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Comparison of ^{252}Cf spontaneous fission with ^{250}Cf(t, pf)

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A comparison is presented of the total kinetic energy and yield distributions for ^{252}Cf spontaneous fission and ^{252}Cf excited to 5–9 MeV via a ^{250}Cf(t, pf) reaction. Systematic differences are observed between trends in these data and similar results for lighter actinides.

[NUCLEAR REACTIONS, FISSION Measured total kinetic energy and yield distributions as a function of excitation energy for ^{252}Cf.]

INTRODUCTION

The detailed characteristics of the mass and kinetic energy distributions for fragments from the fission of nuclei in the actinide region are still rather poorly understood. One of the most intensively studied fission systems is ^{252}Cf, but previous data has been limited to the investigation of the properties of fragments from the spontaneous fission of this nucleus. In this communication we report data on fragment properties for ^{252}Cf excited to energies near the top of the fission barrier via the ^{250}Cf(t,pf) reaction.

Several experiments have been carried out for lighter nuclei in the actinide region to look for the dependence of scission properties in the 0–20 MeV range of excitation energies.[1-10] In particular, the characteristics of fission for ^{240}Pu have been investigated from the ground state,[3,4] the shape isomeric state,[5] and in the excitation energy region near the top of the fission barrier.[1,9,10] For several lighter systems data are available in the excitation energy region near the top of the fission barrier.[2]

EXPERIMENTAL SETUP

The experiment has been carried out at the Los Alamos Van de Graaff Facility using a triton beam at energy $E_t = 16$ MeV. Figure 1 shows the experimental arrangement. The two californium sources were attached to a movable target ladder and could be brought alternatively into counting position without breaking the chamber vacuum. Therefore, frequent calibration runs were possible and systematic errors due to radiation damage or gain fluctuations of the surface barrier detectors were kept to a minimum. The spontaneous fission source consisted of a $10^4\,f$/min ^{252}Cf source deposition on a 100 μg/cm^2 Ni backing. The ^{250}Cf target had a thickness of ~ 50 μg/cm^2 on a 60 μg C backing. A precise correction for the effective energy loss of the fragments in the backing material was achieved by turning the targets 180° around an axis perpendicular to the detector plane.

The arrow symbolizes the incoming t beam with energy $E = 16$ MeV. Outgoing protons from the ^{250}Cf(t,p)^{252}Cf reaction were identified in a semiconductor detector telescope positioned at 100° relative to the beam axis. The telescope consisted of ΔE and E semiconductor detectors. Coincident fission fragments were counted in two pairs of heavy ion semiconductor detectors placed at approximately 0° and 90° with respect to the

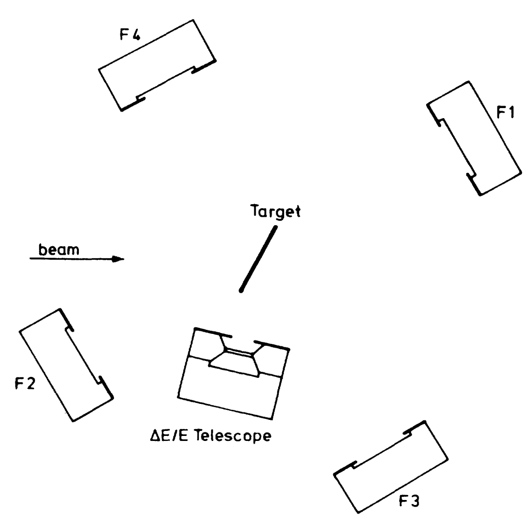

FIG. 1. Schematic diagram of the experimental setup.

recoil axis of the ^{252}Cf nucleus. Five parameters were measured for each event and recorded on magnetic tape: the pulse heights of the two complementary fragments, ΔE and E from the telescope, and time correlation between one fission detector and the ΔE detector. The fission detectors were calibrated according to the Schmitt[11] calibration procedure using the pulse height spectrum of fission fragments emitted by the ^{252}Cf source. The source was brought into target position every few hours between the ^{250}Cf(t,pf) runs. The calibration constants varied slowly with the number of fission fragments stopped in the detectors. The actual values for calibration constants for the ^{250}Cf(t,pf) runs were obtained by interpolation between calibrations. This method assured a close relationship between spontaneous and induced fission data. The telescope was calibrated by observing the known excitation energy states from the ^{208}Pb$(t,p)^{210}$Pb reaction. From the measured pulse heights of two complementary fission fragments, together with the Schmitt calibration constants and the kinematic parameters, the masses and total kinetic energies of the fragments were calculated in an iterative procedure. Corrections were made for the pulse height defects of the detectors and evaporation of neutrons from the fragments. The most probable number of emitted neutrons for a given mass for ^{252}Cf spontaneous fission was taken from the systematics of Terrell.[12] To take care of the increased average number of neutrons emitted for the excited ^{252}Cf fission, it was assumed that the excitation energy was divided between the two fragments in proportion to their mass. The results of an iteration procedure were the preneutron-emission mass and kinetic energy values for each fragment.

RESULTS AND DISCUSSION

Figure 2 shows the total kinetic energy (TKE) of the fragments as a function of excitation energy

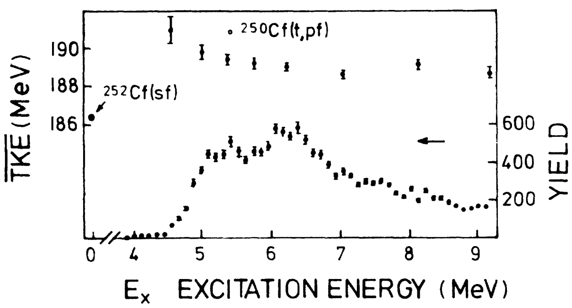

FIG. 2. Average total kinetic energy release and yield from the (t,pf) reaction as a function of excitation energy. Results are averaged over the mass yield distributions.

TABLE I. Characteristics of TKE and mass distributions.

	^{252}Cf(sf)		^{250}Cf(t,pf) ($4.9 < E_x < 9.8$ MeV)	
Mass range	% yield	$\overline{TKE}$ (MeV)	% yield	$\overline{TKE}$ (MeV)
126127	0.6	189.5	1.8	196.4
128129	0.9	190.7	2.8	196.3
130131	2.5	193.4	5.1	197.1
132133	3.9	193.8	6.2	196.8
134135	5.8	193.5	7.4	195.7
136137	7.3	191.4	8.6	194.0
138139	9.0	190.1	9.2	192.8
140141	10.5	189.0	9.2	191.2
142143	11.4	187.7	8.9	189.8
144145	11.5	187.0	8.7	187.9
146147	10.1	185.8	7.4	186.1
148149	8.3	183.5	6.6	184.7
150151	6.0	181.3	5.0	182.8
152153	4.0	178.9	3.8	181.4
154155	2.7	175.8	3.1	179.0
156157	2.0	173.4	1.9	177.0
158159	1.3	171.5	1.5	176.6
160161	0.9	168.1	1.1	173.1

of the fissioning nucleus. (For comparison the fission yield as a function of excitation energy is displayed.) The average total kinetic energy for ^{252}Cf spontaneous fission is fixed at 186.4 MeV by the calibration procedure used. For induced fission the value is 191.0 ± 0.7 MeV near the threshold and it drops with increasing excitation to 188.8 ± 0.7 MeV. The total kinetic energy for spontaneous fission is clearly 4.6 ± 0.7 MeV lower than for induced fission at the threshold. A similar behavior has been found in the case of ^{240}Pu.[5] Most of the increase in $\overline{TKE}$ of ^{250}Cf(t,pf) compared to ^{252}Cf(sf) comes from the region $m = 130$–135, where both the yield and $\overline{TKE}$ increases as shown in Table I [see also Figs. 3(a) and 3(b)]. Average properties for ^{250}Cf(t,pf) and ^{252}Cf(sf) (Ref. 13) are compared in Table II.

Figure 3(a) displays the mass distributions for ^{252}Cf(sf) (solid points) and for induced fission summed over all excitation energies (open circles). The tail at masses 150 to 160 is the same in both cases, whereas for lighter masses for ^{250}Cf(t,pf) a shift to more symmetric values is apparent.

Figure 3(b) compares the average TKE versus mass for the excitation energy range 5–9 MeV to results for spontaneous fission. The largest differences are in the mass region $M = 125$–135. For $M > 135$ the increase in total kinetic energy is roughly the same for all masses except for a limited region near $M \sim 146$. In a detailed analysis of the data as a function of excitation energy it was found that there were no statistically significant differences in the TKE versus mass beyond

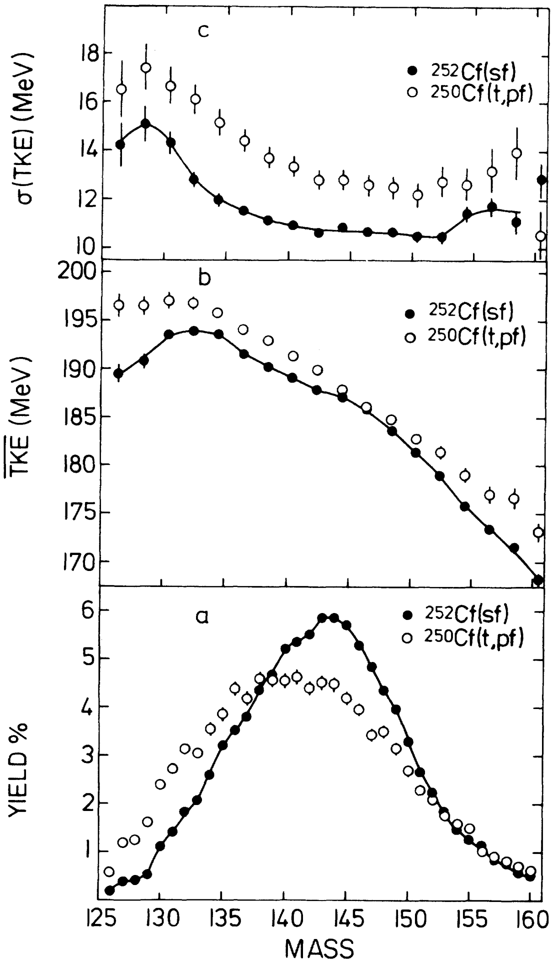

FIG. 3. Yield, average total kinetic energy, and variance of the average total kinetic energy as a function of mass for ^{252}Cf spontaneous fission and for the results of the ^{250}Cf(t,pf) reaction summed over the excitation energy range 5–9 MeV.

the trend of the average values shown in Fig. 2. Figure 3(c) shows that the TKE distributions are consistently broader for excited fission.

The most remarkable effect of excitation energy on the fission of ^{252}Cf is the increase in yield of a component with $M \sim 132$ and an increased TKE. This behavior is in marked contrast to results for lighter actinides where increasing the excitation energy enhances a symmetric mass division which occurs with a relatively lower TKE. This result would be consistent with the enhancement in induced fission of a compact scission shape involving a spherical $M = 132$ shell. However, an increase in yield for such a configuration with excitation energy is contrary to the usual qualitative expectations concerning the relative importance of shell configurations as excitation energy increases.[14] The results could also be explained by a mass dependent change with excitation energy in the kinetic energy of the fragments at scission. In view of the current preference of a one body dissipation model[15] in the theory of fission dynamics this hypothesis would seem even less compelling than the shell hypothesis. In any case the results seem surprising and qualitatively different from results for lighter actinides. A detailed understanding will await a quantitative theoretical treatment of fission dynamics.

TABLE II. Comparison of average properties.

		^{250}Cf(t,pf) (4.4 < E_x < 9.8 MeV)	^{252}Cf(sf) This work	Ref. 13
$\overline{\text{TKE}}$	(MeV)	189.1	186.4	186.5
σ(TKE)	(MeV)	14.9	12.8	12
$\langle m_L \rangle$	(u)	110.2	108.8	108.55
$\sigma(m_L)$	(u)	7.6	6.7	6.72
$\langle m_H \rangle$	(u)	141.8	143.2	143.45
$\sigma(m_H)$	(u)	7.9	6.8	6.72

Another remarkable feature of the results is in the region $M \sim 146$. Here it is seen that the TKE is about equal for induced and spontaneous fission as compared with a difference of ~ 2 MeV for masses above and below this region. Similar results have also been observed[16] for ^{246}Cm and ^{250}Cf. This difference could be consistent with the hypothesis that in this mass region for spontaneous fission the scission configuration contains a compact shape involving a deformed shell in the region $Z = 42$, $N = 60, 62$ in the nascent light fragment as has been suggested by Nifenecker *et al.*[17] and that with increasing excitation energy this fragment becomes more prolate. This interpretation is consistent with the apparent trend in Fig. 3(b) where for induced fission the TKE decreases monotonically while for spontaneous fission there appears to be a "bulge" near $M_H = 146$, $M_L = 106$. Again these speculations can only be confirmed by a quantitative dynamical fission theory.

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