Comitato Nazionale per L'Energia Nucleare
ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione Siciliana
Gruppo di Messina

INFN/BE-69/7
20 Ottobre 1969

L. Fiore, A. Manfredini and C. Ramorino : PHOTOFISSION OF ^{232}Th NEAR THRESHOLD: ANGULAR DISTRIBUTION. -

449

Reparto Tipografico
dei Laboratori Nazionali di Frascati

Istituto Nazionale di Fisica Nucleare
Sezione Siciliana - Gruppo di Messina

INFN/BE-69/7
20 Ottobre 1969

L. Fiore(x), A. Manfredini and C. Ramorino(o): PHOTOFISSION OF ^{232}Th NEAR THRESHOLD: ANGULAR DISTRIBUTION(x). -

ABSTRACT. -

Final measurements on angular distribution of photofission fragments of ^{232}Th at γ-ray energies near threshold, are reported. The data are analysed on the simplifing ipothesis that only $2^+ K=0$, $1^- K=0$ and $1^- K=1$ channels contribute. The values of the barrier height and curvature are estimated and compared with the few data available from other authors.

1. - INTRODUCTION. -

The angular distribution of photofission fragments from ^{232}Th has been measured using monochromatic γ-rays in the energy range $5.4 \leq E_\gamma \leq 9.0$ MeV.

The nuclear emulsion technique has been employed. Pellicles of nuclear emulsions loaded either with thorium or uranium complex, separated one from the other with thin mylar sheets to avoid diffusion of fissile nuclei from one pellicle to the other, have been exposed at the end of the transversal beam hole of the nuclear reactor "Saphir" of EIR

(x) - Istituto di Fisica dell'Università, Messina.
(o) - Centro Studi Nucleari della Casaccia, CNEN, Roma.
(x) - This work was carried out under the auspices of the Euratom CNEN--INFN n. 002-63-11 MPAI contract.

(Würenlingen, Switzerland).

Results on measurements of ^{238}U photofission cross section and angular distribution of fragments, as well as photofission cross section for ^{232}Th have been already published(1, 2, 3, 4) and we refer to our previous paper for all details about the technique employed, the target elements chosen for the γ-ray irradiations, the geometrical conditions, the measurement and the corrections.

2. - EXPERIMENTAL RESULTS. -

For the analysis of our experimental data we followed the same procedure discussed in details in our paper on the angular distribution of photofission fragments from ^{238}U(3).

We give here only a short account of the more significant results.

The measured angular distributions have been fitted either on the

$$W(\alpha) = a + b \sin^2\alpha + c \sin^2\alpha \cos^2\alpha$$

or on the

$$W'(\alpha) = a' + b' \sin^2\alpha$$

functions. A χ^2 test for each γ-ray energy has then been made and the χ^2 values for either the $W(\alpha)$ or the $W'(\alpha)$ functions have been plotted. The obtained distributions are very similar to what is shown in Fig. 3 of ref. (3) for the uranium analysis, forcing us to conclude that the c constant has to be generally considered different from zero, although the statistical error makes it compatible with zero for many energies.

The angular distribution in the space angle $W(\theta)$, after correction for neutron background, is due to the contribution of all the lines of the γ-ray spectrum of the element used as a target and the correction was performed in the same manner as discussed in ref. (3). The correction is generally negligible and the same conclusion can be given as in ref. (3) with the exception of the S target.

From the cross section measurements(4), the yield of fission tracks from the 5.43 MeV line is now not negligible as it was for the uranium photofission and is of the same order of magnitude of the yield of fission tracks from the two lines at 7.78 and 8.64 MeV. The irradiation with the S target was therefore used to have some information at 5.43 MeV, although the final statistical error is very large, due to the large percentual error on the cross section at 5.43 MeV and due to the severe correction. .

In Table I the values of the a, b, c constants of the $W(\theta)$ distributions, normalized by means of $\int_0^{\pi/2} W(\theta)\sin\theta\, d\theta = 1$, are reported both before and after the correction for the low intensity γ-ray lines. The values of the constants before the γ-ray correction are attributed to a mean energy $\bar{E}_\gamma$ (column 2), obtained weighting the energies of the lines in the spectrum with their relative intensities and the fission cross sections.

The energy E_γ of the main line is reported in column 7.

The errors quoted in Table I take into account the statistical error due to the number of measured tracks and to all the introduced corrections.

3.- ANALYSIS OF THE RESULTS. -

Our results are analysed starting from the oversimplifing ipothesis that only the $1^- K=0$ and $1^- K=1$ states from dipole absorption and $2^+ K=0$ states from quadrupole absorption of γ-rays contribute to the measured angular distribution (K is the projection of the total angular momentum on the simmetry axis of nucleus). That is we neglect quasi-state of octupole deformation absorption although there is already many indications of their presence in the threshold region of photofission of double-even nuclei (see for instance ref. (5)).

In the photofission of double-even nuclei the angular distribution of fission tracks has the behaviour of the functions:

$$W(\theta) = \sin^2\theta \qquad \text{for } 1^- K=0 \text{ channel}$$

$$W(\theta) = 2 - \sin^2\theta \qquad \text{for } 1^- K=1 \text{ channel}$$

$$W(\theta) = \sin^2\theta\cos^2\theta \qquad \text{for } 2^+ K=0 \text{ channel}$$

Therefore, if we indicate with σ_0^-, σ_1^- and σ_0^+ the contribution of the considered channels to the total fission cross section $\sigma_T = \sigma_0^- + \sigma_1^- + \sigma_0^+$, the measured constants can be directly related to the yield from each channel by the following:

$$a = \frac{3}{2}\,\frac{\sigma_1^-}{\sigma_T} \qquad\qquad \frac{b+(1/2)a}{a+(2/3)b} = \frac{3}{2}\,\frac{\sigma_0^-}{\sigma_0^- + \sigma_1^-}$$

TABLE I - Values of the a, b and c parameters of the angular distribution.

Target	$\bar{E}$ MeV	a	b	c	Target	E MeV	a	b	c
Dy	5.61	0.099 ±0.067	1.121 ±0.053	1.152 ±0.435	S	5.43	0.478 ±0.631	0.087 ±0.541	3.471 ±2.595
Y	6.14	0.103 ±0.031	1.224 ±0.022	0.607 ±0.231	Dy	5.58	0.099 ±0.073	1.114 ±0.058	1.186 ±0.470
Ca	6.42	0.086 ±0.025	1.164 ±0.018	1.034 ±0.184	Y	6.07	0.098 ±0.037	1.209 ±0.027	0.724 ±0.276
Ti	6.66	0.116 ±0.018	1.287 ±0.014	0.200 ±0.153	Ca	6.42	0.073 ±0.027	1.184 ±0.020	1.033 ±0.199
Be	6.80	0.286 ±0.069	0.952 ±0.103	0.587 ±0.490	Ti	6.75	0.128 ±0.032	1.361 ±0.025	-0.265 ±0.263
Pb	7.28	0.264 ±0.074	0.918 ±0.062	0.931 ±0.611	Be	6.82	0.286 ±0.069	0.952 ±0.103	0.587 ±0.490
S	7.33	0.590 ±0.171	0.389 ±0.147	1.128 ±0.693	Pb	7.28	0.288 ±0.088	0.839 ±0.073	1.143 ±0.721
Cu	7.60	0.495 ±0.031	0.659 ±0.022	0.490 ±0.234	Fe	7.63	0.512 ±0.036	0.685 ±0.026	0.231 ±0.271
Fe	7.63	0.499 ±0.027	0.694 ±0.019	0.291 ±0.197	Cu	7.91	0.624 ±0.059	0.456 ±0.043	0.544 ±0.447
Ni	8.27	0.742 ±0.032	0.381 ±0.023	0.033 ±0.236	Ni	8.86	0.886 ±0.049	0.218 ±0.035	-0.236 ±0.362

$$c = \frac{15}{2} \frac{\sigma_o^+}{\sigma_T} \qquad \frac{a}{b+(1/2)a} = \frac{\sigma_1^-}{\sigma_o^-}$$

The values reported in Table I suggest that the contribution of the quadrupole absorption, taking into account the rather large statistical errors, can be assumed as linearly variable with E_γ ; in such approximation, we disregard the indication of a sharp rise of the $2^+K=0$ channel contribution at 5.43 MeV and we regard our measurements useless for the calculation of the paramters at the corresponding potential barrier.

The yield of fission occurring throughout a given channel for energies near the fission threshold can be expressed by

$$\sigma = \text{const} \int_o^E \frac{\exp\left(-\frac{U_f}{T}\right)}{1+\exp\left(\frac{B-U_f}{E_p}\right)} dU_f$$

where the $\exp(-U_f/T)$ is the probability of concentrating an amount of energy U_f on the fission oscillation rather than on the other degrees of freedom, and the $\left[1+\exp(B-U_f/E_p)\right]^{-1}$ is the fission barrier penetration with B the fission barrier height and $E_p=(\hbar/2\pi)(K/M)^{1/2}$, K characterizing the fission barrier form and M being the effective mass.

The experimental function can now be fitted to obtain the values of B, T, E_p at the $1^-K=0$ and $1^-K=1$ channels. The fit was made using both the a and b values given in columns 3-4 and 8-9 in Table I. No sensible difference has been found in the two cases and in Table II we report the values obtained together with the values calculated by other authors(6, 7).

In Fig. 1 the measured values σ_o^-/σ_T and σ_1^-/σ_T are plotted. The full lines are the same functions as calculated by means of the parameters given in Table 2, while the dotted line gives the contribution from $2^+K=0$ channel approximated with a linear function of the energy as said before.

In Fig. 2 the total fission cross section calculated with the same constants is given, together with the experimental data discussed in ref. (4).

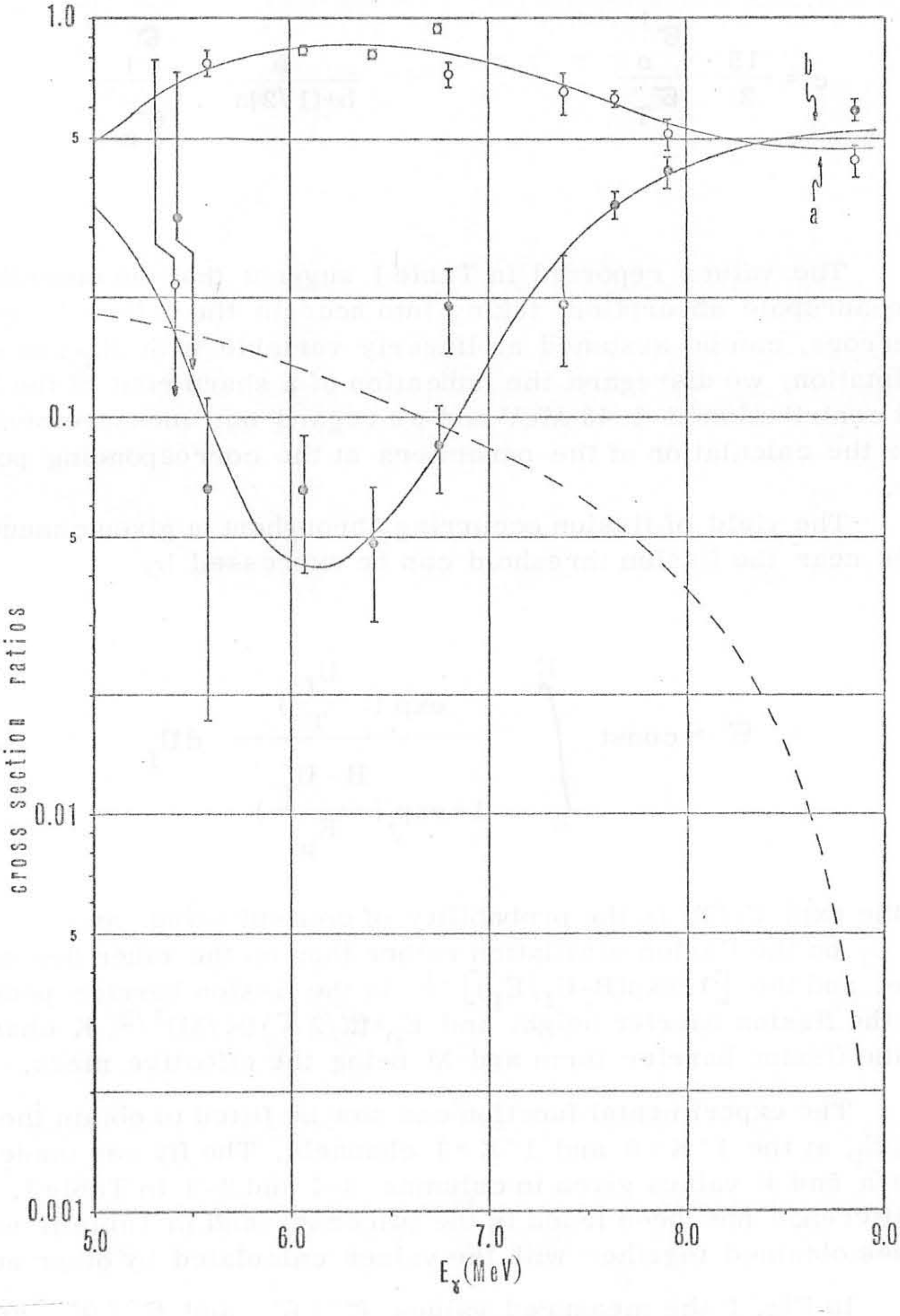

FIG. 1 - Experimental values for σ_0^-/σ_T (a) and σ_1^-/σ_T (b). The full lines give the functions as calculated by means of our values of the parameters given in Table II. The dotted line represents the approximation of σ_0^+/σ_T with a linear function of the energy.

TABLE II - Comparison between the T, B and E_p parameters of the $1^-K=0$ and $1^-K=1$ channels obtained in the present work and those of Albertsson et al. (7) and Rabotnov et al. (6).

Parameter (MeV)	Present work		Albertsson		Rabotnov	
	$1^-K=0$	$1^-K=1$	$1^-K=0$	$1^-K=1$	$1^-K=0$	$1^-K=1$
T	0.553	0.691				
B	5.89	7.49		7.4	5.9	7.2
E_p	0.131	0.259	0.5	0.5	0.242	0.318

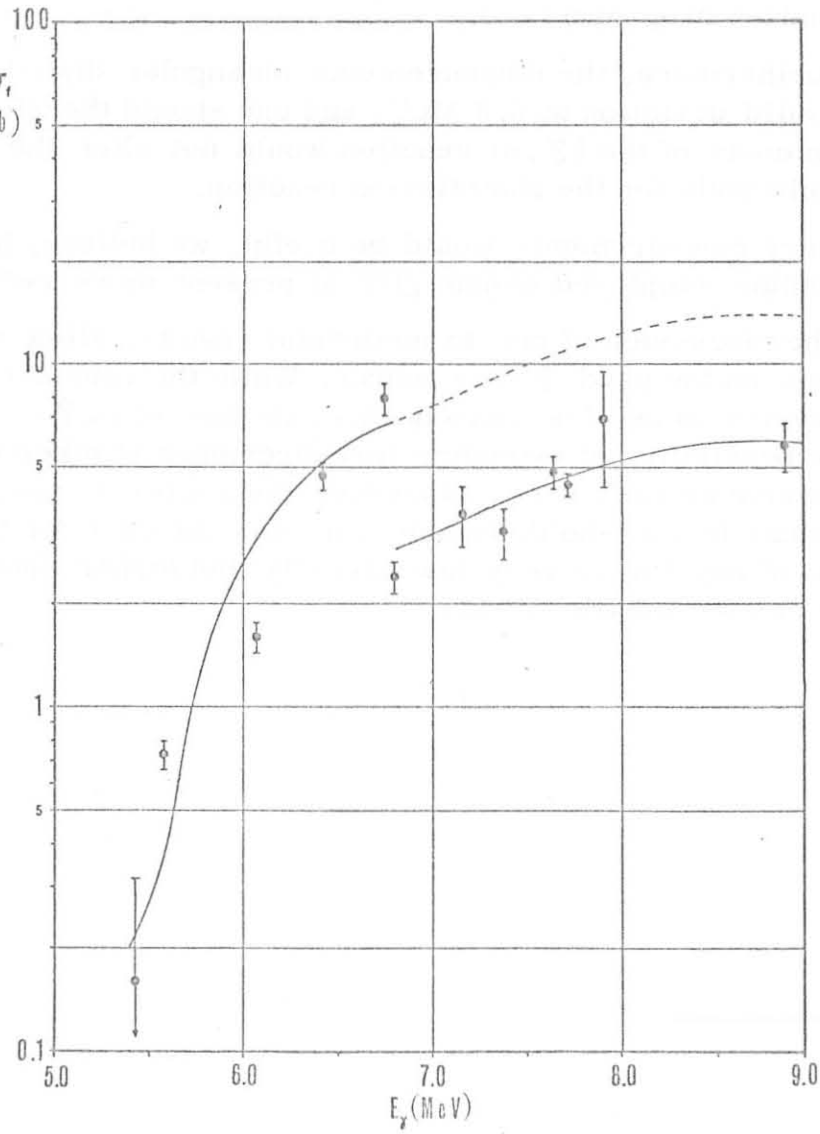

FIG. 2 - Photofission cross section of ^{232}Th (see ref. (4)): experimental data and calculated function.

The calculated curve has been differently normalized to take into account the sharp drop at 6.8 MeV.

4. - CONCLUSIONS. -

Some general considerations can now be made, comparing the results obtained from ^{238}U and ^{232}Th.

The sharp drop of the cross section both for ^{238}U and ^{232}Th, seems rather difficult to be accounted for with simple qualitative considerations.

The presence of a competitive reaction as the (γ, n) would be in agreement with a minimum at $E_{\gamma} = 6.5 \div 7.0$ MeV, but could hardly justify the sudden drop observed.

Furthermore, the measurements on angular distribution show only a very mild deviation at 6.8 MeV, and one should therefore suppose that a sudden onset of the (γ, n) reaction would not alter the opening of the various channels for the photofission reaction.

More measurements would be useful, we believe, however, that the technique employed cannot give at present more refined results.

The discussion of our experimental results, allow us to make somecriticism on the used γ-ray source. While the very narrow γ-ray lines used seems to be of no consequence, the use of (n,γ) reactions prevents the possibility of extending measurements at other energies beside the twelve already used. Moreover the source is useless for energies lower than the threshold, because, as was the case for the S target, the presence of any line of very low intensity and higher energy would prevent any refined measurement.

REFERENCES.-

(1) - A. Manfredini, M. Muchnik, L. Fiore, C. Ramorino, H.G. de Carvalho, J. Lang and R. Müller, Nuclear Phys. 74, 377 (1965).
(2) - A. Manfredini, M. Muchnik, L. Fiore, C. Ramorino, H.G. de Carvalho, R. Bösch and W. Wölfli, Nuovo Cimento 44 B, 218 (1966).
(3) - A. Manfredini, L. Fiore, C. Ramorino, H.G. de Carvalho and W. Wölfli, Nuclear Phys. A 123, 664 (1969).
(4) - A. Manfredini, L. Fiore, C. Ramorino, H.G. de Carvalho and W. Wölfli, Nuclear Phys. A 127, 687 (1969).
(5) - P.E. Vorotnikov, Sov. J. of Nuclear Phys. 7, 732 (1968).
(6) - N.S. Rabotnov, G.N. Smirenkin, A.S. Soldatov, L.N. Usachev, S.P. Kapitza and Yu. M. Tsipeniuk, Proc. Symp. and Phys. and Chemistry of Fission, Salzburg, 1965 (IAEA, Wien, 1965), Vol. I.
(7) - E. Albertsson and B. Forkman, Nuclear Phys. 70, 209 (1965).