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Isomers production in ^{238}U photofission

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Summary. — The fission process induced by gamma quanta up to 25 MeV energy on ^{238}U was analyzed. Experimental observables as cross sections, fragments mass distribution yields of some nuclides of interest and average prompt neutrons multiplicity characterizing ^{238}U photofission process were theoretically evaluated using TALYS 1.9 software. Theoretical evaluations of isomer ratios using Talys supplied by author's own code as well as experimental isomer ratios obtained at MT - 25 Microtron are presented.

1. – Introduction

Fission process induced by gamma quanta is of interest for fundamental researches because furnish new data about configuration of fissionable systems near scission point, anisotropy, emitted gamma spectra, fission products ground states, spin distributions, angular momentum dependence of levels density, etc [1], [2]. Photofission is important also for applied researches related to transmutation and energy projects, new generation nuclear reactors, isotopes production [3].

The fission process induced by gamma quanta up to 25 MeV energy on ^{238}U was analyzed. This study represents a research proposal for photofission investigations and isotopes production at the new pulsed Intense Resonant Neutron Source (IREN), from Frank Laboratory of Neutron Physics (FLNP) at JINR Dubna.

2. – Codes and elements of theory

Fission observables were evaluated by using Talys 1.9. Main reaction mechanisms are implemented in this code together with a wide nuclear database for many nuclei [4]. For the evaluation of fission cross sections the Hauser - Feshbach approach is applied [4], [5]. Fission fragments mass distribution, isotopes yields, prompt neutron distributions were

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evaluated using Brosa model [4], [6]. If the incident particles are Bremsstrahlung gamma quanta then the isomer ratios have the form [7]:

$$(1a)\quad R = Y_m \cdot [Y_g]^{-1} = \int_{E_{thr}}^{E_{max}} N_0 \phi(E)\sigma_m(E)dE \cdot \left[\int_{E_{thr}}^{E_{max}} N_0 \phi(E)\sigma_g(E)dE\right]^{-1}$$

where: $Y_{m,g}$ = yields of isotope in isomer (m) and ground (g) states; N_0 = number of target nuclei; ϕ = flux of incident beam; $\sigma_{m,g}$ = production cross section of m and g states respectively; E_{thr} = threshold energy of emergent particle emission; E_{max} = maximum energy of incident beam.

The incident X - ray flux was evaluated applying the Kramer relation [8]:

$$(2a)\qquad \phi(E_\gamma) \sim I_c = i_b Z(E_0 - E_\gamma)E_\gamma^{-1}$$

where: I_c = gamma quanta intensity; i_b = electrons beam current; E_0 = electrons energy; Z = charge of target stopping element.

Isomer and ground cross sections for fission are not provided by Talys and therefore these values are obtained from a statistical approach and states spin distribution $P(J)$ [9], [10]:

$$(3a)\qquad P(J) \sim (2J+1)Exp[-0.5J(J+1)(\sigma+\lambda)^{-2}$$

where: J = spin; σ, λ = parameters.

3. – Results and discussions

In Fig. 1 the energy dependences of photofission cross sections and fission fragment mass distributions are represented. Photonuclear processes (γ,xn), (γ,xp), (γ,np) followed by fission occur in the interaction of gamma quanta with ^{238}U nucleus together with its photofission. Total photofission cross section represents the contribution of ^{238}U, ^{237}U, ^{236}U (see Fig. 1a)) and of other fissile nuclei which can be neglected. In Fig. 1b) experimental data are compared with theoretical evaluation using default Talys input. A satisfactory description of experimental data was obtained. The shapes of both experimental and theoretical dependences are similar. Low energy part is well described up to 12 - 13 MeV. At higher energies it is necessary to vary Talys input data correlated with analysis of existing measurements. Experimental data are taken from EXFOR [11].

In Fig. 1c) experimental and calculated mass distributions before neutrons emission are represented for 7 MeV gamma energy. Experimental data were obtained by using a Bremsstrahlung X - ray source [12]. A very good agreement between theory and experiment can be observed. In Fig. 1d) evaluated mass distribution of fission fragment are shown for E_γ = 13 MeV for pre and post neutrons emission. Mass distribution demonstrates a slowly increasing symmetry with energy.

Average prompt neutrons multiplicity, prompt neutrons multiplicity distributions, isotopes yields were also evaluated. In Fig. 2a) the average neutrons multiplicity as function of fragment mass for E_γ = 25 MeV, before and after neutrons emission is represented. In Fig. 2b) prompt neutrons multiplicity distribution for 13, 19, 25 MeV gamma energy, respectively, are shown. At these energies photofission cross sections are

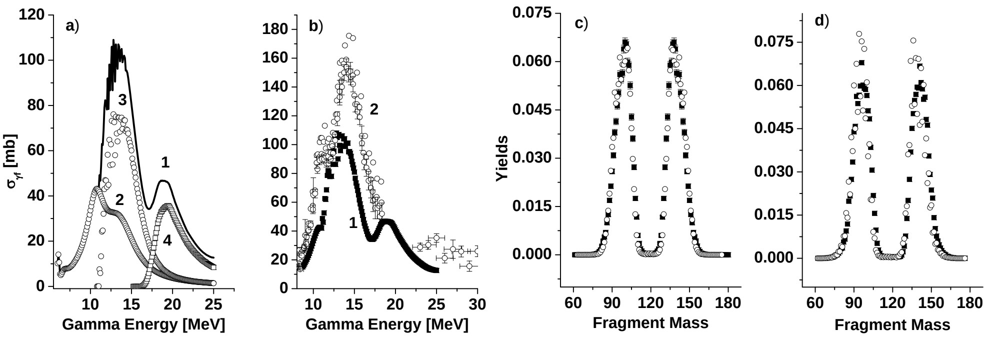

Fig. 1. – ^{238}U Cross sections and mass distributions. Cross sections. a) Total fission cross sections $1- > 2 + 3 + 4$; 2 - ^{238}U; 3 - ^{237}U; 4 - ^{236}U. b) Comparison between theory and experiment; 1 - Talys; 2 - experimental data. Mass distributions. c) $E_\gamma = 7$ MeV - pre neutrons emission. empty circles - Talys; black squares - experimental data. d) $E_\gamma = 13$ MeV - Talys; Neutrons emission: empty circle - pre; black square - post

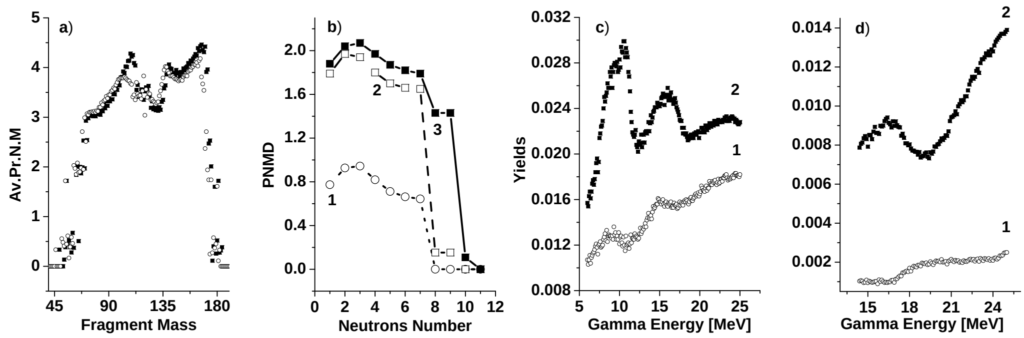

Fig. 2. – Prompt neutrons and isotopes production. Prompt neutrons. a) Average prompt neutrons multiplicity (Av.Pr.N.M.); $E_\gamma = 25$ MeV; Neutrons emission: empty circles - pre; black squares - post. b) Prompt neutrons mutiplicity distribution (PNMD). 1 - $E_\gamma = 13$ MeV; 2 - 19 MeV; 3 - 25 MeV; Isotopes production. c) ^{132}Sb; d) ^{134}I; Neutrons emission; 1 - pre; 2 - post

$\sigma_{\gamma f} = 90.51, 46.67, 12.68$ mb with prompt neutrons mean values $\overline{\nu}_{pr} = 3.74, 4.68, 5.20$, respectively.

Yields for ^{132}Sb and ^{134}I isotopes produced in the photofision of ^{238}U are represented in Fig. 2c) and 2d), before and after neutrons emission. These results are obtained with standard Talys input. For ^{135}I or ^{135}Xe isotopes it is necessary to increase Talys precision for yields and cross sections calculations.

At Microtron MT - 25 from JINR, isomer ratios for ^{130}Sb, ^{132}Sb, ^{134}I, ^{135}Xe were measured using a Bremsstrahlung X - ray source from neutrons threshold up to 16 MeV. Evaluations were realized using cross sections from Talys, relation (1), statistical approach from [10], [12] and incident flux from expression (2). Comparison between experimental and theoretical isomer ratios are given in Table 1.

For ^{130}Sb nucleus a well agreement was obtained. For ^{135}Xe further analyses are necessary. For ^{134}I and ^{132}Sb nuclei calculations will be done in the next study. The errors appear because the integrals from (1) are sums with a given step (1 keV).

TABLE I. – *Isomer ratios.*

Isomer	E_γ	R^{exp}	R^{Talys}
^{135}Xe	16	0.22 ± 0.03	0.43 ± 0.05
^{130}Sb	16	0.86 ± 0.15	0.95 ± 0.08
^{134}I	16	0.67 ± 0.13	–
^{132}Sb	16	0.79 ± 0.13	–

4. – Conclusions

Isotopes and isomer production in photofission of ^{238}U was investigated. Cross sections, mass distributions, dependence of average prompt neutrons multiplicity on fission fragment mass, isotopes production and isomer ratios were obtained for incident neutrons energy starting from 7 up to 25 MeV. Calculations were compared with existing experimental data.

New photofission experimental and theoretical data are necessary correlated with future computer simulations.

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