CAPABILITIES OF THE LDEF-II HEAVY NUCLEI COLLECTOR

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1. Introduction. Less than about half a dozen relativistic actinide ($Z \geq 90$) nuclei have been detected in space experiments--one on HEAO-3 [1], three on Ariel-6 [2] and possibly two on Skylab [3]. Our studies of long-term track fading suggest that partial fading of tracks produced early in the Skylab mission relative to those produced later may have smeared the charge scale and resulted in misidentification of some of the seven events originally reported as actinides. Events attributed to actinide nuclei using plastic track detectors and nuclear emulsions on balloon flights some years ago are now believed to be due mostly to spillover from the platinum and lead peaks, due to a shift in detector response with temperature during the day-night cycle of the balloon payload [4]. The HEAO-3 experiment, which had the best charge resolution to date for ultraheavy cosmic rays, resolved even-Z charge peaks up to $Z \sim 56$ and reported ~60 events with $Z \geq 70$. Although their statistics and resolution were inadequate to resolve charges in this region, they were able to estimate the ratio of Pb-group to Pt-group nuclei to be ~1% based on one actinide event. Their data for all nuclei with $Z \geq 30$ are consistent with a solar system source for the heavy cosmic rays, with the exception of a few elements such as Pb, which may be depleted in the cosmic rays. To take the next big step beyond HEAO-3, the Heavy Nuclei Collector (HNC), to be carried on an LDEF reflight, has the goals of greatly increased collecting power (>30 actinides) and charge resolution ($\sigma_Z \leq 0.25e$ for Z up to ~100), which will provide abundances of all the charges $40 \leq Z \leq 96$ and permit sensitive searches for hypothetical particles such as monopoles, superheavy elements, and quark nuggets.

2. Mission. After the currently orbiting LDEF is retrieved, it will carry 45 trays of plastic track detectors ($A\Omega \approx 100\ m^2\ sr$) into a 28.5 degree orbit for a 6-year exposure at $T < -10°\ C$, after which it will be retrieved for analysis of the tracks. (At this writing, a 2.7-yr exposure in a 57° orbit, which would yield ~10% more actinides, has not been ruled out.)

3. Design. To meet our goal of achieving a charge resolution $\sigma_Z < 0.25e$ at $Z = 92$, we used a number of novel features. Figure 1 is a cutaway sketch of the contents of one of the 45 trays, 41 of which are optimized for identification of nuclei with $Z \geq 70$ and 4 of which are optimized for nuclei with $30 \leq Z \leq 70$. Detector response depends on temperature and oxygen pressure, and stability of the latent track against fading demands a low

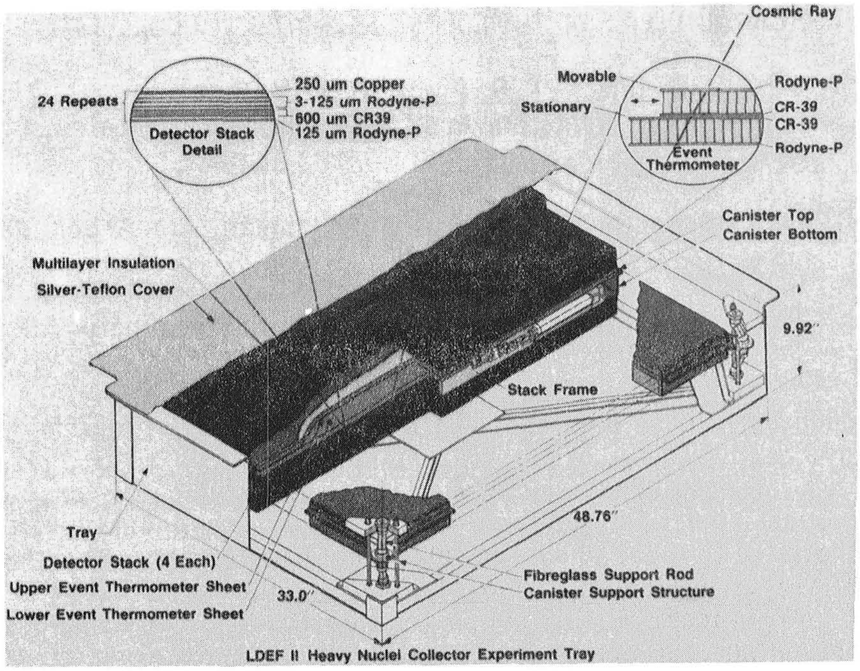

Fig. 1. HNC tray. Composition of stack and design of event thermometer are somewhat different than shown in drawing.

average detector temperature. Thus, each stack is sealed in 0.3 bar of air in a thermally isolated canister shielded from space with multilayer insulation and passive thermal coating, and each stack contains an event thermometer that enables the temperature of the stack at the time of passage of each heavy nucleus to be determined by measuring the displacement of a sliding plastic track-recording sheet with respect to the stack. The sliding sheet is driven by a plunger actuated by a silicone liquid whose volume depends on temperature.

Calibrations at the LBL Bevalac with relativistic beams of U, La, Kr, and Fe ions [5] enabled us to develop improved detectors of two classes: a polycarbonate plastic, Rodyne-P, with outstanding resolution in the region $50 < Z < 120$, and a poly- (allyl diglycol carbonate) plastic, CR-39(DOP), containing 1% dioctyl phthalate and 0.01% of an antioxidant, with outstanding resolution in the region $10 < Z < 70$. (See Fig. 2.) For fully stripped nuclei with $Z < 80$ passing through many sheets, we have verified that the resolution improves as $1/\sqrt{n}$, where n is the number of etchpits measured along the trajectory. For relativistic uranium, an electron is often retained in passage through more than one sheet, with the result that the resolution improves much less rapidly than $1/\sqrt{n}$. We showed that periodic insertion of copper foils in the stack eliminates the correlation in effective charge from sheet to sheet and restores the $1/\sqrt{n}$ dependence [6]. Use of copper, with its high Z, in place of plastic of equivalent mass thickness reduces the fraction of events that fragment within the stack.

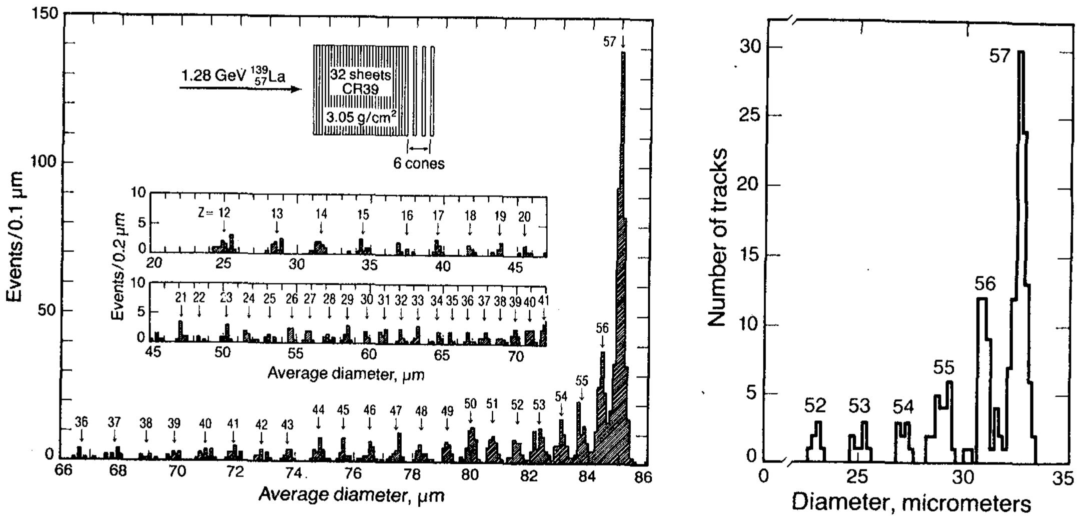

Fig. 2. Bevalac tests showing ability of CR-39 (on left) and Rodyne-P (on right) to resolve individual charges using only a few successive etch pits.

Monte Carlo simulations of detector response enabled us to optimize the sequence of Rodyne-P, CR-39, and copper sheets so as to maximize charge resolution and minimize fragmentation loss within a weight constraint of ~8.7 g/cm^2 per tray. The 41 actinide stacks contain 59 Rodyne-P, 18 CR-39, and 28 copper sheets (not in that order) each 250 microns thick. The four mid-Z stacks contain more CR-39 than Rodyne-P sheets. The weight ratio Cu/plastic = 2.57 corresponds to 0.83 of an interaction length for uranium at normal incidence. For an assumed fractional standard deviation in measured cone length of 1% (2%), the charge resolution at uranium ranges from 0.19e (0.21e) at 1 GeV/amu to 0.21e (0.48e) at 4 GeV/amu. For calibration purposes, two sheets in each stack will be irradiated with a low density of uranium ions over their entire surface before the mission.

Figure 3 shows two Monte Carlo simulations. On the left is the charge spectrum of events with $Z \geq 70$ expected if the source of cosmic rays is entirely material with solar system composition. On the right is the charge spectrum expected if the cosmic rays consist of an equal mixture of material with solar system composition and of 10 million year-old r-process material. In a six year mission, as little as 20% admixture of r-process material would lead to a detectable number of plutonium and curium events. Such an admixture cannot be ruled out by HEAO-3 and Ariel-6 data.

4. Data Analysis. In a 28.5 degree orbit the earth's field will eliminate background tracks of slow, highly ionizing galactic iron nuclei and of solar flare particles. Recoil nuclei produced in interactions of trapped protons in the detector will have no significant effect on the insensitive Rodyne-P sheets and will give rise to a background of short etch pits in CR-39 which, on the basis of accelerator simulations, will not seriously degrade detector performance. The dependence of detector response on temperature

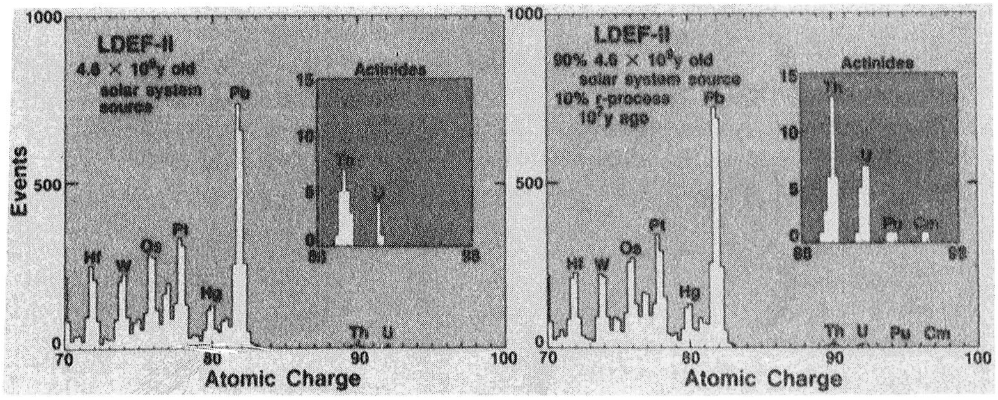

Fig. 3. Simulations of charge spectra.

increases with ionization rate [4]. In a 28.5 degree orbit the worst case is for a ~1 GeV/amu uranium ion, for which the apparent charge shifts by ~0.1e per deg C for Rodyne-P. Passive thermal coatings limit the temperature excursions to ±19 degrees C at the worst locations and ±5 degrees C at the best locations. These temperatures will be measured with adequate sensitivity by the event thermometer. Because all nuclei reaching the detector will be minimum-ionizing, the etching rate for a given plastic type will depend only on Z. For elements up to bismuth, measurements of etch pit elliptical mouths will suffice; for thorium and uranium both the mouth and the entire profile will be measured, using a three-dimensional image-analysis technique [7] illustrated in Fig. 4. We expect roughly 5000 events with Z > 60. About 5 x 10^5 etch pits will have to be measured. Commercial image processors can be used both to locate events and to perform measurements.

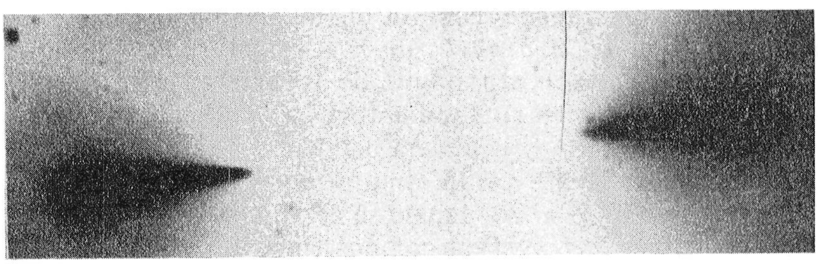

Fig. 4. Digitized, projected image of an inclined etched uranium track.

References

1. W.R. Binns et al., Ap. J. 261, L117 (1982).
2. P.H. Fowler et al., 9th European Cosmic Ray Sumposium, 1984.
3. E.K. Shirk and P.B. Price, Ap. J. 220, 719 (1978).
4. A. Thompson and D. O'Sullivan, Nucl. Tracks & Rad. Meas. 8, 567 (1984).
5. M.H. Salamon et al., Nucl. Instr. Meth. B6, 504 (1985).
6. M.H. Salamon et al., Nucl. Instr. Meth. 224, 217 (1984).
7. P.B. Price and W. Krischer, Nucl. Instr. Meth. A234, 158 (1985).