PROTON SPECTRUM MEASUREMENT IN THE ENERGY RANGE ABOVE I TEV

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To investigate the spectrum of protons in the energy range above I TeV, the "Sokol" apparatus described in ("Sokol" apparatus project 1979; Vernov et al. 198I) had been advanced by the author.

The chief special feature of the apparatus was to visualize separate particle recording results. For this reason the apparatus comprised 95 automatically operating detectors: 80 scintillators included in an ionization calorimeter (IC) served for energy measuring and I5 Cerenkov counters over the IC for primary particle charge measuring. In eleven of the counters the Cerenkov directional radiation was used (DZ-I detectors). Therefore they were not sensitive to the back-scattered particles from IC. These counters served for measuring the charge of protons, Helium nuclei and other light nuclei. The charge measured by them we designate as Z_I. In four Cerenkov counters (DZ-2) located over those of DZ-I the light diffused by white case walls was used. These counters served for measuring the charge of nuclei with $Z > 5$. The charge measured we designate as Z_2.

The experiment with "Sokol" apparatus onboard the Earth satellites "Cosmos" series was organized by Academician S.N.Vernov and the author. The first apparatus was installed onboard the "Cosmos-I543" satellite. The results obtained were published in (Ivanenko et al 1986; Ivanenko et al I987). Came from the measurement results, some improvements were introduced into the apparatus. Measurements with "Sokol-2" apparatus were carried out onboard the "Cosmos-I7I3" satellite. The results were described in detail in (Grigorov et al I988). In this work the criteria of particle selection were considered, the numbers of recorded particles of different charges in different energy intervals were presented.

In the work (Grigorov I989 NIIYaF) the detailed analysis of measurement results has been carried out. Some part of it concerning protons is set forth in the present report.

The visualization of the process of particle recording made it possible to determine the coordinates of cascade axis with an accuracy of ~ 0.5 cm in every IC row. The cascade axis was taken for the primary particle movement direction. The charge of primary particle was determined on the evidence of the cascade axis had passed through, the cascade axis continued from the IC to the level of DZ-I and DZ-2 counters. Simultaneously the pulse amplitude was measured (in the value of Z_I and Z_2 charges) in those DZ-I and DZ-2 counters the primary particle passed by (additionally operating counters).

In Fig.I a primary particle distribution in Z_I at different conditions of particle selection is presented. It is seen from Fig.I, when backscattering is small (cascade beginning is in the depth of IC) and when it is large (cascade beginning is in the first IC row), protons are surely separated from Helium nuclei ($Z_I = 2$).

In Fig.2 the distribution of particles in charge measured by DZ-2 counters, with DZ-I measurement results drawn, is shown (Grigorov I989 JETP). It is seen in the figure that with the help of DZ-2 we record rather unambiguously nuclei with $Z > 5$.

The results of measuring the particles of different charge in different energy intervals with "Sokol-2" apparatus are given in Table I (Grigorov et al 1988).

Table I

E, TeV	1-2	2-3	3-4	4-5	5-7	7-10	10-15	15-20	20-30	30
$N_p(E)$	277/172	102/160	48/58	24/41	30/39	13/23	8/19	2/3	1/4	2/2
$N_\alpha(E)$	222/144	99/148	42/54	17/20	26/34	10/23	5/15	2/0	1/2	5/6
$N_{Z>5}(E)$	361/247	166/223	57/109	27/48	19/36	19/19	9/19	3/8	5/5	6/8

The particles but are included into the Table, that have a cascade axis going through the IC lower base area and the upper or lower plane of DZ-I radiator. The numerator of each fraction is the number of particles in a given energy interval related to an energy E_{meas} measured directly in IC. Denominator is the number of particles related to the energy interval of $E_0 = E_{meas} + \Delta E$, where the correction ΔE is the energy leaving the IC through the lower base and lateral sides, as well as non-detected part of nuclear disintegration energy (Grigorov et al 1988).

Making use of E_{meas} we introduced the correction on non-recorded energy fraction into the spectrum $E = \eta E_{meas}$ (Grigorov 1989 NIIYaF) like that we made with the measurement results from "Proton" Satellites. (Ionization calorimeters of both "Sokol" and SEZ-14 apparatus onboard the "Proton" satellites were practically identical). Thereby the particle flux intensity was determined by the expression:

$$I(\geq E) = (\bar{\eta})^{\gamma} N(\geq E) / W \Gamma T, \qquad (1)$$

where N - the number of particles, W - the probability for particle to go through the charge detectors without interaction in and in the substance above, T - measuring time in a given conditions for master signal to work out, Γ - geometric factor of the apparatus, $(\bar{\eta})$ - the mean value of an correction coefficient. The numerical values of all these coefficients are presented in (Grigorov 1989 NIIYaF).

Into the measured number of particles of each kind the correction +6% on particles with cascade axes to go out beyond the DZ-I bounds (due to the finite accuracy of axis reconstruction) was introduced. To the number of protons, besides that, a correction was introduced equalled to -7% of the number of He nuclei, that are the He nuclei traversing DZ-I radiator in short chords (passing through a lateral radiator side) and so initiating protons. To the number of nuclei with Z 5 the correction +10% was introduced to account for the L group nuclei that do not enter into the statistics.

After the corrections were accounted for, the intensities of various nucleus fluxes were obtained, listed in Table 2, expressed by $m^{-2} h^{-1} sr^{-1}$ (Grigorov 1989 NIIYaF).

The results of Table 2 may be approximated by the expressions: in the range of E 2 TeV for nuclei with $Z \geq 2$:

$I_{Z>2}(\geq E) = (138 \pm 13)\, E^{-\gamma_Z}\, m^{-2}\, h^{-1}\, sr^{-1}$ at $\gamma_Z = 1.61 \pm 0.10$;

$I_\alpha(\geq E) = (120 \pm 15)\, E^{-\gamma_\alpha}\, m^{-2}\, h^{-1}\, sr^{-1}$ at $\gamma_\alpha = 1.60 \pm 0.13$;

for protons in the range of $E \geq 4$ TeV:

$I_p(\geq E) = (274 \pm 32)\, E^{-\gamma_p} m^{-2}\, h^{-1}\, sr^{-1}$ at $\gamma_p = 2.08 \pm 0.15$. (A value γ_p is obtained with measurement results from "Cosmos-1543" satellite attracted (Grigorov 1989 JETP). Particle energies are expressed in TeV).

Table 2

E, TeV	≥ 2	≥ 3	≥ 4	≥ 5	≥ 7	≥ I0	≥ I5	≥ 20	≥ 30
$I_{Z>2}(\geq E)$	48.0± ±2.8	22.3± ±I.9	I3.5± ±I.4	9.3± ±I.2	6.4± ±I.0	3.4± ±0.72	2.0 ± ±0.56	I.55± ±0.49	0.77± ±0.35
$I_\alpha(\geq E)$	36.9± ±2.6	I9.2± ±I.9	II.6± ±I.4	8.8± ±I.3	4.I± ±0.8	2.9± ±0.84	I.7± ±0.64	I.2± ±0.54	I.0± ±0.5
$I_p(\geq E)$	43.I± ±3.I	23.9± ±2.2	I5.I± ±I.8	I0.5± ±I.5	4.5± ±I.0	2.2± ±0.70	0.77± ±0.42	-	-
I_p/I_α	I.I7± ±0.I2	I.24± ±0.I7	I.30± ±0.22	I.I9± ±0.24	I.I0± ±0.33	0.76± ±0.33	0.45± ±0.30	-	-

The intensities of different components may be yeald from the data listed in Table I, by the formula I ($\geq$E) = K N ($\geq$E) $m^{-2}h^{-1}sr^{-1}$ at K = =0.I89, 0.I76 and 0.I55 for protons, He nuclei and nuclei with Z 2, respectively, provided E_{meas} used, and K = 0.I30, 0.I49 and 0.I22 provided E_o used.

In Fig.3 the intensities of proton fluxes of Table 2 and all particle flux (the sum $I_p + I_\alpha + I_{Z>2}$) are compared with the measurement results on "Proton" satellites (Akimov et al. I969). It is seen from Fig.3 that by the identical methods used to introduce the corrections in energy, the measurements carried out by "Sokol" apparatus where the backscattering of particles leaving the IC has not influenced on spectrum shape, give the same proton spectrum as has been recorded onboard the "Proton" satellites.

In the publications (Ivanenko I.P. et al I988; I989; Ivanenko et al I988) another affirmation is stated.

The detailed consideration of denoted reasons of discrepancies in conclusions of the present work and (Ivanenko et al I988, I989 & Ivanenko et al I988) will be published.

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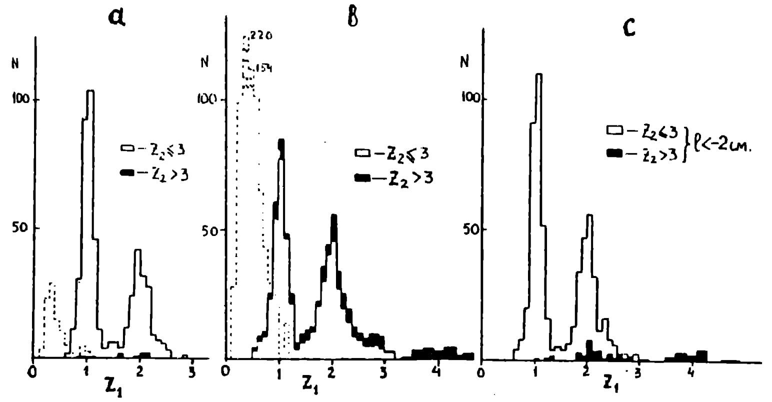

Fig.I. a - cascades begin below the first IC row; b - cascades begin in the first row; c - all the cascades. A primary particle goes not nearer than 2 cm to the DZ-I radiator edge.

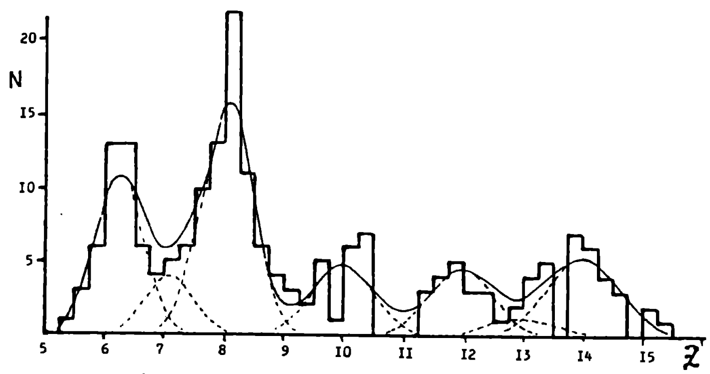

Fig.2. The distribution of particles in Z on the results of measurements by DZ-2 counters in use the data of DZ-I again.

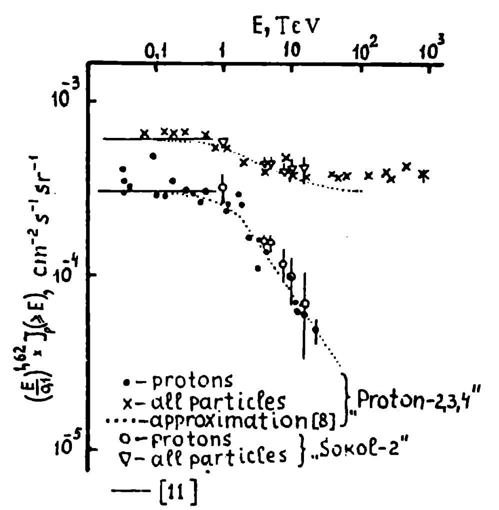

Fig.3. Both protons and all the particles spectra on measurements onboard the "Proton" satellites and in the present work (• , X and o, ∇). Dots, the approximation of spectra given in (Akimov et al I969). Point at E = 1TeV - extrapolation.