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PRODUCT YIELDS OF ^{232}Th PHOTO-FISSION INDUCED BY MONOCHROMATIC GAMMA RAYS

Jing Kexing, Li Ze, Liu Conggui, Liu Yonghui,
Su Shuxin and Huang Shengnian

Institute of Atomic Energy
P.O.Box 275-46, Beijing, China

Abstract: 13 cummulative yields and 10 mass chain yields from ^{87}Kr to ^{143}Ce were determined absolutely for fission of ^{232}Th induced by 7.64 MeV monochromatic gamma rays. The gamma photons were obtained from the thermal neutron capture gamma source installed at the swimming pool reactor of IAE, by using Fe radiator. The samples used were Th metal disks which were sandwiched between two thin Th foils during irradiation. The fission events of these thin Th foils were detected by solid state nuclear track detectors. In this way the fission rate was determined absolutely. The influence of fast neutrons was investigated and corrected accordingly. Fission product activities of irradiated samples were measured by Ge(Li) gamma ray spectrometry.

(Fission yields, photo-fission, ^{232}Th, thermal neutron capture gamma rays.)

Introduction

The photo-fission process has been widely investigated since 1940s. Some authors have published the experimental results of the product yields in ^{238}U and ^{232}Th photo-fission[1--11]. Most of these measurements, however, were performed by using continuous spectrum gamma rays from bremsstrahlung source, and in some cases only relative yields were obtained. Meason et al.[10] reported the yields (relative to that of ^{140}Ba) of ^{238}U fission induced by 17.5 MeV monochromatic gamma rays produced in the ^{7}Li(p,γ)2α reaction. Using the thermal neutron capture gamma rays from Cr, Ni and Fe, Wolf[11] investigated the ^{238}U(γ,f) reaction, but in his paper only the independent yield of ^{134}I was given. In present work the product yields of ^{232}Th fission induced by 7.64 MeV gamma rays were measured by means of direct gamma spectrometry. The 7.64 MeV gamma rays were produced from the thermal neutron capture by Fe. Altogether 13 cummulative yields and 10 mass chain yields from ^{87}Kr to ^{143}Ce were determined absolutely.

Experiment

Gamma source

The gamma source was installed at the swimming pool reactor in IAE. The high energy gamma photons were obtained from the Fe(n,γ) reaction induced by thermal neutrons[12]. The iron radiator was located in the beryllium reflector near the core. The collimated gamma beam was extracted through a horizontal channel. In order to reduce the low-energy gamma ray and neutron backgrounds a series of absorbers were inserted into the collimator.

Many gamma lines are emitted in the de-excitation process of the excited compound Fe nuclei formed after neutron capture. The energies of the main lines above the (γ,f) threshold and the numbers of quanta of that line per 100 neutron captures (figures in parentheses) are[13]: 9298 keV (3.9); 7646 keV (24.4); 7632 keV (27.7) and 7279 keV (5.3); respectively. The estimated intensity for 7646 and 7632keV gamma lines is 5×10^{13} n/s. The detailed description of the gamma source equipment has been published elsewhere[12].

It is unavoidable that some background fast neutrons were existed in such beam together with gamma photons. These fast neutrons can induce ^{232}Th fission too, and the neutron fission cross section is larger than the photo-fission cross section. To estimate correctly the contribution of fission events induced by background fast neutrons is rather difficult. We used the activation reaction ^{238}U(γ,n)^{237}U to determine the gamma fluence rate distribution in the channel along the axis, and the ^{115}In(n,n')^{115m}In reaction to determine the neutron fluence rate distribution. The ^{115}In(n,n') reaction was adopted because its excitation curve is similar in shape to that of the thorium neutron fission reaction below 6 MeV[14], and the contribution of neutrons with higher energy is negligibly small.

To meet both the requirements of high fission rate and low neutron background we chose the irradiation position at a point in the channel 2.0 meters away from the Fe radiator. At that point the gamma fluence rate is 2.0×10^{7}photons/scm^2, and the fluence rate of background neutrons is 2.8×10^{5}n/scm^2 in case that the thermal power of the reactor is 3.8 MW. Then the ratio of the fission events induced by neutrons to that of photo-fission is estimated as R=0.17.

In a separate experiment we checked the inhomogeneity of the gamma beam. A Th plate covered with SSNTD was irradiated and than the fission tracks were counted under a microscope. It is shown that the beam is homogeneous within the size of the sample.

Irradiation of thorium samples

The sample used in the experiment are thorium metal disks. The content of thorium is greater than 99.9 percent. The sample size is 22 mm in diameter. The weight of the sample varies from 1.6115 grammes to 2.1335 grammes. In order to avoid the escape of fission fragments each sample was sealed in Al foil with the thickness greater than 5.6 mg/cm^2.

Two thin Th foils with the same size as the sample were put on the both sides of the sample and irradiated together. The masses of these thin Th foils were 66.76μg and 78.58μg, respectively. Two mica sheets were used as the solid state nuclear track de-

tectors to record the fission fragments of the thin Th foils. After irradiation the mica sheets were etched in the 40 % H_2F_2 solution under 100°C temperature for 15 minutes. Before irradiation the mica sheets used were pre-etched in the same condition for 45 minutes to eliminate the background or parasite tracks. From the number of tracks in the mica sheets the absolute fission rate in the sample could be deduced. For calibrating the detection efficiency of the SSNTD a ^{252}Cf source was put at the same position of the thin Th foil and the tracks were counted. The activity of the ^{252}Cf fission source was determined in a low solid angle equipment. The value of 0.831 0.016 was obtained for the efficiency of mica.

Determination of the radio-activities of the fission products

The activities of the fission products were measured by using a Ge gamma spectrometer. The data were collected by a MCA-computer system. The efficiency of the spectrometer was calibrated by using a series of standard gamma sources. Routine procedure of gamma spectroscopic measurement was adopted. The details of the spectrometer system has been described elsewhere[15].

Results

The data were treated according to the method used in our previous works[15,16]. The nuclear spectrometry data used in the yield calculation were taken from 17 . Altogether five runs of experiments were carried out and for each sample the gamma spectra were taken at different times after irradiation. The results obtained from five runs agree with each other and were averaged.

Some corrections were taken into account, including the self-absorption, effect of imcomplete pile-up auto-correction, cascade gamma coincidence, influence of the delayed neutron emission, etc.

The contribution of fast neutron induced fission was calculated and corrected separately according to the yields data of neutron fission[18].

The resultant cummulative and chain yields were given in the Table. In cases A = 97,99 and 132 we obtained cummulative yields of two nuclides in the same mass chain. From them two values of chain yield could be derived. For A = 97 or 132, we adopted the chain yield calculated from the cummulative yield of the nuclide which is nearer to the stable one in the chain. For A = 99, however, we recommended the value deduced from ^{99}Nb instead of ^{99}Mo, considering the uncertainty of the branching correction in ^{99}Mo data.

The main error terms were coming from the absolute determination of the fission rate, the efficiency calibration of the germanium detector, the statistic uncertainty of the peak areas, the correction of cascade gamma coincidence, the correction of self-absorption, etc. The errors of the branching ratios of the investigated gamma-lines, however, were not included in the summary errors given in Table.

Table The cummulative and chain yields of ^{232}Th photo-fission

mass number	nuclides (A)	(B)	cummulative yield, Y_a(%)	chain yield Y_m(%)
87	^{87}Br	^{87}Kr	6.54±0.57	6.92±0.60
91	^{91}Sr	^{91}Y	7.95±0.44	7.95±0.44
92	^{92}Rb	^{92}Sr	6.54±0.41	7.33±0.46
97	^{97}Y	^{97}Zr	2.93±0.17	
	^{97}Zr	^{97}Nb	3.15±0.20	3.15±0.20
99	$^{99}Nb+^{99m}Nb$	^{99}Mo	1.91±0.11	1.91±0.11
	^{99}Mo	^{99}Tc	2.08±0.11	
132	^{132}Sb	^{132}Te	1.59±0.16	
	^{132}Te	^{132}I	2.12±0.10	2.13±0.10
133	$^{133}Te+^{133m}Te$	^{133}I	3.76±0.22	3.84±0.22
134	^{134}Te	^{134}I	4.41±0.30	4.99±0.37
142	^{142}Ba	^{142}La	8.26±0.43	8.31±0.43
143	^{143}La	^{143}Ce	7.60±0.32	7.60±0.32

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