

PRODUCT YIELDS FOR THE PHOTOFISSION OF ^{241}Am WITH BREMSSTRAHLUNG AT 14.5 MeV ENERGY

O.O. Parlag, V.V. Pyskach, A.I. Lengyel, A.N. Gomonai, E.V. Oleinikov, I.V. Pylypchynets

Institute of Electron Physics, National Academy of Sciences of Ukraine, Uzhgorod, Ukraine

The yields of actinide fission fragments (products) are among the principal parameters characterising the decay mechanism of excited nuclei. The experimental data currently available on the yields of photofission products of minor actinides in the energy region of first-chance fission (without prior emission of pre-fission neutrons) do not meet the requirements for their use in developing model concepts and in applied applications in nuclear engineering. This is especially true for the actinide ^{241}Am , for which experimental data on fragment yields are virtually absent [1].

This work presents the results of the first experimental studies of 16 relative post-neutron (cumulative) yields of ^{241}Am photofission products initiated by bremsstrahlung photons with an energy of 14.5 MeV.

The relative yields of ^{241}Am photofission products were determined by semiconductor gamma spectrometry of an unseparated mixture of fragments accumulated in aluminium foil [2,3]. Irradiation of the fissile target (an active ^{241}Am layer with a diameter of 11 mm was deposited on a disc-shaped substrate with a diameter of 24 mm and a thickness of 1 mm, made of 12X18H10T stainless steel; the isotopic content of ^{241}Am was $> 99\%$) 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, at an initial electron energy of 14.5 MeV and an average beam current of $\sim 5 \mu\text{A}$. Bremsstrahlung radiation was generated by a tantalum converter 1 mm thick. A filter, namely a cylindrical lithium tetraborate ($\text{Li}_2\text{B}_4\text{O}_7$) single crystal with a diameter of 30 mm and a height of 19 mm, placed directly against the tantalum converter, was used to purify the bremsstrahlung beam from residual electrons and secondary photoneutrons. An aluminium ring (inner diameter 11 mm, outer diameter 14 mm, thickness 0.5 mm) was used to fix the aluminium foil on the ^{241}Am sample. The maximum activation time was 4 hours.

After completion of the accumulation of fission products by the aluminium collector, their gamma activity was measured using HPGe and Ge(Li) semiconductor detectors (with volumes of 150 and 100 cm^3 , respectively [3]). The duration of individual measurement series varied from 0.08 to 4.5 hours. Identification of ^{241}Am photofission products was carried out by the energies of their characteristic gamma lines, taking into account their half-lives and, additionally, their precursors in the isobaric chains. Irradiation, cooling and measurement times were also taken into account. The calculations used nuclear-spectroscopic data (gamma-quantum energies, gamma-line intensities, half-lives of the products formed and of their precursors in the isobaric chain) from the NNDC nuclear data library (USA) [4].

The GEANT4 Monte Carlo computational code [5] was used to model the irradiation process of ^{241}Am . The input parameters used in the calculations reproduced the technical parameters of the M-30 microtron (the electron extraction unit into air) [3] and the irradiation scheme of the fissile assembly.

As a result of the calculations, the influence of the structural elements of the activation scheme (converter, filter and stainless-steel substrate) on the final energy spectra of particles (bremsstrahlung photons, residual electrons and photoneutrons) interacting with the experimental ^{241}Am sample was established. The integral flux values of bremsstrahlung photons, residual electrons and secondary photoneutrons present in the bremsstrahlung beam, normalised to one electron and incident on the ^{241}Am sample, are: $2.727\text{E-}2$ photons (with energy $> 6 \text{ MeV} - 3.29\text{E-}3$), $1.44\text{E-}3$ electrons (with energy $> 6 \text{ MeV} - 2.819\text{E-}5$) and $2.7\text{E-}8$ photoneutrons. Thus, 90.63% of the photons (with energies $> 6 \text{ MeV}$) from the generated bremsstrahlung beam and 0.57% of secondary electrons (with energies $> 6 \text{ MeV}$) interact with the ^{241}Am sample.

The filter made of $\text{Li}_2\text{B}_4\text{O}_7$ transmits 90.37% of bremsstrahlung photons (with energies from 0 to 14.5 MeV) and 94.77% of those with energies $> 6 \text{ MeV}$. At the same time, the filter absorbs 63.8% of residual electrons over the entire energy spectrum and 99.37% of those with energies $> 6 \text{ MeV}$.

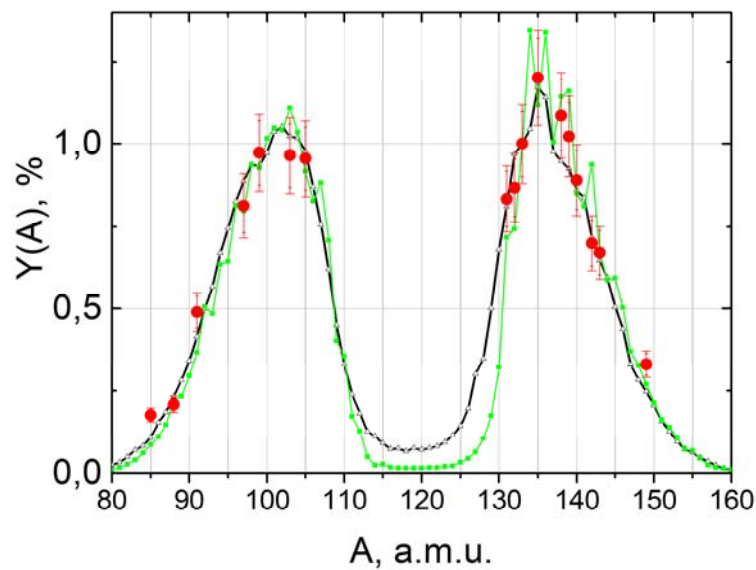
The obtained results were used to estimate the contribution of product yields from accompanying nuclear reactions ($^{241}\text{Am}(\gamma, n)^{240}\text{Am} \rightarrow ^{240}\text{Am}(\gamma, f)$ and $^{241}\text{Am}(n, f)$) to the yields of ^{241}Am photofission products. The calculations used cross-section values for photonuclear ((γ, n) , (γ, f)) and neutron ((n, f)) reactions from the ENDF database [6]. The numerical value of the number of ^{240}Am nuclei formed via the (γ, n) -reaction channel during an irradiation time of 4 hours is $5.92\text{E-}5$; the numbers of photofission events of ^{240}Am and ^{241}Am nuclei and neutron fission of ^{241}Am during irradiation are $2.118\text{E-}29$, $7.12\text{E-}9$ and $5.838\text{E-}13$,

respectively. All numerical values obtained in the calculations were normalised to one initial electron. The analysis indicates that product yields from accompanying reactions have no effect on the accuracy of the final results.

The value of the average excitation energy of the fissile nucleus $^{241}\text{Am}^*$ was 11.32 MeV.

As a result of the experimental studies carried out, the relative (cumulative) yields of ^{241}Am photofission products were measured for the first time: $^{85\text{m}}\text{Kr}$, ^{88}Kr , ^{91}Sr , ^{97}Zr , ^{99}Mo , ^{105}Ru , ^{131}I , ^{132}Te , ^{133}I , ^{135}I , ^{138}Cs , ^{139}Ba , ^{140}Ba , ^{142}La , ^{143}Ce , ^{149}Nd . The product yields were determined relative to the yield of ^{133}I .

In the figure, the experimental values of the relative yields of ^{241}Am photofission products are shown by red circles. In the same figure, the black line with triangles shows the results of modelling (using the nuclear Monte Carlo code GEF 2025/1.3 [7]) the mass distribution of post-neutron product yields for the fissile nucleus $^{241}\text{Am}^*$ at an excitation energy of ~ 11 MeV (the numerical values of the modelled yields were normalised to the yield $Y(A=133) = 5.53\%$ for correct comparison with the experimental results). For comparison, the same figure also presents the recommended values of product yields from ^{241}Am fission by fast neutrons (the numerical values are normalised to the yield $Y(A=133) = 5.82\%$).



The total uncertainty of the relative product yields was estimated taking into account the statistical uncertainty of the peak intensity of the product gamma line, analysis of time dependences, the scatter of values averaged over individual measurements, and the uncertainty of interpolated efficiency values and nuclear physical constants. The total uncertainty in determining the relative yields of ^{241}Am photofission products did not exceed 12%.

The obtained values of the relative yields of ^{241}Am photofission products agree with the results of calculations using the GEF code within the experimental uncertainties and with the recommended values for fission by fast neutrons.

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