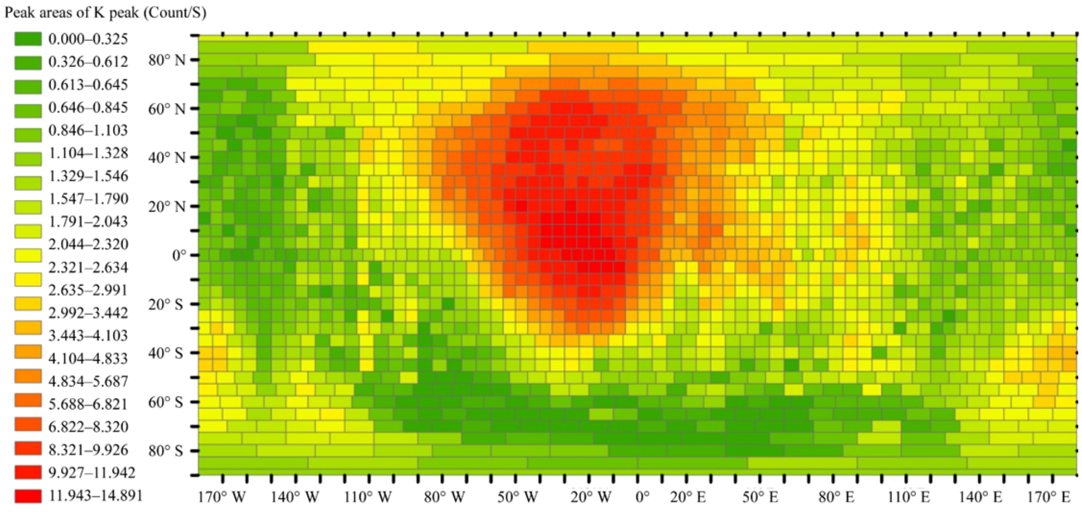

Fig. 9. The global distribution of characteristic peak area of the element K (1.46 MeV).

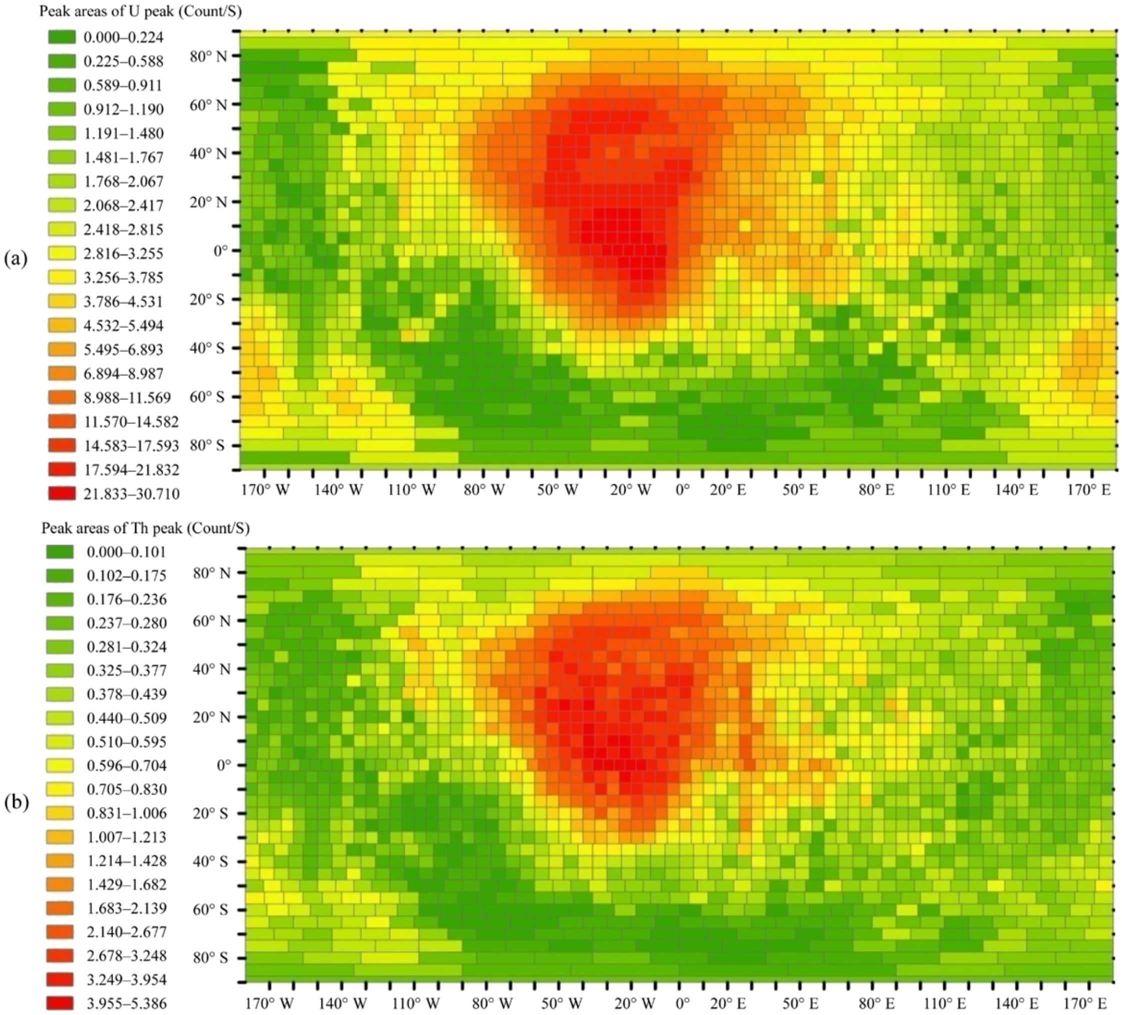

Fig. 10. (a) The global distribution of the characteristic peak area of the element U; (b) the global distribution of the characteristic peak area of the element Th.

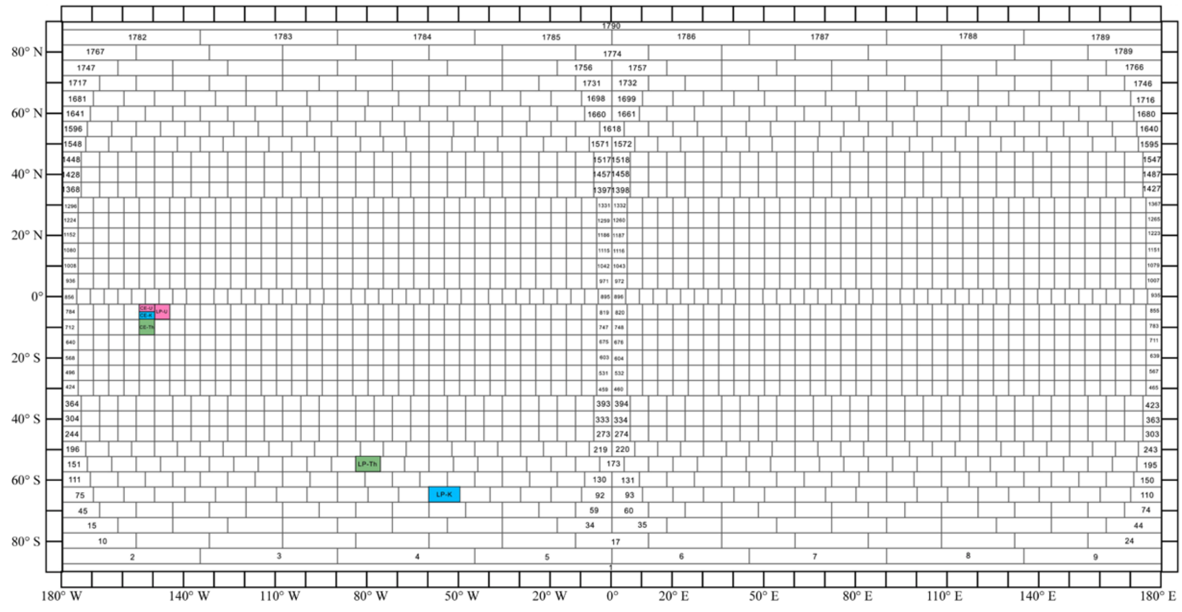

Fig. 11. The regions with the lowest count values of U, K and Th for CE-1 and those with the lowest contents of U, K and Th for LP (pink: U; purple: K and green: Th).

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