The relative yields and half-lives of precursors of delayed neutrons in the fission ^{241}Am by fast neutrons.

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Abstract. At the present time, the most perspective processes, which could form the basis of the technology of transmutation of radionuclides, are the processes associated with using of nuclear reactors, as well as sub-critical systems with high neutron flux generated using charged particle accelerators [1]. The delayed neutrons have an important role in the safe management and kinetics of nuclear power plants. Therefore, the development of any of the above concepts of transmutation of nuclear waste requires the information on nuclear-physical characteristics of delayed neutrons for minor actinides in the reactor energy range of primary neutrons. In this paper the energy dependence of the relative delayed neutron yields and half-lives of their nuclear precursors in the fission ^{241}Am by neutrons in the energy range of 1-5 MeV was measured. The assembly of ^{3}He-counters in neutron moderator block was used as a detector. The measurements of decay curves of delayed neutron activity were carried out in a cyclic mode. The obtained decay curves of delayed neutron activity have been processed in order to obtain the values of the relative yields and half-lives of delayed neutron precursors. The energy dependence of the detection efficiency of neutron detector was obtained as a result of a series of measurements of spectra of monoenergetic neutrons.

Key Words: delayed neutron, Tandetron, ^{241}Am fission, nuclei precursors.

1. Experiment

The measurements were made with beams of protons and deuterons of the accelerator Tandetron (JSC “SSC RF – IPPE”). Generation of neutron beam was carried out by nuclear reaction T(*p,n*) and D(*d,n*). The basic experimental method employed in these experiments is based on cyclic irradiations of the ^{241}Am samples in a well defined neutron flux followed by the measurement of the time dependence of delayed neutron activity [2]. The variation of the sample irradiation times and the registration time of delayed neutrons can enhance the contribution of certain groups of delayed neutrons in the composite decay curve of the neutron activity. This circumstance makes possible to obtain more reliable information about the characteristics of individual groups of delayed neutrons. In the experiment we used a pneumatic transport system for transferring the sample from the irradiation position to the neutron detector. Two electromagnetic valves are responsible for the sample transportation route. The information on the sample location is obtained from two photodiodes and light sources installed on a flight tube at the sample irradiation position and the central point of the neutron detector. The time of sample transportation from the irradiation position to the neutron detector was approximately 150 ms that allowed to obtain information about the most short-lived groups of delayed neutrons.

The Faraday cup served as a device for switching on the ion beam to the accelerator target to start the irradiation of a fissionable sample and switching off the ion beam from the target at the beginning of the delayed neutron counting.

The boron counter of SNM-11 type at the operational potential of 650 V in the proportional mode of operation was chosen as the main detector counting unit. In general the neutron detector is an assembly of 30 boron counters distributed in polyethylene moderator along three concentric circles with diameters of 106, 160 and 220 mm. The outer diameter of moderator is 400 mm, its length is 300 mm. In the centre of the detector there is a through hole with diameter of 36 mm to install the sample flight tube. The detector is shielded against the neutron background by borated polyethylene, boron carbide powder and cadmium sheets. The main difficulty in carrying out of the experiment and processing the data was that the sample of ^{241}Am made of americium dioxide along with a large gamma-ray activity is a source of neutrons produced by the reaction O(α,n). Gamma rays were suppressed by lead cylindrical screen installed in the center of the neutron detector. Neutron background due to the reaction O(α,n) significantly exceeded the background of the experimental hall of the accelerator (the hall plus a sample) and was about 130 counts per second. This is more than two or three order times larger than the value of background that took place, for example, when the characteristics of delayed neutrons on ^{232}Th, ^{233}U were measured (see Table 1).

TABLE 1: Comparison of the background conditions of the experiment with nuclides ^{232}Th, ^{233}U and ^{241}Am. (t – delayed neutron counting interval (s), b – intensity of neutron background (neutron/s), Σ(Nd) – number of counts in appropriate time interval (724.5 or 224.5 s)).

	^{232}Th		^{233}U		^{241}Am		
t, s	724.5	224.5	724.5	224.5	229.5	224.5	100
$\Sigma(b)*t / \Sigma(N_d)$, %	1.10 - 1.84	0.35 - 0.58	5.95	2.69	95.2	95.1	41.5
b, 1 / s	0.16		0.73		129.9		

For obtaining the more information from experiment as possible the optimization of experimental parameters was carried out - such as the time of irradiation, the registration of induced neutron activity, the measurement time of neutron background, the width and the number of channels of a multichannel analyzer designed for measuring the temporal distribution of the intensity of delayed neutrons. As a result the delayed neutron decay curves were obtained from which a statistically significant number of events related to "pure" effect of delayed neutrons was extracted. In Figure 1 you can see an example obtained in one run of measurements of the time dependence of the neutron activity which consists of the induced activity of delayed neutrons and neutrons from the reaction O(α,n) in a sample of ^{241}Am. The dashed line shows separately the contribution of the background from the reaction O(α,n) to the total measured activity. Solid line shows the curve obtained by the estimation of parameters of delayed neutrons using an iterative least squares method [3].

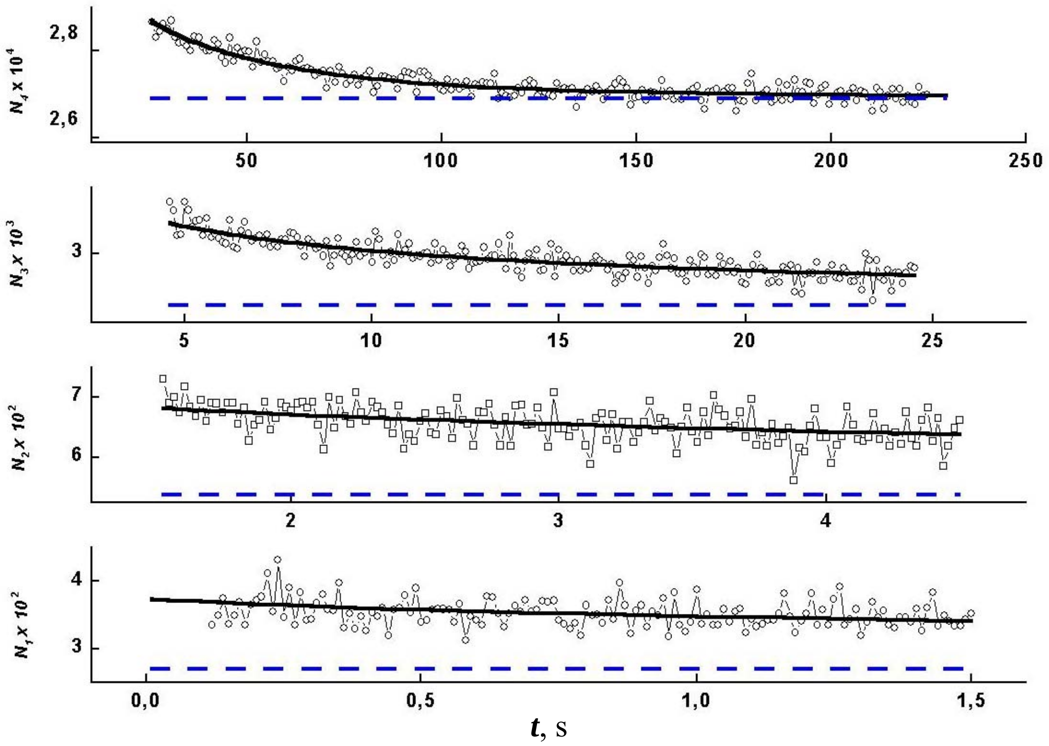

FIG. 1. Time dependence of neutron activity caused by the induced activity of delayed neutrons and neutrons from the reaction O(α,n) in a sample of ^{241}Am. Dashed line - the neutrons from the reaction O(α,n). Solid curve - the time dependence obtained in the process of estimating the parameters.

2. Results

As a result of the measurements a 6-group data on the relative yields of delayed neutrons and half-lives of their precursors were obtained from fission ^{241}Am by neutrons at energies of primary neutrons 0.75 - 5 MeV (see Table 2).

Comparison of parameters (a_i, T_i) obtained in this work with the relevant data from other authors was carried out in terms of the average half-life of delayed neutron precursors $\langle T\rangle=\Sigma a_i T_i$ [4]. A similar approach was used for analysis of the behavior of the energy dependence of relative yields and periods of individual groups of delayed neutrons. Figure 2 presents the energy dependence of the average half-life delayed neutrons precursors from fission ^{241}Am by neutrons calculated and data from other authors.

However, it should be noted that the data of other authors are described as obtained from fission ^{241}Am by fast neutrons. It means that these data are representing the averaged values over a finite energy interval that does not allow a correct comparison of these data with the appropriate data of the present work. Figure 2 shows that the present results averaged in the range of 0.6-1 MeV within the limits of their uncertainties agree with the data from the papers [5, 6].

Figure 2 shows that the behavior of the average half-life of delayed neutron precursors in fission ^{241}Am in the range of 1-5 MeV is similar to the behavior of this quantity in fission of other nuclei (^{238}U, ^{239}Pu, ^{233}U, etc.) – average half-life $\langle T\rangle$ decreases with increasing excitation energy of fissioning nucleus. A specific feature of the energy dependence of the temporal parameters of delayed neutrons in fission ^{241}Am is a sharp increase in the average half-life of delayed neutron precursors near the threshold of fission reaction (0.5-1 MeV) up to a maximum value of 11 at the first plateau of fission cross-section. The effect of increasing $<T>$ at the threshold of fission cross section found in fission ^{241}Am is not observed in case of other threshold nuclides. Moreover, in case of ^{237}Np one can observe the opposite effect - the increase of the average half-life of delayed neutron precursors with decreasing excitation energy of compound nucleus [7].

TABLE 2: The energy dependence of the relative abundances and half-lives of their precursors from fission of 241Am.

E_n, MeV	Group number							$<T>$, s
	i	1	2	3	4	5	6	
0.62 ± 0.06	a_i	0.0434 ± 0.001	0.264 ± 0.008	0.201 ± 0.006	0.317 ± 0.009	0.152 ± 0.005	0.0229 ±0.0007	10.16 ± 0.27
	T_i	54.3 ± 1.6	21.94 ± 0.66	6.08 ± 0.18	2.24 ± 0.07	0.496 ± 0.015	0.179 ± 0.005	
0.86 ± 0.06	a_i	0.0432 ± 0.0005	0.271 ± 0.003	0.199 ± 0.002	0.314 ± 0.004	0.151 ± 0.002	0.0228 ± 0.0003	10.45 ± 0.11
	T_i	53.97 ± 0.61	22.61 ± 0.25	6.08 ± 0.07	2.24 ± 0.03	0.498 ± 0.006	0.179 ± 0.002	
0.96 ± 0.06	a_i	0.0436 ± 0.0007	0.284 ± 0.005	0.199 ± 0.003	0.302 ± 0.005	0.148 ± 0.003	0.0229 ± 0.0004	11.04 ± 0.17
	T_i	53.99 ± 0.93	23.51 ± 0.39	6.27 ± 0.11	2.279 ± 0.039	0.494 ± 0.009	0.179 ± 0.003	
1.06 ± 0.06	a_i	0.0436 ± 0.0009	0.276 ± 0.006	0.202 ± 0.004	0.308 ± 0.006	0.148 ± 0.003	0.0228 ± 0.0005	10.98 ± 0.21
	T_i	54.0 ± 1.1	23.92 ± 0.45	6.13 ± 0.12	2.31 ± 0.05	0.49 ± 0.01	0.179 ± 0.004	
3.27 ± 0.14	a_i	0.0434 ± 0.0009	0.272 ± 0.006	0.199 ± 0.004	0.312 ± 0.007	0.150 ± 0.003	0.0229 ± 0.0005	10.75 ± 0.21
	T_i	54.5 ± 1.1	23.47 ± 0.49	6.10 ± 0.13	2.26 ± 0.05	0.496 ± 0.011	0.179 ± 0.004	
3.81 ± 0.11	a_i	0.0433 ± 0.0007	0.251 ± 0.004	0.201 ± 0.003	0.329 ± 0.005	0.153 ± 0.003	0.0228 ± 0.0004	9.69 ± 0.13
	T_i	54.47 ± 0.93	21.28 ± 0.31	5.85 ± 0.09	2.23 ± 0.04	0.503 ± 0.009	0.179 ± 0.003	
4.27 ± 0.11	a_i	0.0433 ± 0.0009	0.266 ± 0.006	0.202 ± 0.004	0.317 ± 0.006	0.149 ± 0.003	0.0228 ± 0.0005	10.16 ± 0.19
	T_i	54.4 ± 1.2	21.75 ± 0.41	5.99 ± 0.12	2.30 ± 0.05	0.49 ± 0.01	0.179 ± 0.004	
4.97 ± 0.13	a_i	0.043 ± 0.001	0.237 ± 0.007	0.202 ± 0.006	0.336 ± 0.008	0.159 ± 0.005	0.0229 ± 0.0007	9.65 ± 0.21
	T_i	56.5 ± 1.7	22.19 ± 0.39	5.69 ± 0.15	2.18 ± 0.05	0.502 ± 0.015	0.180 ± 0.005	

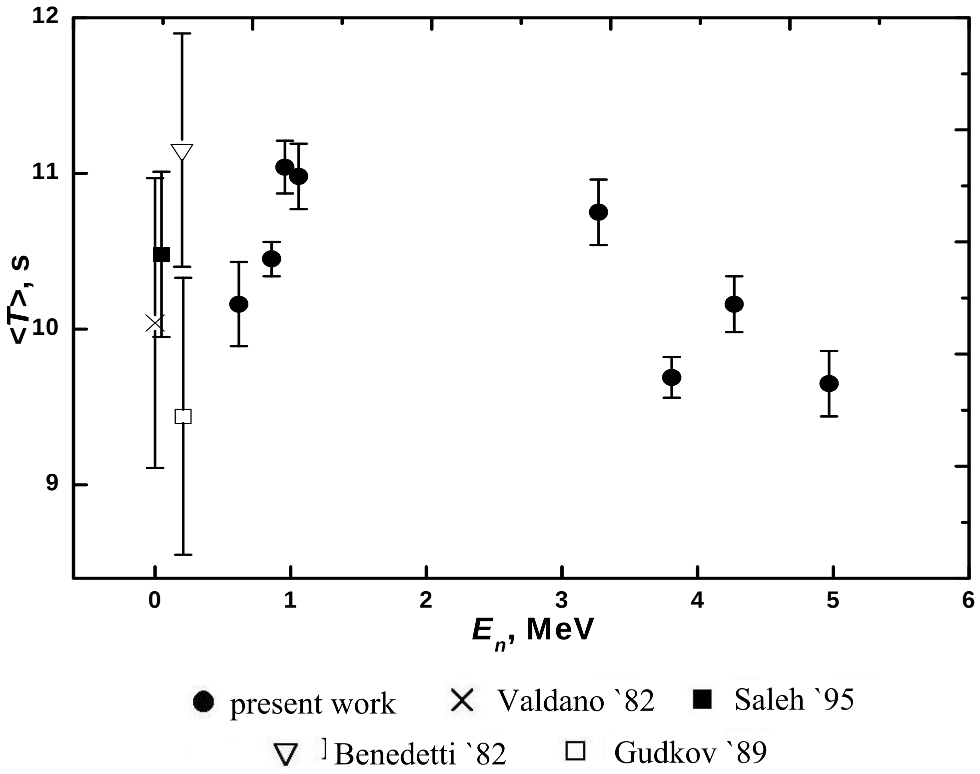

FIG. 2. Energy dependence of the average half-life of delayed neutron precursors from fission ^{241}Am in a 6-group representation (parameters are taken from the compilation of Spriggs and Campbell [8]).

It is well known that the average half-life of delayed neutron precursors for isotopes of one element exponentially depends on the parameters related to nucleon content of compound nucleus – (A_c-3Z) or close to it Z^2/A_c, where A_c – mass number and Z – atomic number of compound nucleus [4]. Estimated value obtained under the systematics of the delayed neutrons characteristics is shown in Figure 3 by dotted line.

As it is seen from Figure 3 the data obtained in this study for the relative yield of delayed neutrons and half-lives of their precursors in fission of ^{241}Am by neutrons expressed in terms of the average half-life agrees with the estimates made with the help of the systematics of the delayed neutrons time parameters [4].

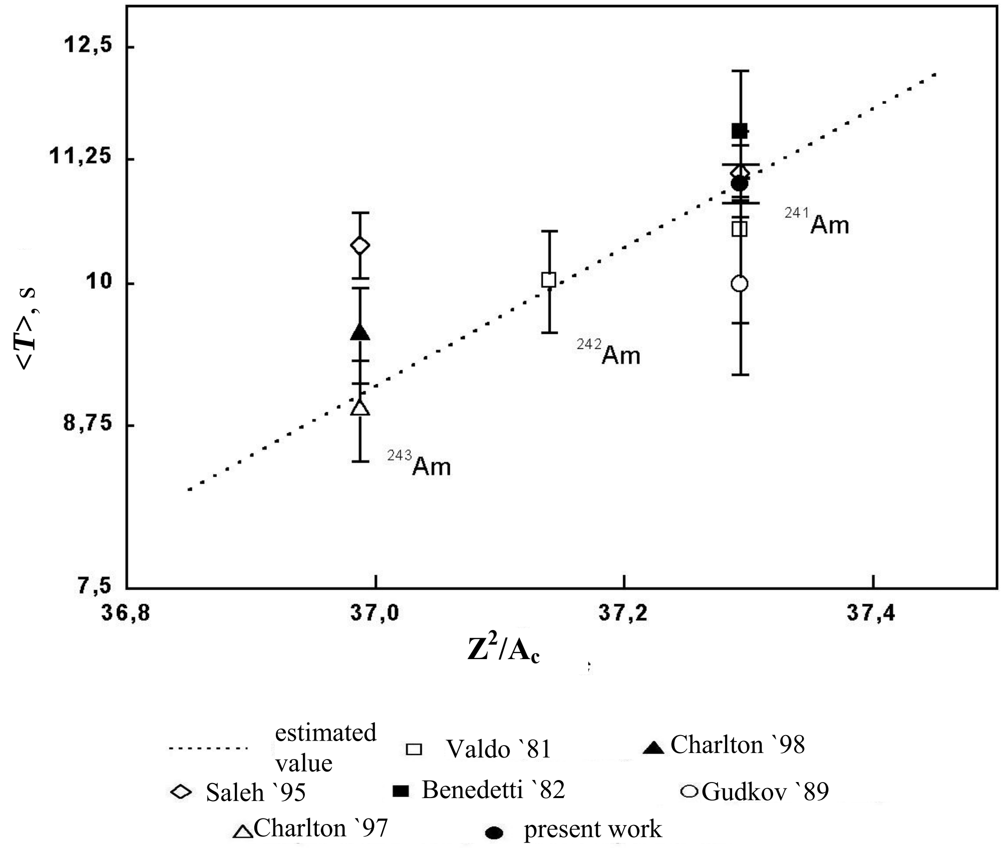

FIG. 3. Systematics of the average half-life as a function of the fissility parameter for americium isotopes [4] (values are taken from the compilation of Spriggs and Campbell (1999)).

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