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MEASUREMENT OF PROTON AND NEUTRON SPECTRA ON SATELLITES OF THE "KOSMOS" SERIES

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SUMMARY

The results of measurements are considered of fluxes and energy spectra of protons and neutrons in satellites of the "Kosmos" series. Measurements were conducted with the help of stacks of nuclear emulsions. The results thus obtained are used for the calculation of cosmic radiation doses.

* * *

In connection with the program of scientific research (announced by the TASS Agency on 16 March 1962), we conducted in the course of 1965-1967 measurements of fluxes and energy spectra of heavy charged particles and neutrons inside hermetic compartments of satellites of the "Kosmos" series; these observations were conducted with the aid of nuclear emulsions in the 200 - 400 km altitude range. The layers of nuclear emulsions were built up in stacks of 15 - 20 layers of 50 mm in diameter and were placed inside round hermetic aluminum containers of same diameters and with wall thickness of 0.3 g/cm^2.

The stacks were fastened in hermetic compartments of the satellites; they were also placed inside the already installed polyethylene spheres of 5, 10 and 15 cm radius with the view of investigating the attenuation and accumulation of radiation in a tissue-equivalent substance.

For the purpose of measurement, charged particle tracks with ±10° dipping angle were chosen; the energy of protons to 50 Mev was determined by the relation path - energy [1].

In the region 50 - 400 Mev the energy of protons was determined with the help of the ionization method. The results of measurements of proton spectra in the region < 400 Mev behind the various polyethylene filters in the satellite's cabin, made from apogee ~ 300 km, are shown in Fig.1. Comparison of the obtained spectra with the proton spectrum of the inner belt, determined by Friden and White [2] at altitudes of about 1200 km, shows that in our case the initial spectrum of protons of the inner belt at altitudes of about 300 km is somewhat softer.

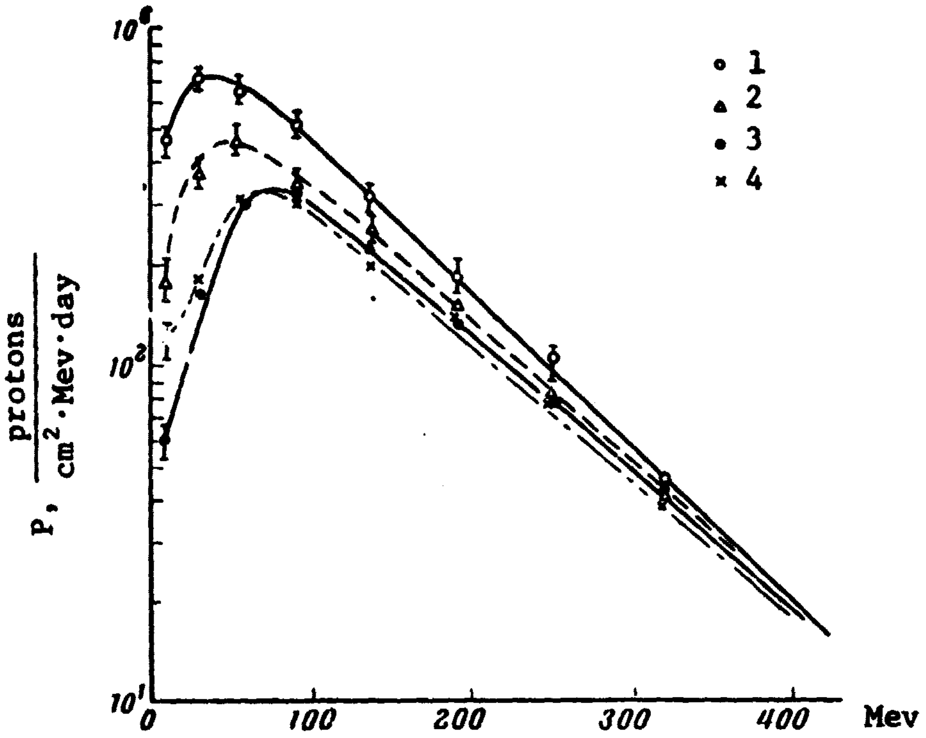

Fig.1. Differential energy spectra of protons behind the polyethylene filters of different thickness in the hermetic compartment of a satellite of "Kosmos" series.

1) 0.3 g/cm^2, 2) 5 g/cm^2, 3) 10 g/cm^2, 4) 15 g/cm^2

In order to determine the energy spectrum of protons in the region > 400 Mev, we conducted analysis of stars in the photoemulsion by the number of rays. At the same time, we started from the case, whereby nucleons with specific energy are capable of creating stars, whose radial composition depends on the energy of nucleons. Let the density of stars with a given number n of rays, formed by nucleons of specific energy interval E_k, be $dN_n{}^k/dV$; then

$$\frac{dN_n{}^k}{dV} = \frac{1}{\lambda_n(E_k)} P_n(E_k), \tag{1}$$

where $P_n(E_k)$ is the flux of nucleons (nucleon/cm^2) in the energy interval E_k) Mev, forming stars with a number n of rays; $\lambda_n(E_k)$ is the length of the free path of the nucleon of energy E_k, required for the formation of a star with a number n of rays.

The aggregate density of stars with the given number n of rays will be

$$\frac{dN_n}{dV} = \sum_k \frac{1}{\lambda_n(E_k)} P_n(E_k). \qquad (2)$$

or, utilizing formula (1),

$$\frac{dN_n}{dV} = \sum_k \frac{dN_n{}^k}{dV}, \qquad (3)$$

Assuming $n = 3, 4, \ldots n$, we obtain a system of linear equations for the determination of the energy spectrum of nucleons $P(E_k)$, where the energy intervals E_k are chosen in the entire nucleon energy range. Function $\lambda_n(E_k)$ may be borrowed from the experimental data on accelerators in the energy range from 100 Mev to 23 Bev. Inasmuch as the numerical values, entering into (3), are given or determined with a certain error, it is appropriate to write the expression (3) in the form of a redetrmined system of equations, when the number of selected energy intervals is smaller than the number of equations ($k < n$), and to resolve this system by the method of least squares with the aid of computers. The spectrum obtained in this manner (Fig.2) differs notably from the spectrum of protons of galactic origin in the region of energies 300 - 700 Mev. This may be explained by the contribution of proton of the inner radiation belt.

For the computation of the doses of protons with energies to 400 Mev, we used the data on specific tissue doses published in the work [3]. When determining the doses due to protons and having higher energies, their specific doses were assumed to be equal to doses of protons with energy of 400 Mev.

The values of doses computed on the basis of the obtained spectra are compiled in Table 1.

TABLE 1

TISSUE DOSES OF PROTONS IN THE HERMETIC COMPARTMENT OF AN AES
OF THE "KOSMOS" SERIES WITH APOGEE HEIGHT ~300 KM AND
A 65° INCLINATION ANGLE, IN "MBER"

Filter thickness, g/cm^2	Superficial		mid-tissue		Dose at 5 cm depth	
	$E_p < 400$ Mev	Total dose	$E_p < 400$ Mev	Total dose	$E_p < 400$ Mev	Total dose
0.3	35	46	7.4	18.6	12	23.2
5.0	23	34	5.6	16.8	8.4	19.6
10.0	16	27	4.4	15.6	8.0	19.2
15.0	15	26	4.0	15.2	8.0	19.2

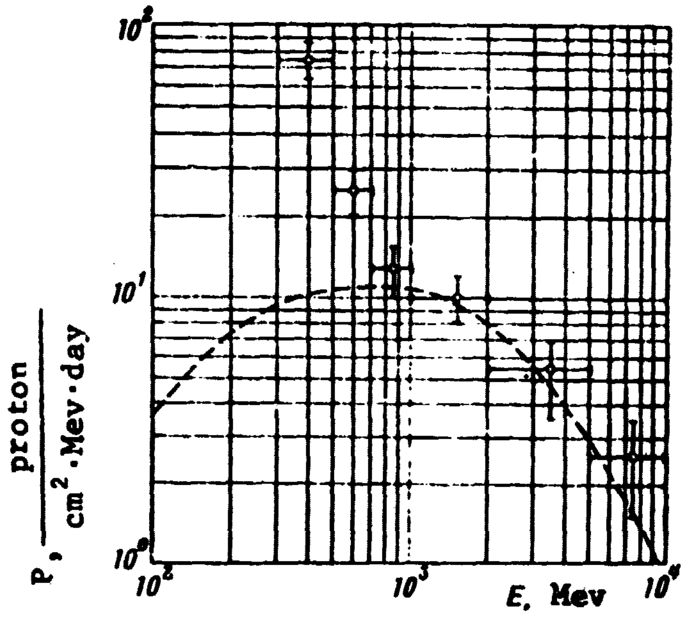

Fig.2. Differential energy spectrum of protons in the energy region $E_p > 400$ Mev

The circles indicate the experimental points, the lines show the energy spectrum of protons of galactic cosmic radiation origin in period of solar activity minimum, constructed on the basis of data of literature and taking into account the geomagnetic cutoff

On the basis of the above data we may derive the following fundamental conclusions.

In the first place, an irregularity is visible in the distribution of the dose in depth of the substance. The superficial dose is nearly twice exceeding that at ~ 5 cm depth.

Secondly, an increase of the screening filter will lead to a notable decrease of only the superficial dose, for the screen absorbs only soft protons.

Moreover, one can see that the basic contribution to the superficial dose behing small filter thicknesses is made by protons with energy < 400 Mev, i.e. protons of mainly the inner radiation belt. Behind greater thicknesses of the filter the contribution to the mid-tissue dose by galactic protons (with energy > 400 Mev) increases the contribution radiation belt protons by nearly three times.

Measurement of energy distributions of neutrons were conducted in the same conditions as for protons. As detectors we used type П-9 and BR nuclear emulsions.

Spectra and neutron fluxes with energies from thermal to 10 Mev were measured. The energy distribution of fast neutrons ($E_n = 1 - 10$ Mev) were determined by recoil of protons forming as a result of (n,p)-scattering of neutrons on the hydrogen of the emulsion. The spectrum of neutrons dN/dE was found by way of differentiation of recoil proton spectrum dP/dE

$$\frac{dN}{dE}\,dE = -\frac{d}{dE}\left(\frac{dP}{dE}\,\frac{1}{f}\right)\frac{E}{n\sigma V}\,dE,$$

where f is a correction factor taking into account the output of recoil protons from the emulsion layer, n is the number of nuclei of H in 1 cm^3 of emulsion, V is the reviewed emulsion volume, σ is the (n,p)-scattering cross section.

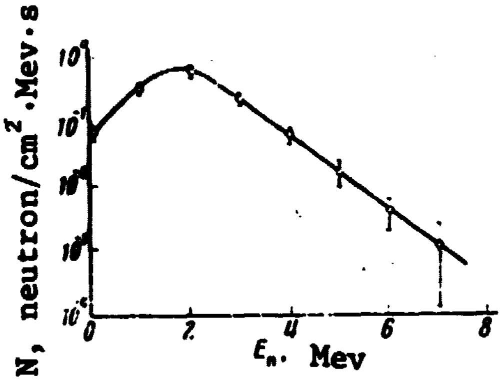

Fig.3. Differential spectrum of neutrons in the hermetic compartment of the satellite of "Kosmos" series in the altitude range 200-400 km

Because of a large reviewing error during the registration of short-path tracks of recoil protons, measurements were less reliable in the neutron energy region $E_n < 1$ Mev. This is why special emulsions were utilized for the determination of low energy neutrons, by filling with $Li_2B_4O_7$ salt with addition of boric acid. A great content in lithium (about 30 mg/cm^3) and bore (~ 160 mg/cm^3) in the emulsion, and also the utilization of compounds, enriched by Li^6 and B^{10}, allowed us to significantly rise the detector response to thermal and intermediate neutrons. Splittings of $Li^6(n, \alpha)T$ and $B^{10}(n, \alpha)Li^7$ were registered in the emulsion. The concomitant irradiation by the emulsion with filling Li, B and without it, allowed us to reliably separate the products of Li^6 and B^{10} splitting from recoil protons. The flux of low energy neutrons I was in that case determined as

$$I = \frac{N_0}{n\sigma},$$

where N_0 is the number of splittings in 1 cm^3 of emulsion, n is the number of $Li^6(B^{10})$ nuclei in 1 cm^3 of emulsion, σ is the reaction cross section, averaged by the spectrum of the form 1/E [4].

The neutron fluxes I with energy less than 1 Mev, determined by the count of the number of splittings of Li^6 and B^{10}, coincide with a precision to 15%.

Measurements of neutrons, conducted on various satellites of the Kosmos series in the 200 - 400 km altitude range, have shown that the form of the spectrum is little dependent on orbit parameters. Plotted in Fig.3 is the characteristic spectrum of neutrons (average over trajectory) inside satellite's hermetic compartment. The presence of a maximum at energy $E_n \sim 1$ Mev points to the vaporizing nature of the spectrum of neutrons forming at inelastic interactions of cosmic radiation protons with the envelope and parts of the spacecraft and with atmosphere oxygen and nitrogen. The spectra obtained in the works [4, 5] have an analogous shape.

The spectrum of neutrons, averaged over the satellite orbit ($E_n < 10$ Mev) constitutes 1.2 ±0.4 neutrons/$cm^2 \cdot$sec, which considerably exceeds the fluxes of albedo neutrons forming at nuclear interactions of cosmic radiation protons with atmosphere oxygen and nitrogen, and reflected from the boundary of the atmosphere. The conducted computational estimates have shown that this distinction may be explained by the fact that, alongside with albedo neutrons, there were registered in our experiment neutrons emerging from the satellite frame and parts. Data of the work [5] also point to the considerable contribution of such neutrons to the general flux. Exact quantitative comparisons with the data of [4 — 6] are difficult in view of the difference in the geometry of the experiments.

Doses of neutrons inside satellite compartments have been computed on the basis of the measured spectra. According to these calculations, the emergence of neutrons into the aggregate dose in units "ber" constitutes 10 to 15 percent.

*** THE END ***

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