YIELDS OF ^{232}Th PHOTOFISSION PRODUCTS INDUCED BY BREMSSTRAHLUNG WITH AN ENERGY OF 14.8 MeV

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One promising direction in the study of the fission process is the investigation of fission-product yields under the action of photons, since the interaction of gamma quanta with nuclei is entirely electromagnetic, which simplifies interpretation of the obtained results and makes it possible to draw practically unambiguous conclusions about the role of the effects under study [1]. Of particular interest for experimental and theoretical studies is information on the yields of photofission products of the ^{232}Th nucleus, which lies at the boundary between pre-actinides and light actinides [2]. However, the experimental data currently available on the yields of ^{232}Th photofission products do not meet the requirements for their use in developing model concepts or for applied applications. It should be noted that existing experimental values of ^{232}Th photofission-product yields obtained using methods of the same type differ from one another even at similar excitation energies [2,3]. Therefore, their investigation remains a relevant task.

This work presents the results of the first experimental studies of 12 relative post-neutron yields of ^{232}Th photofission products initiated by bremsstrahlung radiation with an energy of 14.8 MeV.

The relative yields of ^{232}Th photofission products were determined by semiconductor gamma spectrometry of an unseparated mixture of fragments accumulated in aluminium foil [2].

During the experimental studies, metallic ^{232}Th foils were used (5 pieces, diameter 12 mm, thickness 2 μm), with masses ranging from 209 to 281 μg. Aluminium foils (collectors) 0.1 mm thick, placed directly against the ^{232}Th fissile targets, were used to accumulate photofission products during irradiation. Irradiation of the fissile assembly (which consisted of five ^{232}Th discs and five layers of aluminium foil) was carried out on the electron accelerator of the Institute of Electron Physics of the National Academy of Sciences of Ukraine, the M-30 microtron (electron energy = 14.8 MeV, average beam current ~4 μA). A tantalum converter 1 mm thick, positioned 22 mm from the exit window (titanium, thickness 50 μm) of the electron extraction unit, was used to generate bremsstrahlung radiation. The fissile assembly was installed perpendicular to the beam axis at a distance of 50 mm from the converter. The irradiation time of the fissile assembly varied from 30 min to 120 min. The time parameters (irradiation, cooling and measurement times) were selected taking into account the half-lives of the investigated photofission products and their precursors in the isobaric chain. After completion of fragment accumulation by the aluminium collectors, their gamma activity was measured using HPGe and Ge(Li) semiconductor detectors (with volumes of 150 and 100 cm^3, respectively [2]) from 0.25 to 120 hours after the end of irradiation. The duration of individual measurements varied from 0.5 to 2 hours.

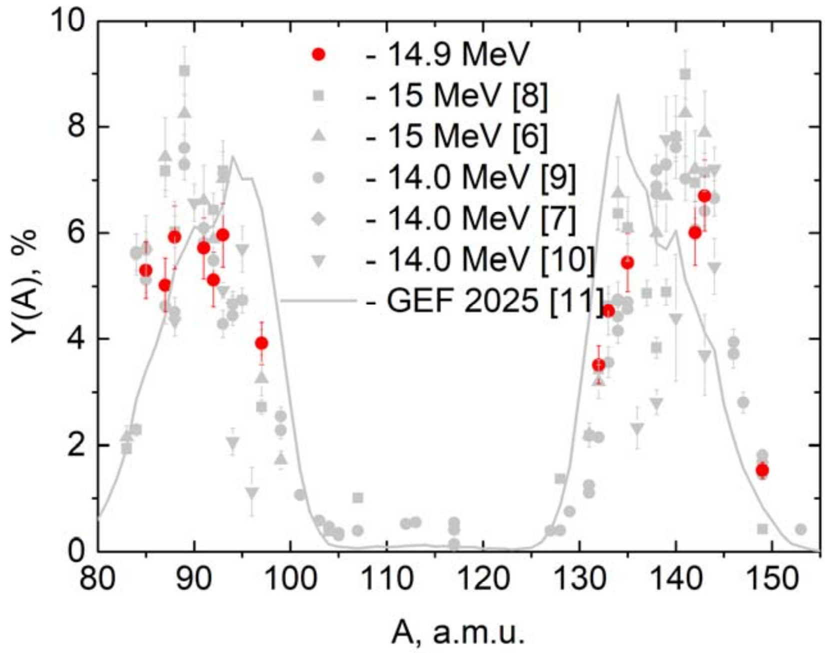
The nuclear Monte Carlo code "GEANT4 10.7" [4] was used to simulate the spectra of bremsstrahlung photons, residual electrons and photoneutrons (as a function of energy, normalised to one electron). The input parameters used in the calculations almost completely reproduced the geometrical dimensions (structural features) of the electron extraction unit [2] and the activation scheme for fissile nuclei implemented on the M-30 microtron electron accelerator. In the modelling, the geometrical dimensions of the output electron beam were taken into account: shape - ellipse, semi-axis dimensions - 22 and 6 mm, thickness - 50 μm.

As a result of the simulations carried out, the energy spectra of particles (bremsstrahlung photons, residual electrons and secondary photoneutrons) incident on the fissile target and their integral values were calculated. The integral values of bremsstrahlung photons, residual electrons and photoneutrons, normalised to one electron, are: 7.99E-2 γ/e (> 6 MeV - 9.21E-3 γ/e), 1.73E-2 e/e (> 6 MeV - 1.53E-2 e/e) and 7.38E-8 n/e neutrons. The obtained results were used to estimate the contribution of product yields from accompanying nuclear reactions (^{232}Th(γ,n)^{231}Th → ^{231}Th(γ,f), ^{232}Th(e,f) and ^{232}Th(n,f)) to the yields of 232Th photofission products. The analysis indicates that product yields from accompanying nuclear reactions generated by photons, residual electrons and photoneutrons have no effect on the accuracy of the final results.

The value of the average excitation energy of the fissile nucleus ^{232}Th* was 10.89 MeV.

As a result of the experiment, the relative (cumulative) yields of 12 ^{232}Th photofission products were measured for the first time^{85m}Kr (151.2 [75.2]), ^{87}Kr (402.6 [50.0]), ^{88}Kr (196.3 [26.0]), ^{91}Sr (1024.3 [33.0]), ^{92}Sr (1383.9 [90.0]), ^{97}Zr (743.4 [50.0]), ^{132}Te (228.2 [88.0]), ^{133}I (529.9 [87.0]), ^{135}I (1260.4 (28.7)), ^{142}La (641.3 (47.4)), ^{143}Ce (293.3 (42.8)), ^{149}Nd (211.3 (25.9)). The energies of the analytical gamma lines (keV) are given in round brackets, and their intensities (%) in square brackets. Product yields were determined relative to the yield of ^{133}I. The total uncertainty of the relative product yields exceeded 10%.

The measurement results are shown in the figure by red circles. For comparison, the same figure presents existing data on post-neutron yields of ^{232}Th photofission products at similar energies [6-10]. In addition, the line shows the results of modelling performed by the authors (using the nuclear Monte Carlo code GEF 2025/1.3 [11]) of the mass distribution of post-neutron product yields for the fissile nucleus ^{232}Th* at an excitation energy of ~11 MeV.



The obtained results agree with existing experimental data at similar energies within the experimental uncertainties and complement them.

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