S. I. Nikol'skiĭ. *Absolute flux and nuclear composition of high-energy cosmic rays.* The accumulation of observational data on the primary high-energy cosmic radiation will go on for decades. Nevertheless, we may speak at this point of a certain stage in this process that calls for a retrospective and the most thorough possible comparison of existing experimental data with models of the origin and propagation of cosmic rays.

The range of cosmic-ray energies above 10^3 TeV is accessible only to indirect investigation through the extensive air showers. The methods used to study the showers, the basics of which, like the concept of the extensive air shower as a nuclear-cascade avalanche, were given more than 30 years ago by D. V. Skobel'tsyn and G. T. Zatsepin, make it possible to create installations with relatively small numbers of recording detectors with effective areas in the tens of km^2. The importance of this fact becomes clear when it is remembered that the intensity of the primary cosmic radiation with energies above 10^7 TeV is less than 1 km^{-2} yr^{-1} sr^{-1}.

The basic difficulty in using extensive air showers to determine the energy spectrum of the primary cosmic radiation arose out of the uncertainty as to the relation between the energy of the primary particle and the number of particles in the shower that it forms in the atmosphere. This uncertainty was tripled by ignorance of inelastic-collision and multiple-hadron-production processes. It was eliminated in experiments after A. E. Chudakov directed investigations of the Cherenkov radiation that appears in the atmosphere on passage of a shower.[1] The energy of the primary particle is assumed equal to the total energy of all shower components. The energy expended by the shower in ionizing the atmosphere at the observing level is determined from the intensity of the Cherenkov emission of the atmosphere. The energy transported by the various shower components below observing level is measured directly. The absolute intensities determined in this way for the primary cosmic radiation are $(9 \pm 2) \cdot 10^{-3}$ m^{-2} hr^{-1} sr^{-1} for particle energies above 10^3 TeV and $(7 \pm 2) \cdot 10^{-9}$ m^{-2} hr^{-1} sr^{-1} for particles with energies above 10^6 TeV.[2,3] Considering the change in the exponent of the energy spectrum discovered by S. N. Vernov, G. B. Khristiansen *et al.*[4] in the energy range $\sim 10^3$ TeV and direct intensity measurements of the primary radiation with energies above 1 TeV, the energy spectrum of the primary cosmic radiation can be expressed in simplified form as $F(>E) = (9 \pm 2) \cdot 10^{-3}$ $(E/10^3)^{-\gamma}$, where E is the primary-particle energy in TeV and $\gamma = 1.65$ for the range $1 < E < 10^3$ TeV and $\gamma = 2.0$ for $10^3 < E < 10^7$ TeV.

Studies of the nuclear composition of the primary radiation by analysis of the relative fluctuations of two different extensive air shower components at a given observing level were begun about 20 years ago. The accuracy of the measurements has now improved considerably, and complete mathematical modeling of the experiment has become possible. In particular, I. N. Stamenov, who developed this procedure for analysis of muon-count fluctuations in showers with a given number of electrons and vice versa, showed that the result of a primary cosmic radiation composition analysis does not depend, within the limits of error, on the hypotheses adopted for the model of the multiple hadron production processes.[5] The only limitation in selection of the hadron-collision model reduces to the requirement that the theoretical and observed relationships for the average muon count in the shower as a function of the averaged electron count agree, if only within the limits of three times the experimental error. Comparison of the composition of the primary cosmic radiation as known from direct measurements near the boundary of the atmosphere with the nuclear composition in the energy range $(2-8) \cdot 10^3$ TeV gives reason to believe that the variation of the energy spectrum exponent at energies above 10^3 TeV does not correspond to a single value of magnetic hardness for primary particles with different charges and masses. It appears that α particles have the lowest energy at the point where the spectrum exponent changes, although the error of determination of the α-particle fraction in the primary cosmic radiation is much greater than that for protons or nuclei of the iron group (12 ± 7, 40 ± 5, and 18 ± 5%, respectively).

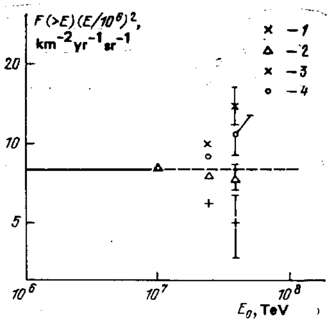

FIG. 1. Energy spectrum of primary cosmic radiation at energies above 10^7 TeV from various Galactic directions. 1—from direction of local cluster (> 30 °N); 2—from Galactic disk (±30°); 3—from half of Galactic disk in direction of Galactic center; 4—from outer half of Galactic disk.

Attention was first drawn to the significant anisotropy of the cosmic radiation with energies above 10^7 TeV by D. D. Krasil'nikov at a European symposium on cosmic rays at Lodz (1974).[6] One of the features of this anisotropy is that its energy range is the same as that of the change in the energy spectrum toward higher hardness. The figure answers the question as to the origin of the additional flux of particles with energies above $3 \cdot 10^7$ TeV. The energy spectra from various galactic directions indicate an excess of the flux over the expected level with no change in the form of the spectrum $F(>E) \sim E^{-\gamma}$ for directions outside of the Galaxy, e.g., for the direction of the local cluster.

It should be noted in conclusion that data on the energy spectrum and nuclear composition of the primary particles that have been obtained without *a priori* hypotheses as to multiple hadron production in inelastic collisions of nucleons with nuclei are highly important for investigation of these processes in cosmic rays at superaccelerator energies.

[1] A. E. Chudakov *et al.*, in: Trudy Mezhdunarodnoĭ konferentsii po kosmicheskim lucham (Proceedings of International Conference on Cosmic Rays), Izd. Akad. Nauk SSSR, Moscow, 1960, Vol. 2, p. 47.

[2] S. I. Nikol'skiĭ, Kosmicheskie luchi i problemy kosmofiziki (Cosmic Rays and Problems of Space Physics), Siberian Division USSR Academy of Sciences, Novosibirsk, 1964, p. 87.

[3] M. N. D'yakonov *et al.*, Izv. Akad Nauk SSSR, Ser. Fiz. **38**, 993 (1974).

[4] G. B. Khristiansen, *ibid.* **29**, 1872 (1962).

[5] S. I. Nikol'skiĭ *et al.*, *ibid.* **44**, 525 (1980).

[6] D. D. Krasil'nikov *et al.*, *ibid.* **39**, 1245 (1975).