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Angular distribution of photofission fragment of even-even and odd mass nuclei studies using SSNTD technique

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Abstract : Fission fragment angular distribution measurements of even-even (^{232}Th) and odd mass (^{237}Np) nuclei were carried out using bremsstrahlung radiation in the energy range 7.4 to 9.2 MeV from variable energy microtron at Mangalore University. In the present work SSNTD lexan polycarbonate films were used to detect the fission tracks from both even-even (^{232}Th) and odd mass (^{237}Np) nuclei. From the knowledge of track density formed from photofission reaction of ^{232}Th and ^{237}Np, angular distribution of fission fragments was measured. The results obtained are discussed on the basis of Age Bohr theory in this paper.

Keywords : Nuclear reactions, fission bremsstrahlung : ^{232}Th (γ,F) and ^{237}Np (γ,F), E_{max} = 7.4–9.2 MeV, Fission-fragment angular distributions, solid state nuclear track detector.

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1. Introduction

The photofission of heavy nuclei at low excitation energies provides several important items of information on the nuclear properties, such as photofission thresholds, the differential cross sections, the distribution of fission fragments in mass, energy and charge, the average number of neutrons per fission and finally, the angular anisotropy in the distribution of fission fragments. The study of the angular distribution of photofission fragments of both even-even and odd mass nuclei near threshold is of unique importance because of its selectiveness in the fission channel. The mechanism of the low energy fission process is explained with the channel hypothesis by Age Bohr [1]. According him, the nucleus excited to energies close to the fission threshold, will have most of its energy bound as deformation energy during the passage from the initially excited nucleus to highly deformed transition state nucleus. Hence these

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deformed nuclei are thermodynamically cold and is expected to have the same spectra of excited states analogous to those of normal nuclei in the ground state. The objective of present studies has been to obtain nuclear properties at excitation energies in the region of the giant dipole resonance and in the region of low energy, near photofission and photoneutron thresholds [2]. The main difficulties in the experimental investigation of photonuclear reactions lie in the absence of intense sources of monochromatic γ quanta. When the bremsstrahlung of an electron beam is used, the optimal conditions from the point of view of intensity and energy resolution are realized with the microtron. In the present study, intense variable energy microtron [3–5] at Mangalore University is used to measure angular distribution of photofission fragments near threshold. For fragments detection we employed the solid state nuclear track detector based technique because of intense bremsstrahlung radiation used in the present work. This technique has spread to various fields such as radiation dosimetry, health physics, nuclear physics and fission physics [6]. Among several kinds of solid state detectors, plastics detectors like cellulose nitrate, polycarbonate (Makrofol, Lexan) are widely used for fission fragment detection. In the present work, Lexan films were employed to measure the fission fragment angular distribution for the both even-even (^{232}Th) and odd mass (^{237}Np) target near fission threshold using bremsstrahlung radiation.

2. Experimental procedure

A self supporting ^{232}Th target of thickness 2 mg/cm^2 and 150 μg/cm^2 of ^{237}Np was used in the present work. The target was kept at 45° to the bremsstrahlung radiation at a distance of 15 cm from the tantalum target. The fission fragments emitted from the target were detected by SSNTD lexan polycarbonates having a dimension 12.6 cm × 4.5 cm and of thickness of 175 μm were kept at distance of 8.0 cm inside an evacuated fission chamber covering the angles 0° to 90°. The detectors were calibrated using ^{252}Cf source. The detailed experimental setup was discussed elsewhere [7]. After irradiation all the lexan films were cut into equal strips and etched in 6N NaOH at 60°C temperatures for one hour [8]. This was done in order to enlarge the tracks made by the penetrating fission fragments. The fission tracks in the lexan films were counted using Research optical microscope with a magnification of 400X.

3. Results and discussion

Figure 1 shows the fission fragments observed in the lexan polycarbonate films used as a detector after the irradiation of ^{232}Th with bremsstrahlung radiation.

The fission fragments angular distributions were obtained at various energies by normalizing the fission track counts to the solid angle and photon intensity. The photon intensity was obtained from the track densities measured along the beam axis at each energy. The measured fission fragment angular distributions were least square fitted

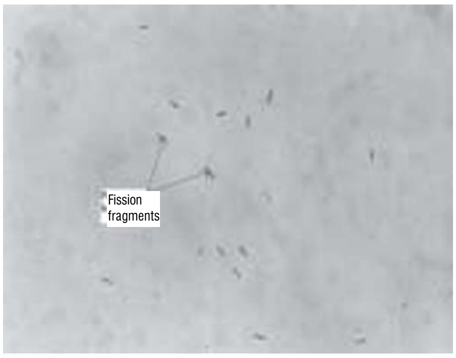

Figure 1. Photograph of the fission fragments were observed in lexan polycarbonates after the irradiation of ^{232}Th target with bremsstrahlung radiation.

with the expression [9] :

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

The values of the coefficients '*a*', '*b*' and '*c*' were determined at various energies from the fits. The fission fragments angular distribution of ^{232}Th induced by bremsstrahlung radiation is as shown in the Figure 2.

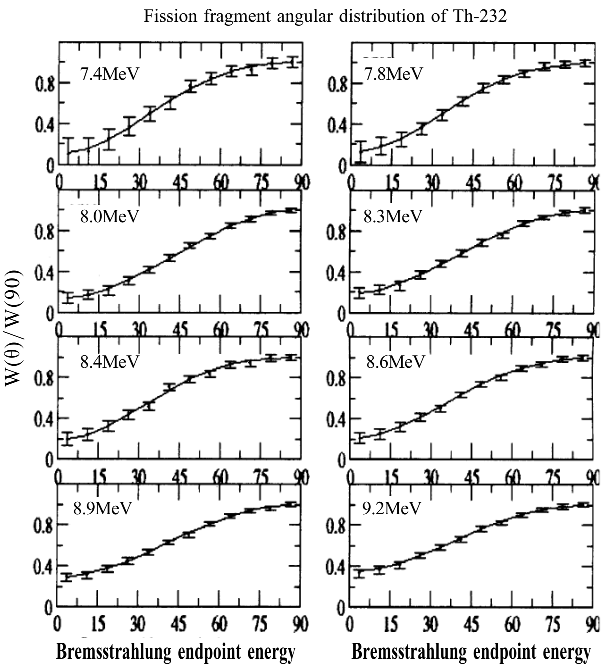

Figure 2. Fission fragments angular distribution of ^{232}Th induced by bremsstrahlung radiation in the region of 7.4 to 9.2 MeV.

The value of ratios, b/a and c/b, represent dipole and quadrupole contribution respectively in photo absorption and its variation as a function of end point energy

(E_{max}) of bremsstrahlung radiation along with the values of Rabotnov *et al* [10] and Baerg *et al* [11] are shown in Figure 3.

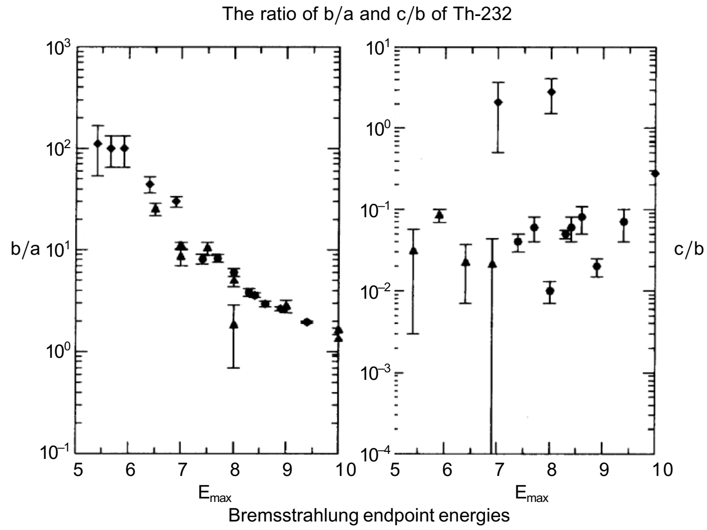

Figure 3. Energy dependence of *b/a* for photofission of ^{232}Th : (●) result of the present work, (♦) measurements of reference [10], (▲) measurement of reference [11].

As shown in the Figure 3 dipole contribution systematically decreases with respect to E_{max}, where as quadrupole contribution (c/b) remains constant at low values within the uncertainties of the measurements. The present measurements are consistent with the earlier observation of lower quadrupole contribution in case of ^{232}Th (γ,f) reaction. The results of fission fragment angular distribution of ^{237}Np induced by bremsstrahlung radiation are as shown in the Figure 4.

The experimental points, shown with error bars corresponding to statistical errors, were normalized at 90°. Angular anisotropics (defined as b/a) are compared with the result of Geraldo *et al* [12] and Baerg *et al* [11] in Figure 5. The values of anisotropy show decreasing trend with increasing end point energy as expected for odd-A nuclei. Almost isotropic angular distribution observed at 8.4 MeV is in good agreement with the result of Geraldo *et al* [12] and Baerg *et al* [11] which was measured at 8.0 MeV.

According Age Bohr [2] theory, isotropic part '*a*' of the angular distribution is almost zero at energies near threshold and then increases and reaches saturation at values near one, while the '*b*' term starts with values larger than one and decreases to values near zero for energies larger than 8 MeV. Such behavior corresponds to the prediction of the Bohr hypothesis for pure dipole absorption and single open channel with K = 0 at threshold, while at higher energies the contribution of the other channels give rise to attenuation. This is because; in case of even-even nucleus at low excitation of the transition state nucleus where a relatively large separation of the levels is expected, only few of the levels will be available for fission, while in the case of odd-

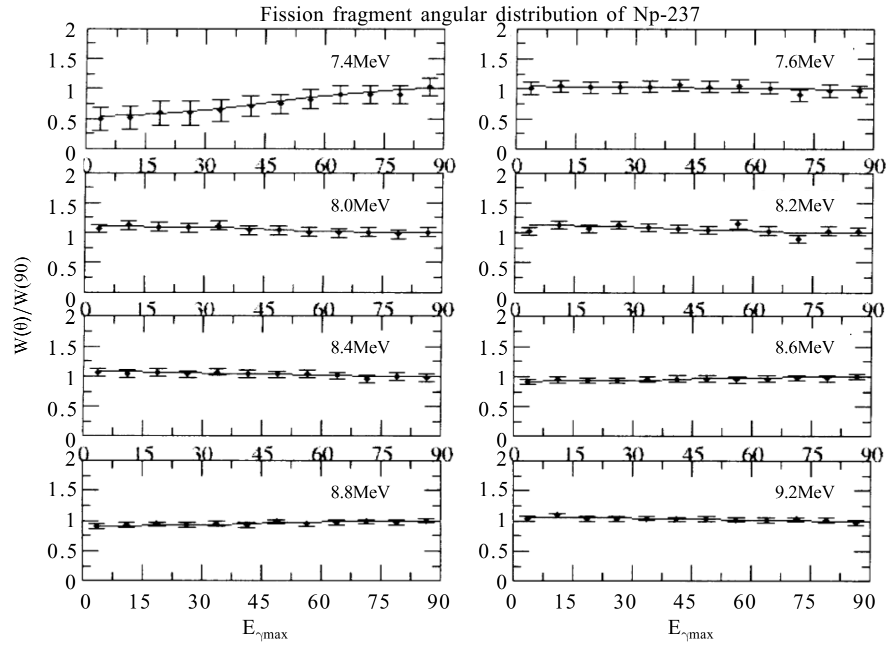

Figure 4. Fission fragments angular distribution of ^{237}NP induced by bremsstrahlung radiation in the region of 7.4 to 9.2 MeV.

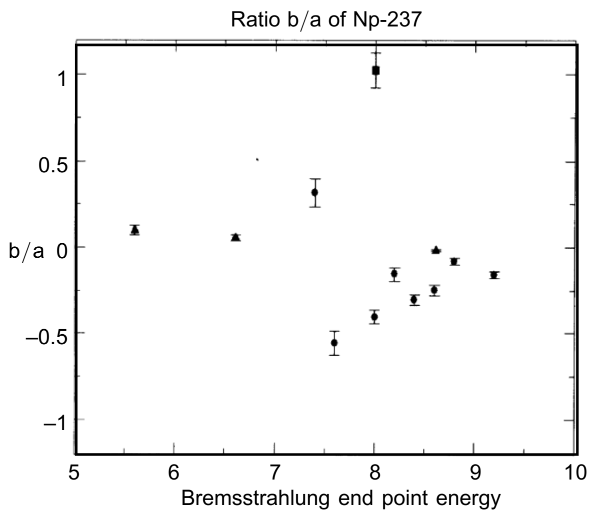

Figure 5. Energy dependence of *b*/*a* for photofission of ^{237}Np : (●) results of the present work, (▲) measurement of reference [12], (■) measurement of reference [11].

mass nucleus show isotropic or nearly isotropic distribution of fission fragments at energies some what higher than fission barrier, because of randomly oriented spin, larger set of angular momentum and its components, higher density of open fission channels near threshold. The present experimental measurements are in good agreement with the theory of Age Bohr for both even-even and odd mass nuclei.

4. Conclusion

From the above measurements, it was concluded that the measured fission fragments angular distribution of even-even nucleus induced by bremsstrahlung radiation shows anisotropy which decreases with increasing energy and odd-mass nuclei shows nearly isotropic distribution above 8.0 MeV using SSNTD technique. They are in good agreement with the theory predicted by Age Bohr.

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