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INVESTIGATION OF THE PROPERTIES OF THE SPONTANEOUSLY FISSIONING ISOMER ^{241}Pu IN THE REACTION (γ,n)

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It is known that quite a number of experimental data (spontaneously fissioning isomers /1/, modulation of subbarrier resonances /2/, angular distribution of fragments near the threshold /3/ etc.) does not enter into the scope of earlier concepts of the fission barrier. All these phenomena manifest themselves in the subbarrier region and reflect therefore a structure of the fission barrier for heavy nuclei. Qualitatively, the character of the above phenomena could be explained by the two-humped barrier hypothesis /4/. However, experimental results obtained by now do not allow to perform a joint analysis of different subbarrier effects though these considered separately provide a possibility to determine various characteristics of such a barrier. Of interest is the comparison of these parameters (height of the first and second barriers, depth of the second minimum) related to the same nucleus but obtained when analysing the data on various classes of subbarrier phenomena. However, experimental data of this kind on one and the same nucleus are not available. The isotope ^{241}Pu with which the modulation of subbarrier fission resonances in the reaction (n,f) /5/ and the existence of a spontaneously fissioning isomeric level in this nucleus /6/ have been discovered for the first time may serve as one of such nuclei. This nucleus could also be produced via the reaction $^{242}Pu(\gamma,n)\,^{241}Pu$. As was shown in the previous paper /7/, the study of the (γ,n) reaction resulting in the formation of spontaneously fissioning isomers permits establishing with a rather good accuracy an excitation energy of such a state.

This paper presents analysis of the investigation of this reaction on the nucleus ^{242}Pu.

The measurements were performed in the microtrone of the Physical Problem Institute of the USSR Academy of Sciences. The method was described in ref./7/.

To detect fission fragments a spark counter was employed; a target thickness was 0.9 mg/cm^2. To avoid discharges in the counter due to quanta which caused a big dead time of the counter ($\approx$ 500 μ sec), the voltage on its electrodes during the pulse was decreased. Thus the detector was insensitive to fragments of the prompt fission and to intense flux of γ-quanta. The voltage on the counter was fully reproduced in about 2 μ sec after the end of γ-quanta pulse and fragments of delayed fission were detected. The isomer formed was identified by its half-life. The pulse time distribution shown in Fig. 1 gives the value of the half-life $T_{1/2} = 23 \pm 1 \mu$sec. The calibration of the counter efficiency was made by the spontaneous fission of nuclei of ^{242}Pu target.

Fig. 2 presents the delayed fission as a function of a boundary energy of γ-quanta (or of an electron energy). The calculation of excitation function for determining its threshold for the reaction $^{242}Pu(\gamma, n)$ $^{241mf}Pu$ was made as follows:

The relative integral yield of delayed fission was calculated by the formula:

$$Y(E_0) = k \int_{E_n}^{E_0} \sigma_f(E_\gamma)\left[1-\exp\left(-\frac{E_\gamma - E_n}{T}\right)\right]\Phi(E_\gamma, E_0)\, dE_\gamma ,$$

where E_0 - the electron energy,

E_γ - the quantum energy,

$\Phi(E_\gamma, E_0)$ - the bremsstrahlung spectrum function,

E_n - the reaction threshold,

T - the nuclear temperature,

σ_f - the cross section of photofission obtained from the measured yield of prompt fission. This cross section makes a certain part of the cross section of the compound-nucleus formation.

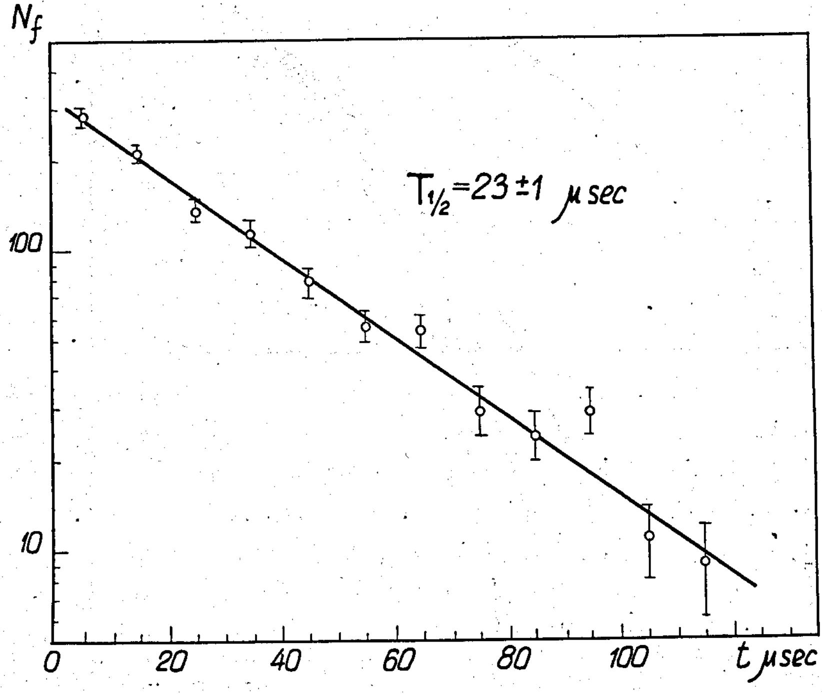

Fig.1. Delayed fission fragment distribution as a function of time when bombarding ^{242}Pu with γ -quanta.

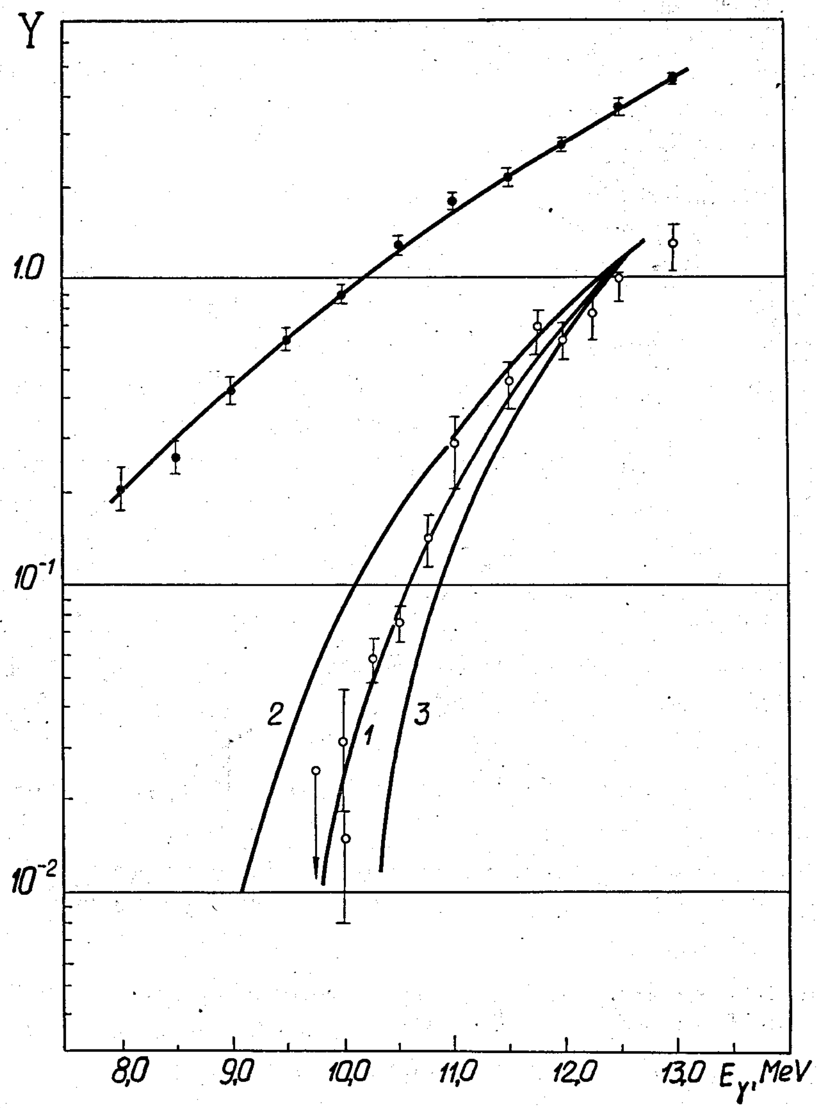

Fig.2. Dependence of the fragment yield of the prompt (♦) and delayed (ϕ) fission Y against the boundary energy of γ -quanta. E_γ in the reaction $^{242}Pu + \gamma$.

I – the calculated curve at T = 1.5 MeV and the threshold energy E_n = 9.1 MeV,
2,3 – at T = 1.5 MeV , E_n = 8.3 MeV (2) and E_n = 9.5 MeV(3).

K –the coefficient involving the experimental geometry and the quantity of the target material.

The curves of integral yield were calculated at different magnitudes of the reaction threshold in the range of 8.3 to 9.5 MeV. The best agreement, as seen in Fig. 2, was obtained at $E_n = 9.1 \pm 0.15$ MeV.

In these calculations $T = 0.7$MeV and $T = 1.5$ MeV and the difference between the obtained curves is not very large.

The energy of isomeric state of ^{241}Pu was determined as a difference of the thresholds of reactions resulting in the isomeric (9.10 ± 0.15 MeV) and ground (6.21 ± 0.02 MeV) states. This difference amounted 2.9 ± 0.15 MeV.

At 12.5 MeV electron energy the ratio of yields of the delayed ($Y_{\gamma i}$) and prompt ($Y_{\gamma f}$) fission was also determined.

The voltage on the counter was not decreased during the pulse. The radiation intensity was diminished up to a value at which there were no discharge because of γ -rays.

The ratio $Y_{\gamma i} / Y_{\gamma f} = (1.15 \pm 0.25) \cdot 10^{-3}$, hence the cross section ratio at this energy $\sigma_{\gamma i} / \sigma_f = (2.5 \pm 0.5) \cdot 10^{-3}$ was calculated with the account of the bremsstrahlung spectrum of γ -radiation.

The cross section σ_f was determined from the measured integral yield of the prompt fission fragments (Fig. 2) using the "photon difference" method. At 12.5 MeV energy we obtained $\sigma_f = 135$ mbarn that is the value $\sigma_{\gamma i} = (3.4 \pm 0.7) \cdot 10^{-28} cm^2$. The measured cross section allowed us to determine also the value $\Gamma_n / \Gamma_f = 2.7$.

It follows from this estimate and from the magnitude of $\sigma_{\gamma i} / \sigma_f$ that the isomeric ratio $\sigma_{\gamma i} / \sigma_{\gamma n} = (9 \pm 3) \cdot 10^{-4}$.

In the two-humped barrier model there the isomeric state is interpreted as a low state in the second well. Thus its energy is the difference of energies E^* between the second and the first minima of potential energy.

The isomeric ratio $\sigma_{\gamma i} / \sigma_{\gamma n}$ in the same model corresponds to that of the level densities in the second and first wells, the level density in the first well being correspondent to the neutron binding energy and in the second one– to the energy at which the fission width (Γ_f) is comparable to the radiation one ($\Gamma_\gamma \approx 0.02$ eV).

In ref.[8] there is the ratio of the level densities in the first and second wells revealed from the analysis of subbarrier resonances[5] at the 5.5 MeV neutron binding energy in ^{241}Pu. It turned out to be of about $2 \cdot 10^{-2}$ that is 10 times greater than the estimate obtained in our work. This difference seems to be due to the fact that when analysing isomeric ratio the level densities in the second well should be taken at a somewhat lower energy when $\Gamma_f \approx \Gamma_\gamma$. The analysis of the fission resonances in the same nucleus ^{241}Pu provides 1.7 MeV [8] to 2.1 MeV[5] for ΔE. These data differ considerably from the isomeric state energy ($\approx$ 2.9 MeV) measured in our experiment. Two assumptions can be made on such a disagreement (within the framework of the two-humped barrier model):

(i) the isomeric state observed is located higher (to about 800 keV) than the bottom of the second well;

(ii) the parameter of the level densities from strongly deformed states has no abnormally big value (≈ 40).

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