Energy Dependence of Average Half-Life of Delayed Neutron Precursors in Fast Neutron Induced Fission of ^{235}U and ^{236}U

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Abstract

The measurements of relative abundances and periods of delayed neutrons from fast neutron induced fission of ^{235}U and ^{236}U have been made at the electrostatic accelerator CG-2.5 at IPPE. The preliminary results were obtained and discussed in the frame of the systematics of the average half-life of delayed neutron precursors. It was shown that the average half-life value in both reactions depends on the energy of primary neutrons.

Introduction

The correlation of the average half-life of delayed neutron precursors with parameter $(A_c\text{-}3\cdot Z)\cdot A_c/Z$ was found in the study [1]. Such parameter was chosen for the systematics of the total DN yield for the whole set of the total DN yields data [9]. However in the study [1] was shown that the whole set of the total DN yields data cannot be presented by only one function of this parameter and each element (isotopes of definite element) has its own dependence of the total DN yield. Therefore the results obtained in the study [1] allows to usse for systematisation of delayed neutron data the parameter Z^2/A_c, which is well known in the physics of nuclear fission. The dependence of the average half-life of DN precursors for thorium, uranium, plutonium and americium isotopes on the fissility parameter Z^2/A_c are shown on Fig.1.

This dependence is exponential for the isotopes of each considered element. Thus one may consider that the average half-life of DN precursors is the constant, which determine by only in one way the form of the delayed neutron decay curve for each fissioning system. Therefore the investigation of the energy dependence of the average half-life of DN precursors is very important both from physics and practical application point of view.

The purpose of the present experimental study was to investigate the energy dependence of the average half-life of DN precursors in the fast neutron induced fission of ^{235}U and ^{236}U. So the group relative abundances a_i and half-lives T_i of delayed neutrons in the fast neutron induced fission of ^{235}U and ^{236}U were measured to obtain the average half-lives of DN precursors $\langle T\rangle = \sum_{i=1}^{i=6} a_i \cdot T_i$. After that the energy dependencies of the average half-life of DN precursors in the fast neutron induced fission of ^{235}U and ^{236}U were obtained and the analysis of this dependencies was made.

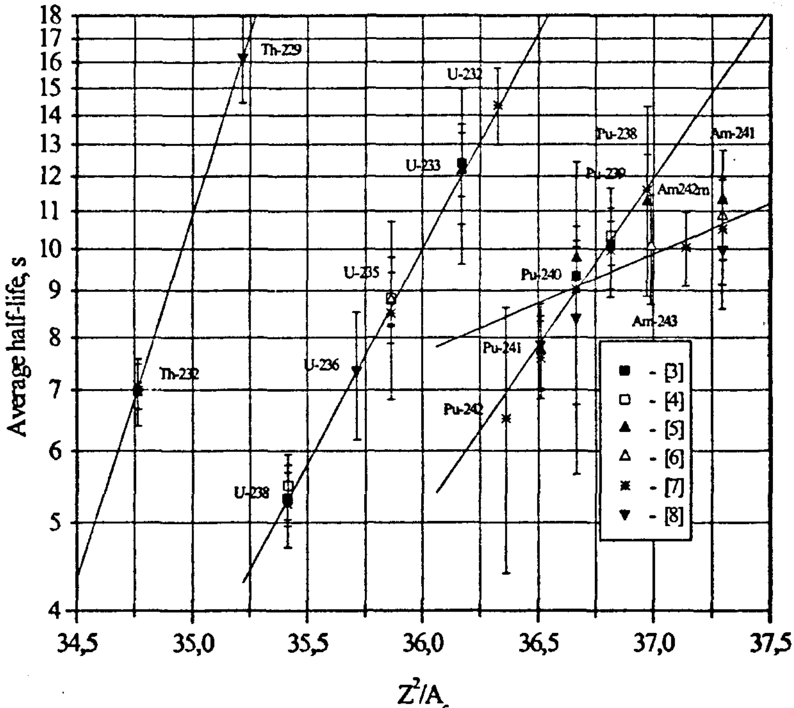

Fig. 1. The dependence of the average half-life of DN precursors for thorium, uranium, plutonium and americium isotopes on the fissility parameter Z^2/A_c

Experimental method

The experimental method employed in the measurements is based on periodic irradiation of the fissionable samples by neutrons generated in a suitable nuclear reaction at the accelerator target and measurements of the decay of delayed neutron activity [2].

The $T(p,n)^3He$ and $D(d,n)^3He$ reactions were used in measurements as the neutron sources. Tritium and deuterium targets were irradiated by ion beam on the electrostatic accelerator KG-2.5 at the IPPE. 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.

The main requirement to be taken into account in designing a sample transfer system was to minimise the sample delivery time. This system is capable to transport the sample with the time short enough to measure the delayed neutron yields with the shortest half-lives. The times of sample transportation from the irradiation position to the neutron detector were about 150 ms depending on gas pressure and the weight of the samples under investigation.

The computer of the IBM type serves as a central processor controlling the irradiation time, the value of neutron flux at discrete time intervals, the number and width of the time channels for the delayed neutron counting. The computer controls also the operation of the pneumatic transport system and the accelerator mode switches. Time-channel widths of 0.01, 0.02, 0.1, 1.0, 10 s following in the automatic sequence were used in the present measurement. Two types of experimental data were used in the present experiment. The first type of data was obtained in the measurements with 15 s irradiation time and 424.5 s counting time. The second type of data was obtained in the measurements with 300 s irradiation time and 724.5 s counting time. Such procedure allowed to increase a relative contribution of delayed neutrons corresponding to definite groups of precursors in the integral decay curve. Thus procedure using in the present experiment allowed to increase the accuracy of obtaining the DN parameters.

The measurements were made in cyclic mode. Each measurement cycle start from the irradiation of the fission sample. After irradiation process ion beam was covered by the Faraday cup and the fission sample was transported into the neutron detector. Position of the sample in the neutron detector and at the irradiation position was detected by photodiodes. The values of sample delivery time and sample delay at the irradiation position were measured in each measurement cycle. After measurements of delayed neutrons activity the experimental data were wrote down on hard disk of PC and measurement cycle repeat again. In the process of measurements stability of neutron detector parameters was under control by (Am-Li) neutron source.

Data processing procedure

Time-dependencies of delayed neutron activity obtained in the runs with the same experimental parameters were summed. The time-dependence of delayed neutron activity in fission of ^{235}U by 1.059±0.064 MeV neutrons with irradiation time 300 s is presented in the Fig.2. Start of delayed neutron counting correspond with signal of irradiation end. The value of sample delivery time was about 150 ms. The value of sample delay time was 60 ms.

Group periods and relative abundance values for the neutron induced fission of ^{235}U and ^{236}U were obtained on the basis of two types of experimental data. In the analysis of the delayed neutron time-dependence the data with irradiation time of 300 s and counting time 724.5 s were used to obtain the group constants for the first and second groups of delayed neutrons. Group constants values from the third group to the sixth one have been obtained from the data measured in the experiment with irradiation time of 15 s and counting time 424.5 s.

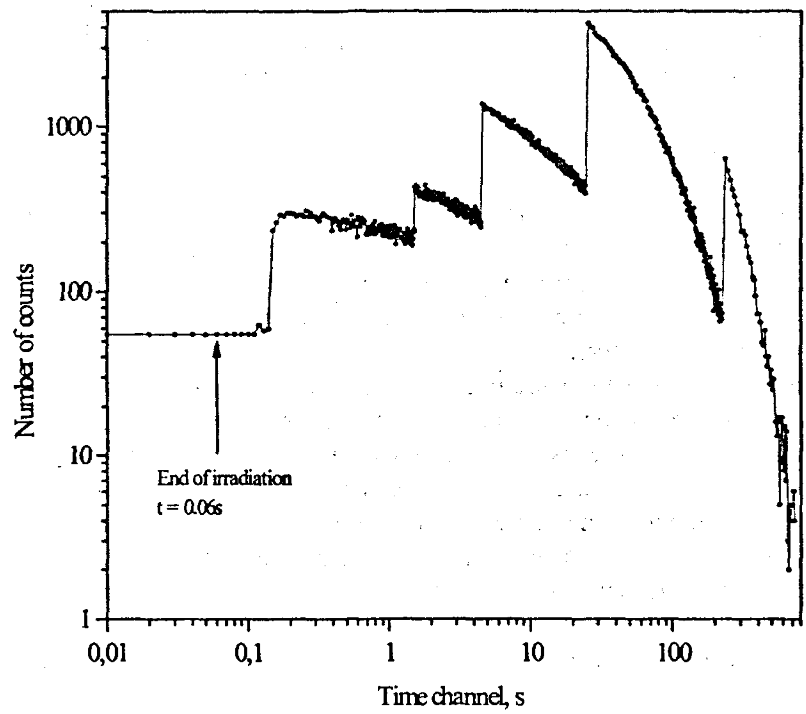

Fig.2. The time-dependence of delayed neutron activity in fission of ^{235}U by 1.059±0.064 MeV neutrons. Irradiation time - 300 s. Counting time - ~~4.5 s. Time-channel widths (s): 0.01, 0.02, 0.1, 1, 10. Number of channel: 150, 150, 200, 200, 50

The group constants for the first group and the second one obtained from the long time irradiation data were fixed in the analysis of the short time irradiation data. The values of group constants from the third group to sixth one obtained from the long time irradiation data were used as the initial approximation in the analysis of short time irradiation data. The experimental data were analysed with the iterative least squares program [2]. The correction for fissionable impurity in the ^{235}U sample was made. The energy-dependencies of relative abundances and periods of delayed neutrons for fast neutron induced fission of ^{235}U and ^{236}U are presented in the Table 1 and Table 2 respectively. The energy-dependencies of the average half-life for the fast neutron induced fission of ^{235}U and ^{236}U are presented in this tables.

Table 1. The energy-dependence of relative abundances, periods of delayed neutrons and average half-life of delayed neutrons precursors for fast neutron induced fission of ^{235}U (preliminary data)

E_n, MeV	Group number							$<T>$
	i	1	2	3	4	5	6	
0.370 (0.057)*)	a_i	0.037 ±0.001	0.227 ±0.007	0.188 ±0.008	0.394 ±0.010	0.131 ±0.006	0.023 ±0.001	9.073 ±0.407
	T_i	54.56 ±0.46	21.87 ±0.24	5.95 ±0.15	2.31 ±0.06	0.435 ±0.021	0.187 ±0.009	
0.624 (0.056)	a_i	0.035 ±0.001	0.222 ±0.006	0.209 ±0.008	0.361 ±0.009	0.152 ±0.007	0.021 ±0.001	8.939 ±0.363
	T_i	55.68 ±0.39	22.08 ±0.20	5.77 ±0.12	2.23 ±0.05	0.484 ±0.023	0.202 ±0.010	
0.859 (0.059)	a_i	0.036 ±0.001	0.228 ±0.006	0.194 ±0.008	0.387 ±0.010	0.132 ±0.006	0.023 ±0.001	9.083 ±0.380
	T_i	55.24 ±0.45	22.02 ±0.22	5.79 ±0.14	2.28 ±0.06	0.482 ±0.023	0.187 ±0.009	
1.059 (0.064)	a_i	0.037 ±0.001	0.225 ±0.006	0.190 ±0.010	0.402 ±0.012	0.122 ±0.006	0.024 ±0.001	9.172 ±0.439
	T_i	55.20 ±0.55	22.06 ±0.28	6.09 ±0.23	2.33 ±0.07	0.562 ±0.031	0.177 ±0.009	
3.274 (0.142)	a_i	0.038 ±0.001	0.213 ±0.007	0.194 ±0.008	0.405 ±0.011	0.124 ±0.006	0.026 ±0.001	8.973 ±0.434
	T_i	56.82 ±0.60	21.90 ±0.29	6.01 ±0.16	2.26 ±0.07	0.514 ±0.025	0.178 ±0.009	
3.805 (0.105)	a_i	0.038 ±0.001	0.210 ±0.006	0.188 ±0.008	0.411 ±0.009	0.127 ±0.006	0.026 ±0.001	8.867 ±0.375
	T_i	55.85 ±0.45	22.00 ±0.24	5.96 ±0.13	2.28 ±0.05	0.491 ±0.024	0.178 ±0.009	
4.269 (0.109)	a_i	0.040 ±0.001	0.209 ±0.006	0.189 ±0.008	0.402 ±0.009	0.133 ±0.006	0.027 ±0.001	8.862 ±0.374
	T_i	55.90 ±0.43	21.72 ±0.25	5.81 ±0.13	2.28 ±0.05	0.506 ±0.025	0.179 ±0.009	
4.805 (0.125)	a_i	0.040 ±0.001	0.192 ±0.006	0.200 ±0.008	0.406 ±0.010	0.135 ±0.007	0.027 ±0.001	8.725 ±0.403
	T_i	55.71 ±0.51	22.33 ±0.31	6.21 ±0.15	2.20 ±0.06	0.515 ±0.025	0.179 ±0.009	

*) - The values in brackets are the average standard deviation of the neutron energy values.

Table 2. The energy-dependence of relative abundances, periods of delayed neutrons and average half-life of delayed neutrons precursors for fast neutron induced fission of ^{236}U (preliminary data)

E_n, MeV	Group number							<T>
	i	1	2	3	4	5	6	
1.008 (0.099)*)	a_i	0.025 ±0.001	0.214 ±0.007	0.299 ±0.009	0.350 ±0.011	0.099 ±0.005	0.013 ±0.001	8.013 ±0.374
	T_i	54.96 ±0.57	21.81 ±0.22	4.57 ±0.08	1.59 ±0.05	0.463 ±0.023	0.215 ±0.011	
3.231 (0.152)	a_i	0.025 ±0.001	0.195 ±0.007	0.360 ±0.011	0.310 ±0.013	0.098 ±0.005	0.012 ±0.001	7.791 ±0.409
	T_i	55.25 ±0.72	22.40 ±0.29	4.27 ±0.09	1.47 ±0.06	0.472 ±0.023	0.214 ±0.011	
3.745 (0.144)	a_i	0.025 ±0.001	0.184 ±0.008	0.211 ±0.011	0.422 ±0.014	0.145 ±0.010	0.013 ±0.001	7.423 ±0.459
	T_i	54.83 ±0.70	22.00 ±0.30	5.41 ±0.17	1.91 ±0.06	0.374 ±0.026	0.218 ±0.015	
4.196 (0.169)	a_i	0.026 ±0.001	0.195 ±0.007	0.321 ±0.010	0.341 ±0.013	0.104 ±0.005	0.013 ±0.001	7.528 ±0.396
	T_i	55.79 ±0.67	21.51 ±0.28	4.27 ±0.10	1.35 ±0.06	0.475 ±0.024	0.214 ±0.011	
4.719 (0.205)	a_i	0.026 ±0.001	0.171 ±0.005	0.202 ±0.008	0.385 ±0.009	0.202 ±0.009	0.014 ±0.001	7.180 ±0.325
	T_i	54.79 ±0.47	22.07 ±0.21	5.56 ±0.11	2.01 ±0.05	0.403 ±0.019	0.223 ±0.011	

*) - The values in brackets are the average standard deviation of the neutron energy values.

Experimental results

The preliminary data on the energy-dependence of the average half-life of delayed neutrons precursors in the fast neutron induced fission of ^{235}U and ^{236}U are presented in Fig.3. and Fig.4. Also in this figure the data obtained for fission neutrons spectra [3, 4, 6, 8] are presented. The values of uncertainties for the average half-life were obtained without accounting of correlation between relative abundances and periods of delayed neutrons. The analysis of the correlation matrix of the relative abundances and periods shows that account of correlation between a_i and T_i reduce the uncertainty in the average half-life because the off diagonal elements are predominantly negative.

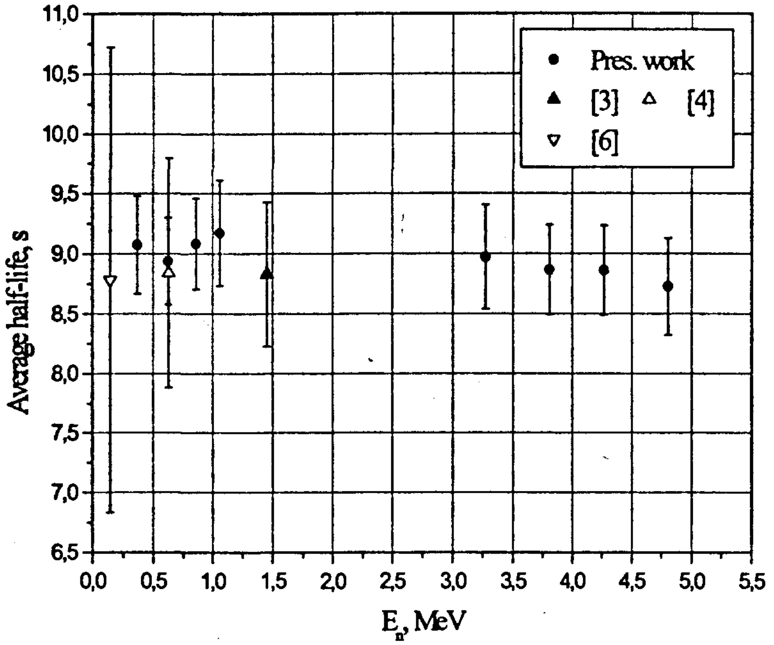

Fig. 3. The energy-dependencies of average half-life of delayed neutrons precursors in fast neutron induced fission of ^{235}U

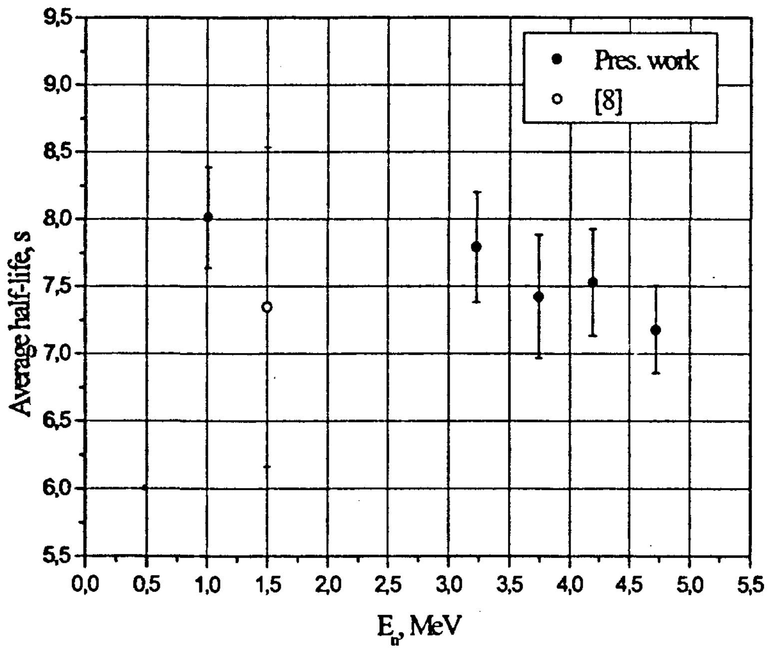

Fig. 4. The energy-dependencies of average half-life of delayed neutrons precursors in fast neutron induced fission of ^{236}U

The analysis of the energy-dependence of the average half-life of delayed neutrons precursors for ^{235}U shows that in the incident neutron energy range 0.37-1.059 MeV the average half-life is practically constant. For ^{235}U and ^{236}U in the incident neutron energy range above 1 MeV the value of average half-life trends to reduce with increase of incident neutron energy. And in the case of ^{236}U this reduction is amounted to 10 % in the considered energy range. This trend can be roughly explained by the increase of relative contribution of the short half-life precursors in fast neutron induced fission of ^{235}U and ^{236}U in the energy range above 1 MeV.

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