# Mass distribution in the 70-MeV bremsstrahlung-induced fission of $^{232}$Th

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Studies of the mass and charge distribution in the low energy fission of actinides provide important information about the nuclear structure effect and dynamics of descent from saddle to scission [1, 2]. The yields of fission products relevant to mass and charge distribution studies in the neutron-induced fission of actinides from Ac to Fm and the spontaneous fission of heavier actinides are available in different compilations [3, 4]. Similarly, yields of fission products in the bremsstrahlung-induced fission of actinides and pre-actinides are available in literature [1,2,5-7]. From these data it is clear that mass yield distribution in neutron and photon induced fission is symmetric for pre-actinides [6, 7], asymmetric with triple humped for Th and double humped for U-Cf and again symmetric for Fm. In case of Th the yields of fission products increases and thus the third peak of mass distribution decreases with excitation energy [1, 2]. However, it is not clear at what energy the third peak in Th vanish. In order to examine this, yields of fission products in the 70-MeV bremsstrahlung induced fission of $^{232}$Th has been determined using off-line γ-ray spectrometry in 100 MeV electron linac of Pohang Accelerator Laboratory at South Korea.

Experimentally bremsstrahlung was generated by impinging electron beam on a 0.1 mm thick W metal foil of size 10 cm x 10 cm placed at a distance of 18 cm from the beam exit window. A known amount (76.8-114.0 mg) of $^{232}$Th metal foil of 0.025 mm thick was wrapped with 0.025 mm thick super pure Al catcher foil and was fixed on a stand in air at 12 cm behind the tungsten metal foil [6, 7]. The target assembly was irradiated for 2-4 hours with bremsstrahlung photon produced by bombarding the 70-MeV electrons on the tungsten metal foil. The current of the electron beam during irradiation was 15 mA at 3.75 Hz with a beam width of 1.5 μs. The irradiated target assembly was cooled for 10 to 30 minutes. The irradiated target of $^{232}$Th along with Al-catcher was taken out from the irradiated assembly, mounted on Perspex plate [5-7]. The γ-ray counting of fission products were done by using an energy- and efficiency-calibrated HPGe detector coupled to a PC-based 4K-channel analyzer. The energy resolution of the detector was 2.0-keV FWHM at the 1332.5-keV peak of $^{60}$Co. The dead time of the detector system during counting was always kept less than 5% by placing the sample at a suitable distance to avoid pileup effects. The γ-ray counting of the sample was done in live time mode and was followed as a function of time.

The net photo-peak areas of different γ-rays of nuclides of interest were calculated by subtracting the linear Compton background from their gross peak areas. From the γ-rays activities ($A_i$) of the fission products their yields (Y) relative to $^{135}$I were calculated by using usual standard decay equation [5].

$$A_i = N\sigma\Phi a\varepsilon Y\,(1-e^{-\lambda t})\,e^{-\lambda T}(1-e^{-\lambda\Delta T})/\lambda \qquad (1)$$

where N is the number of target atom and σ is the fission cross-section of the target nuclei at bremsstrahlung spectrum with end point energy of 70 MeV. Φ is the photon flux. ‘t’, T and ΔT are irradiation, cooling and counting time respectively. ‘a’ is the abundance of γ-ray energy for the fission product of interest [8]. ‘ε’ is efficiency of the γ-ray in the detector system, which was obtained by using standard $^{152}$Eu source. From the relative yield data, mass yield distributions were obtained by using charge distribution correction and normalizing the total yield to 200 %.

The mass yields data in the 70 MeV bremsstrahlung induced fission of $^{232}$Th from present work along with 40 MeV and 10 MeV bremsstrahlung induced fission of $^{232}$Th from earlier work [5] are plotted in Fig. 1. From Fig. 1 it can be also seen that at end point bremsstrahlung energy of 10-70 MeV the yields of fission products are higher around mass number 133-135, 138-140 and 143-145 and their complementary mass number. The oscillation in the interval of five mass units is due to even-odd effect. Besides this, higher yield around mass number 133-135 and 143-145 due to the presence of spherical 82n and deformed 88n shell respectively. These observations indicated the effect of nuclear structure effect in photon induced fission similar to neutron induced fission of actinides. It can be also seen from Fig. 1 that mass yield distribution in $^{232}$Th (γ, f) is triple humped at end point bremsstrahlung energy of 10-70 MeV similar to $^{232}$Th (n, f) [1, 2]. This is due to well known dip in the outer symmetric fission barrier. Further, it can seen from Fig. 1 that the yields of fission products in the valley region decreases from end point bremsstrahlung energy of 10 MeV to 70 MeV and thus peak-to-valley ratio decreases with increasing bremsstrahlung energy, which shows the role of excitation energy.

From the fission yields data, peak-to-valley ratio (P/V) was also obtained at different energy. The present data along with the literature data in bremsstrahlung induced fission of $^{232}$Th and $^{238}$U from literature given in ref. [1] are plotted in Fig. 2. From Fig. 2, it can be seen that the P/V/ at all excitation energy in $^{232}$Th(γ, f) are lower than in $^{232}$U(γ, f). This is due to the tripled humped mass distribution in $^{232}$Th than the double humped mass distribution in $^{238}$U. This indicates a different type of potential barrier in $^{232}$Th than in $^{238}$U.

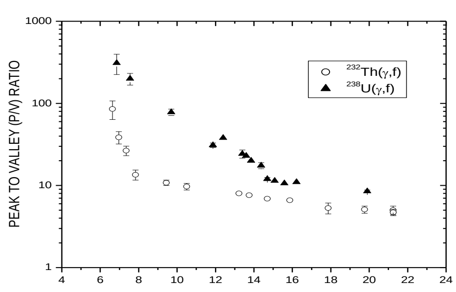


Fig.2. Plot of P/V in $^{232}$Th(γ,f) and $^{238}$U(γ,f)

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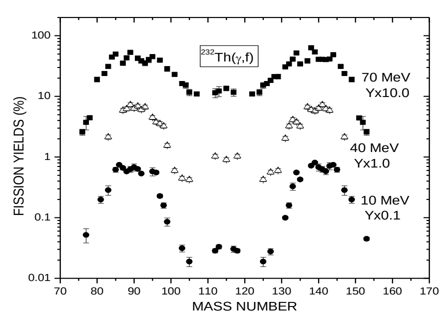


Fig. 1.Yield distribution in $^{232}$Th(γ,f) and $^{238}$U(γ,f)