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THE NON-Z^2 RESPONSE OF THE HEAVY NUCLEI COSMIC RAY DETECTOR ON HEAO–3

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ABSTRACT

A combination of ion chambers and Čerenkov radiators similar to the Heavy Nuclei Experiment flown on HEAO-3 was calibrated at the Bevalac heavy ion accelerator using beams of $_{25}$Mn nuclei at kinetic energies up to ~1700 MeV/nucleon and $_{79}$Au nuclei up to ~1000 MeV/nucleon. The data show only a small deviation (about 2-3 charge units at Au) from the Z^2 scaling used previously to analyze the HNE data. Although at lower energy, the calibration indicates that our published relative abundances of the $_{50}$Sn – $_{56}$Ba group and our published upper-limit actinide abundances are not likely to be significantly affected by non-Z^2 effects.

1. Introduction

The HEAO-3 Heavy Nuclei Experiment (HNE) consists of plastic Čerenkov radiators, two ion chamber modules, and multi-wire ionization hodoscopes (Binns et al. 1981a). Cosmic-ray elemental abundances have been derived from the HNE data using the in-flight response to $_{26}$Fe and assuming Z^2 scaling of ionization energy loss and Čerenkov radiation. These abundances (e.g., Binns et al. 1981b, 1982, 1983) show peaks at even charges from $Z = 14$ up through $Z = 58$, thus establishing the charge scale over this region. Above 58, abundances are much smaller, and the only statistically well-defined peak is a broad one at 78-82 (assuming Z^2). The absence of cosmic ray nuclei in the charge region above 84 (the actinide "gap") and estimates of expected deviations from Z^2 scaling (Derrickson et al. 1981; Ahlen 1980) led to the conclusion that any corrections were less than 4 charge units for nuclei with $Z \sim 80$, thus allowing unambiguous identification of the actinides ($Z \geqslant 89$). However, distinguishing $_{78}$Pt from $_{82}$Pb requires an accelerator calibration.

The HNE was calibrated when beams of particles in this high charge region first became available at the LBL Bevalac in the fall of 1982. The primary beams consisted of $_{25}$Mn at 1713 MeV/nucleon and $_{79}$Au at 1009 MeV/nucleon. Lower energies and lighter nuclei were obtained by degrading and fragmenting the beam with various absorbers, with gold fragments being resolved down to $Z \sim 65$. Fragmentation cross-sections are discussed in Waddington et al. (OG 5.2-6). The calibrated instrument consisted of an identical prototype (the "DVU") of one of the two ion chamber modules with two dual-gap ion chambers replacing the other module. A new Čerenkov counter with a smaller area was constructed from a spare flight radiator.

2. Results

Figure 1 shows data points obtained at 10.3° angle of incidence, plotting the DVU ion chamber signal as a function of the Čerenkov counter signal for various energies. For these runs, the DVU was upstream of the Čerenkov counter. The statistical errors are small compared to the points. The curves also shown in Figure 1 are calculated assuming that the Čerenkov response (Č) is the sum of the three terms (Lezniak 1976):

a) Čerenkov radiation of the primary nucleus ($n=1.528$),
b) Čerenkov radiation of the energetic knock-on electrons , and
c) scintillation of the Pilot 425 radiator (6% of $\beta=1$)

and assuming that the ion chamber response (I) is determined by:

d) the ionization energy loss of the primary nucleus (Barkas & Berger '64), and
e) a correction for energy carried in or out by energetic knock-on electrons.

These calculated lines in Figure 1 assume that each of these terms scales as Z^2 at any particular energy. They are normalized to the Mn data at 1000 Mev/nuc and use the parameter values determined from flight data for Fe. Note that since the particle energy changes along its path through the HNE the calculated Au response is not simply $(79/25)^2$ times that of Mn. It is clear that there is a systematic deviation from Z^2 which corresponds to about +3 charge units at Au for low energies.

The range extension due to electron pickup (Barkas and Berger 1964) is not included in the calculated response. However, electron pickup is expected to be important only at energies lower than represented in Figure 1.

For particles with $\beta \lesssim 0.9$, charge estimation is based on the combination of I and Č as shown in Figure 1. Here, the Bevalac data provide a direct calibration. However, at higher velocities where the charge determination is based on Č alone, we have no direct calibration and must use a theoretical extrapolation. Thus we have examined the deviation from Z^2 in the ion chamber signal and the Čerenkov signal independently.

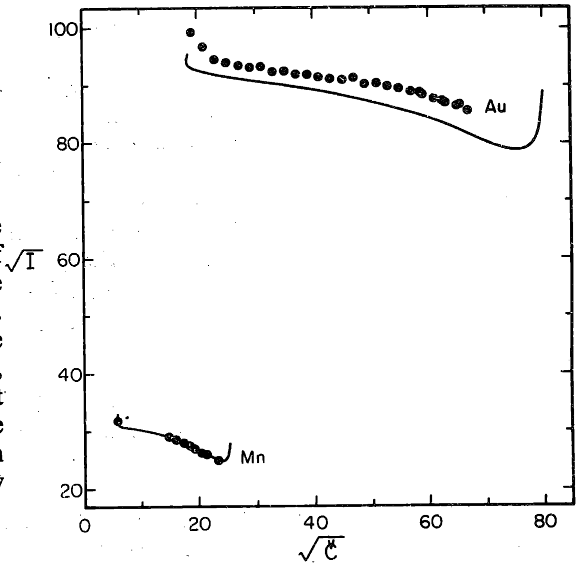

Figure 1. Square-root I (ion chamber signal) versus square-root Č (Cerenkov signal) measured (points) and calculated for Au and Mn. See the text for details of the calculations.

Figures 2 and 3 show I and Č separately as functions of the beam energy in the detector. In calculating the beam energy in the detector from the incoming beam energy, we have used range-energy tables based on the program of Salomon (1980). The use of these tables has been verified at a few discrete energies by Ahlen and Tarle (1983), Waddington et al. (1983), and by our measurements of energy loss of the Au beam in Cu slabs using the LBL magnetic spectrometer. Note that since the energies are derived and not measured, further refinements may result in some change. Note that Figure 1 is not sensitive to these refinements.

Figure 2 shows $\sqrt{I}$, the DVU ion chamber signal, as a function of the beam energy at the center of the DVU. Both the Au and Mn points are shown, with the Au points scaled down to display the deviation from Z^2. As shown in the figure, the energy deposit of the Au in the DVU ion chamber is $\sim$4-8% (in square-root signal) higher than simple Z^2 scaling would predict. We are trying to model this effect which depends on the details of the DVU as well as the physics of energy loss and energy deposit. The calculation of Derrickson et al. is shown as a triangle at 2 GeV/nuc where energy changes in the material of the HNE are small enough to make a direct comparison possible. These calculations use Mott production cross-sections for knock-on electrons. We have scaled the calculation from $_{78}$Pt to Au. The dashed line uses the program of Salomon for the ionization energy loss term (item d above) for Mn. A similar line for Au is omitted for clarity; it is much nearer the dashed Mn line than is the Au data.

Figure 3 plots $\sqrt{\check{C}}$ as a function of beam energy at the center of the two Čerenkov radiators. Again the Au signal has been scaled for direct comparison with Mn, and the deviation from Z^2 is noticeably smaller than in the ion chamber. Modeling is in process, but is complicated by the interposition of the DVU structure in the beam and by angle effects. The Derrickson et al. calculation for Au is shown at 2 GeV/nuc.

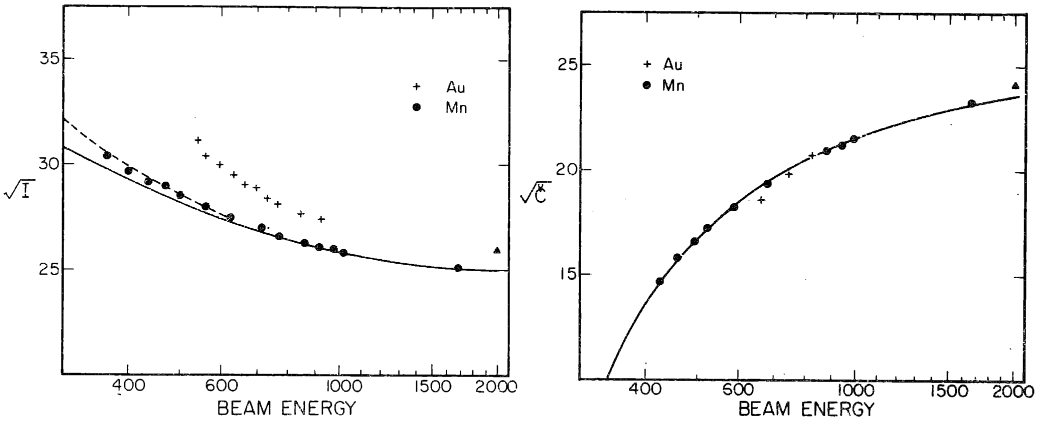

Figure 2. *Figure 3.*

Square-root I (2) and square-root C (3) are plotted as functions of beam energy at the center of the detector. The Au (+) data are scaled down by (25/79) for comparison to the Mn(●). The solid lines are calculated for Mn assuming Z^2 scaling, the dashed line for Mn using Salomon's program, and the ▲ indicates the calculation of Derrickson et al. for Au.

3. Conclusions

As was assumed in Binns et al. (1981b, 1982, 1983), the deviation of the HNE response from Z^2 scaling is not very large and is positive at the energies calibrated. Thus the use of Z^2 scaling has tended to over-estimate charges in this energy region. Models involving higher order terms (Ahlen 1980; Salomon 1980; Derrickson et al. 1981) in ionization energy loss are being developed to aid in the extension to higher energies and details of the structure of the DVU appear to be quite important.

Both the size and the sign of the correction indicate that the abundance peak observed in the 78-82 region does not consist of mis-identified actinides. An analysis of the flight data in this charge region will be presented in Fixsen et al. (OG 1-22). Although at lower energy, the calibration also indicates that our published relative abundances of the ${}_{50}$Sn – ${}_{56}$Ba group (Binns et al. 1983) and our upper-limit actinide abundances (Binns et al. 1982) are not likely to be significantly affected by non-Z^2 effects.

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