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Abstract

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MEASUREMENTS OF RADIATION DURING THE FLIGHT OF THE SECOND COSMIC ROCKET

The apparatus for investigating radiation, installed on the second Soviet cosmic rocket, launched toward the Moon on September 12, 1959, had the aim of obtaining new data on the outer radiation belt of the Earth, recording cosmic radiation along the path from the Earth to the Moon, and also detecting a lunar radiation belt, if such exists.

The number of instruments and the volume of measurements were increased in comparison with the first cosmic rocket (1). In addition, some of the radiation-recording instruments were installed outside the hermetically sealed container (at a distance of 56 cm from its surface), which made it possible to reduce substantially the shielding of these instruments.

The entire set of measuring apparatus consisted of 6 gas-discharge counters and 4 scintillation counters.

Inside the container the following instruments were located:

1. Scintillation counter A (detector—a cylindrical sodium iodide crystal measuring 39.5 × 40 mm). This instrument recorded the total ionization produced by ionizing radiation in the crystal, and the counting rate of pulses corresponding to different energy releases in the crystal: ≥ 60 keV—threshold I; ≥ 600 keV—threshold II; and ≥ 3.5 MeV—threshold III.
2. Gas-discharge counter 4 with working dimensions 1 × 5 cm, surrounded by an additional copper shield 1.5 mm thick.
3. Gas-discharge counter 5 with working dimensions 1 × 5 cm, surrounded by additional shields of 3 mm lead and 1 mm aluminum.

These three instruments were located inside an aluminum shell 1 g/cm^2 thick. In addition, about 20% of the total solid angle was covered by material thicknesses of ~ 10 g/cm^2.

Outside the container the following instruments were installed:

4. Scintillation counter B (detector—a cylindrical sodium iodide crystal measuring 39 × 40 mm). This instrument recorded the total ionization produced in the crystal and the counting rate of pulses corresponding to different energy releases in the crystal: ≥ 45 keV—threshold I and ≥ 450 keV—threshold II. The crystal of this counter was shielded by aluminum 0.8 g/cm^2 thick, and only about 5% of the total solid angle was covered by a large amount of material (up to 10 g/cm^2).
5. Scintillation counter V (detector—a cesium iodide crystal 3 mm thick, 30 mm in diameter, covered on the side of free space by an aluminum layer 1.2 mg/cm^2 thick). The instrument recorded the total ionization produced in the crystal.
6. Gas-discharge counter 1 in a shield 3 mm thick of lead plus 1 mm aluminum, with a window of area 0.28 cm^2.
7. Gas-discharge counter 2 in the same shield, with a window of area 1.6 cm^2, covered with copper foil 0.2 mm thick.
8. Gas-discharge counter 3 in the same shield, with a window of area 1.6 cm^2, covered with copper foil 0.5 mm thick.

In addition, the windows of counters 1, 2, and 3 were covered on the outside with aluminum foil 0.2 mm thick. The wall thickness of all the counters was ~ 50 mg per 1 cm^2 of stainless steel.

Counters 2 and 3 operated only in the high-intensity zone. After exit from this zone, the corresponding telemetry channels were used to transmit information on the counting rate in the scintillation counters (thresholds I and II). This change in the measurement program was made at a definite radiation intensity; for this purpose another counter (without an additional shield) was located inside the container. Program switching was adjusted to the counting rate of this counter, about 500 pulses/sec. The electronics of all the instruments were made with semiconductors. The resolving power of the counting circuits and discriminators was 10^{-5} sec.

This article partially sets forth the results of preliminary processing of measurements in the interval of distances 9-120 thousand km from the center of the Earth and in the circumlunar segment, beginning at 40 thousand km from the surface of the Moon.

1. **Data on the spatial location of the outer radiation belt.** Figure 1 presents the trajectories of the first and second space rockets relative to the Earth’ s magnetic field and the results of ionization measurements. The rocket trajectories differ only slightly from one another: the path of the second space rocket passes through the zone of high intensity 200-300 km closer to the plane of the geomagnetic equator than the path of the first rocket. The indicated displacement of the trajectory cannot be responsible for the change in shape and the displacement of the maximum

Figure 1

Figure 1: Figure 1

of the curve giving the dependence of intensity on flight altitude, but only intensifies this difference.

Fig. 1. Trajectories of the rockets relative to the Earth' s magnetic field. The vertical lines resting on the trajectories depict the radiation intensity at the given point of the trajectory. The figure shows magnetic lines of force intersecting the surface of the Earth at geomagnetic latitudes 50, 55, 60, 65, 70° (the magnetic field is taken to be that of a dipole with coordinates of the geomagnetic pole 78.5° N and 69° W).

The general picture of the deformation of the high-intensity zone on 12 IX relative to its position on 2 I 1959 reduces to a displacement of the zone in the direction of the inner regions of the magnetic field. The maximum intensity on 12 IX was observed at a distance of 17 thousand km from the center of the Earth on the 59° line of force, and on 2 I at a distance of 27 thousand km on the 63° line of force.

What are the causes of the observed deformation of the outer radiation belt? It should be noted that the flights of the first and second space rockets took place along trajectories very close with respect to geographic coordinates, but substantially different with respect to the direction toward the Sun, which could reveal a systematic deformation of the Earth' s magnetic field. It is more probable, however, that the deformations of the outer radiation belt are associated with the variable character of solar corpuscular streams and, correspondingly, with the variable character of the injection of particles into the high-intensity zone. In favor of this speaks the difference observed in the experiments of 2 I and 12 IX in the energy spectrum of the particles, as well as a comparison of the general course of the intensity with data obtained during the flight of the American rocket "Pioneer-3" (^{2}). In the latter case the flight trajectory relative to the direction toward the Sun was close to the trajectory of the first Soviet space rocket, but nevertheless the intensity maximum was recorded at a distance of 22 thousand km from the center of the Earth on a line of force intersecting the Earth' s surface at geomagnetic latitude 57°, i.e., in better agreement with the data from the flight of the second space rocket, and not the first.

2. **Composition of the radiation in the outer radiation belt of the Earth.** Figure 2 gives the readings of some

instruments of the second space rocket as a function of distance from the center of the Earth.

The counting rate of the scintillation counter with a threshold of 3.5 MeV (curve *I*) confirms, with considerably better accuracy than on the first rocket, that particles with a range of several grams per 1 cm^2 are absent in the outer belt.

Fig. 2

Figure 2: Fig. 2

A small (by 30%) increase in the count in the region of the maximum is also possible in this case because of the superposition of pulses of smaller amplitude. Thus the flux of electrons with energy ≥ 5 MeV (or protons with energy ≥ 30 MeV), even at the maximum of the zone, is less than 1 particle/cm$^2 \cdot$ sec.

Substantially new data are found in the readings of gas-discharge counters 4 and 5, placed inside the container and shielded by additional copper and lead filters (curves *II* and *III*). The data from the scintillation counter with a threshold of 3.5 MeV show that the increase in the count in counters 4 and 5 cannot be caused by charged particles penetrating through the shell of the container; hence both counters register photons. Since the intensity of the count in counters 4 and 5 differs by only a factor of one and a half, these photons must be assigned a relatively high energy (more than 300 keV).

Fig. 2. Dependence of intensity on distance from the center of the Earth. *I*—III threshold of scintillation counter A; *II*—counter 4 with a 1.5 mm copper shield (inside the container); *III*—counter 5 with a 3 mm lead shield; *IV*—counter 1 with a window 0.2 mm aluminum thick (inside the zone, the effective area of the window is assumed in the calculation); *V*—ionization in crystal A; *VI*—ionization in crystal B; *VII*—ionization according to the data of the first space rocket.

In principle, two explanations may be proposed for the appearance of photons of the observed energy: 1) due to the X-radiation of electrons with energies of the order of 10^6 eV, or 2) due to bombardment of the container shell by protons with energy ~ 10 MeV.

At the present time the first alternative appears more probable. But even in this case the energy spectrum of the particles (electrons) proves quite unexpected. An estimate of the flux of electrons with energy ~ 1 MeV at the maximum, from the readings of counters 4 and 5, gives a value of $\sim 5 \cdot 10^5$ particles/cm$^2 \cdot$ sec; while the flux of electrons with energy 5 MeV, as already stated, is less than 1 particle/cm$^2 \cdot$ sec. On the other hand, in the experiments on the first space rocket a very large flux of electrons with energy 20-50 keV was detected, namely: $\simeq 10^{10}$ particles/cm$^2 \cdot$ sec. This soft part of the electron spectrum is also detected in the experiment on the second rocket at the edge of the zone by means of the scintillation counters. At the maximum it is expressed more weakly than was the case on January 2, but nevertheless it evidently makes a noticeable contribution to the readings of counter 1 (Fig. 2, curve *IV*).

Thus, data have been obtained on the existence of two energy groups of particles: electrons with energy ~ 20 keV and electrons with energy ~ 1 MeV (or protons with energy ~ 10 MeV). Apparently, the mechanism the formation of the two groups is substantially different. The energy of the particles of the first group is close to the mean energy of the protons of solar corpuscular streams, and this makes it possible to assume the establishment of thermodynamic equilibrium between protons and electrons in the course of their penetration into the Earth' s magnetic field. Conversely, the formation of the second group is apparently due to nonequilibrium processes. It is noteworthy that the momenta of the electrons of the second group are close in magnitude to the momenta of the protons of corpuscular streams, and also to the momenta of electrons arising from the decay of albedo neutrons.

3. Searches for increased radiation near the Moon.

During the approach to the Moon, down to a distance of 1000 km from its surface, no increase in radiation intensity within 10% of the cosmic background was detected. The acquisition of precise data in the range of distances from 0 to 1000 km from the lunar surface was made difficult by the short duration of the passage through this region, but even at these altitudes no appreciable increase in intensity was found.

If the intensity of the radiation in a hypothetical lunar radiation belt is compared with the maximum of the Earth' s outer belt, according to the indications of the detectors most sensitive to soft radiation—scintillation counters—then for altitudes > 1000 km the intensity ratio is 10^{-6} or less, and for altitudes $0 \div 1000$ km it is 10^{-4} or less. Thus, it may be considered that, in practice, a lunar radiation belt does not exist.

4. Measurement of the intensity of cosmic rays.

After emergence from the Earth' s outer radiation belt, beginning at a distance of 70 thousand km from the center of the Earth and over the circumlunar sector, all instruments recorded a constant intensity. The placement of some of the instruments outside the container gave a perceptible result in reducing the contribution of secondary radiation produced by cosmic rays in the surrounding material. Fig. 2 shows the results of measuring ionization inside the container (curve V) and outside the container (curve VI). If within the radiation belt curve VI lies considerably higher than curve V, which is explained by the absorption of comparatively soft radiation, then outside the soft-radiation zone the effect is, as expected, the opposite. An analogous result was obtained for the other parameters as well. A summary of the data on the intensity of radiation outside the Earth' s magnetic field is given in Table 1.

Table 1[1]

Date	Instrument location	Gas-discharge counters: intensity (particles/cm^2 · sec)	Scintillation counters: threshold energy (keV)	Scintillation counters: intensity[4]	Ionization in a crystal weighing 180 g (eV/sec)
2 I 1959	Inside the container	2.3 ± 0.1	4500	1.9 ± 0.1	$(1.42 \pm 0.05) \cdot 10^9$
2 I 1959	Inside the container	2.3 ± 0.1	450	3.0 ± 0.15	$(1.42 \pm 0.05) \cdot 10^9$
2 I 1959	Inside the container	2.3 ± 0.1	45	6.75 ± 0.3	$(1.42 \pm 0.05) \cdot 10^9$
12 IX 1959	Inside the container	2.46 ± 0.1[2]	3500	2.12 ± 0.1	$(1.55 \pm 0.05) \cdot 10^9$
12 IX 1959	Inside the container	2.46 ± 0.1[3]	600	2.77 ± 0.15	$(1.55 \pm 0.05) \cdot 10^9$
12 IX 1959	Inside the container	2.46 ± 0.1[3]	60	6.7 ± 0.3	$(1.55 \pm 0.05) \cdot 10^9$
12 IX 1959	Outside the container	1.98 ± 0.1[3]	450	2.02 ± 0.1	$(1.15 \pm 0.05) \cdot 10^9$

[1] Errors characterize the maximum spread over the detector area. [2] Counter with an additional shield of 1.5 mm Cu. [3] Counter with an additional shield of 3 mm Pb. [4] The number of pulses per second, referred to unit area of the crystal (19 cm^2), is given.

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