JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-III, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-4-20. Energy Spectrum of Nuclear Active Particles as Determined by a Total Absorption Spectrometer at 2.2 kms.

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1. The energy spectrum of nuclear active particles in the energy range $2 \cdot 10^{11}$ ev to 10^{12} ev has been determined at mountain altitude of 2.2 kms (800 g/cm^2) using a total absorption spectrometer.

The spectrometer (Fig. 1) has an effective area of 114 cm×122 cm and consists of alternate layers of iron and end-window liquid scintillation tanks stacked one above the other to a total height of about 2.5 meters. Each layer of iron is 4 cm thick (30 g/cm^2).

The liquid scintillation tanks are of dimension 130 cm×60 cm×2.5 cm and are fabricated from alminum sheets. In each layer two tanks are placed one behind the other, with the glass windows facing two sets of photomultipliers which are DuMont 6364's and are mounted about a meter from the front surface of the spectrometer. The arrangement of photomultipliers is such that the first two sections serve to distinguish between the soft component and nuclear active particles. The amplifiers and two oscilloscope display system are designed to cover a range of 10^4 *i.e.* 10^9 ev to 10^{13} ev for the energy of nuclear active particles.

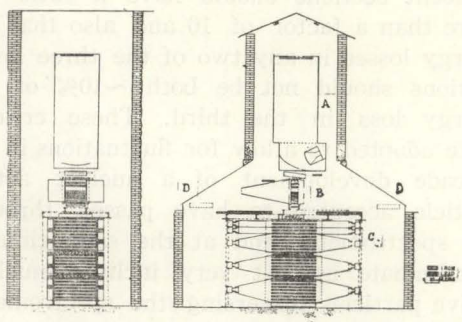

Fig. 1. Experimental arrangement at Ootacamund: Total Absorption Spectrometer, Cloud Chamber and Air Cerenkov Counter.
A=Air Cerenkov Counter.
B=Multiplate Cloud Chamber.
C=Total absorption Spectrometer.
D=Scintillation Counter Trays.

For triggering the spectrometer for nuclear active particles, the pulses from the 5 photomultipliers are added after suitable amplification, and passed through a discriminator, the bias of which could be set at any desired level. For determining the associated spectrum, four plastic scintillators two of area 0.36 m^2, and two of area 0.25 m^2 are placed around 1.70 m from the spectrometer. The amplitudes of pulses from these four scintillators are also recorded on an oscilloscope.

The spectrometer is shielded on all sides with 2″ of iron and 1″ of lead to minimize the energy flow from side showers.

2. Calibration of the spectrometer and errors in energy measurements.

The spectrometer was calibrated using a telescope to trigger the oscilloscope sweeps for vertical cosmic ray particles (μ-mesons) passing through the spectrometer. The average pulse heights thus obtained from the various photomultipliers were related to energy loss by ionisation of fast μ-mesons in the different sections. We have taken 48 Mev as the energy loss per layer of iron (30 g/cm^2) and liquid scintillator.

In using the spectrometer to measure the energies of nuclear active particles, one has to consider the errors due to the following:

(a) errors in calibration and measurement of pulse heights
(b) sampling inefficiency due to the finite striations of the spectrometer
(c) leakage of energy due to finite thickness of the spectrometer.

The errors due to (a) are estimated to be not more than about 10% but those due to

* This paper was combined with III-4-19, III-4-21 and presented by B. V. Sreekantan.

(b) and (c) are somewhat uncertain.

The striation used here of 30 g/cm² of iron is fairly efficient in sampling energy transferred to π^0-mesons in the nuclear cascade; for example even at energies ~1 Bev, the electron photon track lengths are sampled to an accuracy of about 10%. The chief uncertainty comes from energy loss in nuclear disintegrations in iron and production of slow secondaries which are absorbed in a layer itself. It is difficult to estimate this mode of unsampled energy loss, since it involves details of propagation of the nuclear cascade in iron.

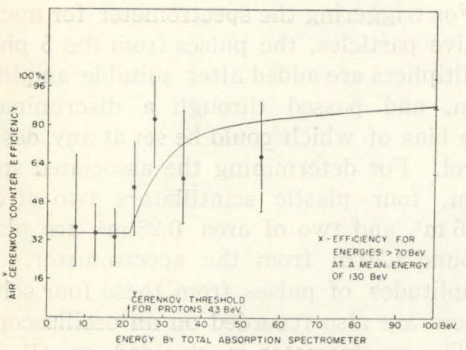

Fig. 2. Efficiency of Cerenkov counter for nuclear active particles as a function of energy observed in the total absorption spectrometer.

To get an idea of this energy loss, we have observed the efficiency of an air Cerenkov counter placed above the cloud chamber which in turn is kept above the spectrometer. Fig. 2 shows such an efficiency plot for nuclear active particles identified by interactions inside the chamber. The break in the efficiency curve indicates that at an energy of 43 Bev for a nuclear active particle incident on top of the spectrometer only 21 Bev is measured in it. This indicates the magnitude of this energy loss. It is to be expected that the fraction of the primary energy unsampled in this manner would decrease with increasing energy because of the increase of energy transferred to π^0-mesons compared to the almost constant energy loss through slow particles (this can be taken to be~1 Bev per collision in iron) in nuclear collisions. The exact variation of the unsampled energy loss is not amendable to calculation without invoking nuclear cascade models. As a first approximation, we have assumed that energies measured by the spectrometer if shifted by 20 Bev would give the correct total energy dissipated in the spectrometer for energies up to 100 Bev. For energies much above 100 Bev the correction can be expected to be a negligible fraction of the primary energy.

Regarding (c), it is not easy to estimate the magnitude of this loss exactly, but if inelasticity of nucleons in collisions with iron nuclei is not too small (*i. e.* inelasticity ≥ 0.5), one can expect~15% of the incident energy to leak out of the spectrometer (~6 m.f.p. for nuclear interactions). If the above mentioned inelasticity factor is not strongly energy dependent, one can expect this fractional leakage energy to be independent of the energy of the incident nuclear active particle.

3. Criteria for the selection of nuclear active particles traversing the spectrometer

A nuclear active particle above the set limit of trigger (100 Bev) is deemed to have passed through the spectrometer (right half or left half) and interacted whenever there were comparable sequence of pulses in at least the three lower sections of corresponding half of the spectrometer with or without energy flow in the top two sections. It is further demanded that in such a sequence of pulses, the energy losses that occurred in adjacent sections should have a ratio not more than a factor of 10 and also that the energy losses in any two of the three lower sections should not be both ~10% of the energy loss in the third. These criteria were adopted to allow for fluctuations in the cascade development of a nuclear active particle accepted to have passed through the spectrometer and at the same time to discriminate against very inclined nuclear active particles traversing the spectrometer suffering only partial energy loss in the spectrometer. It is thought that no energy dependent bias is introduced by the above procedure since the cascade of nuclear active particles, judged from events observed in the cloud chamber for energies greater than 100 Bev (the trigger limits for obtaining the spectra have been set above this value), have ranges of the order of the entire depth

of the spectrometer and definitely satisfy the above ratio requirements in energy losses in the different sections. With these criteria it was possible to distinguish the incidence of one or more nuclear active particle in each half of the spectrometer from cases of inclined nuclear active particle traversing part of both halves of the spectrometer from a scrutiny of the pulse height distributions in the different sections of the two halves of the spectrometer.

A nuclear active particle is considered to have been accompanied by an air shower when more than one of the plastic scintillators kept near the spectrometer indicated passage of at least one minimum ionizing particle through them or there was energy flow due to electron-photon component in both halves of the spectrometer on top when only one plastic scintillator registered particles. In cases where a nuclear active particle is judged to be accompanied by air showers, the energy in the top two sections of the spectrometer were not added to the energy of the nuclear active particle; this was done only if the second section energy loss was less than or equal to the energy loss in the first section. In other cases, twice the energy registered by the first section was considered to be the energy flow due to soft component of air showers. This criterion is consistent with the expectation that even near cores of air showers the mean energy per electron is only~1 Bev.

4. Energy spectra

Data obtained during 101 hrs of operation of the spectrometer during which time trigger bias was set at 100 Bev for 27 hrs, and for the rest of the time at 250 Bev, were analysed. Fig. 3 gives the integral spectrum of nuclear active particles above 150 Bev for all nuclear active particles "associated" with air showers. The points at 150 Bev are considered to have a bias due to threshold effect. The two integral spectra can be represented as power laws with negative exponents 1.45 ± 0.15 and 1.25 ± 0.15 respectively.

It should be remarked that the two spectra as drawn here are not directly comparable (for fraction of "association" to total) because the data have not been normalised to the same operating time. The observed percentage of "association" at energies >250 Bev, is $81\pm9\%$. It is likely that this "association" has been enhanced by the high walls surrounding the spectrometer and some of the "associated" cases may be the result of true unassociated nuclear active particles in air just outside above the apparatus. It is also to be remarked that while the energy spectrum of all nuclear active particles is meaningful, it is difficult to interpret spectra termed "associated" and "unassociated" since the data is relevant only to the apparatus used. We give in Fig. 4, the integral spectrum of nuclear active particles obtained in the energy region

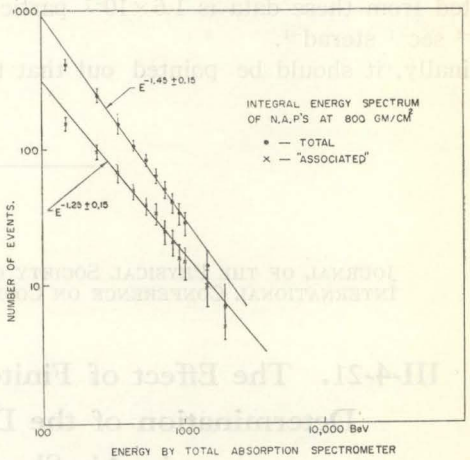

Fig. 3. Energy spectra of nuclear active particles obtained with the total absorption spectrometer (10^{11}–10^{12} ev).

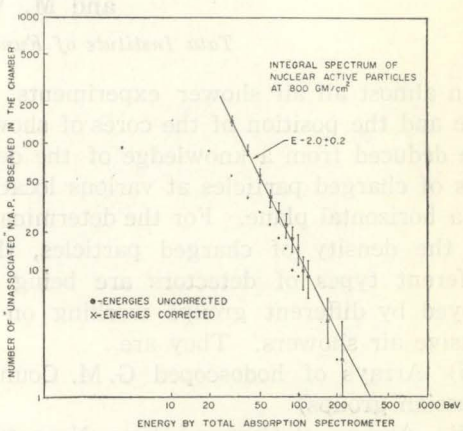

Fig. 4. Energy spectrum of "unassociated" nuclear active particles with the total absorption spectrometer (10^{10}–10^{11} ev), and cloud chamber.

10-100 Bev for events observed in the cloud chamber triggered for nuclear active particles "unassociated." The spectrum has a slope of 2.0 ± 0.2.

The absolute flux value for nuclear active particles at 800 gm/cm^2 for energies greater than 450 Bev deduced from our data is $(1\text{-}2.3)\pm0.1\times10^{-7}$ particles cm^{-2} sec^{-1} sterad^{-1}. The uncertainty in the flux comes from the inexact definition of solid angle of acceptance for the spectrometer by the selection criteria detailed above. This value is consistent with the value expected from other similar estimates made at mountain altitudes reduced to our altitude by using an absorption mean free path for the nuclear active particles value of 120 g/cm^2. The flux expected from these data is 1.6×10^{-7} particles cm^{-2} sec^{-1} sterad^{-1}.

Finally, it should be pointed out that the measured energy spectrum of nuclear active particles would deviate from the true spectrum at sufficiently high energies depending upon the size of the detectors used. This is because at high energies depending upon the size of detectors used, many nuclear active particles are incident at the same time over the area of a single detector, the effect of which will be to flatten the spectrum. It will be ambiguous to interpret spectra obtained without considering this effect. For example, the average separation of nuclear active particles at 10^{12} ev for simultaneously incident particles are expected to be of the order of 70 cm and hence spectra deduced with detectors ~1 m^2 (as is our case) for energies $>10^{12}$ ev lose their significance unless other means of resolution of nuclear active particles are incorporated in such large detectors.

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III-4-21. The Effect of Finite Thickness of Scintillators on the Determination of the Densities of Charged Particles in Air Shower Experiments

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In almost all air shower experiments, the size and the position of the cores of showers are deduced from a knowledge of the densities of charged particles at various locations in a horizontal plane. For the determination of the density of charged particles, three different types of detectors are being employed by different groups working on extensive air showers. They are

(i) Arrays of hodoscoped G. M. Counters (Russian groups)

(ii) Arrays of Conversi type Neon tubes (I.N.S. Tokyo)

(iii) Scintillators (M.I.T., Cornell, I.N.S., Bombay, Sydney)

It is to be expected that the densities determined from G. M. counter arrays will be close to the true values of the densities of charged particles, since the G. M. counters are known to have very low efficiency for the detection of γ-rays and the amount of matter by way of wall thickness will be almost negligible for either absorption of electrons or for the interactions of nuclear active particles. If the efficiency of Neon Hodoscopes are also small for γ-rays, then

* This paper was combined with III-4-19, III-4-20 and presented by B. V. Sreekantan.