Contribution ID: **248** Type: **Oral report**

SPONTANEOUS AND INDUCED TERNARY AND QUATERNARY FISSION AS A VIRTUAL PROCESSES

Tuesday, 21 September 2021 13:50 (25 minutes)

In experimental papers [1, 2] the yields, angular and energy distributions of the pairs of light third and fourth particles, such as α-particles pair (α_1, α_2), were obtained for the spontaneous quaternary fission of the nuclei ^{252}Cf, ^{248}Cm and for the induced by thermal neutrons quaternary fission of compound nuclei ^{234}U, ^{236}U. Using the theoretical concepts [3-5] of ternary and quaternary fission as virtual processes [6], we consider spontaneous quaternary fission from the ground states of even-even actinides [1,2] with the sequential emission of two α-particles from nuclei A and (A-4) with the formation of the intermediate nuclei $(A-4)$ and $(A-8)$ in the virtual states, and the subsequent binary fission of the residual fissile nucleus $(A-8)$ into light and heavy fission fragments. Induced quaternary fission occur from the excited states of compound nucleus A, which is formed when the neutron is captured by the target nucleus, and after that the process goes in the same way as in analogous spontaneous fission. These α-particles, in contrast to the α-particles that fly out in the sub-barrier α-decay from ground states of the studied nuclei A and $(A-4)$, when the energies $Q^A_{\alpha_1}$ and $Q^{(A-4)}_{\alpha_2}$ of this decays are close to $4-6$ MeV, are long-ranged, since their asymptotic kinetic energies $T_{\alpha_1} \approx 16$ MeV and $T_{\alpha_2} \approx 13$ MeV, are markedly larger than energy values $Q^A_{\alpha_1}$ and $Q^{(A-4)}_{\alpha_2}$.
The quaternary fission yield $N^A_{\alpha\alpha f}$ normalized to the yield of the binary fission of the nucleus A for spontaneous fission using the formula [4] for the virtual quaternary fission width of nucleus A can be presented as
$N^A_{\alpha\alpha f} = \frac{1}{(2\pi)^2}\int\int \frac{(\Gamma^A_{\alpha_1})^{(0)}(T_{\alpha_1})(\Gamma^{(A-4)}_{\alpha_2})^{(0)}(T_{\alpha_2})(\Gamma^{(A-8)}_f)^{(0)}}{(Q^A_{\alpha_1}-T_{\alpha_1})^2(Q^{(A-4)}_{\alpha_2}-T_{\alpha_2})^2(\Gamma^A_f)^{(0)}} dT_{\alpha_1}dT_{\alpha_2}$, (1)
where index (0) denotes to the configuration of fissile nuclei, corresponding to the appearance of two deformed fission prefragments, connected by the neck; $(\Gamma^A_{\alpha_1})^{(0)}$ and $(\Gamma^{(A-4)}_{\alpha_2})^{(0)}$ are the width of the α-emission from the fissile nucleus neck. In (1) the ratio of the binary fission widths $(\Gamma^A_f)^{(0)}/(\Gamma^{(A-8)}_f)^{(0)} \approx 1$. In the case of the induced quaternary fission the energy Q^A_α should be replaced by $Q^A_\alpha + B_n$, where B_n is neutron binding energy in compound nucleus A. Using Gamov formulae for $(\Gamma^A_{\alpha_1})^{(0)}$ and $(\Gamma^{(A-4)}_{\alpha_2})^{(0)}$, taking into account the fact that the probabilities of formation of the α_1 and α_2 particles are close to each other and the neck radius r^A_{neck} before the emission of α_1-particle does not differ from the neck radius $r^{(A-4)}_{neck}$ before the emission of the second α_2-particle, the specified estimation of the yield $N_{\alpha\alpha f}$ for spontaneousand induced quaternary can be derived.

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Session Classification: Section 2. Experimental and theoretical studies of nuclear reactions

Track Classification: Section 2. Experimental and theoretical studies of nuclear reactions.