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Azimuthally controlled observation of heavy cosmic-ray primaries by means of the balloon-borne emulsion chamber

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ABSTRACT

We have exposed an emulsion chamber of area 1.22 m^2 on board the balloon at an atmospheric depth of 8.9 g/cm^2 for 15.8 h, which has been azimuthally controlled within the accuracy $\Delta\phi = 0.5°$. With use of the east-west asymmetry effect of arriving cosmic-ray primaries, we can obtain energy spactra for individual elements in the energy range from a few GeV/n to $\sim$ 15 GeV/n. We find that they are in excellent agreement with those obtained by the fragment-opening-angle method, which has been applied for the energy determination in the previous experiment.

1. INTRODUCTION

We have exposed twice a new type of emulsion chamber on board the balloon with extensive use of screen-type x-ray film, which were launched from the Sanriku Balloon Flight Center ([N, E] = [39.2°, 141.8°]), Japan, in May 1989 and May 1991. Result of the first experiment in 1989 has been already reported (Ichimura, M., et al., 1992, 1993), and the present work is focussed to the second one performed in 1991. Since the emulsion chamber here has been azimuthally controlled, we can estimate the energy spectrum in the energy region 2 $\sim$ 15 GeV/n with use of the east-west asymtetry effect of arrival cosmic rays. The present data are quite interesting and important for the calibration of our energy determination with use of the fragment-opening-angle method, covering the energy range from a few GeV/n to a few TeV/n, which has been applied for the first experiment in 1989.

2. EXPERIMENTAL PROCEDURE

The chamber design is illustrated in Fig. 1, and the flight situation has been reported in detail in another paper (Ichimura, M., et al., 1992). The chamber structure shown here is nearly the same as that of the first observation in 1989, though removing here heavy target material, stainless steel plate. We have observed 69236 tracks of cosmic-ray heavy primary nuclei of $Z \gtrsim 8$, passing through the trigger layer. We present the charge histogram in Fig. 2, together with Gaussian curves fitted by the least square method. Charge resolution, σ_Z, of primary element is, for instance, 0.43 charge unit for Si, and 0.82 charge unit for Fe, which are slightly better than those obtained by 1989 observation.

3. EAST-WEST ASYMMETRY OF ARRIVAL COSMIC RAYS

In Fig. 3, we present a scatter plot, $\cos\theta$ v.s. ϕ, where θ and ϕ are zenith and azimuthal angles of arriving particles, respectively. One finds clearly that heavy primaries come much more frequently from the west ($\phi \simeq 270°$) than those from the east ($\phi \simeq 90°$).

In Fig. 4, we demonstrate numerical results of the cutoff rigidity as a function of the azimuthal angle for several cases of zenith angle at [N, E] = [40.0°, 141.5°], the most effective position of the present observation. The black area corresponds to the forbidden zone of heavy cosmic-ray primaries arriving at our chamber, indicating that the primaries come from the west more easily than those from the east, particularly for larger zenith angle.

To see the so called "east-west asymmetry effect" more clearly in Fig. 3, we present the azimuthal distribution of arrival cosmic-ray primaries for several ranges of the zenith angle (solid circle) in Fig. 5, since the asymmetry is expected to be much more prominent in large zenith angle than that in small zenith angle. In the figure, we give simulated data together in the form of histogram. We find the coincidence between the observed data and the simulated ones, is surprisingly excellent, where the azimuthal angle of experimental data is shifted in parallel along ϕ-axis by 5°, probably due to the calibration of gondla direction just before launching.

4. FLUXES OF HEAVY COSMIC-RAY PRIMARIES

In the last section, we confirmed that the azimuth control system of the present observation had been well functioned. Now, we can get straightforwardly the *integral* energy spectrum of each primary element as shown in Fig. 6, where the contamination effect of the fragment process in air is of cource corrected. In the figure, we plot also the HEAO-3 data, after integrating the differential energy spectra presented in their original paper (Engelmann, J.J., et al., 1983, 1990). They are in satisfactory agreement with each other, though there exists 10 $\sim$ 15 % fluctuations between the two for rare elements such as argon and calcium, which might be due to our limited charge resolution (see Fig. 2).

Since the integral spectra are approximately expressed by power form in the energy range 2.5 ~ 15 GeV/n as found in Fig. 6, we can get easily the differential energy spectra for individual elements. In Fig. 7, we present them together with those obtained by fragment-opening-angle method in 1989 experiment (Ichimura, M., et al., 1992), where the vertical axis is multiplied by $E_0^{2.5}$. They continue smoothly from lower energy to the higher, in turn the energy spectrum with pretty wide energy range obtained by the first experiment in 1989 is quite reliable not only in the relative value, but also in absolute one. Comparison of the present result with other group data is discussed in separate papers (Ichimura, M., et al., 1993).

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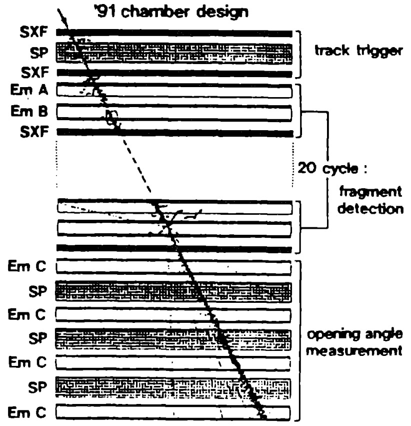

Fig. 1: Chamber structure
SXF : Screen-type x-ray film
Em A : Emulsion plate
(50 μm + 1.0 mm acrylic base)
Em B : Emulsion plate
(55 μm + 1.0 mm base + 55 μm)
Em C : Emulsion plate
(50 μm + 1.0 mm base + 50 μm)
SP : Spacer with 2 mm

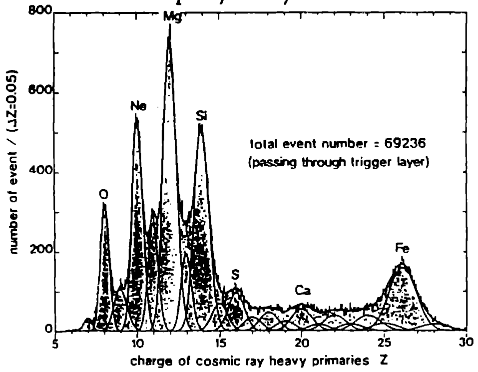

Fig. 2: Charge histogram

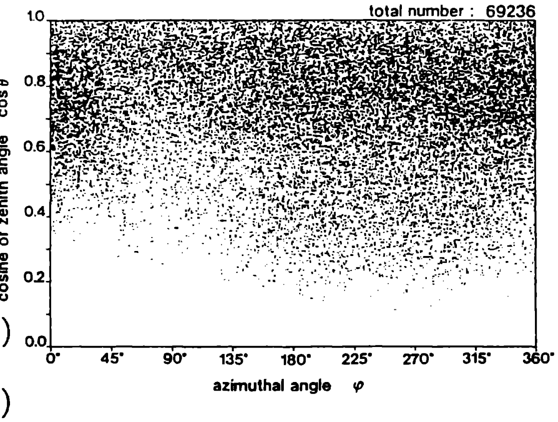

Fig. 3: Scatter plot of $\cos\theta$ v.s. ϕ

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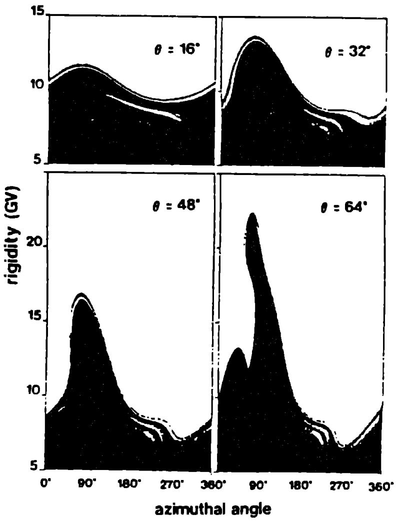

Fig. 4: Numerical results of cutoff rigidity as a function of the azimuthal angle for four cases of the zenith angle at [N, E] = [40.0°, 141.5°]. Black area corresponds to forbidden zone for arrival cosmic ray nuclei at our chamber.

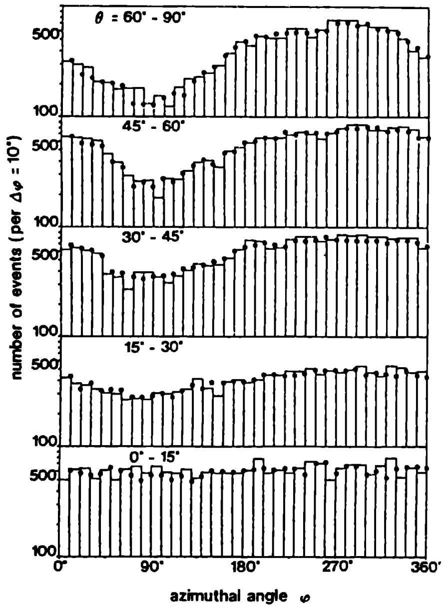

Fig. 5: Azimuthal angle distribution of arrival cosmic-ray primaries (solid circle) for several zenith angle ranges. Histograms are obtained by simulation calculation.

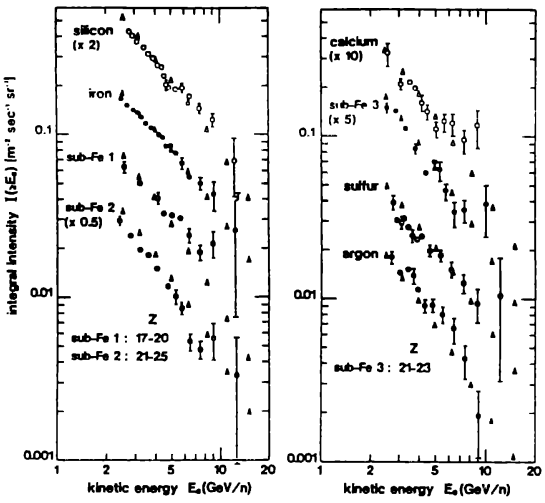

Fig. 6: Integral energy spectra for several primary species. Circle marks are obtained by the present work, while the triangle ones by HEAO-3.

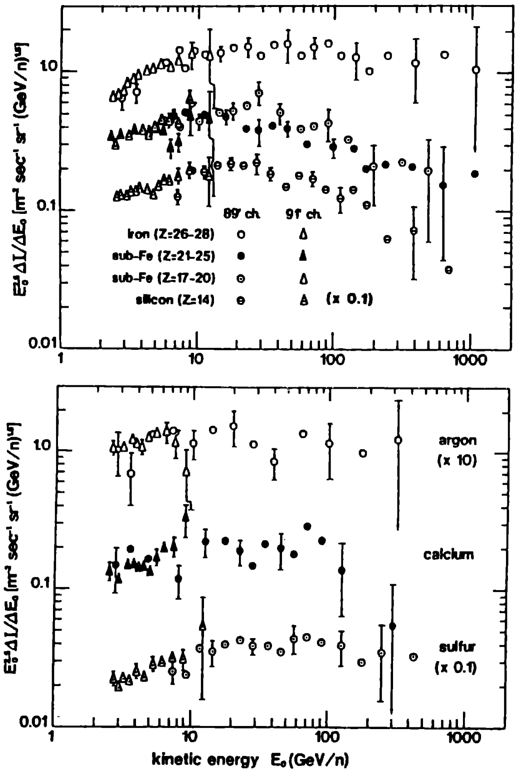

Fig. 7: Differential energy spectrum multiplied by $E_0^{2.5}$. Circle marks are obtained by the fragment-opening-angle method in 1989 experiment, while the triangle ones by the east-west asymetry effect in the present work.