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SEARCH FOR γ TRANSITIONS EMITTED IN THE FORMATION OF A FISSION ISOMER†

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A search for γ-rays preceding isomeric fission in the reaction $^{238}U(\alpha,2n)^{240m}Pu$ yielded negative results. Upper limits are given for the number of unconverted photons per isomer formed.

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The phenomenon of isomeric states decaying by fission was first discovered by Polikanov [1]. It was first suggested by Strutinsky [2], and is now generally accepted [3,4] that nuclei exhibiting fission isomerism undergo fission after being trapped briefly in a secondary minimum in the potential-energy surface. A probable [4] mechanism by which fissioning isomeric states could be populated involves γ decay in the second potential well after evaporation of neutrons from the compound nucleus.

In our search for γ-rays preceding delayed fission we chose to study the reaction $^{238}U(\alpha,2n)^{240m}Pu$. This reaction has a relatively high ratio of isomeric to prompt fission [4] (4.4×10^{-5} at $E_\alpha = 25$ MeV). With a half-life [4] of 3.8 ± 0.3 nsec the isomer decay can be observed between bursts of the 25-MeV α beam at the 88-inch cyclotron.

A target consisting of 0.6 mg/cm^2 UO_2 on a 0.2 mg/cm^2 carbon foil was mounted at 45° to the beam. Fission fragments were detected by a 450-mm^2 ·

surface barrier Si detector on one side of the target, at about 100° to the beam. The target was viewed on the opposite side through a thin Al window by a 5-cm^3 Ge(Li) γ-ray detector. Both detectors were placed close to the target to maximize geometric efficiencies.

The arrival time of the beam burst was derived from the zero-cross-over point on the cyclotron rf voltage. A bi-level time pickoff system was used with the Si detector. The lower threshold provided fast timing of the fission events, while the upper threshold rejected the more abundant pulses from scattered α particles. Gamma-ray timing was obtained from a leading-edge discriminator on the preamplifier output. The time delays between the beam burst and a fission event, T_{Bf}, and between a γ-ray and a fission event, $T_{\gamma f}$, were measured, as well as E_γ. Baseline stabilization of the T_{Bf} signal corrected for any rf phase drift [5] during long runs. The $T_{\gamma f}$ signal was compensated [6] for energy dependence of the γ timing.

Most of the width of the T_{Bf} curve (fig. 1) is due to the time structure of the beam burst. This width does not permit complete separation of delayed from prompt fission. However, it was possible to set a window on the T_{Bf} signal, as shown in fig. 1, such that about 17% of the events in the window should be due to the isomer. This amounts to an enhancement of 4×10^3 relative to the overall isomer/prompt ratio.

The two parameters E_γ and $T_{\gamma f}$ were stored serially on magnetic tape for every fission-γ coincidence event that also fell within the T_{Bf} window. One out of every 100 events falling outside the window was also stored; marker flags distinguished these events from those gated by the T_{Bf} window. A total of 5×10^8 fission events were counted during the 36-hour measurement. The results are shown in fig. 2. The plotted points correspond to events for which T_{Bf} fell within the delayed fission window, while the solid curve, normalized to the points near the peak, was obtained with no restrictions on T_{Bf}. The excess of γ-delayed fission coincidences, evident from the right-hand portion of fig. 2, totals 57 ± 8 counts. These counts cannot be related to the time structure of the beam bursts (because the timing of a true fission-γ coincidence is independent of the beam time structure), but may be ascribed to one or more of the following effects:

(1) Gamma rays emitted in the formation of the 3.8-nsec isomer.

(2) Chance coincidences between (apparently) delayed fission fragments and prompt γ rays emitted during the same beam burst by another nucleus.

(3) Tailing in the time-response curve of the fission detector.

At the observed counting rates we would expect 47^{+21}_{-18} chance coincidences between prompt γ-rays and those fission events occurring within the T_{Bf} window. The validity of this estimate for effect (2) was checked in a separate experiment, in which fission fragments were counted in chance coincidence with prompt γ-rays from the preceding beam burst. Thus chance coincidences alone can account for the observed excess of fissions delayed with respect to the γ-rays; an upper limit of 36 counts can be ascribed to the effect (1) we have sought to observe. Since chance coincidences alone can account for the data, the spurious effect (3) due to tailing in the fission detector time-response curve is apparently small. We have attempted to check this conclusion by repeating the experiment with the ^{232}Th + 25-MeV α reaction, which produces no known fission isomer. However, an increased chance coincidence rate, due to a poorer time structure of the beam, makes these results inconclusive.

In summary, our results give no definite evidence for γ-rays feeding isomeric fission. If the isomeric state is 2.6 MeV above the ^{240}Pu ground state [4], the maximum energy available for γ decay would be 5.4 MeV. From the gross γ detection efficiency (photopeak plus Compton), we conclude that an average of < 2 γ-ray photons precede isomeric fission of ^{240}Pu.

The energy spectrum of prompt γ-rays coincident with (apparently) delayed fission reveals no discrete lines. Table 1 gives limits on possible discrete photon transitions as a function of energy. The low intensity in the Pu K x-ray region (100 keV) indicates that the isomeric state is not populated by transitions that are strongly K-converted. The present results do not contradict the recent report [7] of the observation of rotational transitions in the second well, since these transitions are strongly L-converted, but are of too low an energy to convert in the K shell.

We are grateful to B. G. Harvey and the staff of the 88-inch cyclotron for help in performing extended experiments requiring difficult beam tuning, to A. Shihab-Eldin, J. B. Wilhelmy and R. C. Jared for help in making the measurements, and to S. G. Thompson and J. Cerny for helpful suggestions and discussions of the results.

FOOTNOTES AND REFERENCES

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Table 1. Limits on the intensities of possible discrete photon transitions preceding delayed fission.

E_γ (keV)	Maximum γ's per fission isomer
50 - 120	0.2
175	0.3
250	0.5
300	0.7
400	1.0

FIGURE CAPTIONS

Fig. 1. Time distribution of fission relative to beam bursts. The dashed line indicates isomer activity calculated for a 3.8-nsec half-life with overall isomer/prompt-fission ratio of 4.4×10^{-5}.

Fig. 2. Time distribution of fission relative to γ-rays for all γ energies above 25 keV. The plotted points correspond to events for which T_{Bf} falls within the delayed fission window (fig. 1). The solid curve, obtained with no restrictions on T_{Bf}, is normalized to the points in the vicinity of the peak.

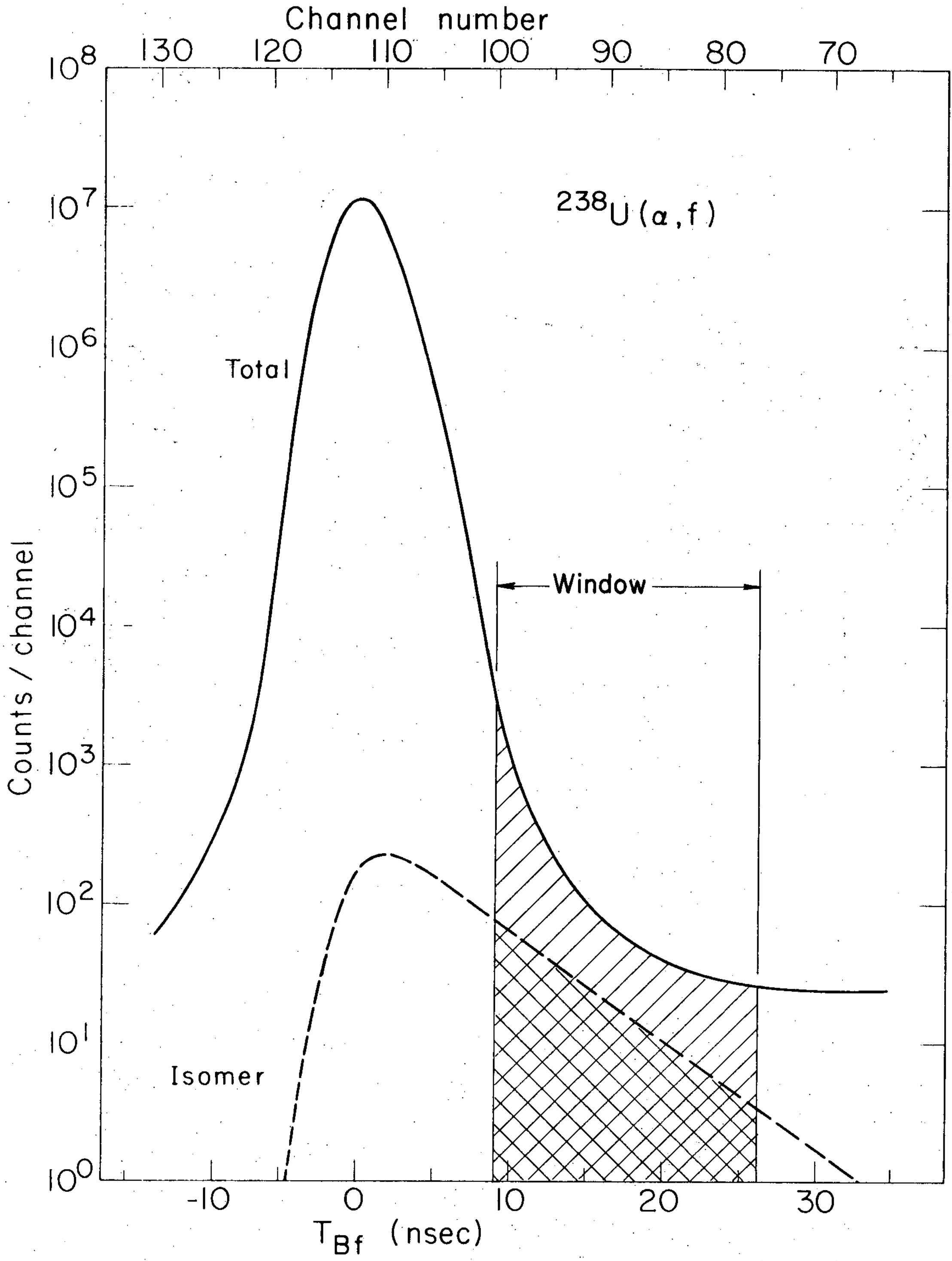

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Fig. 1

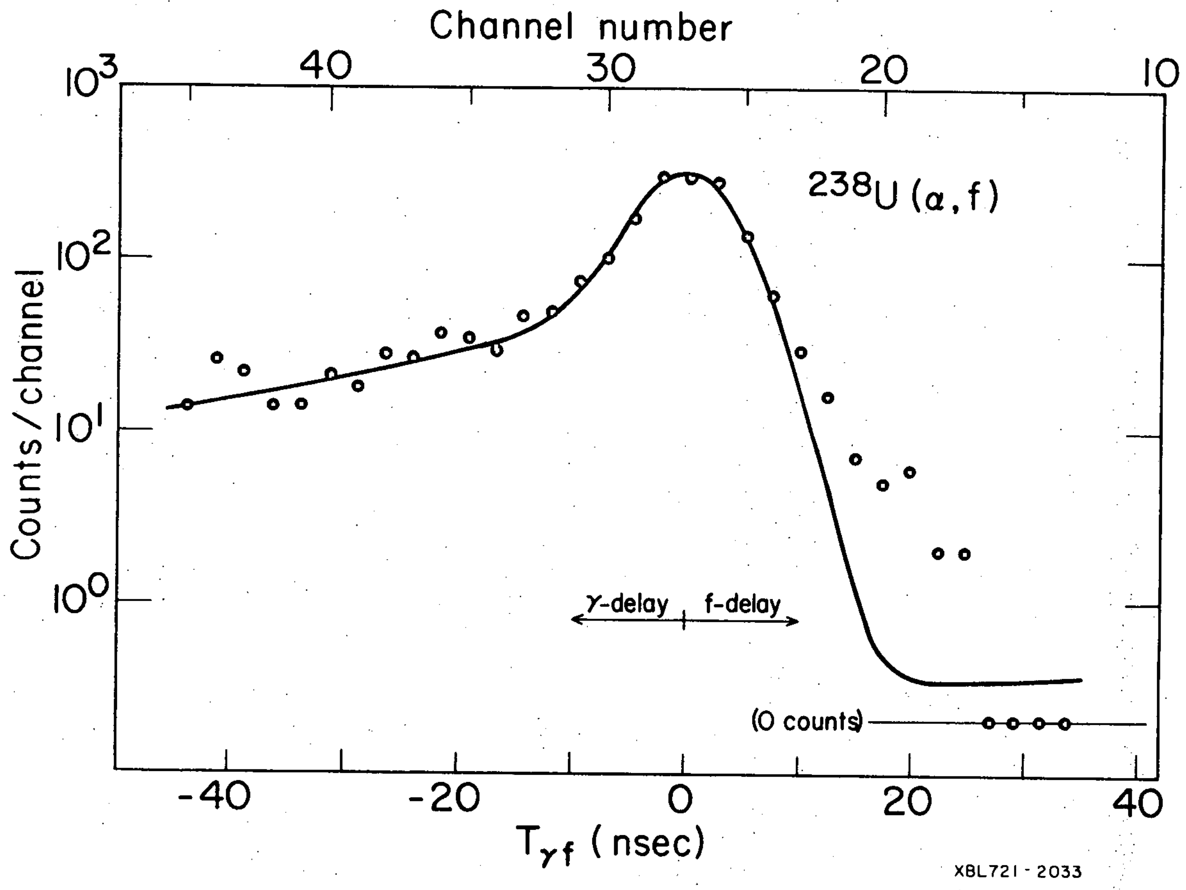
Channel number
40
30
20
10
10^3
10^2
10^1
10^0
Counts/channel
$^{238}U(\alpha, f)$
γ-delay
f-delay
(0 counts)
-40
-20
0
20
40
$T_{\gamma f}$ (nsec)
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Fig. 2

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