DECAY OF HIGHLY EXCITED NUCLEI

EMISSION OF INTERMEDIATE MASS FRAGMENTS NORMAL TO THE FISSION AXIS IN HOT HEAVY NUCLEI

D.E. Fields, J.L. Wile, K. Kwiatkowski, K.B. Morley, E. Renshaw,
S.J. Yennello, and V.E. Viola
Indiana University Cyclotron Facility, Bloomington, Indiana 47408

R.G. Korteling
Simon Fraser University, Burnaby, BC Canada

In a recent experiment designed to study the source properties of complex fragments emitted in the 270-MeV ^{3}He + ^{232}Th reaction, an unusual component was observed in the fragment spectra at backward angles. The experiment was carried out at the Indiana University Cyclotron Facility using a beam of 270-MeV ^{3}He ions to bombard a ^{232}Th target. The experimental apparatus consisted of two major components: (1) two fission fragment detector arrays placed asymmetrically on opposite sides of the beam, and (2) several low-threshold, large dynamic range detector telescopes placed 25-cm from the target at angles between 20° and 160° for detection of coincident $Z = 1-10$ ejectiles. Here we will focus only on the backward hemisphere detectors, placed at 100°, −130° and ±160°. Each fission fragment array consisted of four, 28-strip passivated silicon detectors[1] of area 4×6 cm^2 placed 30 cm from the target. The strip detectors provided fragment energy, position, and timing information with an angular coverage of 46.7° for each array and $\Delta\theta = 0.41°$/strip. The centroid of one array was at 64.0° and that of the second was at −96.0°.

The intermediate mass fragment (IMF) detector telescopes consisted of a gas-ionization chamber operated at 32 Torr of CF$_4$, a 500-μm passivated silicon detector of area 5 cm × 5 cm and a CsI (Tl) scintillator of thickness 2 cm. These devices provide charge resolution for $Z = 1-15$ fragments, with low-energy thresholds of approximately 0.5 MeV/nucleon. In addition, the timing signal from the silicon detector and that from the cyclotron RF provided time-of-flight mass identification with a timing resolution of about 300 ps. Both Z and A identification were obtained for $Z \leq 4$ fragments; for $Z \geq 5$ only charge identification was possible, in part due to low statistics.

In Fig. 1 we show spectra for ^{10}Be fragments observed at +160°, −160°, +100°, and −130° in coincidence with binary fission events; i.e., triple coincidences. The solid angle acceptance of both ±160° IMF detectors is identical. The +160° detector is oriented approximately midway between the two detector arrays, i.e., normal to the fission fragment separation axis (with corrections for the kinematic folding angle). Correspondingly, the

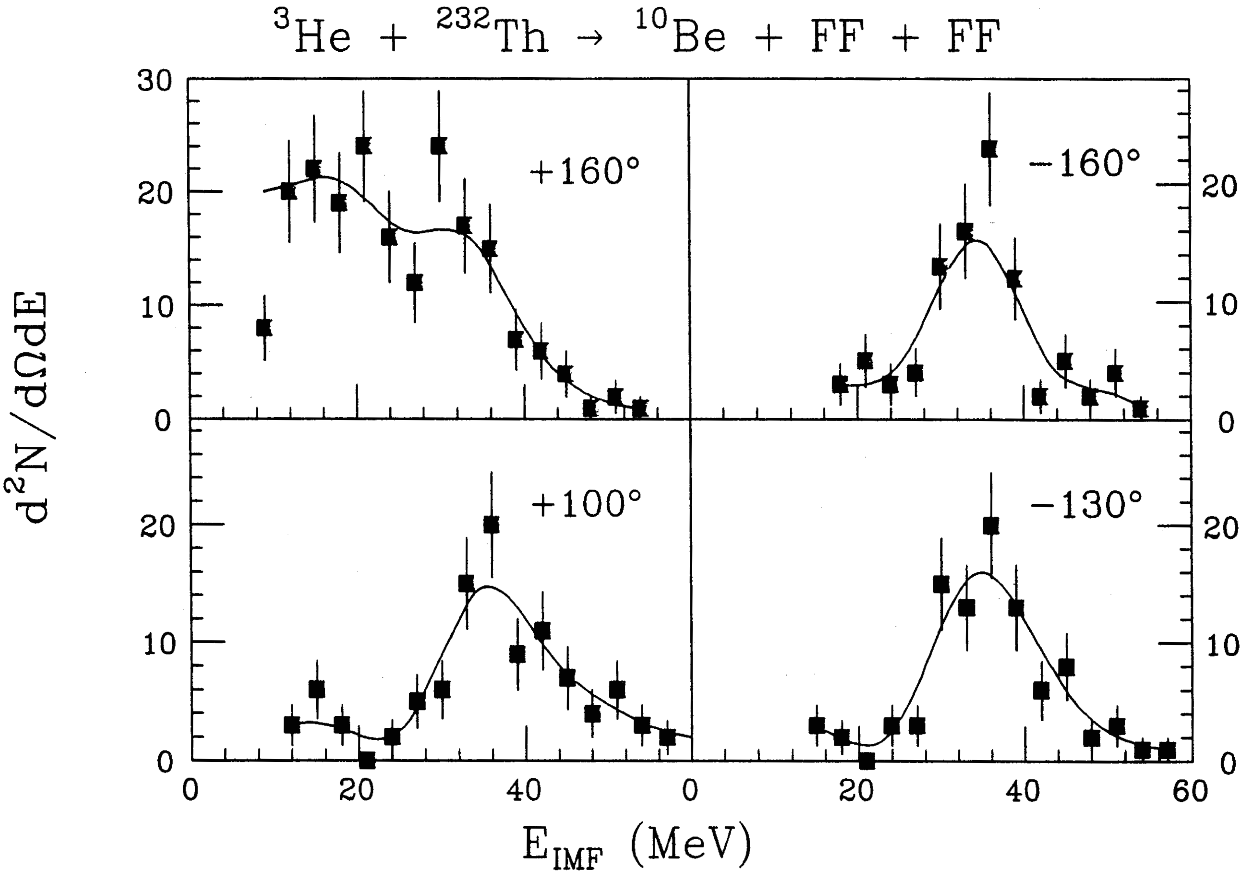

Figure 1. Spectra of ^{10}Be fragments at angles of ±160°, 100°, and −130°, in coincidence with angle-correlated fission fragments.

−160° detector is at an angle aligned 40° closer to the fission axis. It is observed that the +160° spectrum of ^{10}Be fragments contains a pronounced low-energy component. Similar events are essentially absent from the same spectrum in the −160° detector, as well as for detectors at −130° and +100°. These latter three spectra are all nearly identical in both counts and the location of peaks in the spectra, which occur near 35-40 MeV as expected for Coulomb repulsion of ^{10}Be fragments from a ^{232}Th-like source.

Because this effect is observed in only one detector, it would be desirable to make it appear in the −160° detector. Unfortunately, there is no combination of fission fragment detectors that allow us to examine the −160° detector in an orientation normal to the fission-fragment axis. However, there does exist a narrow angular range in the fission-fragment array (25 strips) that is symmetric about the beam axis. In this case both ±160° detectors are equally distant (20°) from the normal to the fission axis; hence the spectra should be identical. In Fig. 2 the symmetric configuration is compared for all Z = 3−6 fragments with the results of the full fission array test. Since, for ^{10}Be alone, the statistical significance is low, the spectra here are summed over the range of Z = 3−6. The difference spectrum shows a net of 5 counts, whereas for the full array a net of 518 counts is found

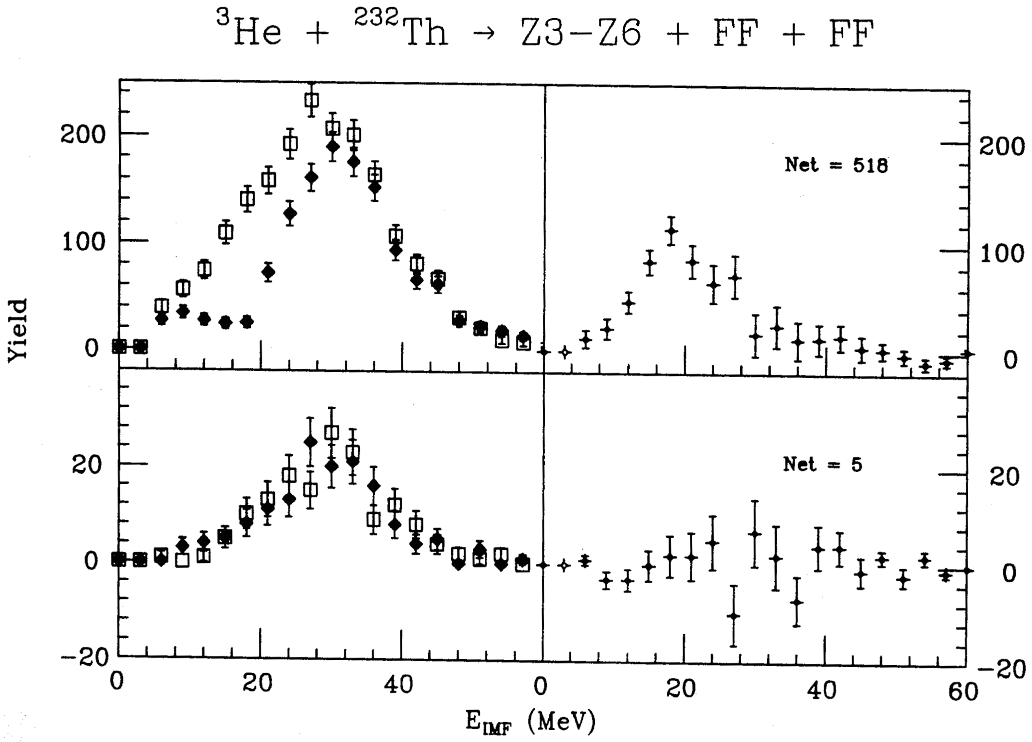

Figure 2. Top frame: Left-Sum spectrum of Z = 3–6 fragments in coincidence with angle-correlated fission fragments from full array; open squares are +160° data, closed triangles are −160° data. Right-Difference between +160° spectrum and −160° spectrum. Bottom frame: Left-Sum spectra as above for symmetric subset of fission array. Symbols and right frame are same as above.

in the difference spectrum. Thus, while the effect cannot be made to appear in the −160° detector due to detector geometry, it can be made to disappear in the +160° detector by selecting fission fragment angles well-removed from the normal.

In order to examine this angular focussing in more detail we have gated on the +160° detector and examined the angular correlation relative to the fission array. In Fig. 3 this correlation is shown, where the angle $\theta_{\mathrm{IMF-FF}}$ is the angle between the IMF detector and the angle in the left-hand fission array. The normal to the fission axis for the average fission event is approximately 98° for the fragments, as measured previously by Fatyga *et al.*[1] The high-energy component is found to be nearly isotropic across the fission array, whereas the low-energy component is sharply peaked near 97°, with a full-width-at-half-maximum of about 12°. The deflection of the IMF is seen to be greater for fission fragments with $A > A_{cn}/2$ than for those with $A < A_{cn}/2$. This angular correlation behavior resembles the strong focussing of light-charged particles normal to the separation axis in low-energy fission–a phenomenon commonly associated with emission from the neck region during the fission process.[2,3] In both cases the most probable kinetic energy for the focussed fragments is significantly lower than the isotropic component of the fragment spectra. Integrating

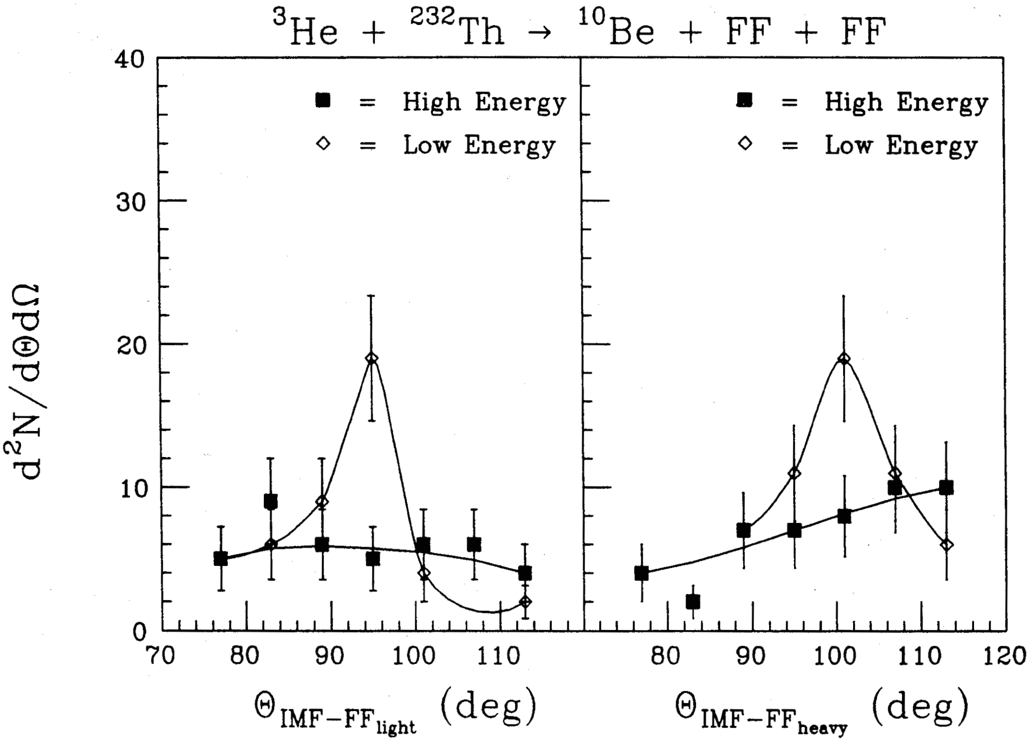

Figure 3. Fission-IMF correlation angles for high energy IMFs (solid squares) and low energy fragments (open triangles). Left frame is gated on light fission fragments ($A < A_{cn}/2$) and right frame is for heavy fragments ($A > A_{cn}/2$).

over all angles, the low-energy component appears to be about 20% of the ^{10}Be yield originating from equilibrium-like processes.

The linear momentum transfer measured for both high- and low-energy ^{10}Be events is about $p_{\|}/p_{beam} \approx 0.80$. Thus, all events reported here are consistent with large momentum transfers, corresponding to excitation energies in excess of 150 MeV.

Finally, we observe this same low-energy component in all IMF spectra at +160° (and none at −160°), although the statistics are poor for $Z \geq 8$. The charge distributions for the high and low energy components have been fit with a power law of the form $\sigma(z) \propto z^{-\tau}$. The charge distribution for the high energy component is in good agreement with previous studies,[4] i.e. $\tau \cong 4$ for IMFs emitted at back angles in these light-ion bombardments. In the low-energy component, a value of $\tau = 2.8$ is found, indicating a much flatter charge distribution for this process.

1. M. Fatyga *et al.*, Phys. Lett. B **185**, 321 (1987).
2. Z. Frankel, Phys. Rev. **156**, 1283 (1967).
3. C. Wagemans, The Nuclear Fission Process (CRC Press, Boca Raton, FL) p. 545*ff* (1991).
4. K. Kwiatkowski *et al.*, Phys. Lett. B **171**, 41 (1986).