observed until the vial was opened.

4. Composition of the radioactive gas. Gas chromatography with charcoal and silica gel columns was used to analyze[1] the chemical composition of the radioactive gas liberated from 9.5-mg/cm^2 polyethylene. The composition was found to be 57% methane, 36% acetylene, 6% ethylene, and 1% ethane. No CO or CO_2 was observed.

Absolute measurements of the $C^{12}(p, pn)C^{11}$ cross section may have been affected by the loss of C^{11} in those cases where thin plastic targets were used. Recent measurements in the Bev region[2,3] have used polystyrene targets sufficiently thick so that the correction is less than 1%. The loss effect may also account for some of the discrepancies in the $C^{12}(p, pn)C^{11}/Al^{27}(p, 3pn)Na^{24}$ cross-section ratios which have been reported.

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[2]J. B. Cumming, G. Friedlander, and C. Swartz, Phys. Rev. 111, 1368 (1958).

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EXTREMELY ENERGETIC COSMIC-RAY EVENT*

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This note is a preliminary report on an extremely large cosmic-ray air shower. The event was observed at the M.I.T. Volcano Ranch station, elevation 5800 ft, near Albuquerque, New Mexico. An array of scintillation counters was used to detect and measure air showers by the technique used in the earlier M.I.T. Agassiz experiment.[1] The main array was made up of 19 detectors arranged in a pattern of triangles as shown in Fig. 1. The area of each detector was 3.3 m^2, and the spacing of adjacent detectors was 442 m. The area enclosed by the array was 2 km^2, but the sensitive area for detecting very large showers was considerably greater. An additional detector shielded by 10 cm of lead sampled the penetrating component of showers.

The event to be described was one of two, nearly equal in size, which were the largest observed in the period of operation September, 1959, to May, 1960. The total on-time of the equipment during that interval was about 180 days. The particle densities (particles/m^2) registered at the various points of the array are given in Fig. 1. The shower core struck several hundred meters outside the array boundary.

We found the direction of the shower axis by making a least-squares fit of the observed arrival times to those expected for a plane shower front. The values 41°, 41°, and 70° were found for the zenith angle, declination, and right ascension, respectively. The deviations of the ob-

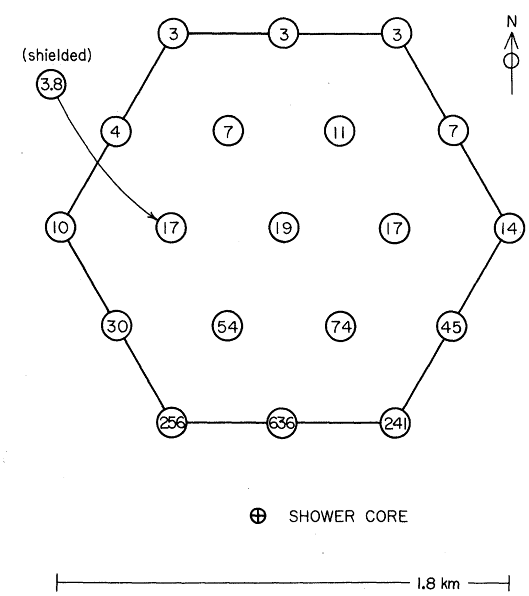

FIG. 1. Diagram of the Volcano Ranch 2-km^2 array, showing the location of the shower axis and measured densities in particles/m^2 for this event, No. 39565. The shielded detector was located very near the indicated main detector.

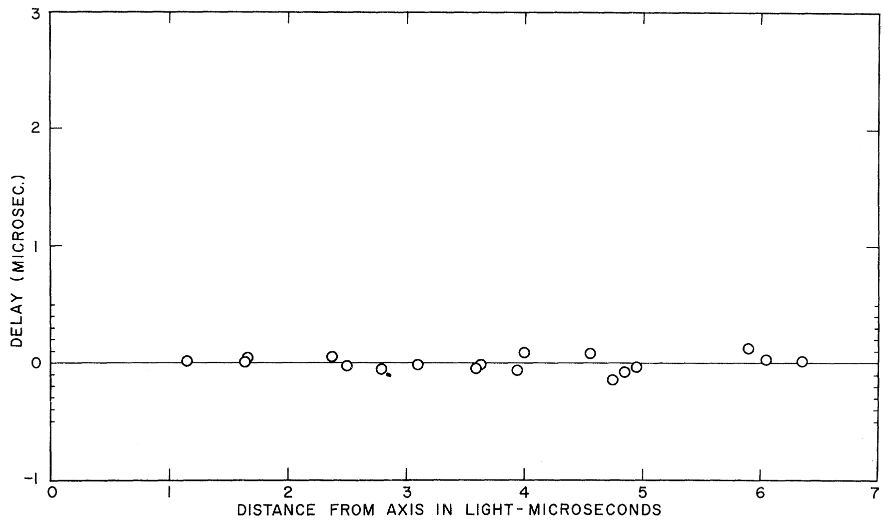

FIG. 2. Apparent delay of the extreme front of the shower, with respect to a plane which best fits the timing data, as a function of distance from the shower axis. Distance from the axis is given in light-microseconds (units of 300 m). Ordinate and abcissa have the same scale.

served data from the computed values are shown in Fig. 2 as a function of distance from the shower axis. The rms deviation is 0.07 μsec.

We found the location of the shower core by fitting the density observations to the following trial lateral distribution formula:

$$\Delta = 0.18(N/R_0^2)(R/R_0)^{-1.2}(1+R/R_0)^{-2.3}, \qquad (1)$$

where Δ is the total density of particles at a perpendicular distance R from the shower axis, $R_0 = 100$ m, and $N = \int_0^\infty 2\pi\Delta R dR$. This formula fits the experimental data obtained at Volcano Ranch for the range of shower sizes $5\times10^7 < N < 2\times10^8$, and the range of distances from the axis $100 < R < 1000$ m. In this case, the value obtained for N was 5.5×10^9. There are two sources of uncertainty in relating this number to the real shower size; i.e., to the actual total number of particles in the shower. The first is the uncertainty in core location resulting from statistical and instrumental errors in the data. We estimate the error from this source to be no greater than about 10%. The second is the uncertainty whether Eq. (1) is applicable for such a large shower, especially for distances less than 350 m from the axis. A preliminary inspection of several showers with $N > 8\times10^8$ which struck within the array indicates that for such showers the particle density increases more rapidly with decreasing distance from the axis than Eq. (1) predicts. This implies that the value given above for N is an underestimate of the actual size of this shower, perhaps by a factor of 2. We intend to discuss the problem of relating shower density measurements to shower size, for very large showers, in a later publication.

If the figure 5.5×10^9 is accepted, tentatively, as the size of this shower, it follows on any reasonable shower model that the energy of the primary particle was about 10^{19} ev. Taking the usual estimate 3×10^{-6} gauss for the galactic magnetic field, one finds the radius of curvature of the path of a proton of such energy to be about 10^4 light years. Since, according to current estimates, the radius of the galactic halo is only about five times this value, while the thickness of the galactic disk is about five or ten times smaller, it seems certain that the primary particle acquired its energy outside our galaxy.

An important question is whether the primary particle was a proton or a heavier nucleus. In this connection, we note that other results obtained at Volcano Ranch, not yet published, show that most, if not all, showers have nearly the same proportion of penetrating to nonpenetrating particles, when observed near maximum shower development. We interpret this to mean that most, if not all, air shower primaries in the energy range 10^{17} to 10^{18} ev have about the same mass, and are probably protons. It is not yet clear whether some apparent exceptions are real or spurious. In any case, the shower described here had a "normal" proportion of penetrating particles (see Fig. 1).

Turning again to the time measurements, we note that the times shown in Fig. 2 correspond, generally speaking, to the arrival of the first particle at each of the various detectors. The distinction is important, since we find that at large distances from the core, shower particles arrive over a time span of the order of microseconds. The distributions in arrival time of the particles at the 8 detectors furthest from the axis of this shower are shown in Fig. 3. The distributions were obtained by an analysis of the shapes of the recorded pulses. The number of particles that make up each distribution is not great, and the (graphical) method used for deriving the true scintillation pulse from the recorded pulse has limited accuracy. However, some general features seem to emerge. (1) The "extreme front" of the shower, corresponding to the initial rise of the pulse, is well defined. (2) Many particles are delayed by as much as one or two μsec. (3) Few particles are delayed by more than twice the mean delay. While this type of direct evidence is not available except for a few exceptionally large showers, we find by statistical analysis that similar conclusions hold, on the average, for smaller showers.

Figure 2 can be considered a profile of the extreme front of this shower, and shows that the curvature of the extreme front is quite small. The precision of our method is sufficient to establish that the extreme front of an individual shower has a finite radius of curvature, R_C, if the value of R_C is less than about 7 km. For this shower the most likely value for R_C is 10 to 12 km, but any value in the range 7 km $< R_C < \infty$ will fit the data reasonably well. To date we have not found any shower for which we could establish that R_C is less than 7 km.

These timing results suggest a model in which an appreciable fraction of air shower particles that arrive at distances greater than 1500 m from the axis, at elevation 5800 ft, begin to diverge strongly from the shower axis at heights greater than 7 km above ground level. Thus, such particles may provide new information about the early stages of shower development.

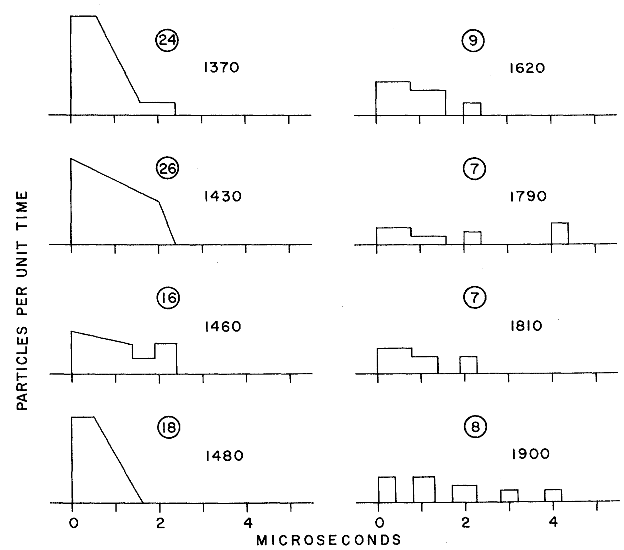

FIG. 3. Distributions in arrival time of shower particles at the eight detectors furthest from the shower axis. The number of particles included in each distribution (to which the areas have been normalized) is shown circled. Distances from the shower axis are also given.

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