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Academician A. P. Vinogradov, Yu. A. Surkov, G. M. Chernov

STUDIES OF THE INTENSITY AND SPECTRAL COMPOSITION OF THE GAMMA RADIATION OF THE MOON ON THE AUTOMATIC STATION LUNA-10

To study the intensity and spectral composition of the γ-radiation of lunar rocks, a 32-channel scintillation gamma spectrometer was installed on the space station Luna-10, placed on a selenocentric orbit on April 3, 1966. The absence on the Moon of an atmosphere that absorbs γ-radiation makes it possible to record it directly from the satellite' s orbit. The decrease in counting rate that occurs in this case is associated with the decrease in the solid angle under which the lunar surface is visible.

Just as is observed on Earth, the γ-radiation of the lunar surface must be associated with the presence in lunar rocks of natural radioactive elements–thorium and uranium with their decay products, as well as the natural radioactive isotope of potassium K^40.

As is known, for terrestrial rocks methods have been developed for determining the content of potassium, thorium, and uranium with the aid of a gamma spectrometer. The experiment with the gamma spectrometer on Luna-10 was arranged in such a way as to attempt, from the γ-radiation of the Moon, to estimate the relative content of K, Th, and U in the rocks of which the lunar surface is composed.

The content of the radioactive elements K, Th, and U is an important indicator of the geological processes that may have taken place on the Moon. Of greatest interest is the question of the degree of physicochemical differentiation of lunar matter (^1). At present there are no data on the chemical composition of lunar rocks. It is unknown whether the Moon has a crust analogous to the Earth' s crust (basalts, granites), or whether its surface is composed of rocks close in composition to primary undifferentiated matter (stony meteorites–chondrites, ultrabasic rocks).

Fig. 1. Gamma-radiation spectra

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From the analysis of terrestrial rocks of various types it is known that the highest content of radioactive elements is observed in the rocks composing the lithosphere—granites—and somewhat less in continental basalts. In passing to the material of stony meteorites and ultrabasic rocks, the concentration of radioactive elements decreases by 2–3 orders of magnitude. Thus, on the basis of knowledge of the concentrations of K, Th, and U in a rock, it is in principle possible to estimate the type of rock and, consequently, its composition.

At the same time, unlike the Earth, on the surface of the Moon there exists γ-radiation arising from the interaction of primary cosmic particles with lunar matter. At low concentrations of K, Th, and U, the intensity of this radiation may prove to be higher than the level of γ-radiation from the decay products of Th, U, and K^40 (^2) and may make it difficult to determine the concentrations of K, Th, and U.

The scintillation gamma spectrometer included a γ-radiation detector, consisting of a NaJ(Tl) crystal measuring 30 $\times$ 40 mm, coupled with an FEU-16 photomultiplier, and a pulse-amplitude analyzer.

The instrument made it possible to measure the spectrum of γ-radiation against the background of charged particles.

The instrument recorded γ-radiation spectra in two ranges: from 0.3 to 3.1 MeV and from 0.15 to 1.5 MeV. Switching between the ranges was carried out by sending a special command to the station.

Below we present the first preliminary results of processing the γ-spectra obtained in the orbit of the Moon' s satellite, as well as along the Earth–Moon flight trajectory.

Results of the experiment. During the first month of operation of the automatic station Luna-10, 6 spectra of γ-radiation were obtained in the energy range from 0.3 to 3.1 MeV. In addition, the intensity of γ-radiation in the same energy range was measured at approximately 15 points. The measurements covered fairly broad areas of the surface, including regions of "continents" and "seas," both on the visible and on the far side of the Moon.

Figure 1 (curve *1*) shows one of the measured γ-radiation spectra of lunar rocks after subtraction of the background caused by the interaction of cosmic rays with the material of the automatic station. The intensity of γ-radiation corresponds to the altitude at which the station was located at the moment of measurement (700 km).

Fig. 1. *1* –spectrum of γ-radiation of lunar rocks after subtraction of the background; *2* –spectrum of γ-radiation caused by processes of interaction of cosmic

rays with lunar rocks (prompt γ-radiation and decay of cosmogenic isotopes); *3* –spectrum of γ-radiation associated with the decay of the natural radioactive elements K, Th, and U contained in lunar rocks

Analysis of the shape of the lunar γ-spectra showed that they differ substantially from the spectra of terrestrial γ-radiation, whose form is determined mainly by the content of natural radioactive elements in the rock. For the Moon, the principal part of the γ-radiation is γ-radiation arising from the interaction of cosmic rays with lunar matter and from the decay of cosmogenic radioisotopes.

When primary cosmic-ray particles collide with the nuclei of the rock, free nucleons are formed in reactions of the type (p, xpn), which, in turn, by interacting with other nuclei, form nucleon cascades. The residual nuclei may be in an excited state; their transition to the ground state is accompanied by the emission of γ-quanta, whose energies for each isotope depend on the scheme of its energy levels, i.e., the radiation is characteristic.

Some of the daughter nuclei formed as a result of nuclear reactions are radioactive and may emit γ-rays during decay. These are the so-called cosmogenic radioisotopes. On the lunar surface all cosmogenic radioisotopes will be in radioact–

equilibrium, i.e., both long-lived and short-lived radioisotopes will be present among the emitters, their content being proportional to the effective cross section for their formation.

Calculations show that the principal contribution is made by the decay of the following cosmogenic isotopes: O^{14}, O^{19}, F^{20}, Na^{22}, Na^{24}. These radioisotopes are formed with an appreciable yield on the main rock-forming elements O, Al, Mg, Si.

Table 1

Energies of γ-rays identified in the lunar γ-spectrum

Energy, MeV	Principal nuclear reactions leading to the emission of γ-quanta of the given energy
0.84	$Al^{27}(p,p'\gamma)Al^{27},\ Si^{28}(p,2p\gamma)Al^{27},\ Fe^{56}(p,p',\gamma)Fe^{56}$
1.01	$Al^{27}(p,pn\gamma)Al^{26},\ Si^{28}(p,2pn\gamma)Al^{26}$
1.37	$Mg^{24}(p,p'\gamma)Mg^{24},\ Al^{27}(p,pt\gamma)Mg^{24},\ Si^{28}(p,p\alpha\gamma)Mg^{24}$
1.78	$Mg^{24}(p,p\alpha\gamma)Ne^{20},\ Al^{27}(p,2p\gamma)Mg^{26},\ Si^{28}(p,p'\gamma)Si^{28}$
2.31	$O^{16}(p,2pn\gamma)N^{14}, Mg^{24}(p,pn\gamma)Mg^{23},\ Mg^{24}(p,2p\gamma)Na^{23},\ Al^{27}($
2.62	$O^{16}(p,2pn\gamma)N^{14}, Mg^{24}(p,pn\gamma)Mg^{23},\ Mg^{24}(p,2p\gamma)Na^{23},\ Al^{27}($

Table 1 gives the energies of the γ-rays identified in the lunar γ-spectrum. The same table also lists the principal nuclear reactions on probable rock-forming elements of lunar rock as a result of which γ-rays of the given energies are emitted.

Along with nuclear reactions leading to the emission of characteristic γ-quanta (prompt γ-radiation and the decay of cosmogenic radioisotopes), some contribution is made by the decay processes of π^0-mesons and by the bremsstrahlung of electrons and protons. The spectra of the latter two processes are continuous in character. As a consequence, the overall spectrum of lunar γ-radiation becomes less structured.

According to preliminary data from the processing of the γ-spectra, the total intensity of γ-radiation at the lunar surface exceeds the intensity over rocks of the Earth' s crust by a factor of 1.5–2 and changes little in passing from one region of the lunar surface to another. This result is apparently explained by the fact that the main source of γ-rays is irradiation by cosmic particles—a factor that acts practically identically over the entire surface.

An estimate of the level of natural activity and a determination of the concentrations of natural radioelements can be made if, from the obtained lunar γ-spectrum, one subtracts the effect of γ-radiation caused by the interaction of cosmic rays with lunar rock.

Assuming that the spectra of γ-radiation induced by cosmic rays in the material of the station and in lunar rock are identical in shape and differ only in intensity, we obtained the spectrum of γ-radiation of lunar rocks caused only by cosmic rays (Fig. 1, curve 2).

Curve 3 (Fig. 1) is the difference between curves 1 and 2. This part of the γ-radiation may be attributed to the decay of natural radioactive elements.

As can be seen from the spectra shown in Fig. 1, in the total intensity of γ-radiation from lunar rocks, about 90% is γ-radiation caused by cosmic rays, and no more than 10% is due to the decay of K, Th, and U.

The gamma spectrometer intended for investigation of lunar γ-radiation was preliminarily calibrated under terrestrial conditions using reference samples with known contents of K, Th, and U, as well as on rock samples with different contents of these elements. On the basis of these data it proved possible to calculate the γ-spectra that should be obtained in measurements in satellite orbit for rocks with different contents of natural radioactive elements (in the absence of

radiation caused by cosmic rays). The mean values of the concentrations of K, Th, and U used in constructing the spectra were taken from work (3).

Comparison of the intensity of γ-radiation from the decay of the natural radioactive elements K, Th, and U with the results of calibration of the instrument on terrestrial rocks makes it possible to assign to lunar rocks concentrations of radioactive elements close to those in terrestrial rocks of basic composition (of the basalt type with a low content of radioactive elements). The data obtained make it possible to exclude, for those regions of the lunar surface where the measurements were carried out, the existence of rocks with a content of the radioactive elements K, Th, and U the same as in terrestrial acidic rocks (granites), and still more, rocks with ore concentrations of these elements. At the same time, it is not at present possible to exclude the possibility of the existence in these regions on the surface of the Moon of ultrabasic (meteoritic) material.

Institute of Geochemistry and Analytical Chemistry
named after V. I. Vernadsky
Academy of Sciences of the USSR

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Note: Figure translations are in progress. See original paper for figures.