Experimental report

05/07/2022

Proposal: **3-07-396**

Council: 4/2020

Title: Absolute yield and kinetic parameters of delayed neutrons from the neutron-induced fission of 233U

Research area: Nuclear and Particle Physics

This proposal is a resubmission of 3-07-390

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Samples: 233U

Instrument	Requested days	Allocated days	From	To
PF1B	16	12	16/03/2021	30/03/2021

Abstract:

There is currently a strong request, supported by IAEA/Coordinated Research Program, to provide new high quality data of delayed neutron (DN) yield and group constants for nuclear reactor and criticality/safety applications, as well as to validate fission models with calculations like FIFRELIN or GEF.

In this proposal, the PF1B instrument is requested to deliver a collimated cold neutron beam to an active target of U233 in the form of a flat fission chamber. The latter is surrounded by a neutron detector consisting of a cylindrical PE block, with 16 He3 tubes. A fast beam stop system will be placed prior to this device, in order to drive repeated cycles of irradation and decay phases. The DN emission will be recorded as well the prompt neutron emission, in parallel with the monitoring of the fission events from the target. This experimental set-up is providing better conditions for DN measurement at very short-time compared to other reported experiments.

This proposal is a continuation of a similar proposal dedicated to U235 (3-07-380) and Pu239 (3-07-385). It is financially supported by EDF and FRAMATOME, as well as from the NEEDS/NACRE collaborative program hosted by CNRS.

Experiments n°3-07-385 and n°3-07-396 – Final report

"ALDEN-3": delayed neutron emission induced by the thermal fission of ^{235}U, ^{239}Pu and ^{233}U

Scientific context

The ALDEN (Average Lifetime of DElayed Neutrons) project aims at studying the thermal fission of major actinides (^{235}U, ^{239}Pu, ^{241}Pu, ^{233}U) with the objective to provide the nuclear data community with new data sets of delayed neutrons (DN) kinetic parameters. The project is conducted by CEA within a large collaboration of laboratories (CEA/DES, CEA/DRF, IRSN, CNRS/LPSC, CNRS/CENBG, CNRS/LPC Caen and Caen University). The present experiment was funded by the CEA, the I3P R&D platform, regrouping CEA, EdF and Framatome, and by the CNRS/Defi-NEEDS.

Experiment principle and setup at PF1b

Experiments n°3-07-385 and n°3-07-396 were a follow-up of Experiment 03-07-380, during which the experimental setup (LOENIEv2) was tested and optimized. It is based on 16 He^3 proportional counters arranged in a polyethylene matrix, in such a manner that the detector efficiency is nearly flat on the DN energy range (0.1 – 1 MeV). Background from scattered neutrons is limited thanks to a borated rubber shielding. The central cavity accommodates an airtight container at the center of which a miniature fission chamber that contains the target fissile material can be irradiated by the cold neutrons beam. Two beam shutters allow controlling the irradiation time: the first one is a rotating device, motioned by a brushless motor, with two vertical B4C/Cd screens. The second one is block of borated high density polyethylene, vertically motioned by a pneumatic system.

The data acquisition system was designed by the ILL. It was based on a VME rack including two CAEN V1724 digitizers and one Ioxos TTL acquisition card. Detection events issued by the neutron counters were digitized and processed, so as to record energies and time stamps. To monitor the fission rate inside the target, the signal from the fission chamber was shaped by an analog amplifier (Canberra 7820), processed by a discriminator, and then fed into the acquisition system to get the counting rate. ILL software NoMad was used to synchronize acquisition runs with the beam shutters.

List of measurements

Three targets were irradiated during the campaign: ^{235}U (~210 µg, 3 days), ^{239}Pu (~140 µg, 12 days) and ^{233}U (~210 µg, 6 days). Additionally, a dummy target was used to measure the counting rate of background scattering neutrons. Each experiment was made of several cycles of irradiation and cool-down. By varying the irradiation time t_i and the cool down time t_c, the weight of different DN precursors could be modified (since the amplitude of their response depends on the ratio t_i/t_c) to obtain different decay curves. Three kinds of experiments were performed:

- Short length cycles (SLC), with t_i ~ 3.15 s and t_c ~ 0.25 s, to get the delayed neutron yield;
- Long length cycles (LLC), typically t_i > 100 s, t_c ~ 500 s, to get the entire decay curve and focus on long lived DN;
- Medium length cycles (MLC), typically t_i ~ 10 s, t_c ~ 10 s, to get high statistics on the beginning of the decay curve.

Additional measurements were done to study the dead time (DT) of the measurement chain and the background (BG) with the dummy target. Table 1 gives a comprehensive list of measurements and associated irradiation configurations.

Data analysis

Introducing the fission rate F, the prompt neutron yield ν_p, the detection efficiencies to prompt neutrons ε_p and to DN ε_d, and the background b_i, the average counting rate during the irradiation phase is given by:

$$n_i = F\left(\nu_p \epsilon_p + \nu_d \epsilon_d\right) + b_i \quad (1)$$

Now, let a_k, λ_k and ε_k be respectively the abundance, decay constant and detection efficiency of the k^{th} group of DN, b_d the background when the beam was off and Δt_0 some veto time window. One can write the emission rate of DN as follows:

$$n_d = F\nu_d \sum_{k=1}^{8} \epsilon_k a_k \left(1 - e^{-\lambda_k t_i}\right)\left(1 + e^{-\lambda_k t_c}\right) e^{-\lambda_k (t + \Delta t_0)} + b_d \quad (2)$$

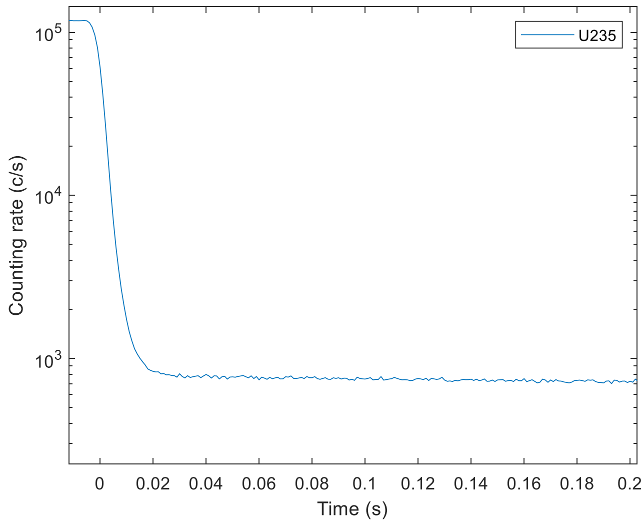
Dividing equation (2) by equation (1), it can be shown that the delayed neutron yield ν_d is a factor proportional to the ratio n_i / n_d ($t=t_i$). This ratio could be experimentally determined by fitting the first 200 ms of the decay curve and then extrapolating the activity to the time were the beam was cut off ($t=t_i$). The proportionality coefficient depends only on the ratio of detection efficiencies $\varepsilon_p/\varepsilon_d$ and was obtained by simulating the detection setup with the TRIPOLI-4® Monte Carlo code and JEFF3.3 nuclear data library.

Preliminary result: DN yield of ^{235}U

The beam time was split into 50 runs of 550 s (n°3331 to n°3380). A set of 6732 cycles (3.15 s of irradiation, 0.25 s of cool down) were analyzed separately. A significant number of cycles (784) had to be excluded from the analysis because of minor issues during the acquisition. The average counting rate of the U235 target, obtained from the fission chamber's signal, was estimated at $1.18\ 10^5 \pm 500$ c/s. The counting rate from the 16 proportional counters, corrected for dead time, and averaged over the set of cycles is displayed on Figure 1. The time window chosen for the fit ranged from 30 ms to 200 ms. The delayed neutron yield issued by the CEA-developed CONRAD optimization tool is given in Table 2. The overall uncertainty of 0.01 % (0.7 % in relative) includes the systematic errors of input parameters. The present estimation is in good agreement with the IAEA recommended value (1.621 % ± 0.050 %). It is also consistent with the value obtained from the previous ALDEN campaign in June 2019 (1.631 % ± 0.014 %).

Table 1 : List of measurements. H113 is the PF1b beam shutter, FS and PE are ALDEN's beam shutters. O = Open, C = Closed, I = Intermediate position, M = in motion.

Runs	Target	Type	Ti (s)	Tc (s)	H113	FS	PE	Comments
3331-3380	U235	SLC	3.15	3.4	O	M	O	
3450-3719	U235	LLC	100	500	O	M	M	
3720-3859	U235	LLC	50	450	O	M	M	
3895	Dummy	BN			O	O	O	Configuration of U235 and Pu239 measurements
3898	Dummy	BN			C	O	O	
3899	Dummy	BN			C	C	O	
3939-4003	Pu239	SLC	3.15	0.25	O	M	O	65 runs of 550 s => 160 cycles per file
4025	Pu239	BN			O	C	O	
4026	Pu239	BN			O	C	C	
4207 - 4688	Pu239	LLC	150	750	O	M	M	
5237-5536	Pu239	SLC	10	10	O	M	O	300 runs of 60 s
5537 - 5776	Pu239	MLC	5	5	O	M	O	240 runs of 60 s
5777 - 6016	Pu239	MLC	3	3	O	M	O	240 runs of 60 s
6017 - 6414	Pu239	MLC	5	395	O	M	M	638 runs
6438-6444	Dummy	BN			O	I	O	FS angles 50, 52, 54, 56, 58, 60, 90 Configuration for target U233
6446-6450	Dummy	BN			O	I	O	FS angles 50, 54, 56, 58, 60, 90 Configuration for targets U235 and Pu239
6470-6481	U233	DT			O	I	O	Angles: 52:2:60 then 65:5:90.
6482-6546	U233	SLC			O	M	O	65 runs of 550 s
6547	U233	BN			O	C	O	
6548	U233	BN			O	C	C	
6549	U233	BN			C	C	C	
6550-6684	U233	LLC	100	500	O	M	M	135 runs. Inversion of channels 2 and 3
6686-6789	U233	LLC	100	500	O	M	M	
6790-7005	U233	LLC	50	450	O	M	M	
7006-7275	U233	LLC	5	395	O	M	M	
7276 - 7939	U233	MLC	10	10	O	M	O	664 runs of 65 s
7940 - 8271	U233	MLC	5	5	O	M	O	332 runs of 65 s
8272 - 8471	U233	MLC	3	3	O	M	O	200 runs of 65 s



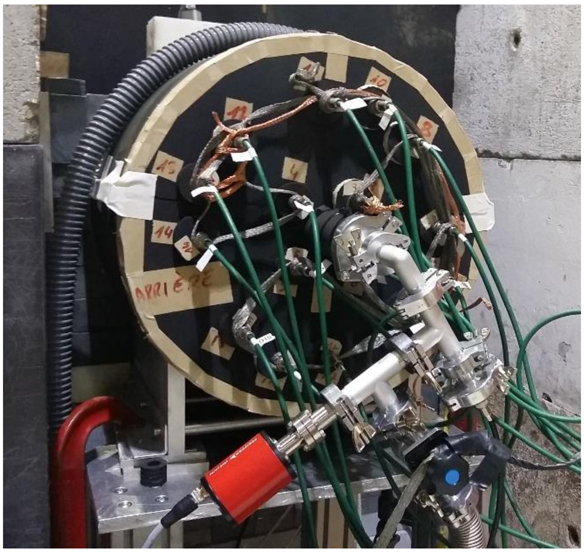


Figure 1 : Neutron emission for SLC with U235 target (left) and back view of LOENIEv2 detection setup (right).

Table 2 : Delayed neutron yield for U235 target and associated uncertainty.

ν_d (%)	Uncertainty (stat.)	Uncertainty (sys.)	Uncertainty (overall)
1.617%	0.002	0.010	0.011