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UHCR: A COSMIC RAY MISSION TO STUDY NUCLEI IN THE CHARGE RANGE FROM $20 \leq Z \leq 100$.

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ABSTRACT

A definitive study of the elemental abundances of nuclei over the charge range of $20 \leq Z \leq 100$ requires a satellite mission capable of obtaining high statistics and excellent charge resolution over the full charge range. Such a mission, utilizing an electronic instrument which is an evolution of the HEAO-3 Heavy Nuclei Experiment, is described here.

1.<u>Introduction:</u> Our present knowledge of the elemental abundances for the ultra heavy (UH) cosmic ray nuclei ($Z \geq 30$) has been obtained predominantly from the HEAO-3 (Binns, et al., 1989) and Ariel-6 (Fowler, et al., 1987) experiments which were flown circa 1980. These experiments measured the abundances of all even-charged elements for $30 \leq Z \leq 60$. For elements heavier than Z=60, a combination of limited statistics and resolution resulted in the measurement of abundances for charge groups only. Our objectives for new measurements are: 1) the determination of the age of the heaviest cosmic rays ($Z \geq 90$); 2) a definitive study of neutron capture nucleosynthesis over the charge range $20 \leq Z \leq 100$; 3) search for recent nucleosynthesis of cosmic rays (e.g. search for $_{96}$Cm; $\tau_{1/2} = 1.6 \times 10^7$ yr); 4) study the propagation history of the entire range of charges; 5) search for superheavy nuclei ($Z \geq 110$) which may exist in the cosmic radiation; and 6) study the effects of preferential acceleration over this broad charge region (e.g. first ionization potential effects). Achieving these goals requires the detection of roughly 100 times the number of particles detected by HEAO-3, and a charge resolution of ≤ 0.25 charge units (cu) over the full charge range. An instrument and mission concept capable of achieving these objectives is described below.

2. <u>Instrument</u>: The instrument is modular with each module consisting of two Scintillator dE/dx counters and a Cherenkov counter which combined give a measurement of charge and velocity, a time of flight detector to determine the particle trajectory sense (up/down), and a scintillating fiber hodoscope (Davis, et al., 1989) giving up to 4 x,y coordinates (H1-H4) for angle and position corrections to the dE/dx and Cherenkov counter signals (Fig.1). The Cherenkov counter could consist of two radiators as was the case for HEAO, one mounted on top and the other on the bottom of a light diffusion box, and will be composed of Pilot-425 or Fused Silica. The scintillator counters (S1 and S2) each have one radiator mounted on the inboard sides of the light diffusion boxes, thus providing a large acceptance geometry. The preferred scintillator material is plastic scintillator or other higher-Z scintillator. The light from each counter (S1, S2, C) will be viewed by ~36 five inch photomultipliers (PMT's). Signals from S1 and S2 are also used for time of flight

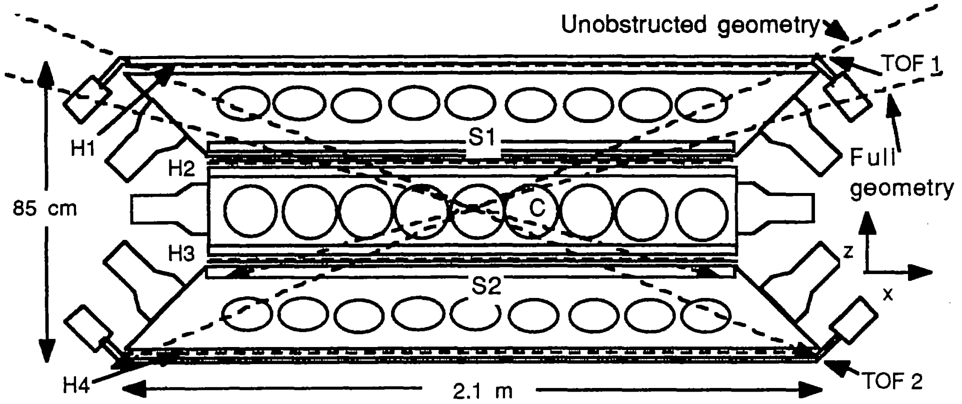

Fig. 1--The UHCR instrument is symmetrical in x and y and accepts particles entering from above and below. The dashed lines show the "full" and "unobstructed" geometry.

determination, especially for wide angle particles not traversing the primary time of flight counters (TOF1 and TOF2) on the outboard sides of the detector, since these particles are at wide angles and should provide sufficient separation to make the TOF measurement useful. Thin scintillator strips viewed by photomultipliers will be used to determine the TOF for particles traversing H1 and H4. The instrument is symmetrical and accepts particles from either direction. It has dimensions as shown in Fig. 1 with the radiator being 1.6 m square, a size very similar to that used on HEAO, thus giving a fairly direct means of estimating detector performance and engineering parameters.

This design results in a module with a "full" geometry factor (event criterion S1·H2·C·H3·S2) of 10 m^2sr, assuming that particles traverse each radiator at a distance >3 cm from the radiator edge. The "unobstructed" geometrical factor (H1·S1·H2·C·H3·S2·H4) for nuclei traversing the radiators at a distance >3 cm from the edge is 5.7 m^2sr. These geometrical factors include nuclei entering the instrument from both the top and bottom.

3. The UHCR Mission: The experiment would consist of 3 or 2 modules launched into an elliptical orbit such that it is outside the magnetosphere 80% of the time. The number of particles which should be detected assuming solar minimum for 5 years and the full geometry factor is shown in the table below. The calculations assumed that nuclei had an energy of >350 MeV/n as they exited the Cherenkov counter. The numbers of $_{90}Th+_{92}U$ in the table labeled (a) were estimated assuming Anders and Ebihara (1982) abundances, while those labeled (b) assumed the HEAO/Ariel (Binns et al., 1989) abundances. For comparison of the number of nuclei detected, the total number of Fe nuclei collected by HEAO-3 was 1.7 x 10^7 particles, with only about half of these being of sufficiently good quality to be included in abundance estimates. Interactions will reduce the number of good events; e.g. $_{92}U$ would be reduced by 40-65%, depending upon the detector thickness and material. The detector radiator parameters will be optimized to minimize interaction losses, while retaining good charge resolution. The

number of $_{90}$Th+$_{92}$U expected allows precise measurements of the age of the heaviest nuclei. For example, if the nuclei were synthesized 10^7 years ago, and we assume the detection of 200 noninteracted Th+U, the age determination using the $_{92}$U/$_{90}$Th ratio, as derived from Blake et al. (1974), has a statistical precision of $(1^{+1.1}_{-0.7}) \times 10^7$ years. The $_{92}$U/$_{96}$Cm ratio for these conditions gives an independent and more precise estimate of $(1 \pm 0.2) \times 10^7$ years. If the cosmic ray age is 10^9 years, the $_{92}$U/$_{90}$Th ratio gives an age precision of $\pm 0.3 \times 10^9$ years. For this case, the $_{96}$Cm would be decayed and have a zero abundance. Likewise, the $_{92}$U/$_{94}$Pu ratio provides a good measure if the correct age is about 10^8 years.

Z	3-Modules	2-Modules
26	3.3×10^9	2.2×10^9
32-40	5×10^5	3.5×10^5
41-49	9×10^4	6×10^4
50-61	9×10^4	6×10^4
62-73	$3. \times 10^4$	$2. \times 10^4$
74-80	1.8×10^4	1.2×10^4
81-83	5.3×10^3	3.5×10^3
90-92 (a)	430	290
90-92 (b)	150	100

4. Charge Resolution--The charge resolution expected for the Cherenkov detector can be scaled from that obtained with the HEAO detector which was 0.4 cu at $_{56}$Ba. The UHCR Cherenkov counter would have a much larger photocathode to box surface area, as well as improved PMT's, and should yield about 4 times more signal than HEAO which had a light collection efficiency of about 5%. Thus, for a radiator like that used on HEAO, a charge resolution of about 0.2 cu in Cherenkov for relativistic nuclei up through Ba should be obtained. In addition, we have demonstrated Cherenkov resolution for 1 Gev/n $_{79}$Au nuclei of 0.25 cu at the Bevalac (Kertzmann, 1987). Thus, based on our experimental work to date, we expect to be able to achieve adequate Cherenkov resolution at least to $_{79}$Au for particles with energy near the Cherenkov plateau . We anticipate that as the Cherenkov charge resolution degrades for particles near threshold, the dE/dx resolution will improve.

We have recently exposed plastic scintillator counters to $_{47}$Ag and its interaction fragments at the Bevalac (See Paper OG 10.1.15), and a resolution of ~0.25 cu was obtained. Since the S1 and S2 signals are independent, the two measurements should give a resolution <0.25 cu.

At the highest charges ($Z \geq 90$) electron capture and stripping reactions become important and must be carefully evaluated. There are two effects that must be considered. The first is a lowering of the "effective" charge as the particle captures electrons while traversing detector material, and the second is a statistical broadening in signal due to the finite number of capture and stripping reactions that occur for a detector of given thickness and material type. We have used the electron capture and stripping cross sections for $_{92}$U (Crawford, 1991) to calculate the effective charge for Uranium penetrating through carbon (plastic) and Silicon using the method described in Price et al. 1987. We find that the effective charge for U drops to 91.5 in Si and to

91.2 in C at 600 MeV/n. This has a negligible effect in reducing the spacing between, e.g., $_{90}$Th and $_{92}$U since the effective charge of $_{90}$Th also droops, though not quite as strongly.

To estimate the significance of the statistical broadening due to electron capture and stripping, we have performed a Monte Carlo calculation which follows $_{92}$U nuclei through either carbon or silicon. The calculation includes only single electron capture and stripping reactions. In silicon the statistical broadening in the charge estimate is typically 0.10 cu over the full energy range, while in carbon the effect is about 0.23 cu at 1200 MeV/n and 0.18 cu at 400MeV/n. Fig. 2 shows the results of this calculation for 1000 MeV/n. This resolution degredation is very small for a silicon detector, but is more significant for a carbon like detector (e.g. plastic scintillator).

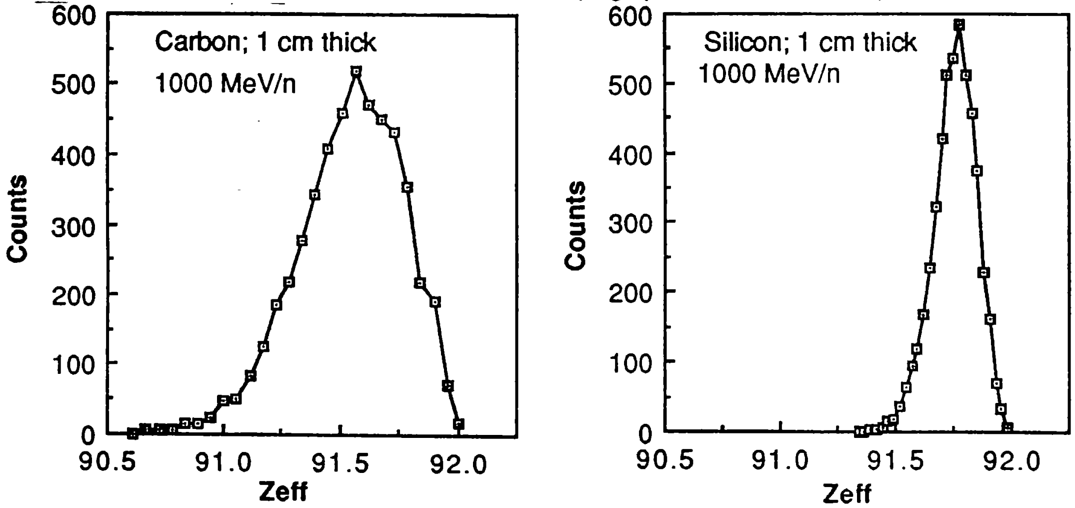

Fig. 2-Monte Carlo calculation of Z_{eff} distribution for U nuclei in a) plastic scintillator (carbon) and b) glass (silicon).

Thus we see that the resolution obtainable with this instrument should be ≤ 0.25 cu up through Pb, with only a small degradation due to electron capture occurring in the Th-U charge region. We plan additional tests at the Bevalac to study the properties of various scintillator types for the detection of $_{92}$U group nuclei.

5. References

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