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Measurement of the temporal characteristics of delayed neutrons from neutron induced fission of ^{237}Np in the energy range from 14.2 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 ^{237}Np in the energy range above 14 MeV was obtained using T(d,n)^{4}He.

1. Introduction

In recent years efforts for improving the delayed neutron database were directed mainly to analysis of delayed neutron characteristics for neutron induced fission of ^{235}U, ^{238}U, ^{239}Pu using thermal and fast neutrons [1]. Nuclides and energy range used in this work were determined first of all by the needs of power engineering.

At the same time energy ranges of primary neutrons exist for which the physical characteristics of delayed neutrons are poorly known. First of all, this is an issue for that energy range above 14 MeV. This energy range is interesting for practical applications related to the development of non-destructive methods used for the analysis of fissile materials which are based on delayed neutron measurement.

2. The neutron source

The reaction T(d,n)^{4}He was used to generate neutrons in energy range from 14.2 to 18 MeV. A solid tritium target was irradiated by a beam of accelerated deuterons from cascade generator CG-2.5 SSC RF-IPPE. The energy of accelerated deuterons was varied from 0.5 to 2 MeV. Interruption of the beam was achieved using a Faraday cup. The energy dependence of neutrons generated using the T(d,n)^{4}He reaction for different incident deuteron energy is shown in Fig. 1.

Beams of neutrons emitted at both the angles of 0 and 90 degrees relative to the deuteron beam direction were used. This allowed study of the temporal characteristics of delayed neutrons in the energy range from 14.2 to 18 MeV.

3. Experimental method and processing of the obtained data

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

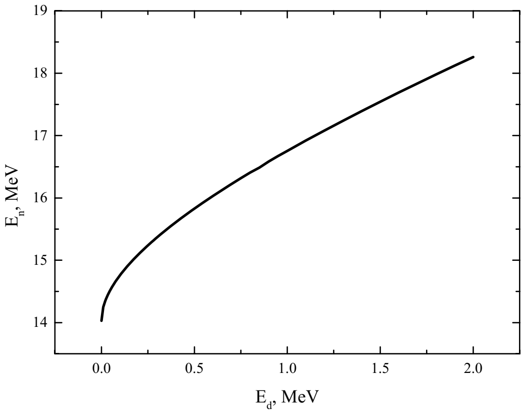

Figure 1. Energy dependence of neutrons generated in the T(d,n)^{4}He. reaction on the incident deuteron energy.

The basic components of the set-up are shown on the Fig. 2.

SNM-11 boron counters were chosen as the main element of the detector system, because of their low sensitivity to γ-rays. The detector array consisted of 30 counters, distributed in a polyethylene moderator. It consisting of three concentric rings of counters, which have radii of 53, 80 and 110 mm. The inner ring contained 6 boron counters, with the medium and outer rings having 12 counters each. The outer diameter of the moderator was equal to 400 mm with a length of 300 mm. The counters were operating in proportional mode at a bias voltage of 650 V [2]. There was an opening 36 mm ∅ in the centre of the detector array designed for placement of the

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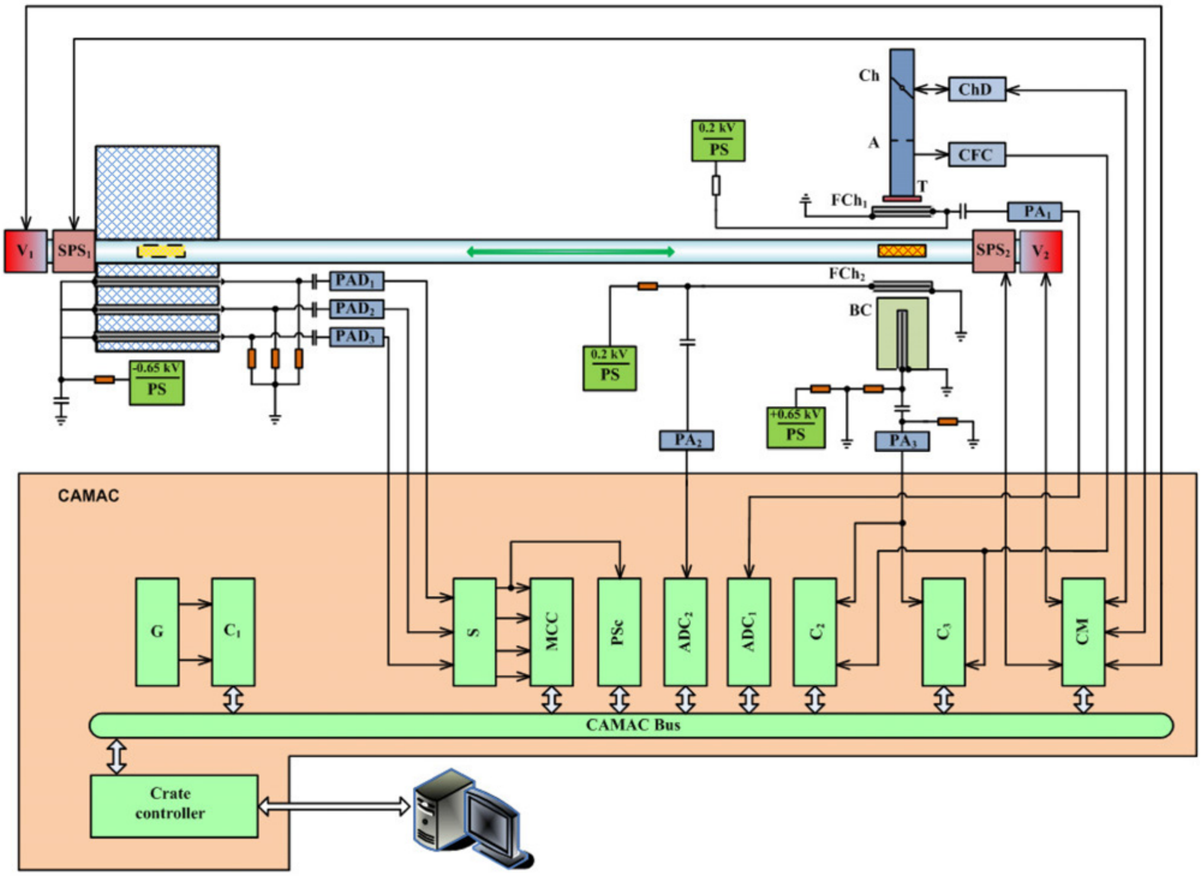

Figure 2. Block diagram of the experimental setup: (PAD) preamplifier, amplifier, and discriminator; (S) summator; (PA) preamplifier and amplifier; (V) electromagnetic valve; (SPS) sample position sensor; (CM) controlled unit; (CFC) current-to-frequency converter; (ADC) analog-to-digital converter; (PSc) 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.

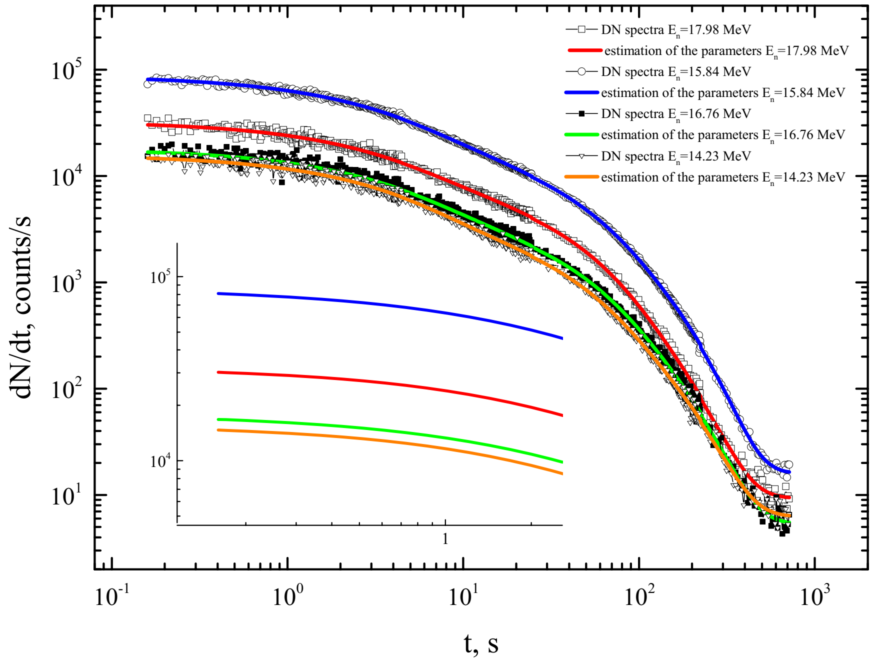

Figure 3. Time dependence of ^{237}Np sample activity at different neutron energies. Irradiation time 180 s. Symbols are experimental data including corrections for the blocking effect and the effect of concomitant sources. Curves were obtained as a result of fitting of the delayed neutrons parameters.

Table 1. Relative abundances and half-lives for neutron induced fission of ^{237}Np in the energy range from 14.2 to 18 MeV.

E_n, MeV	*Group number*							*Average half-life, s*
	i	1	2	3	4	5	6	
14.2±0.2	a_i	0.0450±0.0007	0.181±0.003	0.211±0.006	0.451±0.010	0.100±0.003	0.013±0.004	8.24±0.23
	T_i	58.2±0.5	20.2±0.2	4.58±0.11	2.12±0.04	0.46±0.5	0.196±0.5	
15.8 ± 0.2	a_i	0.0498±0.0005	0.170±0.002	0.219±0.006	0.439±0.007	0.107±0.003	0.014±0.004	8.76±0.17
	T_i	55.5±0.3	20.7±0.1	4.92±0.09	2.01±0.03	0.45±0.01	0.196±0.006	
16.7 ± 0.2	a_i	0.0472±0.0007	0.186±0.003	0.220±0.006	0.428±0.009	0.105±0.003	0.013±0.004	8.78±0.24
	T_i	58.2±0.5	21.5±0.2	4.93±0.12	2.10±0.04	0.46±0.01	0.196±0.006	
18.0 ± 0.2	a_i	0.0408±0.0005	0.205±0.003	0.202±0.005	0.447±0.009	0.094±0.003	0.012±0.003	8.58±0.20
	T_i	55.2±0.4	21.4±0.2	5.04±0.12	1.97±0.04	0.46±0.01	0.196±0.006	

investigated fissile sample. The detector was shielded with boron carbide, cadmium and borated polyethylene.

The short transportation time of the sample (∼100–150 ms) from the irradiation position to the detector was accomplished by the fast pneumatic system. This allowed us to measure delayed neutron yields of short-lived precursors. The general equation for modelling the temporal delayed neutron characteristics (a_i, λ_i) in the case of a cyclic irradiation with a pulsed proton beam can be represented by the expression reported in work [3].

4. Results

The time dependence of the neutron activity from neutron induced fission of ^{237}Np in the energy range from 14.2 to 18 MeV was obtained in the present work considering both the blocking effect and the effect of concomitant sources (filled squares, open squares, circles, triangles) shown on Fig. 3. Data was obtained as a result of the estimation of delayed neutrons parameters represented by the continuous curves. Estimation of the parameters A, B, a_i, λ_i ($i = 1$, ..., n) on the observed values of time dependence $N(t_k)$ ($k = 1, \ldots, m$) (Eqs. (1), (2)) were made assuming the 6-group representation using the iterative least squares method [4].

The results obtained for the energy dependence of relative abundances of the separate delayed neutron group a_i and the half-lives of their precursors T_i are presented in Table 1. Values of group parameters (a_i, T_i) shown in the Table 1 for the six-group representation were obtained by averaging of these parameters for several series of measurements, with a similar energy of the primary neutrons. The average half-life was calculated for each energy using the following formula

$$<T>= \frac{\sum\limits_i a_i T_i}{\sum\limits_i a_i}, \qquad (1)$$

where a_i is the relative abundances of the i-th delayed neutron group and T_i is the half-life of the i-th delayed neutron group.

Figure 4 shows the energy dependence of the average half-life of delayed neutron precursors for neutron induced fission of ^{237}Np in the neutron energy range from 14.2 to 18 MeV. The value of the average half-live obtained using the summation method for 14 MeV neutron induced fission is shown the in Fig. 4 for comparison.

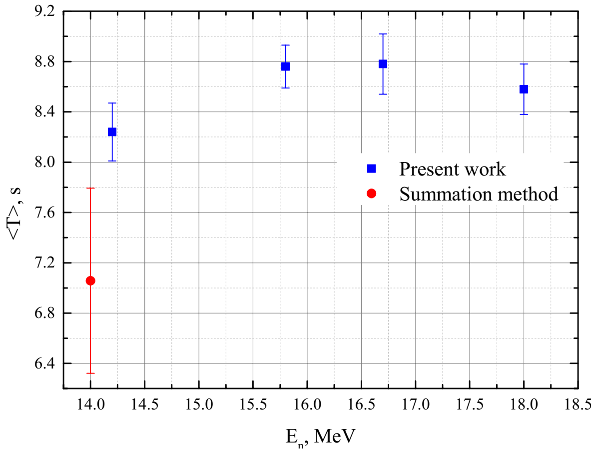

Figure 4. Energy dependence of the average half-life of delayed neutron precursors for neutron induced fission of ^{237}Np in the energy range from 14.2 to 18 MeV. Blue squares are data obtained in the present work and the red circle is the average half-life of delayed neutron precursors obtained using the summation method.

A correlation matrix of delayed neutron parameters was obtained for each energy of incident neutrons.

5. Conclusion

Measurements of the temporal dependence of neutron activity for the case of neutron induced fission of ^{237}Np in energy range from 14.2 to 18 MeV have been made for the first time. The obtained decay curves were analyzed considering the effect of concomitant sources and blocking effects, inevitably arising when the T$(d, n)^4$He reaction is used as a neutron source. Values of the group parameters based upon the analyzed decay curves have been obtained for each incident neutron energy, which in turn have been used for calculation of average half-lives of delayed neutron precursors. Data on the energy dependence of relative abundances and half-lives of their precursors for neutron induced fission of ^{237}Np in the energy range from 14.2 to 18 MeV are presented in numerical form.

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