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PRODUCTION OF SPONTANEOUSLY FISSIONING ISOMERS ^{242}Am AND ^{244}Am AT THE SLOW NEUTRON CAPTURE

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The spontaneously fissioning isomers, discovered at the Laboratory of Nuclear Reactions of JINR /1/, have unusual properties: a very high probability of spontaneous fission and strong forbiddenness for the γ -transitions. Hypothesis of large deformation of a nucleus in the isomeric state /2/ was proposed to explain these unusual properties. The spontaneous fission is the only observable mode of the decay of these isomers. Therefore the source of information about these states properties is the analysis of nuclear reactions of fissioning isomer production. This analysis is most reliable in the case of simple reactions, for example, of reactions of slow neutron capture. As a rule, the energy, spin, parity, partial widths of obtained at neutron capture levels are known.

It is interesting to compare the cross sections of fissioning isomer production for various states excited at neutron capture, especially for the states with different fission widths. The states of ^{242}Am and ^{244}Am excited at the thermal neutron capture are placed about 0.9 MeV lower that the fission barrier, have the same spin and parity (2^- or 3^-), but very different partial widths for fission (2.10^{-4} ev for ^{242}Am and $< 10^{-5}$ ev for ^{244}Am).

It was shown in our previous paper[3] that the fissioning isomer ^{242}Am was produced at thermal neutron capture with cross sections of about 10^{-28} cm^2. These investigations were extended with using more intense neutron flux: the measurements of cross sections of fissioning isomers ^{242}Am and ^{244}Am production for thermal and higher neutron energies were performed.

The isochronous cyclotron of the Laboratory of Nuclear Reactions of JINR was used to produce the intense pulsing beam of neutrons[4]. The experimental equipment is shown in Fig. 1. A thick berrylium target was irradiated with deuteron beam with the energy of deuterons of 20 MeV and the mean intensity of about 25 μ A. The intensity of neutron flux was about 10^{12} neutron per second. The neutrons were slowed down in the iron and then in the paraffin.

The neutron spectrum inside the paraffin is shown in Fig.2. This spectrum was determined with the activation method employing samples of In , Au , J and Al with and without cadmium filters. The yields of radioactive capture reactions and those ^{115}In(n,n′)^{115m}In , ^{27}Al(n,p)^{27}Mg , ^{27}Al(n,α)^{24}Na were measured. The neutron spectrum determined by this method coincides with the calculated one.

The cadmium and boron filters were used to measure the cross sections of the fissioning isomer formation for various regions of the neutron spectrum. These filters cut various parts of spectrum in the region of low energy of neutrons.

Fission fragments were detected with the spark counter[5] filled with the mixture of N_2 (10 tor) and He (750 tor). Targets of

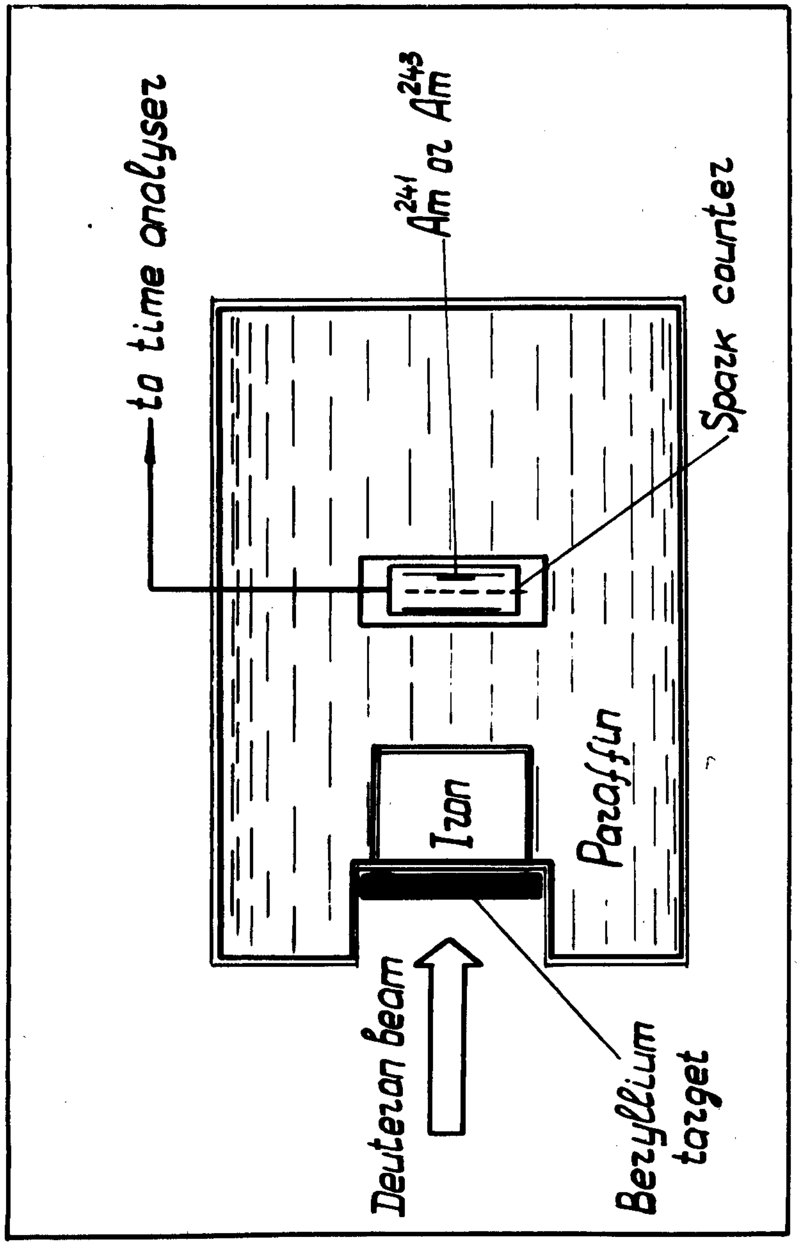

Fig.1. Schematic diagram of experimental set-up.

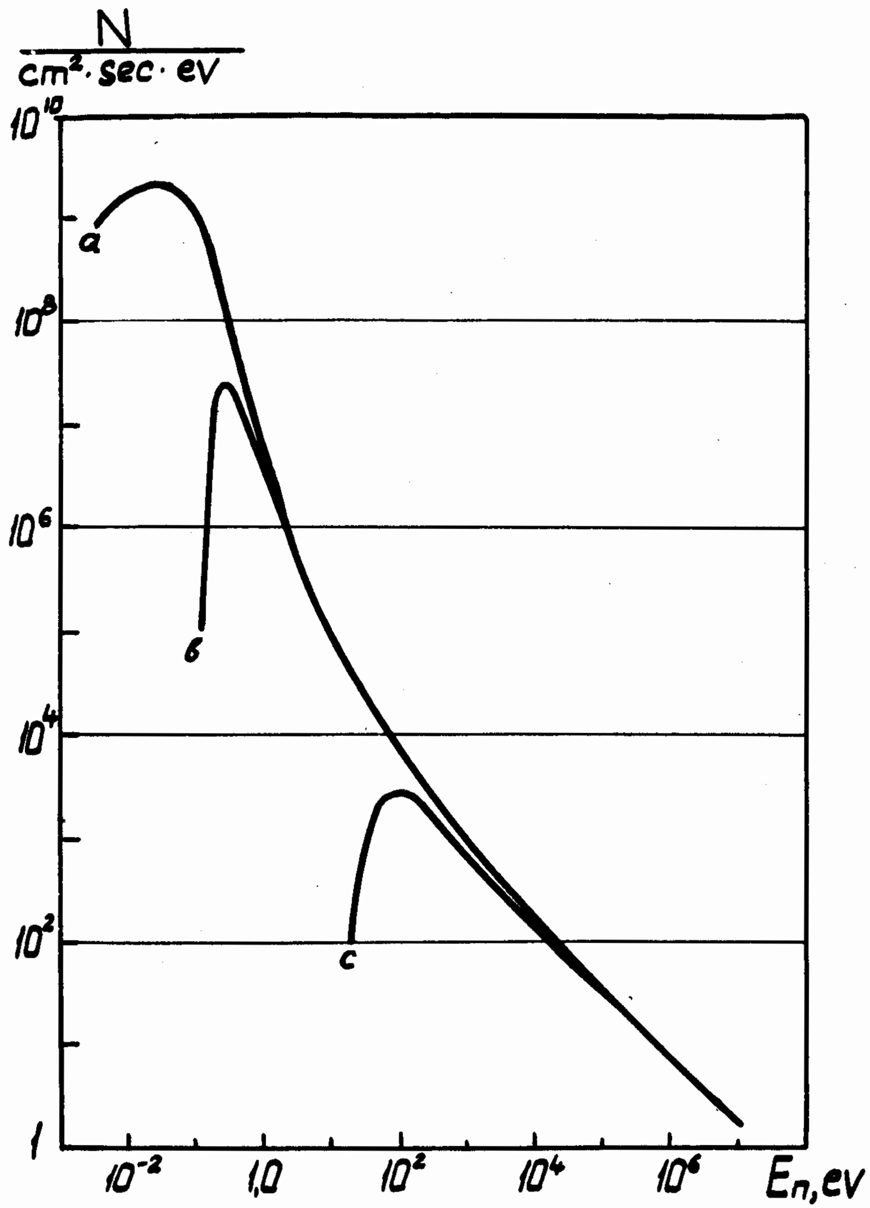

Fig.2. Neutron spectra

a - without filters

b - with cadmium filter (1 mm)

c - with cadmium (1 mm) and boron (5 mm) filters.

^{241}Am and ^{243}Am of 0.4 $\frac{mg}{cm^2}$ in thickness and 12 cm^2 in area were used. The enrichment of both targets was about 98%. These targets were placed inside the counter. Despite a very high α -radiation of the targets the counter was insensitive practically to α -particles (α -radiation background was about 4-5 counts per hour). The spark counter was connected with an electronic circuit recording a prompt fission fragment number and a time distribution of delayed fission fragments occuring between beam bursts. The measured time spectra of delayed fission fragments showed the known half-lives of isomers ^{242}Am (14 msec) and ^{244}Am (1.1 msec).

The ratios of yields of delayed and prompt fission for three neutron spectra (without filter and with cadmium and boron filters) were determined. These neutron spectra are shown in Fig.2. The ratios of cross sections of isomer production (σ_i) and of prompt fission (σ_f) for neutron absorption spectra were obtained from comparison of yields with and without the filter. These cross section ratios corrected for a dead time of the spark counter and decay of fissioning isomers, are listed in Table I. The cross sections of fissioning isomer formation were deduced using the known prompt fission cross sections and the measured ratios. In the case of ^{243}Am the prompt fission with thermal neutrons were not observed and the upper limit of isomer production cross section was estimated from the measured flux of thermal neutrons. For the last neutron spectrum (the measurements with boron filter) the principal part of observable yield of prompt fission and, probably, delayed fission was produced with neutrons with the energy of around 1 MeV. The cross section ratio measured for this spectrum is close to that presented in paper /6/, obtained for about 1 MeV neutron energy. In our previous paper/3/ the ratio $\frac{\sigma_i}{\sigma_f}$ was measured for the broad neutron spectrum. Therefore this ratio is less than one obtained in the present measurements for the thermal neutron.

The correlation of prompt and delayed fission is seen in the table. Both processes are observed for ^{241}Am and are not observed at thermal neutron irradiation of ^{243}Am. It is possible to explain this correlation on the basis of the two-hamped fission barrier hypothesis /7/. The ground and isomeric states are assumed to be separated with the potential barrier (Fig.3). If the second well is deep enough, the fission and the fissioning isomer production will be two-stage processes. At the two-stage mechanism of reaction the ratio of isomer formation to fission is determined by the equation /8/ :

$$\frac{\sigma_i}{\sigma_f} = \frac{\Gamma_{\gamma_2}}{\Gamma_{f_2}}, \qquad (1)$$

where Γ_{γ_2} and Γ_{f_2} are the radiation and fission partial widths for the levels in the second well. The observed correlation of fission and isomer formation is explained with the same first stage of both processes (penetration through the first barrier). The probability of tunneling through the first barrier is enhanced, when the excitation energy coincides with one of the vibrational states in the second well /9/.

It is seen from the equation (1) that the ratio $\frac{\sigma_i}{\sigma_f}$ falls with neutron energy increasing (the fission width grows, but radiation widths remain nearly constant). It is possible to estimate the fission width for the levels in the second well using the equation (1), the measured ratio $\frac{\sigma_i}{\sigma_f}$ and proposing the same radiation width, as in the first well (≈ 0.03 ev). At the excitation energy near to the neutron binding energy (5.5 MeV) $\Gamma_{f_2} \approx 300$ ev, and it is close to

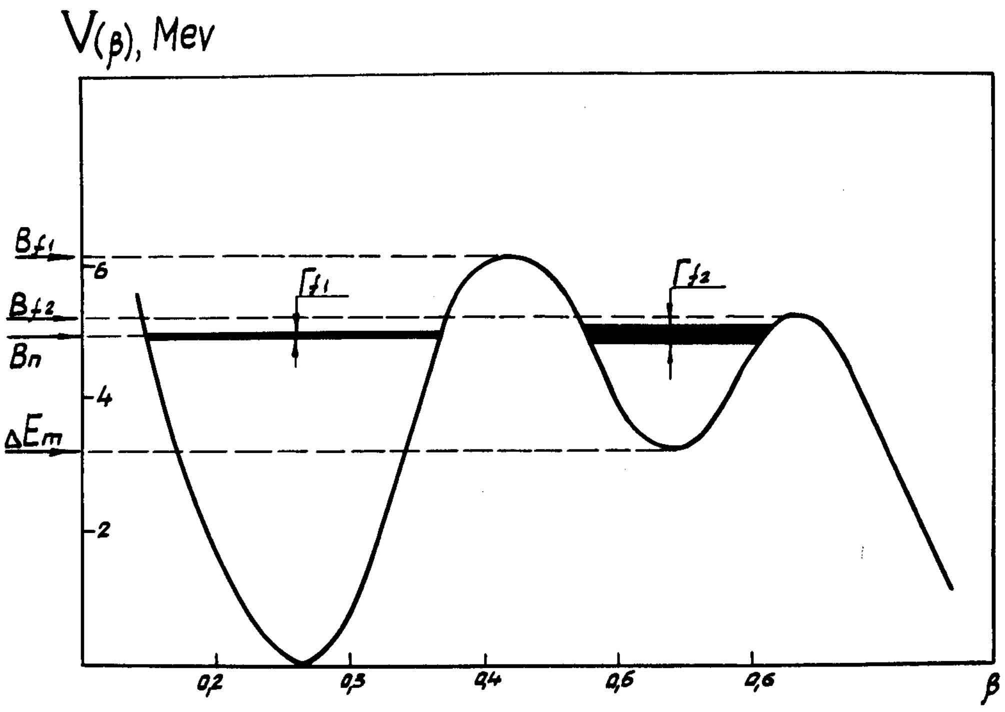

Fig.3. Potential energy (V) as a function of nuclear deformation (β)
ΔE_m -isomeric level energy
B_{f_1} -height of the first barrier
B_{f_2} -height of the second barrier
B_n -neutron binding energy
Γ_{f_1} - fission width of levels in the first well
Γ_{f_2} - fission width of levels in the second well

about 100 ev, obtained in the paper /9/ at the subbarrier resonance analysis. The levels with this fission width are placed, probably, near the top of the second barrier.

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Table I

Cross sections of prompt fission and fissioning isomer production

E_n ev	^{241}Am + n			^{243}Am + n		
	σ_i/σ_f	σ_f barns	σ_i μbarns	σ_i/σ_f	σ_f barns	σ_i μbarns
<0.2	$(1.0 \pm 0.3) \cdot 10^{-4}$	3.13 x/[10]	300 ± 100		<0.05 x/[10]	<10
0.2–20	$(0.8 \pm 0.3) \cdot 10^{-4}$	0.5 xx/[10]	40 ± 15			
> 20	$(0.2 \pm 0.06) \cdot 10^{-4}$	1.2 xxx/[11]	24 ± 6	$(0.3 \pm 0.1) \cdot 10^{-4}$	1.4 xxx/[10]	42 ± 15

x/ cross section for the thermal neutrons

xx/ mean cross sections for the neutron spectrum 0.2-20 ev.

xxx/ cross section for the neutrons with energy of about 1 MeV.