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Publication Date

1961-06-16

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PROMPT FISSION YIELDS AND TOTAL KINETIC ENERGY BEHAVIOR FROM
TIME-OF-FLIGHT MEASUREMENTS

J. C. D. Milton and J. S. Fraser

June 16, 1961

PROMPT FISSION YIELDS AND TOTAL KINETIC ENERGY BEHAVIOR FROM
TIME-OF-FLIGHT MEASUREMENTS

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An improved version of the time-of-flight apparatus described previously^{1,2} has been used to study the thermal neutron fission of U^{233} , U^{235}

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1. J. C. D. Milton and J. S. Fraser, Phys. Rev. 111, 877, 1958.
 2. J. S. Fraser and J. C. D. Milton, Nucl. Instr. 2, 275, 1958.
-

and Pu^{239} using a neutron beam of intensity about 10^9 neutrons $\text{sec}^{-1} \text{cm}^{-2}$ from the NRU reactor. The sources, ranging from 20 to $40 \mu\text{g cm}^{-2}$, were electro-sprayed onto two cross-laminated VYNS films of total surface density $7 \mu\text{g cm}^{-2}$ which had been previously coated with $18 \mu\text{g cm}^{-2}$ of gold to make them electrically conducting. The energy loss caused by source and backing thickness was measured for the actual sources used in the experiment and found to be 1.1 ± 0.3 Mev in good agreement with the value calculated from the known thicknesses.

The fragments were detected at the end of their nearly equal 178 cm flight paths by 4 inch diameter secondary electron detectors which

† On leave of absence from Atomic Energy of Canada, Ltd.

gave the apparatus a resolving time (FWHM) of 2.5 manosec. The mass resolution including the contribution of timing jitter, recoil from neutrons and source thickness was calculated to be 2 mass units.

In all, well over 10^6 events were processed on $U^{235} + n$ (including some with the unequal flight paths of 270 - 180 cm) but the most carefully controlled series consisted of 1.48×10^5 , 1.55×10^5 and 1.03×10^5 events for U^{233} , U^{235} and Pu^{239} respectively and it is on this set that the data presented here are based. The experimental results on Cf^{252} are not new but are those of Reference 1.

An experiment of this type conveys an enormous amount of information. The purpose of this letter is to note 3 points:

- 1) there is a dramatic drop in the total kinetic energy near symmetry,
- 2) there is a clearly marked fine structure in the mass yield which is most prominent at high total kinetic energies, and
- 3) a possible explanation for the phenomenon 1).

The behavior of the kinetic energy is illustrated in Fig. 1. Except in the case of Cf^{252} , there is a drop in kinetic energy of 30-40 Mev in approaching symmetric mass division. At first it seemed impossible to account for this dip in terms of the balance of energy between the mass energy release E_R , and the excitation energy made up of components E_B (neutron binding), E_{nk} (neutron kinetic) and E_γ (gamma rays), but this turned out to be incorrect. The solid points in Fig. 1 are calculated from the formula $E_K = \max \langle E_R \rangle - \nu (\langle E_B \rangle + E_{nk}) - E_\gamma$. The quantities E_{nk} and E_γ were assumed to be independent of mass and given the approximate values $E_{nk} \approx 1.2$ Mev, $E_\gamma \approx 7.5$ Mev. The averages were taken over a Gaussian charge distribution with an rms deviation of 0.7 charge units.

Using the mass formula of Cameron, $\langle E_B \rangle$ was found at the point where $\langle E_R \rangle$ had³

³ A. G. W. Cameron, Can J. Phys. 35, 1021, 1957.

its maximum value. These quantities have been calculated for 25 fissioning species between Ra²²⁶ and Fm²⁵⁴ using an IBM 709 computer. However, the principal difference between the E_K calculated here and those done previously lies in the selection of ν . It was assumed that ν depends only on the mass of the fragment and not on the fissioning nuclide. This may seem to be a good assumption by looking at the values of ν calculated by Terrell.⁴

⁴ James Terrell, Bull. Am. Phys. Soc. 6, 16, 1961; and private communication.

Accordingly a smooth curve was drawn through Terrell's family of curves. The values of $\bar{\nu}$ given by this smooth curve are 2.50, 2.63, 2.86 and 3.81 for U²³³, U²³⁵, Pu²³⁹ and Cf²⁵², respectively. This procedure makes ν available for all masses between 82 and 159 with the exception of the region 120 to 130. In this region the two ends of Terrell's curve were joined by a straight line. At first sight this may seem to be a very shaky business but in fact, almost any interpolation between Terrell's two curves will do since in U²³⁵ (for example) it affects the shape of the kinetic energy between mass 130 and 118 but not the value at these two masses. There would still be a drop of nearly 40 Mev even if ν were taken as identically zero for the region 121-130.

The total excitation energies at symmetry predicted by this picture are large, about 48 Mev for U²³⁵ and about 6 neutrons would be expected. The existence of two types of fission - symmetric fission with highly excited fragments of low kinetic energy and asymmetric fission with moderately excited fragments of high kinetic energy - might be associated with the existence of

two barriers and two saddle-point configurations in the liquid drop-drop calculations of Cohen and Swiatecki. The height of the second barrier ⁵

⁵S. Cohen and W. J. Swiatecki, The Deformation of a Liquid Drop, IV, Aarhus University Report. Jan. 1961.

relative to the first falls rapidly as x increases above a critical value in the vicinity of 0.7 and its relatively low energy and apparent stability against asymmetry⁵ suggest identifying this barrier with symmetric fission.

All three of the fissioning species showed fine structure in the mass yield between masses 134 and 146. This fine structure shows up in the total yields⁶ but it is perhaps more instructive to look at the contour diagram, Fig. 2. Here it is clearly seen that the structure appears predominantly at high kinetic energies.⁷ It seems to be more a result of

⁶J. C. D. Milton, Proceedings of the Kingston Conference on Nuclear structure, Kingston, Canada, University of Toronto Press, 1960, p. 866.

⁷This is also shown in the work of Gibson, Thomas and Miller. See accompanying letter.

inhibition than of preference and must be closely related to the fact that the events in this region are "running out of energy" so that the nuclei formed are nearly in their ground states. The contours along the north east face of the mountain are nearly parallel to the line of maximum energy release. The structure is less pronounced in Pu²³⁹ and scarcely discernible in Cf²⁵². In these cases the mountain is further away from the limiting energy.

A full account of this work will shortly be submitted to the Canadian Journal of Physics. I am indebted to Dr. W. J. Swiatecki for pointing out the connection with the liquid drop calculations.

MUB-684

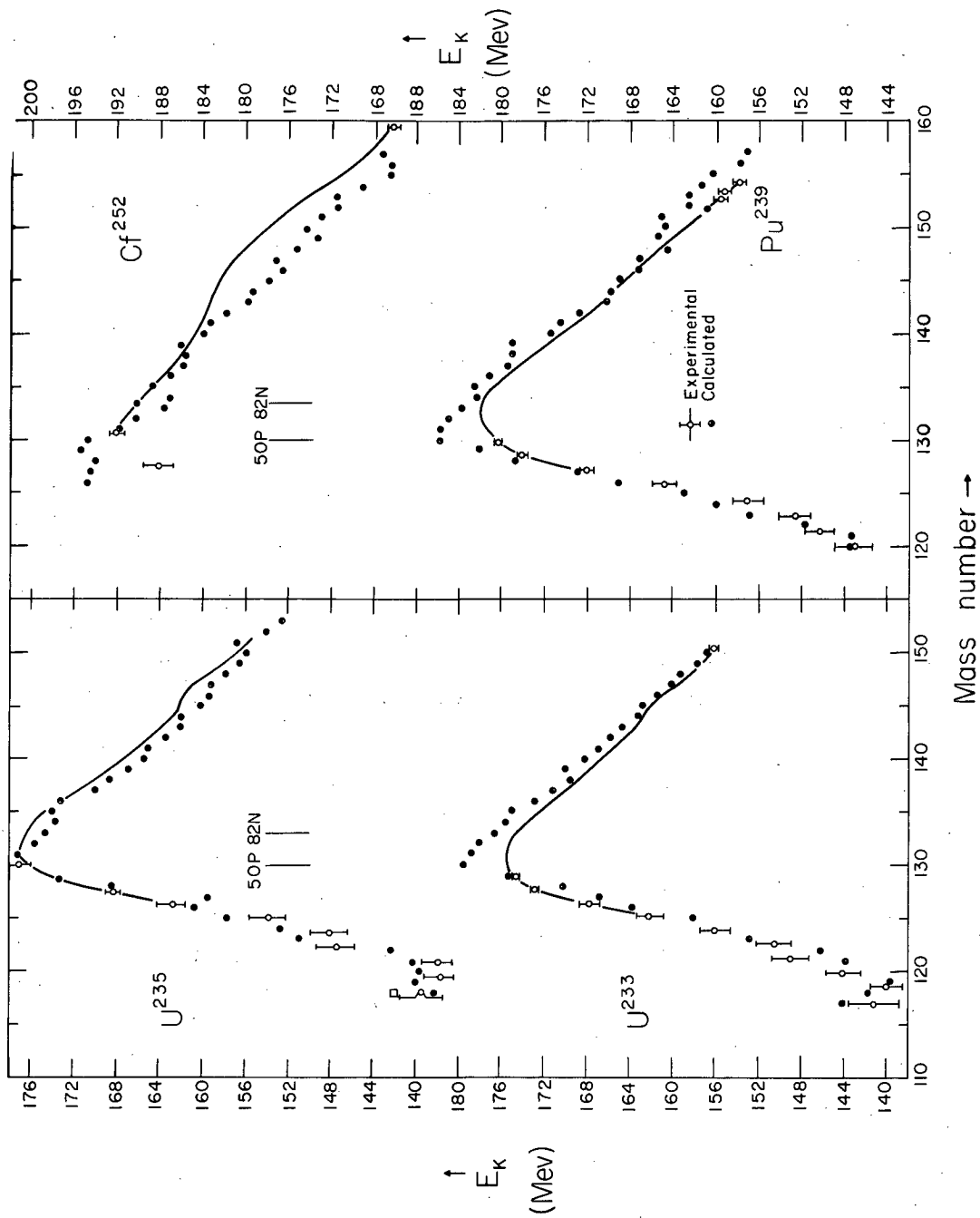
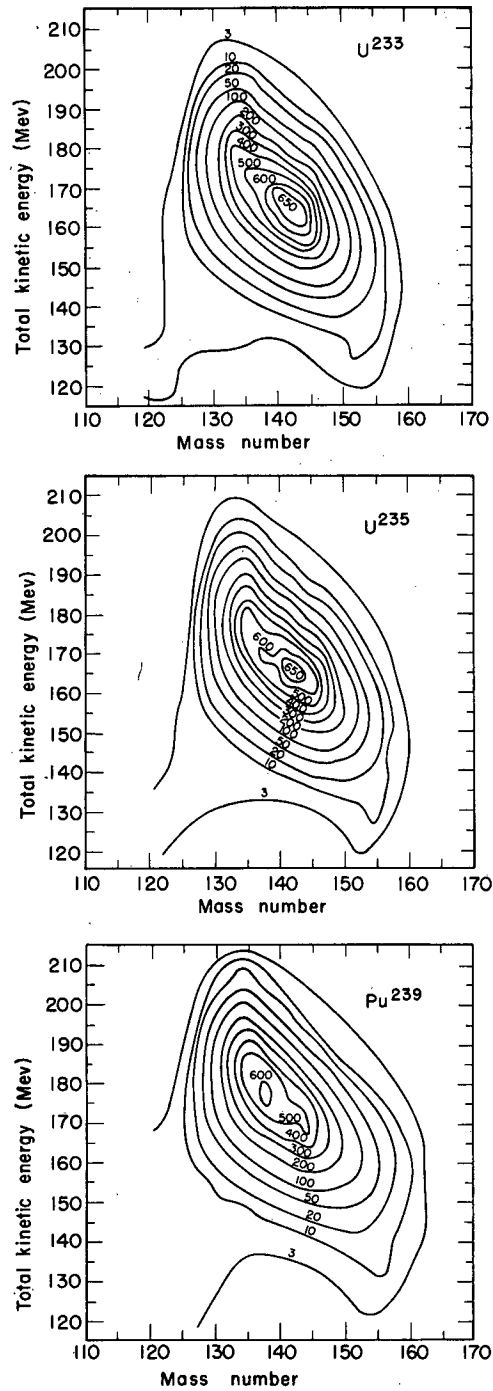


Fig. 1. The average total kinetic energy as a function of the mass of the heavy fragment. In the mass region 130-150 the experimental curve is determined by over 20 points, each with a statistical error of less than 0.25 Mev.



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Fig. 2. Mass-energy contours for U²³³, U²³⁵, and Pu²³⁹. The numbers attached to the contours are events / 10⁵ fissions/mass unit / 2.5 Mev. Some idea of the statistical accuracy may be gained from the fact that the number of events in each cell of the matrix from which the contour diagram was made is approximately 2 1/2 times the contour label.

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