Exotic nuclei production by photofission at many energies

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Introduction

The use of energetic electron is a promising tool to get intense neutron-rich ion beam. For producing n-rich radioactive ion beam by the photofission method, nuclei are excited by photons covering the GDR peak where the energetic incident electron beam of ∼10-50 MeV can be slowed down in a tungsten (W) converter or directly in the target (U) itself, generating bremsstrahlung photons which can induce fission [1].As an extension of the present RIB development, a facility called ANURIB will be coming up at VECC with e-LINAC as primary accelerator for photofission [2].

In the present work, we perform a comparison of the behavior of the symmetric and asymmetric modes of photofission of ^{238}U induced by bremsstrahlung photons with mean energies of 9.09−15.90 MeV [3], which includes the GDR peak corresponding to the electron energy in the range 11.5 to 67.7 MeV.

Theoretical framework

The total photoabsorption cross sections are calculated with help of hydrodynamic theory of the interaction between photons and nuclei, where the shape of fundamental resonance in the absorption cross-section is given by [4]

$$\sigma_a^{GDR}(E_\gamma) = \mathbf{\Sigma}_{i=1}^{2} \frac{\sigma_i}{1+\left[\frac{(E_\gamma^2-E_i^2)}{E_\gamma \Gamma_i}\right]^2} \qquad (1)$$

where σ_i, E_i and Γ_i are the peak cross section, resonance energy and full width at half maximum, respectively. We find that like the photoabsorption, the photofission cross sections can also be described quite well by Eq.(1). The list of parameters σ_i, E_i and Γ_i for $i = 1, 2$ extracted by fitting experimental data [4] are provided in Ref.[5]. Therefore, we find by fitting data of all the eight actinide nuclei that ratios $R_1 = \frac{(\sigma_1)_f}{(\sigma_1)_a}$, $R_2 = \frac{(\sigma_2)_f}{(\sigma_2)_a}$ for γ absorption and subsequent fission scale as:

$$R_{i=1,2} = a_{2i} f^2 + a_{1i} f + a_{0i}, \qquad (2)$$

where fissility $f{=}Z^2/A$ with Z, A being the charge,mass numbers of target nucleus. The scaling parameters obtained: a_{01}=118.5486, a_{11}=−6.9389, a_{21}=0.1015, a_{02}=175.5418, a_{12}=−10.2748 and a_{22}=0.1504.

In the multimode-fission model, the mass distribution is interpreted as a sum of the contributions from the symmetric and asymmetric fission modes. For each fission mode, the mass and the charge yield is described by a Gaussian function. The details are given in Ref.[5]. Thus, the production cross sections of individual fragments for ^{238}U photofission induced by bremsstrahlung photons are obtained by multiplying fission cross section by mass and charge distribution which means $\sigma_f(A, Z) = \sigma_f^{GDR}.Y(A, Z)/100$.

Calculations and Results

The photofission cross sections σ_f^{GDR} are calculated using Lorentz line shape of Eq.(1) for γ absorption while replacing σ_i by the ratio method as shown in Fig.1.In Fig.-2, plots of the ratios of cross sections for mean photon energies 9.09 MeV and 15.9 MeV to that for 13.7 MeV are shown as a function of exoticity parameter ξ defined as $\frac{A-A_s}{A_d-A_s}$ where A, A_s and A_d are, respectively, the fragment mass number, mass number of stability line nucleus and mass number of neutron drip line nucleus for the same charge number Z of the fragment.

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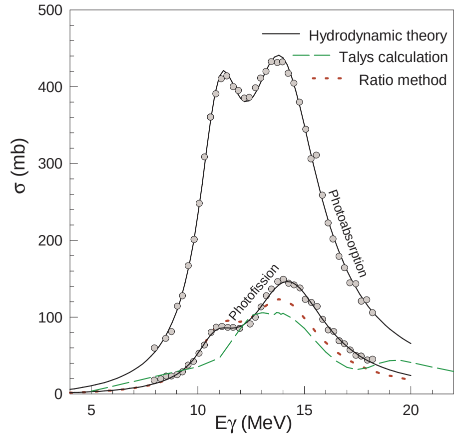

FIG. 1: Comparison of the measured photoabsorption and photofission cross sections for ^{238}U.

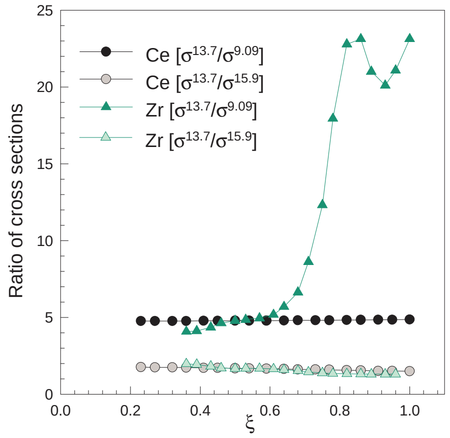

FIG. 2: Ratios of cross sections for different photon energies as a function of ξ.

In Fig.-2, it may be noticed that with increasing ξ, the energy dependence remains flat irrespective of the fact whether cross sections are 5 times more or less by a factor of 2. The Table-I contains the production cross sections of some r-process nuclei for mean photon energy of 13.7 MeV only, where cross sections are found to lie in μb range: *e.g.* ^{80}Zn and ^{134}Sn, the waiting point nuclei are produced with 2.6 μb and 0.18 μb.The reduction of cross section is consistent since cross sections fall rapidly with increasing mass number because of the neutron richness.In the r-process path neutron capture stops as neutron separation energy falls approximately below 2 Mev. In our calculation, the production cross section of ^{162}Ce is found to be 3.2×10^{-15} mb, where calculated value of last neutron separation energy is 2.2 MeV.

TABLE I: Calculated production cross sections

Ele	A/Z	Z_s	A_s	$Z_s - Z$	$A^F - A_s^F$	σ(mb)
^{80}Zn	2.66	36	64	6	16	2.6×10^{-3}
^{96}Kr	2.66	42	84	6	12	2.1×10^{-3}
^{106}Zr	2.66	46	91	6	15	3.9×10^{-3}
^{133}Sn	2.66	56	119	6	14	2.2×10^{-3}
^{143}Xe	2.66	60	131	6	12	6.6×10^{-3}
^{154}Ce	2.66	64	140	6	14	2.2×10^{-3}

Summary and Conclusion

We find that like the photoabsorption, the photofission cross sections can be well described by the ratio method.The production cross section in the range 11.5−67.7 MeV, which includes of 29.1 MeV, corresponding to the mean γ energy of 13.7 MeV, which is maximum and coincides with GDR peak of ^{238}U photofission. Moreover, many r-process nuclei in intermediate mass range can be produced for three different energies that are close to 13.7 MeV. Therefore, so far marching away from β-stability towards n-rich nuclei is concerned, it appropriate to keep electron energy within 50 MeV for e-LINAC construction.

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