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X-RADIATION OF THE MOON AND ROENTGEN COSMIC BACKGROUND ACCORDING TO DATA OF AMS "LUNA-12"

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SUMMARY

The results of measurements are presented of soft X-radiation of the Moon probably occurring during fluorescence of the lunar surface under the action of Sun's X-radiation. The flux of Moon's X-radiation in the 8 − 14 A spectral region constituted in different time periods ∿ 10 − 150 photons/cm² sec sterad. The cosmic roentgen background constituted ∿ 7.5 photons cm²/sec sterad kev in the spectral region 8 − 12 A. Corpuscular fluxes, apparently electrons of solar origin with energy E > 50 kev and reaching ∿ $1 \cdot 10^3$ particles cm sec sterad, were registered near the Moon. The intensity of these fluxes agrees well with the index A_p of geomagnetic disturbance.

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* *

Investigations of Moon's X-radiation, begun on AMS LUNA-10 [1], have been pursued with the help of AMS LUNA-12. The problem of the experiment centered on the further search of soft X-radiation emitted by the superficial layers of the Moon, which has a roentgen-fluorescent nature and occurring under the action of Sun's X-radiation.

The apparatus' response was raised by comparison with that used on LUNA-10. Two identical Geiger counters (Cr.1 and Cr.2) served as radiation receivers; they have aluminum windows 10 μm thick and an area of 3 cm², with effective field of vision of 0.8 sterad. The geometrical factor for the registration of the hard isotropic aadiation constituted 12.6 cm². The curve of counters' spectral sensitivity, the counters being filled with a neon-xenon-oxygen gas mixture, is plotted in Fig.1 (see [2]). Thus the counters were sensitive to characteristic lines of Al and Mg atoms entering in the composition of the lunar surface. A third identical counter (Cr.3) was additionally shielded by an Au-Ag filter; it controlled the contribution to the counting rate of the penetrating radiation constituted by cosmic rays and electrons with energy > 50 kev that are present in the vicinity of the Moon [1]. Still another counter (Cr.4) with aluminum window of 0.05 cm area served for the measurement of the intensity of

(*) RENTGENOVSKOYE IZLUCHENIYE LUNY I RENTGENOVSKIY KOSMICHESKIY FON PO DANNYM SPUTNIKA LUNY "LUNA-12"

X-radiation arriving from the Sun in the 8 – 14 Å spectral region. Its geometrical factor constituted at registration of hard isotropic radiation 6.3 cm . The assurance that the Sun hit the field of vision of the counters was controlled with the aid of an optical sensor (ОД), which is a silicon phototransformer wuth two outputs of different sensitivity, namely a Moon sensor with hifher sensitivity output and Sun sensor with lesser sensitivity. The disposition of the counters and of the optical sensor is schematically represented in Fig.2.

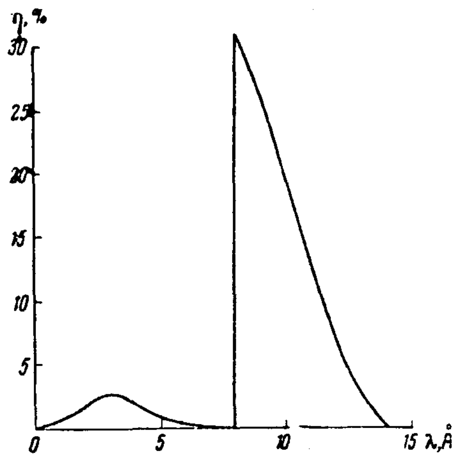

Fig.1 Spectral sensitivity of the X-ray counter

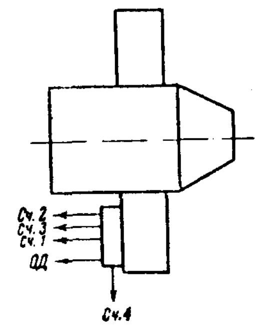

Fig.2. Disposition of the receivers of X-ray radiation and of the optical sensor on AMS LUNA-12

The photon counters' readings were registered by logarithmic intensimeters and scaling circuits; they were telemetered to Earth alongside with the readings of the optical sensor. The measurement sessions with duration from a few minutes to 1.5 hours were conducted in the period from 26 October 1966 to 6 Jan. 1967. During the first sessions the windows of the counters were shielded by an aluminum cover 1 mm thick which then was opened up on special command.

AMS LUNA-12 was during measurements in an nonoriented flight regime and its free motion about its center of masses was close to pure spinning. The axis of rotation was perpendicular to the longitudinal axis of the satellite, which is about perpendicular to the plane of the drawing in Fig.2; it lied almost in the orbit plane of the satellite. Because of satellite rotation the counters were alternately oriented at the Sun, the outer space and the Moon at time of its motion over a substantial part of the illuminated surface of the Moon. As to Cr.4, the Sun hit its field of vision only at time of certain sessions (28, 30 and 31 October, 13 and 16 December 1966); during the remaining days it was outside the counter's field of vision.

During the measurement period the registrations of the control counter Cr.3 and of Cr.4 with small window area have shown in the course of a series of sessions that the counting rate exceeds very considerably the background level induced by cosmic rays. This is evidence of the appearance near the Moon of intense corpuscular fluxes, as a consequence of which the sessions in question could not be utilized for X-radiation measurements.

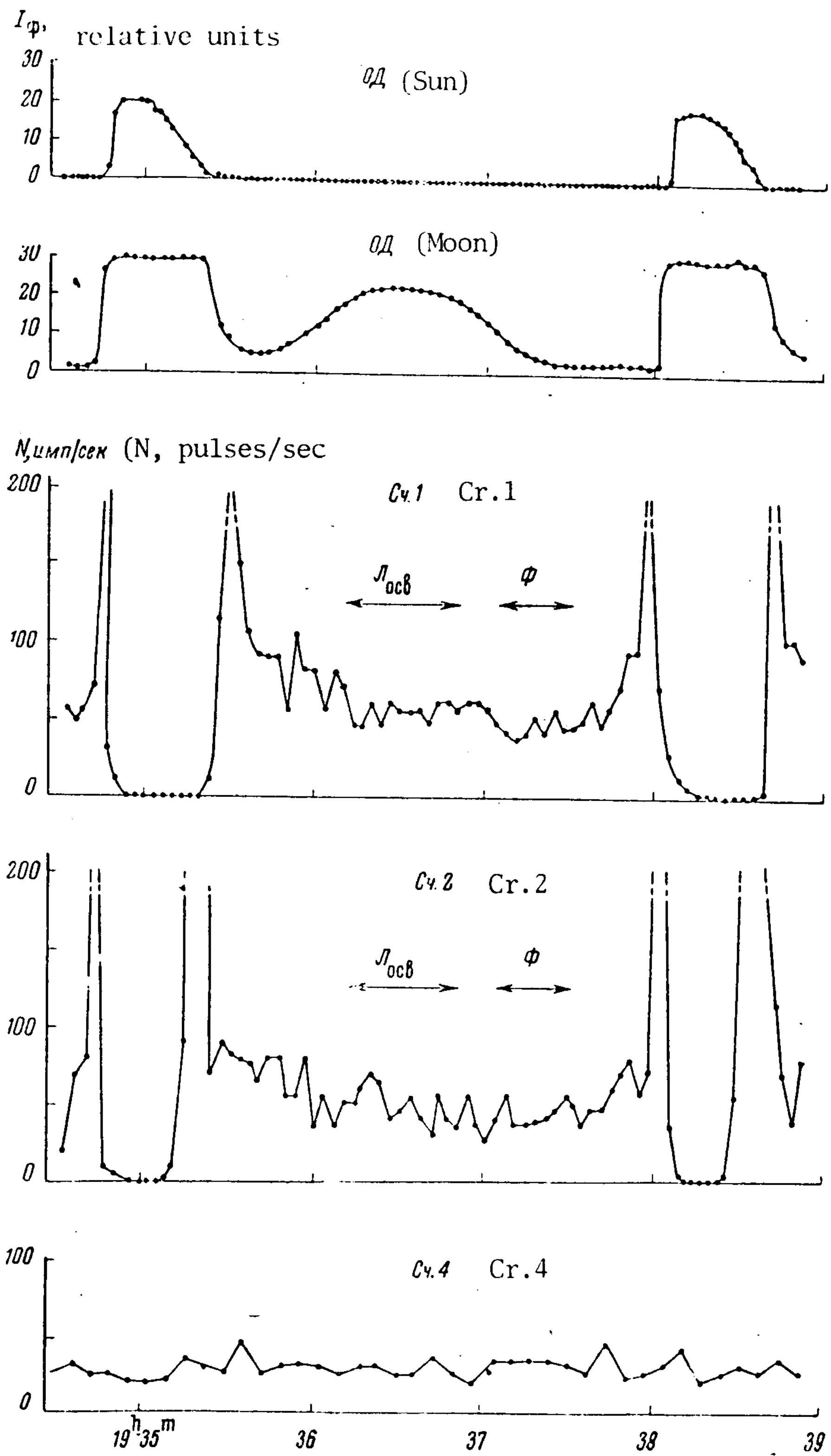

Fig.3. Registration of readings of X-ray counters and of the optical sensor of the Sun and of the Moon in a period of low solar activity on 2 Nov.1966

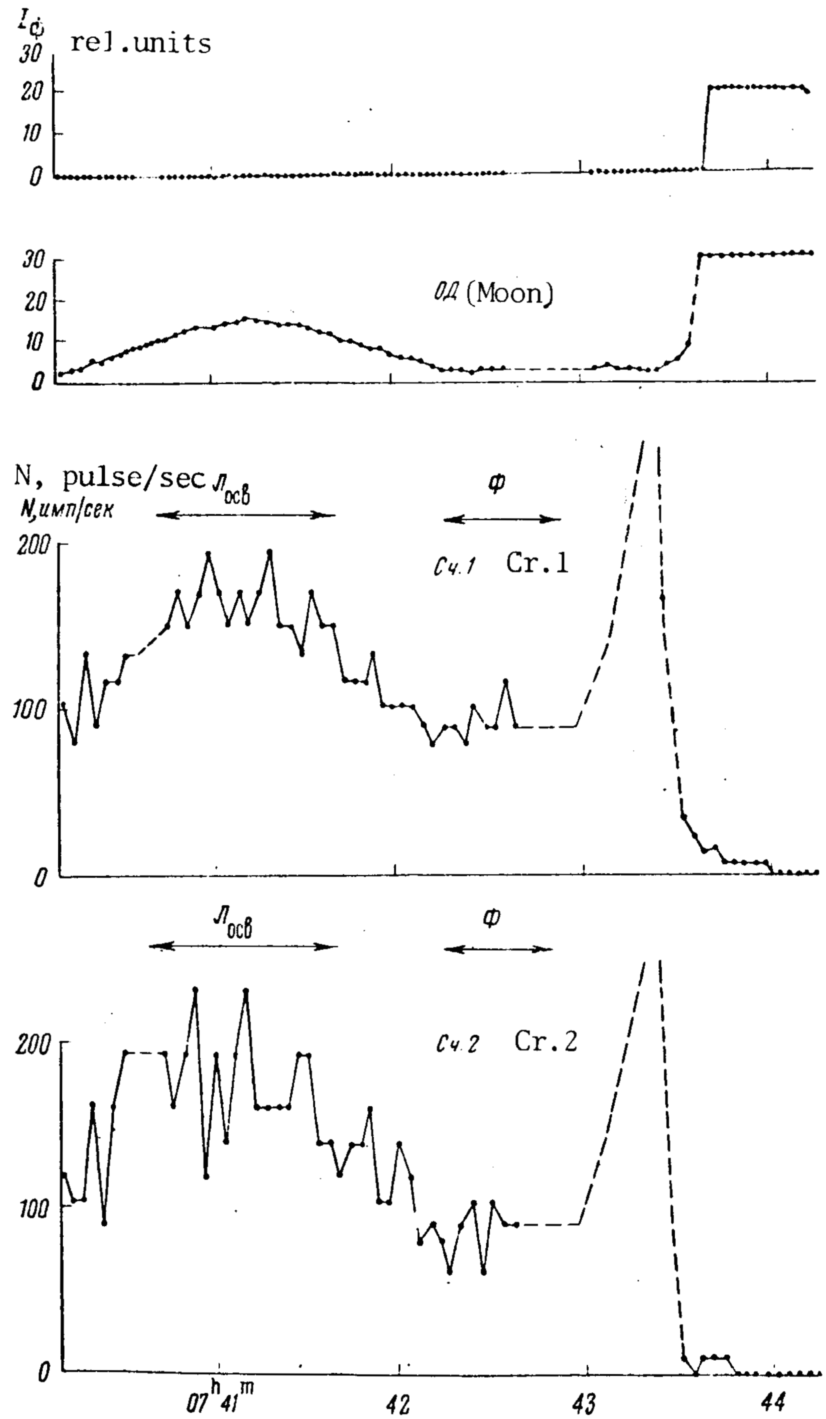

Fig.4. Registration of readings of X-ray counters and the optical sensor of the Sun and of the Moon in a period of high solar activity of 5.Jan.1967

Let us examine the results of measurements during the days free from interferences due to corpuscular fluxes. Shown in Figures 3 and 4 are the typical specimens of readings of the counters and the optical sensor at the time when LUNA-12 was above the illuminated part of the Moon. The moments of time when the Sun hit the visual field of the apparatus are seen in the readings of the Sun's sensor, and those of the Moon are seen in the readings

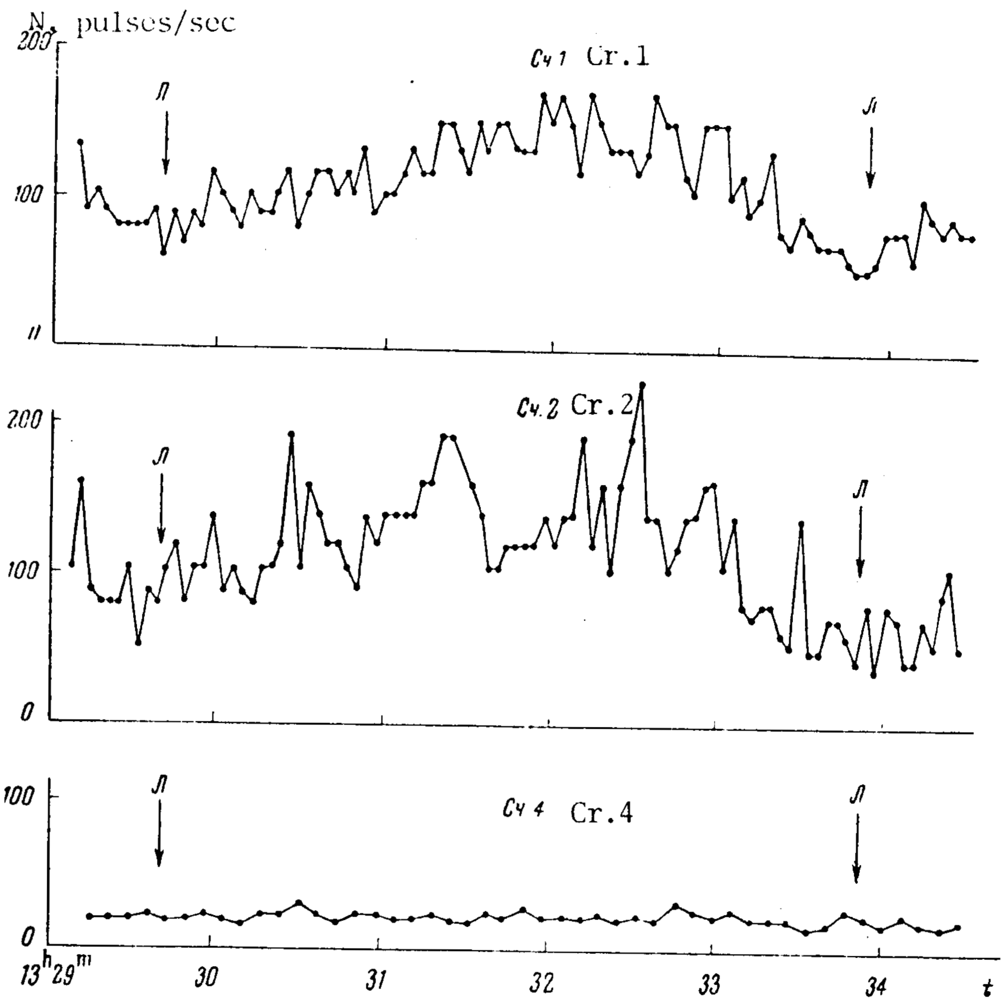

Fig.5. Registration of the readings of X-ray counters during during the recording of increased corpuscular fluxes on 16 Dec. 1966

of the Moon's sensor (because of its high sensitivity the sensor is off-scale when the Sun hits it). The readings of X-ray counters 1 and show the portions when the Sun hits them, which are attended in its central part by the "off-scale", i.e. a drop of readings to zero, and also the portions corresponding to hits by the Moon and the outer space. The portions corresponding to the times when the counters are directed at the Moon are marked by ($Л_{осв}$) and when they by-pass the Moon and aim at the outer space - by ($Ф$).

Plotted in Fig.3 is also the reading of the solar counter Cr.4, showing that during the session the Sun did not hit its field of vision*)

It may be seen in Figures 3 and 4 and also on analogous registrations during other measurement sessions, free from interferences, that the counting rate of Cr.1 and Cr.2, when they are directed toward the illuminated side of the Moon, is somewhat higher than when the direction by-passes the Moon and heads toward the outer space.

Data for eight sessions are compiled in Table 1; the values of $I(Л_{осв})$ and $I(Ф)$ averaged by the entire segment $Л_{осв}$ and along the segment $Ф$ are brought up for each session. Consideration of Table 1 shows that the count excess

$$I_л = I(Л_{осв}) - I(Ф)$$

varies from session to session within a considerable range. In order to verify the reality of this excess, that is, to prove that it is not the result of counter "racing" conditioned by a preliminary exposure to the Sun, two sessions were used, namely those of 28 October and 23 November 1966; during these sessions the Moon remained outside the field of vision of the counters. The respective averagings by two sessions have shown that the difference $I(Ф_л) - I(Ф)$ does not exceed 1 pulse/sec **) This is evidence of the fact that within the limits of measurement precision the "racing" does not distort the results of observations.

Let us refer again to Table 1. In order to separate the X-ray radiation of interest to us from the quantity $I_л$ its is necessary to take the following into account· contribution to the counting rate $I(Л_{осв})$ is made by X-radiation of the Moon and by cosmic rays, while the diffusive X-radiation of outer space and cosmic rays contribute to the counting rate of $I(Ф)$

The contribution from the diffusive X-radiation of outer space was determined from comparison of readings from Cr.1 and Cr.3 (control) insensitive to X-radiation.

TABLE 1

X-radiation of the Moon ($I_{рл}$) according to data of experiment on LUNA-12 pulses/sec

	Cr.1			Cr.2			$I_{рл}$
	$I(Л_{осв})$	$I(Ф)$	$I_л$	$I(Л_{осв})$	$I(Ф)$	$I_л$	
1.XI 1966 г.	—	—	—	68	50	18	17
2.XI	52	45	7	51	45	6	5
12.XI	54 *	44	10	52 *	46	6	6
24.XI	—	—	—	50	43	7	6
3.XII	67	54	13	63	51	12	11
3.XII	70	57	13	66	47	19	15
9.XII	91	63	28	—	—	—	27
5.I 1967 г.	240 *	90	150	250 *	93	157	152

* Correction is introduced to $I(Л_{осв})$ for the incomplete filling of the visual field of the counter illuminated by part of Moon

TABLE 2

Readings of X-ray counters of LUNA-12 during flight over the dark part of the Moon (height 250 km, 9 Dec.1966), expressed in pulses/sec

Orbit	Сч. 1		Сч. 2		Сч. 4	
	$Л_{тем}$	$Ф$	$Л_{тем}$	$Ф$	$Л_{тем}$	$Ф$
1	55,8	50,9	51,6	46,9	23,9	23,6
2	55,5	49,1	48,3	45,7	24,2	23,4
3	47,6	46,1	45,4	41,6	24,1	22,0
4	46,5	43,4	40,0	39,9	25,2	23,9
5	44,0	44,3	48,2	42,2	26,1	22,5
average	49,9	46,6	46,8	43,3	24,7	23,1
$I(Л_{тем}) - I(Ф)$	3,1±1,4		4,4±2,7		1,6±1,0	

The underscript TEM refers to dark part.

*) **) see these notes on page 10

In first sessions, when the windows of the counters were shut by a cover, the counting rate for these counters constituted respectively 44.5 and 44.7 pulses/sec (the observed difference is caused by the calibration imprecision of intensimeters and the difference in counters). Following this a counting rate of 46.9 and 44.3 pulses/sec was registered with the open cover (with the Sun and the Moon outside the field of vision). Taking into account the difference in the counters this gives an estimate of the contribution of X-radiation from the outer space ∿ 2.7 pulses.sec, which corresponds in the region 8 12 A to about 7.5 Photons/cm^2 sec sterad kev [3, 4].

When determining the background of cosmic rays, constituting during the days of measurements about 3.4 pulses/cm^2 sec, one should bear in mind that the corresponding contribution to $I(Л_{осв})$ and $I(\Phi)$ readings is somewhat different because of the presence of lunar surface's albedo for the component of cosmic rays registered by our counters. [5, 6]. Cosmic rays, reflected by the surface of the Moon, penetrate into our counters through the windows and through the lateral walls; the visual field of all counters is centered for this radiation in the direction of minimum screening by the matter of neighboring systems located on the satellite and just about coincides with the direction of our device's optical axis. This explains the difference in the background of cosmic rays when the windows of the counters are oriented at the Moon or toward the outer space. The contribution of lunar albedo of cosmic rays to $I_Л$ was estimated by us by comparing the counter readings with 3 cm^2 and during measurements above the dark side of the Moon with 0.05 cm^2 windows. These readings are compiled in Table 2 for five consecutive hittings by the Moon of the visual field of apparatus during one of the measurement sessions; the rotation phase (relative to the direction at the Moon) was extrapolated by us according to data on the rotation period and orientation on the nearest illuminated portion of flight. As may be seen from Table 2, the contribution of albedo constitutes for the Cr.1 and Cr.2, 3.1—4.4 pulses/sec, and for Cr.4, 1.6 pulse/sec, which corresponds to the geometric factors' ratio for the registration of cosmic rays. The absolute value of albedo is ∿ 8% and it is somewhat less than that measured in [6], which may be explained by our registration of only the soft component of the reflected cosmic rays.

The thus determined intensity of Moon's X-radiation, taking into account the corrections for the diffusive roentgen background of the outer space and for the Moon's albedo for cosmic rays ($I_{pЛ}$) pulses/sec, registered in the described experiment, is presented in the last column of Table 1. If we take into account the efficiency of our counters, the flux of X-radiation of the Moon constitutes from ∿ 10 to 150 photons/cm^2 sec sterad. Let us compare these values with those of computed values of X-radiation in K_α -lines of Al and Mg [1]:

$$N_\lambda = N_{кр} \frac{PwK_Z\tau}{4\pi} \int_0^\infty e^{-l\left(\frac{\mu_1}{\cos\varphi} + \frac{\mu_2}{\cos\psi}\right)} dl \quad \text{photon/cm}^2\cdot\text{sec}\cdot\text{sterad.}$$

Here $N_{кр}$ is the flux of Sun's X-radiation with wavelength $\lambda < \lambda_{k\alpha}$ in photon/cm^2 sec, P is the relative probability of transition of the measured line, w is the fluorescence yield factor, K_Z is the weight concentration of Al and Mg in the rocks of the lunar surface. τ is the true absorption coefficient of the lunar rock for incident radiation, μ_1 and μ_2 are the absorption coefficients of the lunar rock for the incident and outgoing radiation, ϕ and ψ are respectively the angles of incidence and outgoing radiation. We shall assume $\cos\varphi \approx \cos\psi \approx 1$, $K_{Al+Mg} \approx 0{,}1$, $\tau \approx \mu_1 \approx \mu_2$, $P \approx 1$ and $w \approx 3\cdot10^{-2}$. The flux of solar radiation in the region 1 – 10 A constituted according to our data $\sim$ $\sim 2.5\cdot10^{-4}$ erg/cm² sec during the first day of measurements, which corresponds to $N_{кр} \approx 5\cdot10^4$ photons/cm² sec; in the period from 3 December to 9 December

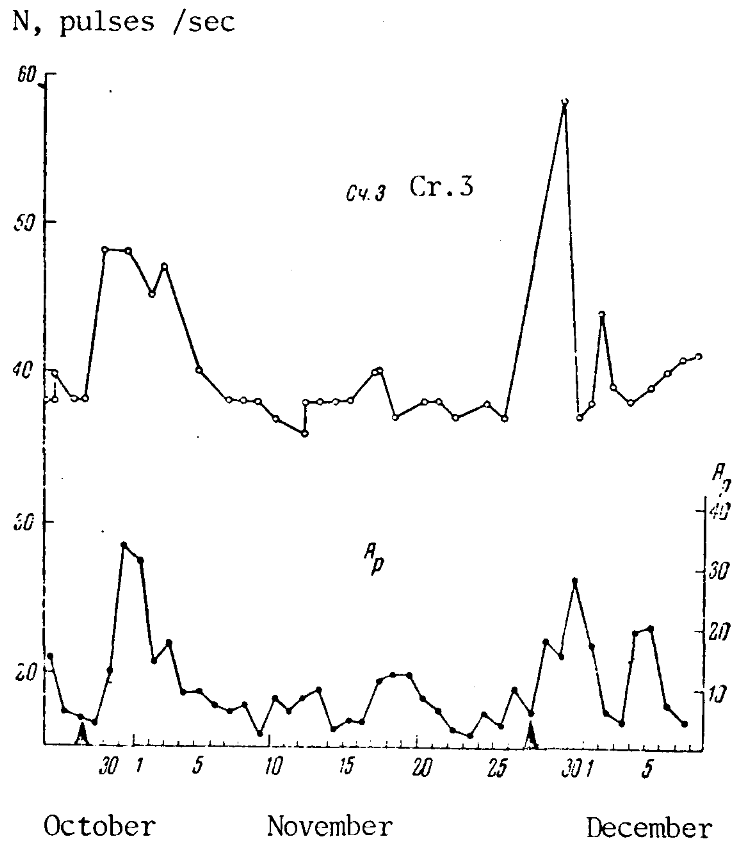

Fig.6. Readings of the control counter Cr.3 and index of geomagnetic activity A_p
Triangles indicate the fullmoon times

the radiation intensity increased and reached $\sim 2.6\cdot10^{-3}$ erg/cm² sec [7], which corresponds to $N_{кр} \approx 5\cdot10^5$ photons/cm² sec.

Utilizing the above values of constants and $N_{кр}$, we obtain for the flux of fluorescent X-radiation of the surface of the Moon for the above indicated days of measurements $N_\lambda \approx 10 - 100$ photons/cm²·sec·sterad. Such a coincidence of experimental and computed data, account being taken of the low measurement precision and the estimated character of calculation, is unquestionably casual. However, the presence of parallelism between the increase of the flux of Moon's X-radiation and the rise of Sun's X-radiation, and also the agreement within the limits of one order of absolute values of measured and computed radiation fluxes compels us to assume that the registered Moon's X-radiation is really the roentgen-fluorescent emission of lunar surface. The absolute value of this emission agrees well with the representations on the basaltic character of lunar rocks.

It is quite probable that the observed enhanced signals of Cr.3 on AIS LUNA-10 on 8, 23, 27, 28 April and 29 May 1966 [1] also correspond to the registration of the roentgen-fluorescent emission of the Moon.

Let us consider now the data related to the registration of corpuscular fluxes, enhanced by comparison with the background og cosmic rays. Plotted in Fig.5 are the results of measurements of 16 December 1966. Cr.1 and Cr.2 give a high counting rate, nearly not modulated by the rotation; counter 4 (Cr.4) shows a lesser increase in the counting rate on account of the relatively smaller window area. Readings of Cr.1 and Cr.2 are evidence of nearly full isotropy of registered fluxes. The observed relatively shallow minima, annotated by arrows, correspond to the direction at the Moon and indicate the screening effect of the fluxes by the Moon. The maximum flux of particles registered on 13 December constituted about $1.4 \cdot 10^3$ particles/$cm^2 \cdot$sec$\cdot$sterad. In other days, such as 16, 29 December 1966 and 6 January 1967 there were observed fluxes of nearly 30 particles/$cm^2 \cdot$sec $\cdot$ sterad.

The results of measurements of the control counter (Cr.3) for the period from 26 October to 8 December 1966 are plotted in Fig.6.

The positions of the maxima are notably displaced relative to the boundaries of the extension of the Earth's magnetosphere "tail", crossed by the Moon 1 to 2 days prior and 1 to 2 days after the relative moments of time of fullmoon, as this was revealed on AIS LUNA-10 in April-May 1966 [8]. The assumption that the registered particles have a solar origin correspond better to the combination of the observation data. This assumption is also corroborated by the comparison with the indices of geomagnetic field disturbance K_p and A_p for these days (see Fig.6, where data for A_p are shown).

The authors extend their gratitude to A. P. Popov, V. F. Sukhanov, V. P. Fridshtand and V. G. Chaykovskiy for their help in the preparation and checking of the experiment.

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INFRAPAGINALES NOTES FROM PAGE 6 FOLLOW ON PAGE 10 AFTER REFERENCES

R E F E R E N C E S

[1]. S. L. MANDEL'SHTAM, I. P. TINDO, V. I. KAREV. Kosm.Issl. 4, 6, 827, 1966.

[2]. L. S. SOROKIN, A. B. DMITRIYEV, V. G. CHAYKOVSKIY, I. P. TINDO. Pribory i tekhniki eksperimenta (Apparatus and technology of the experiment). In print 1968.

[3]. S. L. MANDEL'SHTAM, I. P. TINDO. Pis'ma (Letters) ZhETF, 6, 796, 1967.

[4]. L. A. VAYNSHTEYN, V. G. KURT, S. L. MANDEL SHTAM ET AL. Kosm.Issl. 6, 2, 1968 (still not issued)

[5]. S. N. VERNOV, P. V. VAKULOV, E. V. GORCHAKOV ET AL. Dokl.AN SSSR, 195, 5, 1044, 1966.

[6]. N. L. GRIGOROV, V. L. MADUYEV, N. F. PISARENKO, I. A. SAVENKO. Ib.170, No.3, 565, 1966.

[7]. SOLAR WIND AND GEOPHYSICAL DATA, HAO Boulder, Colorado, USA

[8]. N. L. GRIGOROV, V. L. MADUYEV, S. L. MANDEL'SHTAM ET AL. Dokl. AN SSSR, 170, No.3, 567, 1966.

INFRAPAGINAL NOTES FROM PAGE 6

*) The fluctuations of the registered counting rate from point to point, noticeable in Figures 3 and 4, are partially induced by signal fluctuations and partially also as a consequence of errors arising during the action of the discrete system of reading codings. Fluctuations are less noticeable on the registration by Cr.4 than in the case of Cr.1 and Cr.2, as the interrogation on the former is twice as small.

**) ($Л_{осв}$) are the readings when the counters aim at the free space, in the rotation phase of the AMS corresponding (in other sessions) to the direction at the illuminated Moon.