INSTALLATION FOR MEASURING TO PRIMARY ENERGY SPECTRUM OF COSMIC RAYS IN THE ENERGY RANGE ABOVE 10^{15}-10^{16} eV

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A lower energy threshold version of the installation proposed earlier by A.E.Chudakov is described. The installation permits the energy spectrum of primary cosmic ray particles to be measured in the energy range exceeding 10^{15}-10^{16} eV on the basis of high-altitude observations of the light spots formed by Cerenkov light of EAS particles an snowy surface at night.

Studies of the energy spectrum in the range of $\gtrsim 10^{15}$ eV is of great interest from viewpoint of both cosmophysics (the presence and form of the second knee in the spectrum at particle energies of 10^{17}-10^{18} eV, existence of relict cut-off of the spectrum at energies $\sim 10^{20}$ eV) and the studies of the particle interaction mode at high-energies by studying the EAS characteristics.

At present, the energy spectrum of cosmic ray particles in the $\lesssim 10^{15}$ eV range is being intensively studied by direct colorimetric methods. At $\sim 10^{15}$ eV the data on particle flux obtained using different methods differ by not over 2-3 times [1].

In the energy range above 10^{15}-10^{16} eV, however, all the available experimental data have been obtained using large EAS installations. The data of the various authors differ by 10 and more times. This is associated with difficulties in determining the EAS total particle number and with the necessity of using the model representations of the EAS development mode to convert the EAS particle number into primary energy.

The total Cerenkov light of EAS particles in the entire atmospheric depth is known to be proportional to the total ionization loss of all EAS particles which, in its turn, is the major part of the primary particle energy.

In 1972, A.E.Chudakov [2] set first the idea about a possibility of measuring the energy spectrum in the $\gtrsim 10^{18}$eV energy range by photographing with an electron-optical image converter and subsequent photometering the light spot of EAS particle Cerenkov light on snowy surface at night from high altitudes.

The specific version of installation considered in [2], when airborn up to an altitude of ~ 10 km, had a $\sim 10^{18}$eV energy threshold and, with a reasonable exposive time, would permit the spectrum to be measured up to energies of $\sim 10^{20}$eV and maybe higher. In the above version, the energy threshold was determined mainly by the maximum possible value of the diameter of the lens which projects the image on the electron-optical image converter (D was ssumed to be 2 cm).

Considered in the present work is the installation version whose manufacture is now underway and which will permit the energy threshold to be significantly decreased. The main differences of the considered installation from the installation in [2] are: (1) electron-optical image converter is replaced by a mosaic of photomultipliers located on the focal surface of a spherical mirror of a large diameter (see Fig.1); (2) the altitude of the installation operation can be lowered from 10 km down to ~ 3 km; (3) in case of measurements in the near-threshold energy range, the integration time is reduced from 10^{-5} sec to 10^{-6} sec (it is assumed that only the showers incident into snow at angles sufficiently close to vertical will be analyzed and that this angle is determined using the form of the light spot).

The use of spherical (instead of parabolic) mirror permits a large viewing angle ($\Omega \sim 1$ ster) to be retained, which gives a $\sim 10\ km^2$ area for detecting the shower core at ~ 3 km of installation altitude.

Since the light spot diameter on snow is ~ 1 km, the spot image on the focal surface can be viewed by 6-7 photomultipliers (see Fig.2).

Spherical mirror is known to have spherical aberration which deteriorate the image. Because of low requirements to the image quality, however, it appeared possible in the examined case to use a simplest correcting system which is a diaphragm cutting-off the extreme rays. With the diaphragm dimensions shown in Fig.1, additional diffusion of light spot fails to exceed the photomultiplier radius and the angles of ray incidence onto the photocathode surface fails to exceed 50^0 relative to a normal to the photocathode.

The number of photoelectrons from photocathode of each of seven photomultipliers, on which the spot image is projected, is

$$n \approx \frac{E}{2 \times 10^4 eV} \times \frac{S}{\pi H^2} \times 0{,}1 \times \frac{1}{7}$$

where 2×10^4 eV is the energy per 1 C-photon ($300\ nm \lesssim \lambda \lesssim 600$ nm), 0.1 is the photocathode effectiveness, S is the area of the inlet aperture of the mirror system, H is the altitude of mirror above the snowy surface.

The number of photoelectrons from photocathode of each of 61 photomultipliers produced by illumination from starry sky is

$$\delta n \approx \sqrt{S \times T \times 2 \times 10^8 \times 0.1 \times 10^{-2}}$$

where T is the integration time (in case of detection of the showees incident onto the snow at any angle it is necessary to take $T \simeq 10^{-5}$ sec [2], in case of detection of the showers incident into snow at zenith angles $\lesssim 30^0$ it is possible to take $T \simeq 10^{-6}$ sec); 10^{-2} is the solid angle from which the light is accumulated on each of the photomultipliers;

2×10^8 $cm^{-2}sec^{-1}ster^{-1}$ is the light quantum flux (300 nm $\lesssim \lambda \lesssim$ $\lesssim$ 600 nm) from starry sky.

For the installation dimensions shown in Fig.1 $S=7.6\times10^3$ cm^2 (including the overlap of a part of the inlet aperture by the detecting photomultiplier system).

For the observation level altitude H = 3 km and E = 10^{16}eV, we get

$$n \approx \frac{10^{16}}{2\times10^4}\times\frac{7.6\times10^3}{\pi\times9\times10^{10}}\times0.1\times\frac{1}{7} = 190$$

$$\delta n \approx \sqrt{7.6\times10^3\times10^{-6}\times2\times10^8\times0.1\times10^{-2}} = 39$$

The found signal/noise ratio $\simeq$ 5 will hold for each of 6-7 photomultipliers on which the light spot image is projected. This circumstance may be used to trigger the installation by requiring the coincidence of pulses above the threshold in 3-4 any, but adjoining, photomultipliers.

If can be seen from Fig.2 that, when using the photomultiplier mosaic, a portion of light will fall between photomultiplier and lost. For a square photomultiplier grid, disregarding the insensitivity of the side sections of cathode, the portion of lost light would be 22%. For the grid used in our experiment (see Fig.2) this portion is 13%. When the inrensitivity of the side parts of cathode and the narrow gaps between photomultipliers are taken into account, this portion increases up to 40%. When the loss for reflection from the photomultiplier glass is included, this portion increased further up to 46%. This value can be significantly reduced by placing a mirror reflector in front of cathode of each photomultiplier to concentrate the light on photocathodes.

The energy threshold may be reduced down to several unities of 10^{15} eV by lowering the observation level and connecting the photomultipliers in parallel. This is reasonable when the detailed studies of the light spot shapes show that the extreme effects may be sufficiently safely included (as the observation level becomes lower, the portion of events in which a part of image will fall beyond the area covered with photomultipliers will increase).

In order to obtain data on the energy spectrum in the range of extremely high energies, the installation may be launched on a high-altitude balloon up to altitudes of $\sim$ 35 km by, for example, using the closed circulating air flows in arctic regions, or onboard a high-altitude aircraft.

Table 1 lists the expected intensities of the detected events on the assumption that for $10^{16} \lesssim E \lesssim 10^{18}$ eV the integral spectrum exponent $\gamma \sim 2.0$ and at $E \gtrsim 10^{18}$ eV $\gamma \sim 1.5$.

Table 1

E, ev	I(> E) $m^{-2}.hour^{-1}ster^{-1}$	H m	S m^2	F(> E) $hour^{-1}$ T=10^{-6}sec $\Omega \approx 1$ ster	T=10^{-5}sec $\Omega \sim 5$ ster
10^{16}	4.10^{-5}	3000	10^7	4.10^2	-
10^{17}	4.10^{-7}	"	"	4	20
10^{18}	4.10^{-7}	"	"	4.10^{-2}	0.2
"	"	35000	10^8	4	20
10^{19}	10^{-10}	"	"	10^{-1}	0.5
10^{20}	3.10^{-12}	"	"	3.10^{-3}	$1.5.10^{-2}$

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References.

1. P.A.Antonov, I.P.Ivanenko. Report EA 1-8 at the present Conference.

2. A.E.Chudakov. Proc.Symp. on Cosmic Rays, Yakutsk, 1972.

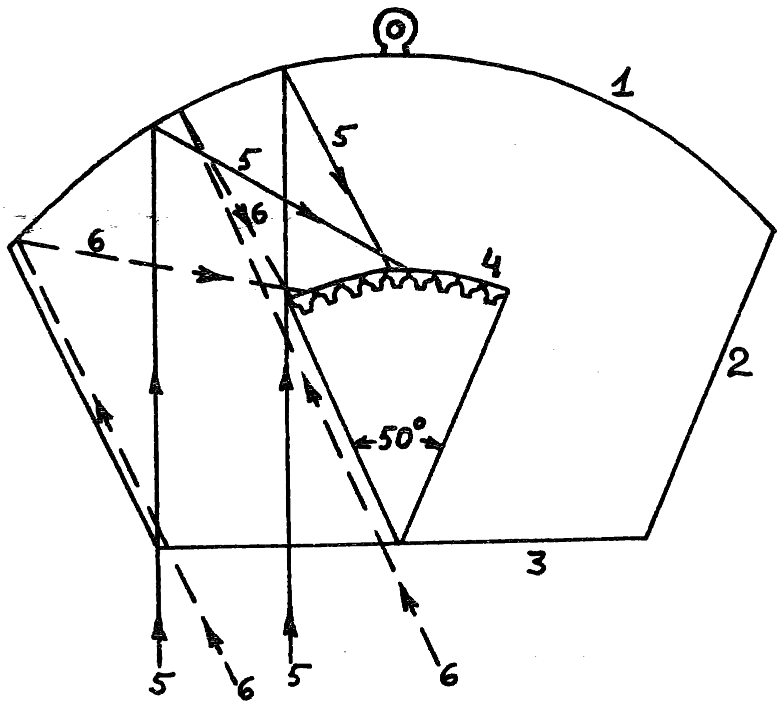

Fig.1. Schematic view of the Cerenkov installation. 1-spherical mirror (150 cm curvature radius); 2 - blackened conical screen; 3 - round aperture of 118 cm diameter, 4 - spherical focal surface on 61 photomultipliers are positioned; 5,6 - light rays reflected from snow and focused on the focal surface (the rays arriving from the same direction are focused into a round spot of a 3-4 cm diameter).

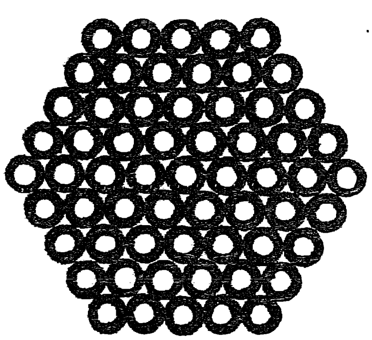

Fig.2. Arrangement of photomultipliers on the focal surface. Diameter of each photomultiplier is 8 cm.