Measuring Method of the Delayed Neutron Time Parameters for U-236 Fission by Neutrons with Energies from 14 to 18 MeV

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Abstract

Analysis of existing database on the relative abundances of delayed neutrons and half-lives of their precursors measured for neutron induced fission of heavy nuclei in the energy range above 14 MeV shows that such data are not available for many nuclides which are important for nuclear fuel cycle. In the present work for the first time the time dependence of delayed neutron activity for the neutron-induced fission of ^{236}U in the energy range from 14.2 to 18 MeV.

Introduction

In the last decades the efforts on improvement of the database on delayed neutron characteristics have been dedicated to analysis of delayed neutron characteristics for the fission of ^{235}U, ^{238}U, ^{239}Pu by neutrons from thermal to several MeV [1]. Energy range and choice of nuclei under investigation have been determined by the needs of nuclear energy. At the same time in the range from 5 to 20 MeV these characteristics are studied much worse. Firstly, it related to the range from 14 MeV or more.

The delayed neutron data at present could be used not only in calculation and control of reactor kinetics but in broad range of applications. Due to development of compact neutron generators based on D(d,n) and T(d,n) reactions delayed neutrons can be used in geology (well logging industry), investigations of nuclear physical characteristics, security applications, control of non-proliferation of the nuclear materials, medicine, educational purposes [2].

The origin of ^{236}U

^{236}U could be produced in three ways. The first one is radioactive capture of thermal neutrons by ^{235}U, and consequent gamma emission it consist for 15% of all reactions in the core of nuclear reactors. The second source of ^{236}U production is alpha decay of ^{240}Pu ($T_{1/2}$=6561 y.) formed in the result of radioactive capture of thermal neutron by ^{239}Pu, the second of the most used isotopes in nuclear energy [3, 4]. The third way of ^{236}U production is the ^{238}U(n, 3n) reaction which goes by fast neutrons, this reaction is the main contributor of the ^{236}U abundance in the atmosphere due to the restrictions on the spreading of the ^{236}U formed in nuclear reactors.

Experimental method and preliminary analysis of the obtained data

The experimental method used in present experiments is based on cyclic irradiation of the fissile sample in a well-known neutron flux and consequent measurement of the time dependence of delayed neutron activity. For that, the guide tube of pneumatic transport system with the sample under investigation have been placed between two ionization fission chambers near the target of the electrostatic generator CG-2.5.

Experimental set-up used in the present work has been placed on the beam of electrostatic accelerator CG-2.5 of SSC RF – IPPE. The basic components of the set-up are shown on the Fig. 1.

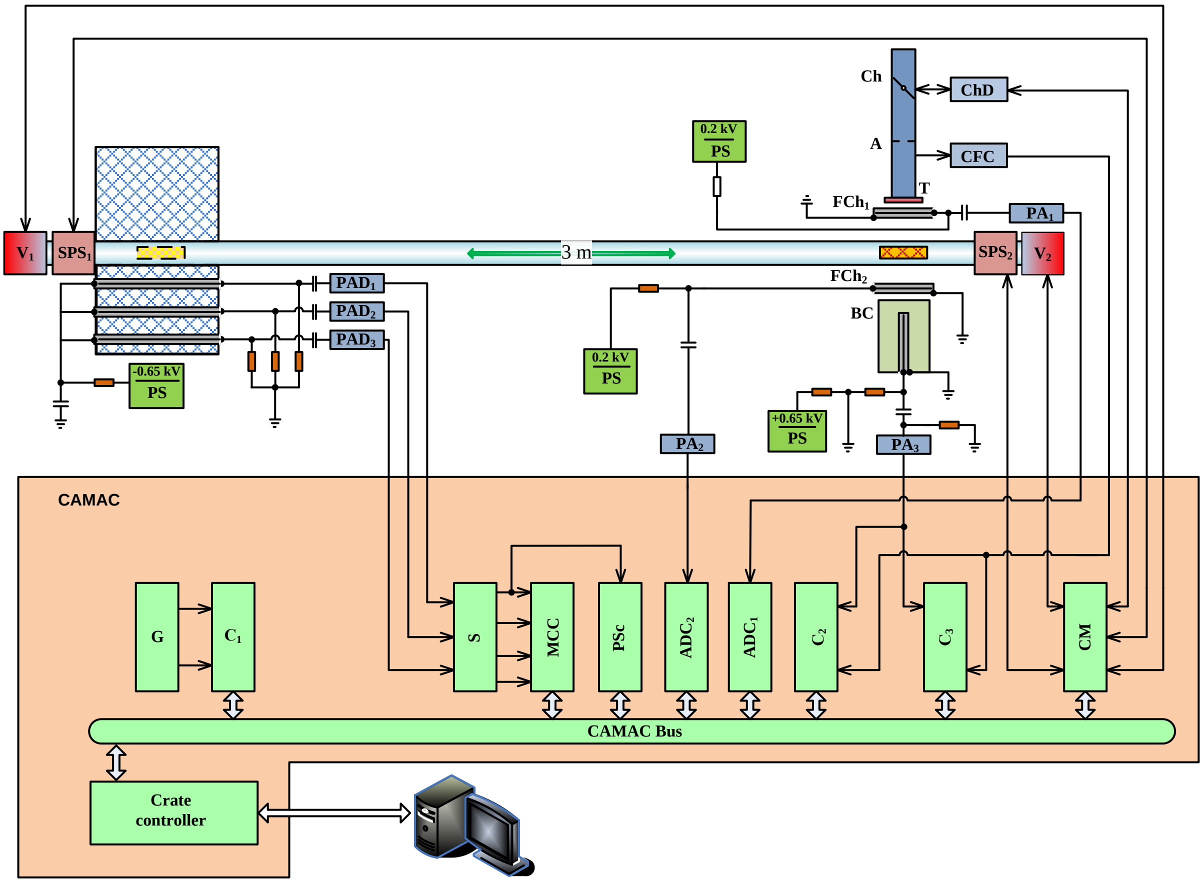

Fig. 1. Block diagram of the experimental setup: (PAD) preamplifier, amplifier, and discriminator; (A) adder; (PA) preamplifier and amplifier; (V) electromagnetic valve; (SPS) sample position sensor; (CM) controlled unit; (CFC) current-to-frequency converter; (ADC) analog-to-digital converter; (PSc) preset-scaler ; (MCC) multichannel counter; (G) quartz generator of pulses; (PS) power source; (Ch) chopper; (ChD) magnetic chopper drive; (A) ion guide aperture; (T) accelerator target; (FCh) fission chamber; (BC) boron counter of neutrons; (C1) counter with a preset exposure time; (C2) counter of total counts from the CFC and BC; and (C3) counter of the CFC and BC counts within preset time intervals.

Boron counters SNM-11 have been chosen as the main element of the registration of detector, because of their low sensitivity to γ-rays. Detector presents the assay of 30 counters, distributed in polyethylene moderator. It consists of three concentric circles, which have radiuses 53, 80 and 110 mm. Inner ring consists of 6 boron counters, medium and outer rings consist of 12 counters each. Outer diameter of moderator was equal to 400 mm, length – 300 mm. The counters were operating in proportional mode at bias voltage 650 V [5]. There was an opening ∅36 mm in the center of detector provided for installation of the fissile sample under investigation. The detector was shielded with boron carbide, cadmium and borated polyethylene. Detector has been installed 3 meters away from accelerator target.

Experimental technique used in the present work is based on the periodical irradiation of the fissile samples in the well-known neutron flux and the consequent measuring of the time dependence of the delayed neutron intensity. It have been possible to irradiate the samples under investigation for different time intervals to increase the abundance of the concerned delayed neutrons' group in the integral delayed neutron curve.

Experimental conditions and additional experiments

It should be noted that specific features of the T(*d,n*)^{4}He reaction, concerned with high intensity and high energy of generated neutrons beams essentially increase the complexity of the processing procedure of measured data, which is usually used for the work with neutron sources based on T(*p,n*)^{3}He and D(*d,n*)^{3}He reactions. Analysis of the existing data on the time parameters of delayed neutrons have shown that the data obtained by different authors for the energy above the 14 MeV are significantly differs from each other. One of the possible reasons of such significant difference could be related to the effect of additional source – D(*d,n*)^{3}He reaction, which is inevitably arising in the investigations using the T(*d,n*)^{4}He reaction on the solid targets. Another possible reason should be the blocking effect of the detector in the intensive neutron flux generated in the T(*d,n*)^{4}He reaction. To estimate the magnitude of the effect, concerned with blocking of the neutron detector being in the intensive neutron flux and the effect of the additional source additional experiments have been made.

Processing of the experimental data

The number of counts of delayed neutron detector $N(t_k)$, registered in the *k*-channel of time analyzer t_k with duration Δt_k after the sample irradiation using the neutrons from T(*d,n*)^{4}He and D(*d,n*)^{3}He reactions can be represented as follows

$$N_l(t_k) = A_l \cdot \sum_{i=1}^{n} F_{li} \cdot \frac{a_{li}}{\lambda_{li}} \cdot \exp(-\lambda_{li} \cdot t_k) \cdot \left(1 - \exp(-\lambda_{li} \cdot \Delta t_k)\right) + B_l(t_k) \cdot \Delta t_k, l = (T, D), k = (1, \ldots, m) \quad (1)$$

where T and D related to the measurements using T(d,n)^{4}He and D(d,n)^{3}He reactions correspondingly, a_{li} and λ_{li} – relative abundance and decay constant of *i*-th delayed neutron group, $B_l(t_k)$ – intensity of neutrons background, A_l – saturation activity,

$$F_{li} = (1 - \exp(-\lambda_{li} \cdot t_{ir})) \cdot \left(\frac{N}{1 - \exp(-\lambda_{li} \cdot T)} - \exp(-\lambda_{li} \cdot T) \cdot \left(\frac{1 - \exp(-n \cdot \lambda_{li} \cdot T)}{((1 - \exp(-\lambda_{li} \cdot T))^2} \right) \right) \quad (2)$$

presents the expression considering the irradiation history of the sample and registration of accumulated activity, which includes the following experimental parameters: *N* – the number of irradiation cycles, *T* – duration of the one measurement cycle, which consisted of irradiation time in one cycle t_{ir}, transportation time of the sample to the neutron detector and the count time of delayed neutron intensity [6].

Results

Time dependence of neutron intensity after neutron induced fission of ^{236}U in the energy range from 14.2 to 18 MeV obtained in the present work considering the blocking effect and effect of additional source (circles) are shown on figure 2. Data obtained as result of estimation of delayed neutrons parameters represented by continuous curves. Estimation of the parameters A, B, a_i, λ_i (i = 1, ..., n) on the observed values of time dependence $N(t_k)$ (k=1,...,m) (eq. 1, 2) was made within the 6-group representation using the iteration least squares method.

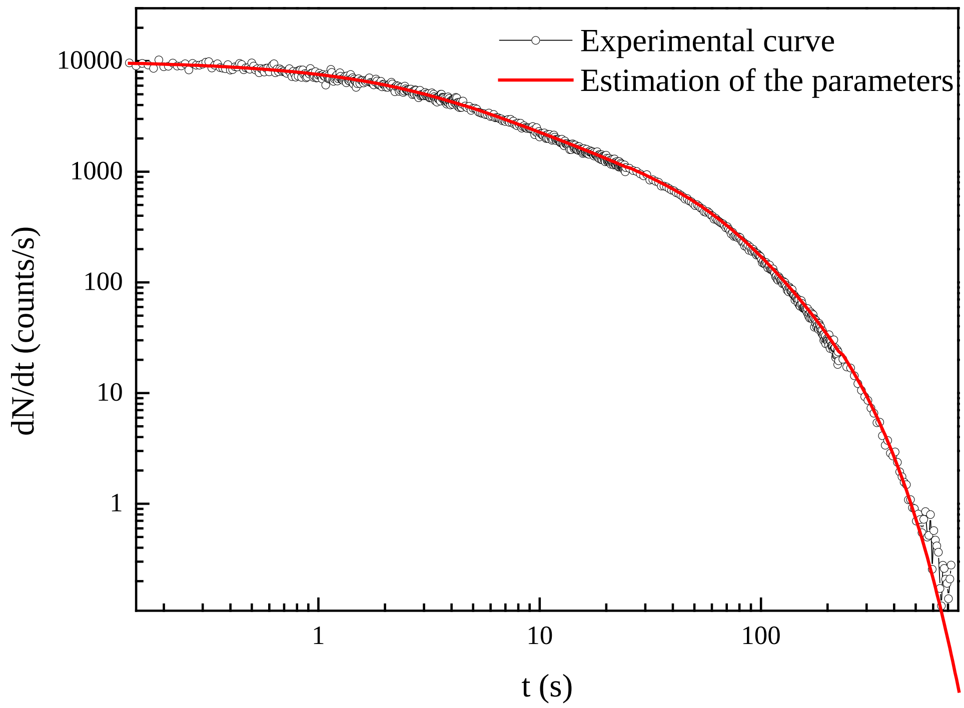

Fig. 2 – Time dependence of ^{236}U sample intensity after irradiation by 15.83 MeV neutrons. Irradiation time 180 s. Rings – experimental data including the corrections on the blocking effect and effect of additional source; red curve – data obtained as result of estimation of delayed neutrons parameters.

The obtained results on energy dependence of relative abundances of the separate delayed neutron group a_i and half-lives of their precursors T_i for the fission of ^{236}U by neutrons in the energy range from 14.2 to 18 MeV are presented in the Table 1. Values of group parameters (a_i,T_i) shown in the Table 1 in a six-group representation was obtained by averaging of these parameters of several series of the measurements, corresponding to the similar energy of the primary neutrons. The average half-life was calculated for each energy using the following formula

$$<T>=\frac{\sum_i a_i T_i}{\sum_i a_i}$$

where a_i – the relative abundance of the i-th delayed neutron group; T_i – the half-life of the i-th delayed neutron group.

The obtained values of relative abundances and half-lives of the DN precursors for the fission of the ^{236}U by neutrons in the range from 14.23 to 17.98 MeV shown in the Table 1.

Table 1 – Relative abundances and half-lives for the fission of ^{236}U by neutrons in the energy range from 14.23 to 17.98 MeV.

E_n, MeV	*Group number*							Average half-life, s
	i	1	2	3	4	5	6	
14,23±0,23	a_i	0,0389 ±0,0006	0,165 ±0,003	0,321 ±0,005	0,431 ±0,007	0,025 ±0,001	0,0190 ±0,0004	7,48 ± 0,07
	T_i	55.01 ±0,32	20,46 ±0,17	4,09 ±0,04	1,49 ±0,02	0,47 ±0,01	0,214 ±0,005	
15,83±0,20	a_i	0,040 ±0,001	0,172 ±0,003	0,318 ±0,007	0,423 ±0,008	0,026 ±0,001	0,020 ±0,001	7,79 ± 0,22
	T_i	54,78 ±0,31	20,58 ±0,19	4,32 ±0,05	1,57 ±0,03	0,48 ±0,01	0,214 ±0,006	
17,98±0,25	a_i	0,0393 ±0,0006	0,199 ±0,003	0,324 ±0,005	0,391 ±0,007	0,026 ±0,001	0,0194 ±0,0004	8,20 ± 0,09
	T_i	52,95 ±0,32	20,62 ±0,16	4,31 ±0,05	1,51 ±0,03	0,47 ±0,01	0,214 ±0,005	

Energy dependence of the average half-life of DN precursors from the fission of ^{236}U by neutrons in the energy range from 14.23 to 17.98 MeV is shown on fig. 3. There are values obtained in the separate measurements and the data points obtained in the result of averaging on the values obtained in the separate measurements.

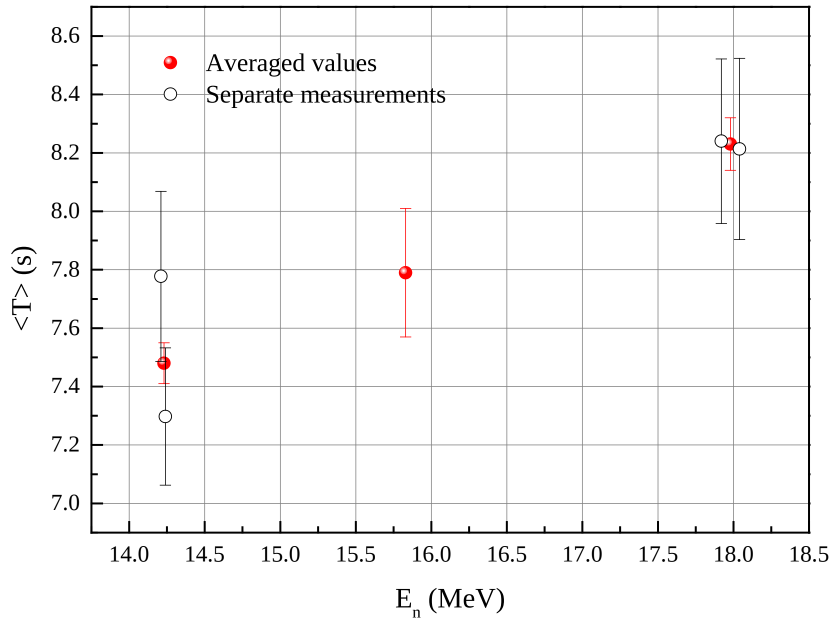

Fig. 3. Energy dependence of the average half-life of delayed neutron precursors for neutron induced fission of the ^{236}*U in the energy range from 14,2 to 18 МэВ. Black rings – values obtained in the separate measurements, red points – data obtained in the result of averaging of the separate measurements.*

For each neutron energy the correlation matrix has been obtained. Correlation matrix of the DN group parameters for the fission of ^{236}U by 15.83 MeV neutrons is presented in the Table 2.

Table 2 – Correlation matrix of DN group parameters obtained for the fission of ^{236}*U by 15.83 MeV neutrons.*

	a1	T1	a2	T2	a3	T3	a4	T4	a5	T5	a6	T6
a1	1	0	0	0	0	0	0	0	0	0	0	0
T1	0	1	0.79	0.43	0.46	0.15	0.55	0.12	0.02	0.01	0.01	0.01
a2	0	0.79	1	0.18	0.43	-0.19	0.42	0.15	0.01	0.01	0.01	0.01
T2	0	0.43	0.18	1	0.42	0.59	0.56	0.06	0.01	0.01	0	0.01
a3	0	0.46	0.43	0.42	1	-0.27	-0.1	-0.45	0	0	0	0
T3	0	0.15	-0.19	0.59	-0.27	1	0.63	0.14	0.01	0.01	0	0
a4	0	0.55	0.42	0.56	-0.1	0.63	1	0.18	-0.02	-0.02	-0.01	-0.01
T4	0	0.12	0.15	0.06	-0.45	0.14	0.18	1	0.03	0.01	0.01	0.02
a5	0	0.02	0.01	0.01	0	0.01	-0.02	0.03	1	0	0	0
T5	0	0.01	0.01	0.01	0	0.01	-0.02	0.01	0	1	0	0
a6	0	0.01	0.01	0	0	0	-0.01	0.01	0	0	1	0
T6	0	0.01	0.01	0.01	0	0	-0.01	0.02	0	0	0	1

Conclusion

Measurements of the time dependence of delayed neutron intensity after the fission of ^{236}U by neutrons with energies from 14.23 to 17.98 MeV have been done for the first time. Obtained decay curves have been corrected for the effects that affect to its shape inevitably when reaction T(d,n)^{4}He is using as a neutron source. Using the least square technique on the basis of result dependences the time parameters of delayed neutrons have been obtained for any energy of primary neutrons. Energy dependence of the average half-life is calculated on the basis of the obtained time parameters.

References

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