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

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Abstract: The spontaneously fissioning isomers ^{242}Am and ^{244}Am were produced by slow neutron capture. The cross sections of isomer production were measured at different neutron energies. The correlation between isomer formation and prompt fission was observed. This correlation is discussed on the basis of the two-humped fission barrier hypothesis.

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NUCLEAR REACTIONS ^{241,243}Am(n, γ), (n, f) $E = 0.2$-20 eV;
measured delayed, prompt fission σ ratios, (n) (fission fragment)-delay.
^{242,244}Am(SF-isomers) deduced $T_{\frac{1}{2}}$.

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. A hypothesis of a 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 the properties of these states lies in the analysis of nuclear reactions leading to the fissioning isomers. This analysis is most reliable in the case of simple reactions, for example, of thermal and resonance neutron capture. In several cases, the energy, spin, parity and partial widths of levels populated by neutron capture are known.

It is interesting to compare the cross sections for the production of fission isomers through various states excited in neutron capture, especially for states with different fission widths. The states of ^{242}Am and ^{244}Am excited by thermal neutron capture are about 0.9 MeV below the fission barrier and 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 [3]) that the fissioning isomer ^{242}Am is produced by thermal neutron capture with a cross section of about 10^{-28} cm^2. These investigations are extended by using a more intense neutron flux. Measurements of cross sections for the production of the fission isomers ^{242}Am and ^{244}Am with thermal and higher neutron energies are performed.

The isochronous cyclotron of the Laboratory of Nuclear Reactions of JINR was used to produce the intense pulsed beam of neutrons [4]). The experimental equipment is shown in fig. 1. A thick beryllium target was irradiated with a deuteron beam with an energy of 20 MeV and an average intensity of about 25 μA. The intensity of the neutron flux was about 10^{12} neutrons per second. The neutrons were slowed down in iron and paraffin.

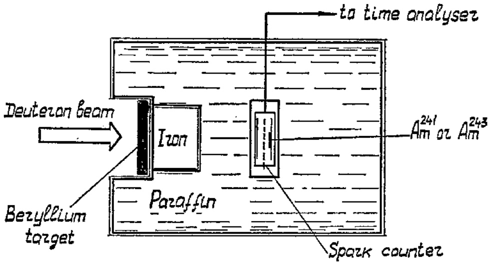

Fig. 1. Schematic diagram of experimental set-up.

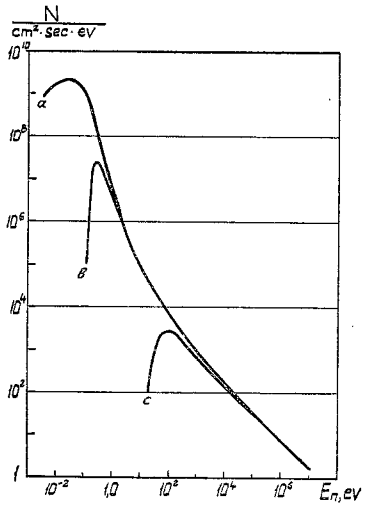

Fig. 2. Neutron spectra, a - without filters, b - with cadmium filter (1 mm), c - with cadmium (1 mm) and boron (5 mm) filters.

The neutron spectrum inside the paraffin is shown in fig. 2. The spectra were determined by the activation method, employing samples of In, I and Al with and without cadmium filters. The yields of the radioactive capture reactions and of ^{115}In(n, n')^{115m}In, ^{27}Al(n, p)^{27}Mg and ^{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 isomers formation for various regions of the neutron energies. These filters cut out various parts of the low-energy spectrum.

Fission fragments were detected with a spark counter 5) filled with a mixture of N_2(10 torr) and He(750 torr). Targets of ^{241}Am and ^{243}Am of 0.4 mg/cm^2 thickness and with an area of 12 cm^2 were used. The enrichment of both targets was about 98 %. These targets were placed inside the counter. Despite a very high α-radiation from the targets the counter was practically insensitive to α-particles (α-radiation background was about 4-5 counts per hour). The spark counter was connected with an electronic circuit recording the prompt fission fragments and the time distribution of the delayed fission fragments occurring between the beam bursts. The measured time spectra of delayed fission fragments showed the known half-lives for the isomers ^{242}Am (14 m sec) and ^{244}Am (1.1 m sec).

TABLE 1

E_n (eV)	^{241}Am+n			^{243}Am+n		
	σ_i/σ_f ($\times 10^{-4}$)	σ_f (b)	σ_i (μb)	σ_i/σ_f (1×0^{-4})	σ_f (b)	σ_i (μb)
0.2	1.0±0.3	3.13 a)	300±100		< 0.05 a)	< 10
0.2-20	0.8±0.3	0.5 a)	40± 15			
> 20	0.2±0.06	1.2 a,c)	24± 6	0.3±0.1	1.4 a,c)	42±15

a) Ref. 10). b) Ref. 11). c) Cross section for the neutrons with an energy of ≈ 1 MeV.

The ratios of yields of delayed and prompt fission for the three neutron spectra (without a 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 the dead time of the spark counter and the decay of fissioning isomers, are listed in table 1. The cross sections of the fission isomer formation were deduced using the known prompt fission cross sections and the measured ratios. In the case of ^{243}Am no prompt fission was observed after bombardment with thermal neutrons 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 the boron filter) the principal part of the observed yield of prompt fission and, probably, the delayed fission was produced by neutrons with an energy of ≈ 1 MeV. The cross-section ratio measured for this spectrum is close to that presented in ref. 6), obtained for about 1 MeV neutron energy. In our previous paper 3) the ratio σ_i/σ_f was measured for the broad neutron spectrum. Therefore this ratio is less than that obtained in the present measurements with thermal neutrons.

The correlation between prompt and delayed fission is seen from table 1. Both processes are observed for ^{241}Am and are not observed by thermal neutron irradiation of ^{243}Am. An attempt to explain this correlation on the basis of the two-humped fission barrier hypothesis 7) is made in the present paper. The ground state and isomeric state are assumed to be separated with a potential barrier (fig. 3). If the second well is deep enough, the fission and the fissioning isomer production can be described by a two-stage process. In the two-stage mechanism the ratio of isomer formation to fission is determined by the equation [8]:

$$\frac{\sigma_i}{\sigma_f} = \frac{\Gamma_{\gamma 2}}{\Gamma_{f_2}}, \tag{1}$$

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 could be explained by the identical 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]. If this probability is unlikely, then there is neither fission nor a spontaneously fissioning isomer observed as in the case of ^{243}Am.

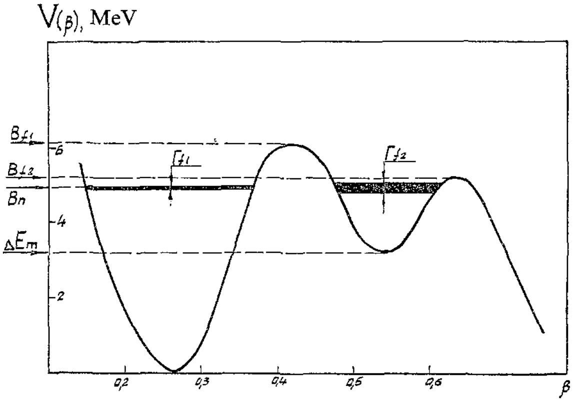

Fig. 3. Potential energy (V) as a function of nuclear deformation (β), where ΔE_m is the isomeric level energy, B_{f_1} is the height of the first barrier, B_{f_2} is the height of the second barrier, B_n is the neutron binding energy, Γ_{f_1} is the fission width of levels in the first well and Γ_{f_2}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

It is seen from eq. (1) that the ratio decreases with increasing neutron energy (the fission width increases but the radiation widths remain nearly constant). It is possible to estimate the fission width for the levels in the second well using eq. (1), the measured ratio σ_i/σ_f and proposing the same radiation width, as in the first well ($\approx$ 0.03 eV). At the excitation energy near to the neutron binding energy (5.5 MeV) $\Gamma_{\gamma_2} \approx$ 300 eV, and this is close to the value of 100 eV, obtained through a subbarrier resonance analysis [9]. The levels with this fission width are probably placed near the top of the second barrier.

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