BEVALAC CALIBRATION OF THE SOFIE RANGE AND HODOSCOPE DETECTORS

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1. Introduction. The Scintillating Optical Fiber Isotope Experiment (SOFIE) is a Cherenkov-dE/dx-Range experiment being developed initially for balloon flight to study the isotopic composition of cosmic rays in the iron region. The electronic range and hodoscope detectors in this experiment use scintillating optical fibers to image the tracks of stopping charged particles and to determine their trajectory. From this information the particle range can be determined and used together with a Cherenkov measurement to determine the mass of the stopping particle. This paper describes preliminary results of a Bevalac calibration performed in August, 1984 with a prototype of the balloon flight instrument, for the purpose of studying the measurement precision in range and trajectory which could be attained with this detector.

2. Experiment. Figure 1 shows a cross-section of the instrument exposed at the Bevalac. Incident particles pass through two thin plastic scintillator counters which provide a coincidence signal after which a Cherenkov measurement is obtained in a 2.5 cm thick Pilot 425 counter. Particles exiting the Cherenkov counter pass through a 0.794 cm thick steel passive absorber. This thickness was chosen so that particles stopping in the range detector would be above threshold in the Cherenkov counter. The range detector consists of a bundle of scintillating optical fibers which are proximity focused onto the face of a fiber optic reducer which was coupled to an image intensified video camera system consisting of a G.E. TN-2505 camera and an ITT-4144, dual microchannel plate image intensifier tube (Binns *et al.*, 1983a and b). The CID sensor in the camera is a rectangular array of 244x388 pixels, with each pixel having dimensions 23x27 microns^2. The fiber bundle which is coupled onto this array consists of about 7×10^4 fibers with length 30 cm and a 100 micron square cross-section joined together into a solid rod with cross-section 2.7×2.7 cm^2. The fiber bundle was constructed by first making a boule with plastic scintillator core material (KSTI-415) and acrylic cladding. Fibers with 1.5 mm square cross-section were then drawn and 225 of these were fused into a "multifiber boule" which was then drawn again into fibers with a 1.5 mm square cross-section. These multifibers were then fused into solid rods with cross-section 1.4 cm square. Four of these rods were then joined together and coupled to the intensified camera to form the detector. When a coincidence signal occurred, the image intensifier was gated off and a video frame was then processed along with Cherenkov, dE/dx, and penetration counter pulse heights.

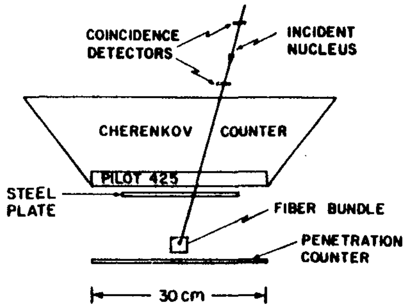

Figure. 1
Experiment cross-section

3. Range Detector Results. Iron-56 nuclei stopping in the fiber bundle produced tracks with a breadth of about 10 fibers (full width half maximum) near the end of the particle range. The energy deposition in plastic scintillator should, however, extend over a range of less than 1 fiber width. This track broadening is believed to be predominately the result of coupling between fibers due to incomplete conversion of ultraviolet photons within the fiber in which they were produced. Imperfections in the fibers may also contribute to cross talk. Curve a) in Figure 2 is a plot of light output from the fiber bundle versus residual particle range where the light output is obtained by summing the light intensity along pixel columns which are nearly perpendicular to the tracks. A running sum of three pixel columns is then taken to smooth the data. The theoretical energy loss versus particle range is also plotted (curve b) and has been smeared in one dimension by a gaussian with a sigma of 400 microns to simulate the track broadening due to fiber cross talk and broadening within the intensified camera system. These curves have been arbitrarily normalized using a "best eyes fit" so that the energy loss and light output match for the entry end of the track. Qualitatively these curves are similar. However in detail it is evident that there are fluctuations in light output along the track, and these fluctuations occur roughly on the scale of a single multifiber (about 1.5 mm). These fluctuations are believed to be the result of nonuniformities within the fiber bundle. In addition there is evident saturation in the scintillator output as the particle slows down and stops.

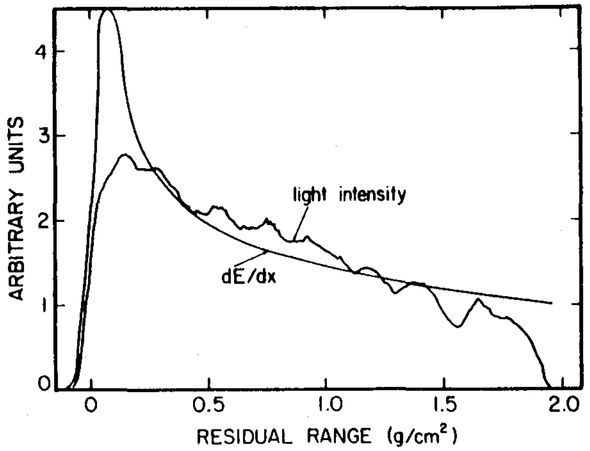

Figure 2
Curve a) is a plot of the light intensity from the fibers vs. residual range and curve b) is the calculated dE/dx (Henke and Benton, 1966) vs. residual range spread by a gaussian function with $\sigma = 400$ microns.

Figure 3 shows the distributions in range that we obtained for iron-56 nuclei with beam energies 473 and 529 MeV/amu and having an incidence angle of 10 degrees with respect to the normal to the fiber bundle entry side. These nuclei were selected to have a low penetration counter signal, and they have had a first order mapping correction applied to account for variations in the flatness of the entry window into the fiber bundle. The range algorithm searches from the end of the track until it finds the maximum in light intensity as shown in figure 2. The half maximum intensity point is then taken to be the end point of the track. From Figure 3 we obtain a sigma in the range distributions of 260 and 280 microns for the beam energies 473 and 529 MeV/amu respectively. (The sigma was obtained from the full width half maxima of the distributions.) The 529 MeV/amu distribution appears to have non-gaussian wings which we hope to reduce by further data analysis. Calculations show that the combination of multiple coulomb scattering, range straggling, and the finite fiber size will result in a range uncertainty of about 150 microns sigma. The additional broadening which we observe in our measurements is believed to be the result of imperfections in our fiber bundle. We have calculated that for a range measurement uncertainty of 300 microns and using a Cherenkov counter similar to that developed by Webber and Kish, (1983) appropriate hodoscopes, and an Aluminum passive absorber, a mass resolution of better than 0.25 amu can be obtained for incident angles less than 30 degrees and better than 0.30 amu for most particles with incident angle less than 55 degrees. We expect to be able to improve the quality of our fiber bundles which should result in improved range measurement precision.

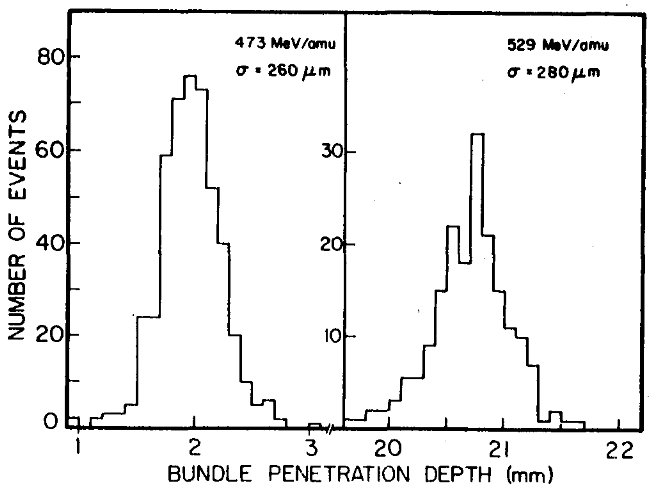

Figure 3
Range distributions for iron-56 nuclei with energies 473 and 529 MeV/amu stopping in the fiber bundle.

4. Hodoscope Results. To study the positional resolution that we could expect to obtain with a hodoscope made of scintillating fibers we have calculated, for a single track, the weighted mean position in fiber layers perpendicular to the track direction. These layers are adequately separated so that they are optically decoupled from one another. These points were then fit by a straight line as shown in Figure 4. The rms deviation of these "individual layer means" from the straight line should then give an indication of the trajectory measurement capability of this technique. Our measurements show a deviation from the best fit line of about 35 microns rms over the entire track length and 10 microns over a limited track segment. It seems clear that the larger deviation over the entire track length (about 200 fiber layers) is the result of systematic nonuniformities in the fiber bundle and that something approaching 10 microns is the true measuring precision which was obtained. This measurement precision is actually better than could be obtained if the fibers were optically decoupled from each other. (If light were detected only from the fibers through which the primary nucleus penetrates, then 100 micron fibers would give a measurement precision of 30 microns rms.) This is the result of the additional information contained in the fibers adjacent to the fibers actually traversed by the particle, thus improving our ability to estimate the "center of gravity" of the track.

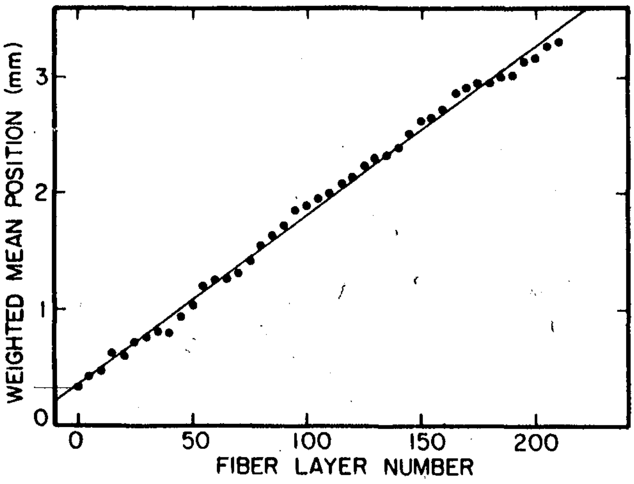

Figure 4.
Weighted mean position in the fiber bundle plotted vs. the penetration depth into the fiber bundle. Each fiber layer is 100 microns thick.

4. Conclusions. We have developed a new type of electronic detector which is capable of measuring range and trajectory to the precision required for resolving individual isotopes.

5. Acknowledgements. This work was supported in part by NASA grants NGR-26-008-001, NAGW-122, and NASA contract NAS5-27996 and in part by the McDonnell Center for the Space Sciences.

6. References

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