THE ENERGY SPECTRA OF PRIMARY COSMIC RAY NUCLEI UP TO 1 TeV/NUCLEON

Dietrich Muller, John Grunsfeld, Jacques L'Heureux, Peter Meyer, Simon Swordy
Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637, USA

ABSTRACT

Prevailing models of cosmic ray origin and acceleration predict that the relative intensities of cosmic ray particles at their sources do not vary with energy. In order to investigate this question, the University of Chicago's High Energy Cosmic Ray detector was designed to measure the flux of cosmic ray nuclei to much higher energies than previously accessible. The instrument was flown on Spacelab-2 in Summer, 1985. In this paper, we shall present and discuss initial results on the energy spectra of the major source nuclei from carbon to iron up to energies of a few TeV/nucleon.

Most models of cosmic ray acceleration predict that the primary cosmic rays (i.e. those that originate at the acceleration site) are generated with power law spectra over a wide range of energies or rigidities. The observed spectra near earth may however be different from the source spectrum due to (a) energy losses during propagation, (b) interactions with the solar wind (solar modulation), (c) spallation reactions during propagation, (d) losses due to escape from the galaxy. For highly relativistic nuclei ($E \gtrsim 10$ GeV/amu) the first two processes (a) and (b) are insignificant, and the spallation cross sections become nearly independent of energy. Thus, in the leaky box approximation, assuming a source spectrum $\propto E^{-\Gamma}$ and assuming that there is no reacceleration during propagation, the observed spectrum is expected to be of the form

$$N(E) \propto E^{-\Gamma} \left(\frac{1}{\Lambda_P} + \frac{1}{\Lambda_i} \right),$$

where Λ_P, Λ_i are respectively the propagation and interaction pathlengths. As measurements of the L/M ratio indicate, the propagation pathlength decreases with energy approximately as $\Lambda_P = \Lambda_0 E^{-\alpha}$ ($\alpha \approx 0.5 \pm 0.1$). One can then define an Energy E_c at which $\Lambda_i = \Lambda_P$. Beyond that energy, nuclear reactions become progressively less significant as compared to propagation losses, and the observed spectral shape should approach $\sim E^{-(\Gamma+\alpha)}$. The value of E_c is different for different nuclear species: for carbon, with $\Lambda_i \sim 8$ g/cm^2, E_c is of the order of a few GeV/amu, but for Iron, with $\Lambda_i \sim 2.5$ g/cm^2, E_c will be larger by about a factor of 10. If the value of Γ is the same for all cosmic ray sources and nuclear species, the observed energy spectra of the individual components should all reach the same slope provided that the energies are well above the characteristic values E_c.

The presently available data do not cover a sufficiently wide range of elements and energies to test these predictions with any certainty. For instance, the spectrum of Fe appears to be significantly flatter than that of other nuclear species. However, the accuracy of the data becomes quite marginal at energies beyond ~ 50 GeV/amu, and the asymptotic spectra at higher energies cannot easily be extrapolated from the available measurements. To improve this situation, we have constructed a large instrument which was flown on the Spacelab-2 mission in Summer, 1985. Some details on the design and performance of the detector are given by L'Heureux et al (1987, paper OG 9.2-1 at this conference).

Our instrument is sensitive to cosmic ray nuclei from Boron to Nickel, and it covers an energy range up to several TeV/nucleon. An accompanying paper (OG 4.1-11, Meyer et al, 1987, this conference) will address our results on the relative abundances of secondary cosmic rays, produced by spallation in interstellar space. The present report concentrates on primary nuclei, the most abundant species being C, O, Ne, Mg, Si and Fe.

The energy of cosmic rays traversing our detector are measured from 40 to 150 GeV/amu with gas Cerenkov counters, and beyond 0.5 TeV/amu with transition radiation detectors (TRD). In addition, the relativistic increase in the ionization signal measured with multi-wire proportional chambers (which are part of the TRD), provides an energy measurement of limited resolution between a few GeV/amu and the onset of the transition radiation signal at 0.5 TeV/amu. The upper end of the energy region is limited by counting statistics due to the relatively short duration of the flight. Only for the most abundant nuclei will we be able to present data up to several TeV/amu.

As an example of the character of the data, figure 1 shows a cross correlation plot of a sample of high energy data for iron (Z=26) measured with the gas Cerenkov counters and with the TRD. As expected, in the low energy region 40 - 500 GeV/amu, the Cerenkov signal increases and reaches saturation, while the TRD shows a signal due to the ionization energy loss of the particles. At higher energies, the TRD signal increases due to the appearance of transition X-rays. The highest energy iron nucleus identified in this sample of data has an energy of 1.4 TeV/amu (0.8×10^{14} ev total).

As the analysis of our data is still in progress, we cannot include results in the printed proceedings, but we expect to present individual abundances and spectra at the time of the conference.

Acknowledgements. This work was supported, in part, by NASA under contract NAS 8-32828. J.G. was supported by a NASA Graduate Student Research Grant (NGT 14-020-804).

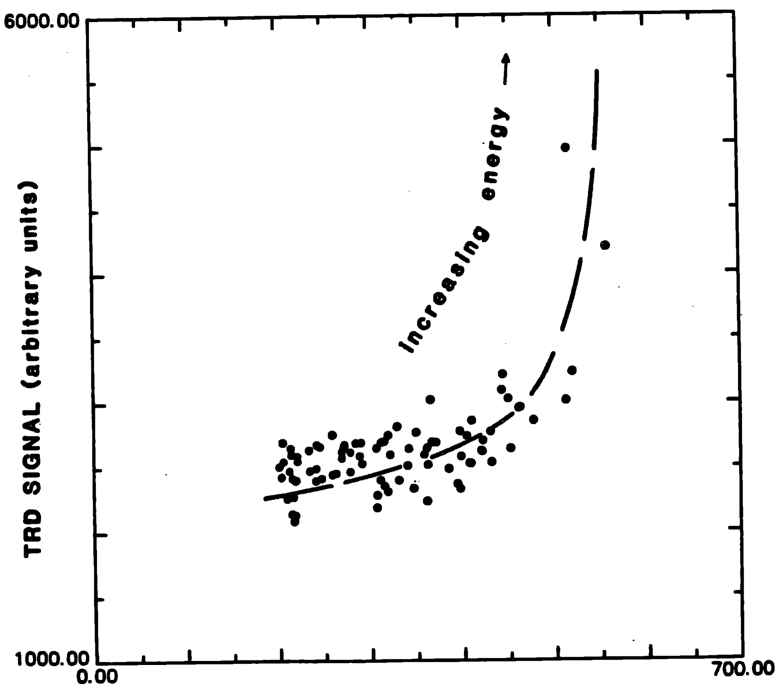

Fig. 1. A sample of iron nuclei covering the energy interval 50 GeV/amu to 1.5 TeV/amu. Shown is a scatterplot of the Cerenkov signal (with a lower cut-off corresponding to 50 GeV/amu) vs. the TRD signal. The dashed line illustrates the average locus of particles with increasing energy