

INITIAL RESULTS FROM THE CALTECH/DSRI BALLOON-BORNE ISOTOPE EXPERIMENT

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ABSTRACT

The Caltech/DSRI balloon-borne High Energy Isotope Spectrometer Telescope (HEIST) was flown successfully from Palestine, Texas on 14 May, 1984. The experiment was designed to measure cosmic ray isotopic abundances from neon through iron, with incident particle energies from ~ 1.5 to 2.2 GeV/nucleon, depending on the element. During ~ 38 hours at float altitude, $> 10^5$ events were recorded with $Z \geq 6$ and incident energies ≥ 1.5 GeV/nucleon. We present results from the ongoing data analysis associated with both the pre-flight Bevalac calibration and the flight data.

1. Introduction. The experiment described here is a joint undertaking by Caltech and the Danish Space Research Institute. A large-area (geometric factor ~ 0.25 m² sr) balloon-borne instrument has been developed to measure cosmic-ray isotopic abundances from neon through iron, with incident particle energies from ~ 1.5 to 2.2 GeV/nucleon, depending on the element (1). The experiment was first flown on 14 May, 1984, from Palestine, Texas. Prior to flight, the detector was exposed to beams of carbon, neon, argon, and manganese at the Berkeley Bevalac, with the latter exposure providing the principal calibration for the instrument. Preliminary results associated with the development of mapping techniques and position-determining algorithms are discussed, with application to flight data.

2. Instrument Description. The experiment employs either Cerenkov- ΔE -Cerenkov or Cerenkov-total energy techniques for isotope resolution (see reference 1), depending on whether the incident particle traverses the entire detector, or stops at an intermediate position in the instrument. Figure 1 shows a schematic diagram of the detector. A stack of twelve NaI(Tl) disks (each nominally 2 cm thick, 52 cm diameter; 87.2 gm/cm² total thickness) directly measures the energy change ΔE for an incident particle. Two Cerenkov counters (C1 and C2), measure the change in Lorentz factor, $\Delta\gamma = \gamma_1 - \gamma_2$, for the event. For a stopping particle $\gamma_2 = 1.0$. Mass M is obtained from:

$$M = \Delta E / \Delta\gamma$$

Each disk making up the stack is viewed by six individually digitized photomultiplier tubes (PMT). This permits not only a measurement of the energy deposition per layer, but through intercomparison of the six PMT responses, yields the particle's position in that layer (2,4). Because of the large amount of material

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necessary to slow down the high-energy nuclei, typically 85% of the incident particles meeting the trigger requirements will undergo charge-changing fragmentation reactions in the detector. For the NaI stack, these events are removed through a comparison of the individual layer responses. Plastic scintillators (S1 and S2), define the geometry factor, and provide additional rejection against events fragmenting within the Cerenkov counters.

The top Cerenkov counter consists of a mosaic of 48 aerogel radiators of refractive index $n \sim 1.1$, while the bottom counter employs a combination of teflon ($n = 1.34$) and Pilot 425 ($n = 1.49$). Results associated with the ^{55}Mn Bevalac calibration of the aerogel counter have been presented previously (3).

In its flight configuration, the detector and associated electronics are mounted in an insulated pressure vessel. An on-board evaporative cooling system is employed to maintain constant detector temperature, minimizing the need for thermal corrections in the data. Along with housekeeping information, the 108 digitized PMT outputs are recorded on-board using two video recorders, and are also transmitted to the ground through a telemetry link for real-time analysis.

3. Flight Details. The experiment was flown from Palestine, Texas on 14 May, 1984, using a $17.2 \times 10^6 \text{ ft}^3$ Winzen balloon. The instrument maintained float altitude for ~ 38 hours, at a typical atmospheric depth of $\sim 5.5 \text{ gm/cm}^2$. During the flight, the geomagnetic cutoff ranged from ~ 4.5 to 5.5 GV . The experiment was recovered with minimal damage to the instrument.

For the flight, $\sim 4.25 \times 10^5$ events were recorded, which included $> 10^5$ events with $Z \geq 6$ and kinetic energy $> 1.5 \text{ GeV/nucleon}$. While only a fraction of the events will be usable for isotope analysis, the remainder are being employed for in-flight mapping of the detector, gain balancing, and stability checks.

Analysis of the flight data has shown that with minor exceptions, all systems performed as designed. The evaporative cooler maintained a constant detector temperature of $25.0 \pm 0.5^\circ\text{C}$ for the majority of the flight, with a gradient across the NaI stack of $\leq 0.2^\circ\text{C}$. Examination of threshold settings and detector gains and offsets, have indicated an overall average stability for the flight of better than 1%.

4. Data Analysis. One innovation in this experiment is that the NaI stack provides both trajectory and energy loss information for an incident particle. However, this requires that the response of the individual disks making up the stack be accurately mapped. Previous analysis results have been presented based on the November, 1982 Bevalac calibration, which employed a beam of ^{55}Mn ions, at 1.75 GeV/nucleon (4). Those results were based on analysis of data from two central regions of the instrument. Our primary analysis objective has been to use the ^{55}Mn calibration data to generate full-disk response maps of each PMT viewing each stack layer, and to obtain full-disk maps of the response ratios with various PMT combinations, for position determination.

The response maps for each PMT are generated using an overlay of 1 cm bins on each NaI disk. Typically, the response of a single PMT varies by a factor of 5 to 7 across the disk. The current mapping technique uses calibration data to assign an average response to the center of each bin. For each event, a multi-point interpolation process is employed to obtain correction factors from the maps, with the final response generated from a weighted average over all six PMT's viewing the disk.

Figure 2 shows a histogram of the normalized energy loss (response) for layer 1, averaged over the entire disk. The resolution achieved of $\sim 2.8\%$ FWHM is only slightly worse than the 2.4% previously reported for central regions of the stack (4). We estimate that Landau fluctuations account for approximately one-half the distribution width. Results for layers 2 and 3 exhibit similar distributions, with a FWHM of $\sim 3.0\%$. Additional refinements in the mapping technique are expected to improve the energy

resolution further.

In addition to generating full-disk response maps, work is progressing on developing position determining algorithms for the disks. Position resolution is obtained from the calibration data, by comparing the measured event position obtained from Bevalac wire-chamber data, and that inferred from algorithms employing ratios of disk PMT responses. The use of PMT response *ratios* effectively removes the energy dependence from the position determination. Currently, six ratio maps are generated for each NaI disk, using a 1 cm spatial grid. The maps employ ratios of opposite sums of two and three adjacent PMT's viewing each disk. Intermediate positions are obtained using an interpolation process. For a given event, the best estimate of particle position is determined from an algorithm which minimizes the difference between the mapped ratios and the measured event ratios.

Figure 3 shows the difference distribution for a single position coordinate (ΔX), as determined from ^{55}Mn calibration data averaged over approximately the central two-thirds area of layer 1. The central portion of the distribution has a FWHM of 4mm, in good agreement with the results previously presented, that were limited to data near the stack axis (4). Similar results are obtained for the orthogonal coordinate ΔY . Combining both position coordinates for layer 1 produces the difference distribution shown in Figure 4, where:

$$\Delta R = (\Delta X^2 + \Delta Y^2)^{1/2}$$

From these results, the rms position resolution for layer 1 is found to be of order 3mm. In extending the analysis to deeper stack layers, the distribution broadens to $\sim 4.4\text{mm}$ by layer 5. We consider these results as upper limits to the intrinsic stack resolution, in that contributions from wire-chamber uncertainties and multiple Coulomb scattering have not yet been unfolded from the data.

5. Discussion. While we anticipate further improvement in the analysis results described here, our results for energy resolution are already consistent with the design goals for isotope resolution in the instrument. In particular, if we extrapolate these results to the full 12 layers of the stack for stopping ^{55}Mn , the expected contribution to mass error from uncertainty in ΔE is of order 0.3%. This uncertainty results in an associated mass error for the instrument of ~ 0.19 amu for Mn at the Bevalac energies, with a correspondingly smaller uncertainty for the lighter elements.

Prior to the detailed analysis of the flight data, the maps and position-determining algorithms developed from the ^{55}Mn Bevalac exposure must be extended to the remaining stack layers. Concurrent with this effort, we are optimizing techniques for trajectory determination, and extending the position-determining algorithms to the outer edges of the disks.

6. Acknowledgements. This work was partially supported by NASA, under grant NGR 05-006-160.

References

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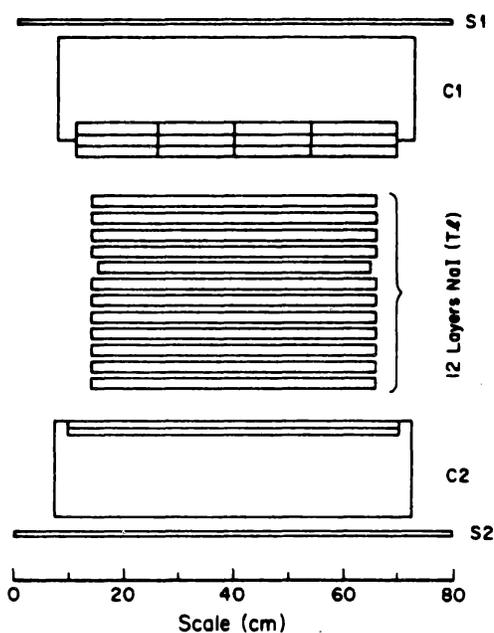


Fig. 1. Schematic diagram of the detector.

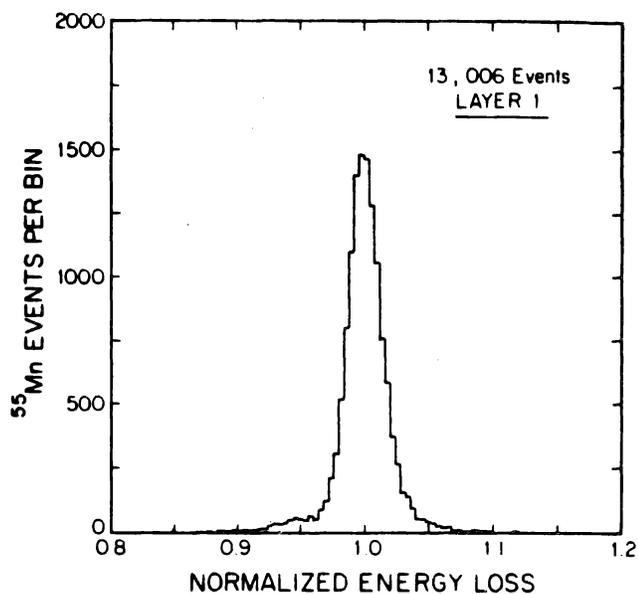


Fig. 2. Layer 1 response distribution for ^{55}Mn , averaged over the full NaI disk.

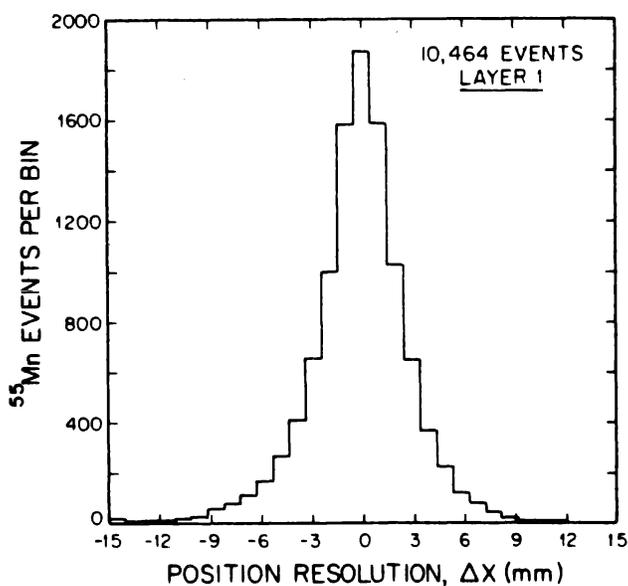


Fig. 3. Difference distribution between a single Bevalac wire-chamber coordinate, and that obtained from layer 1 NaI response ratios, averaged over the central two-thirds area of the disk, for ^{55}Mn ions.

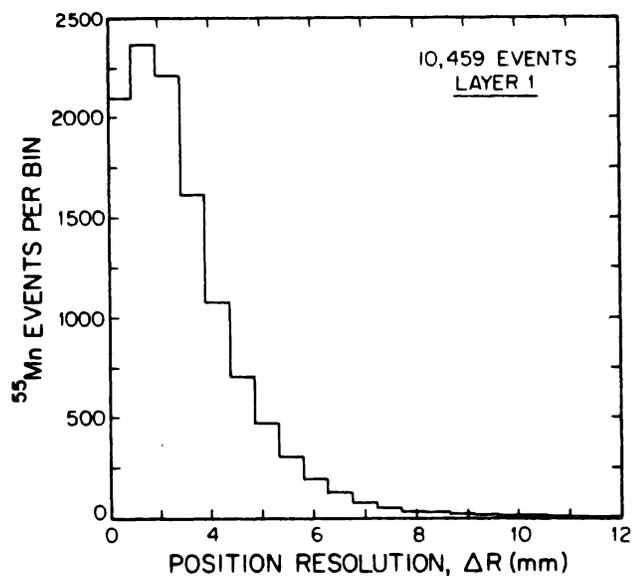


Fig. 4. Difference distribution between Bevalac wire-chamber positions, and those obtained from layer 1 NaI response ratios, averaged over the central two-thirds area of the disk, for ^{55}Mn ions.