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Tests of a prototype pulsed thermal neutron source

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Abstract

In the pulsed neutron experiments, an increase of the thermal neutron flux is necessary when weakly-moderating materials are measured as sole samples, without an extra moderator. A prototype of the pulsed thermal neutron source has been designed and constructed at the 14 MeV pulsed neutron generator. The moderator array is made of small paraffin cells ($1.8\times1.8\times4.4$ cm^3) separated with a Cd layers which prevent the thermal neutron diffusion between the cells. The width of the array has been optimized concerning the efficiency of the slowing down the 14 Mev neutrons to the thermal energies. The decay of the thermal neutron flux from such a moderator is very rapid. Test measurements of the presented pulsed thermal neutron source are described. The decay constant of the thermal neutron flux is equal to about 92 000 s^{-1}. The repetition time and the duration of the pulses are controlled by the parameters of the primary fast neutron source.

1. Introduction

The thermal neutron diffusion parameters of various material are measured with pulsed method on the experimental set-up at the 14 MeV pulsed neutron generator in the Institute of Nuclear Physics (IFJ PAN) in Kraków, Poland. The main principle of the experiment is following. The fast neutron burst (repeated cyclically) irradiates an investigated sample, the neutrons slow-down inside the sample, the thermal neutron flux (decaying in time) is detected by the thermal neutron detectors, and the time distributions of the pulses are registered with the multiscalers. The time decay constant λ of the fundamental exponential mode of the flux, $\phi \propto \exp(-\lambda t)$, is determined from the scored data. This decay constant depends on the material properties and on the geometry of the system and is a fundamental magnitude in interpretation of the experimental results. The measuring system was presented by Burda *et al.* (1999). A number of thermal neutrons is sufficient for accurate measurements when the samples themselves are good neutron moderators (Drozdowicz 2002) or other samples are surrounded by a moderator (Czubek *et al.*1996, Krynicka *et al.* 2005). When weakly-moderating materials (for example, geological samples) are to be measured as sole samples the amount of appearing thermal neutrons can be insufficient to obtain a good counting statistics (Drozdowicz 2003, Drozdowicz *et al*. 2006).

In such a situation the best way would be to use a pulsed thermal neutron source. A chopper is not a good solution for the measurements in the microseconds' range which is here the case. Any conversion of the pulsed fast neutron burst into a pulsed thermal neutron burst with the use of a moderator brings a non-sharp falling edge of the burst. The decay time of thermal neutrons from the moderator can then overlap the decay of the thermal neutron flux from the sample. On the other hand, a very small piece of the moderator could be used which assures a rapid decay of the source thermal neutrons. In this case, however, a total flux from this pulsed source is very low and gives no improvement of the counting statistics. A concept of the pulsed thermal neutron source, which overcomes the mentioned problems, was given by Mayer *et al.* (1990). In the present report, first results of measurements on a prototype pulsed thermal neutron source built at the IFJ neutron generator are shown.

2. Experimental realization of the pulsed thermal neutron source

In order to fulfil requirements of the mentioned experiments with rock materials, the decay constant of the pulsed thermal neutron source to be used at the neutron generator in the IFJ should be equal to $\lambda \approx 100\,000\ s^{-1}$. As said, the high decay constant corresponds to a small volume of the moderator, and to a low thermal neutron flux. The essential principle of an efficient pulsed thermal neutron source is to join together separated small cells of a moderator in such a way that the diffusion of thermal neutrons is impossible between the cells. A layer of the strong thermal neutron absorber (e.g. cadmium) between the cells can be inserted. The decay constant corresponds then to the rapid decay in the single cell but the total thermal neutron output is a sum of neutrons from whole array of the cells.

The time decay constant λ of the thermal neutron flux in a finite volume of the medium can be calculated theoretically. It depends (Beckurts and Wirtz 1964) on the thermal neutron parameters of the medium and on the size:

$$\lambda = \langle \nu\Sigma_a \rangle + D_0 B^2 - C B^4 + O(B^6) \qquad (1)$$

where $\langle \nu\Sigma_a \rangle$ is the thermal neutron average absorption rate, D_0 is the diffusion constant and C is the diffusion cooling coefficient. The B^2 parameter is called the geometrical buckling and depends on the shape and dimensions of the medium. In case of the paralellepiped, for instance (Weinberg 1952):

$$B^2 = (\pi/a_1)^2 + (\pi/a_2)^2 + (\pi/a_3)^2 \qquad (2)$$

where a_1, a_2, a_3 are the edges of the solid body, including the extrapolation length (Nelkin 1960). When the moderator is chosen and its neutron parameters ($\nu\Sigma_a$, D_0, C) are known the required decay constant [Eq.(1)] can be achieved by a play with the sizes, a_1, a_2, a_3 in Eq.(2). In this way a primary version of the source was designed and used (Drozdowicz *et al.* 2003)

There two problems appear. First, the same geometric buckling B^2 (so, the same λ) can be realized with various geometric sizes. Different widths correspond, however, to different moderating abilities of the elementary cells and whole array. There is no information whether a given ratio of the sizes, a_1, a_2, a_3, assures the best thermalization of neutrons. Second, the theoretical decay constant in Eq.(1) comes from the diffusion theory extended by an inclusion of the diffusion cooling effects. It should be applied with caution to a very small objects. One should remember also that the development in Eq.(1) is always cut at a certain term. Therefore, the results for small cells can be inaccurate.

An optimization of the source can be made with a use of numerical simulations. The Monte Carlo simulations was performed (Tracz 2006) using the MCNP code (X-5 Monte Carlo Team 2003). Polyethylene was chosen as the neutron moderator. The width of the array of the polyethylene cells was optimized to get a maximum ratio of the thermal-output to fast-incident neutrons, keeping all the time the geometric buckling corresponding to $\lambda \approx 100\,000$ s^{-1}. The width of the Cd layer between the cells was also optimized. Finally, the following geometrical parameters of the designed pulsed thermal neutron source are obtained:

Single cell: $1.8\times1.8\times4.4$ cm^3;

Total array: $11.5\times11.5\times4.4$ cm^3; 36 cells;

Width of the Cd layer separating the cells: 1 mm;

External Cd shield:2 mm;

The real moderator array is made of paraffin (which is equivalent to polyethylene in respect to the neutron properties), density $\rho = 0.8649$ g cm^{-3}. A photo of the constructed moderator array is shown in Fig.1.

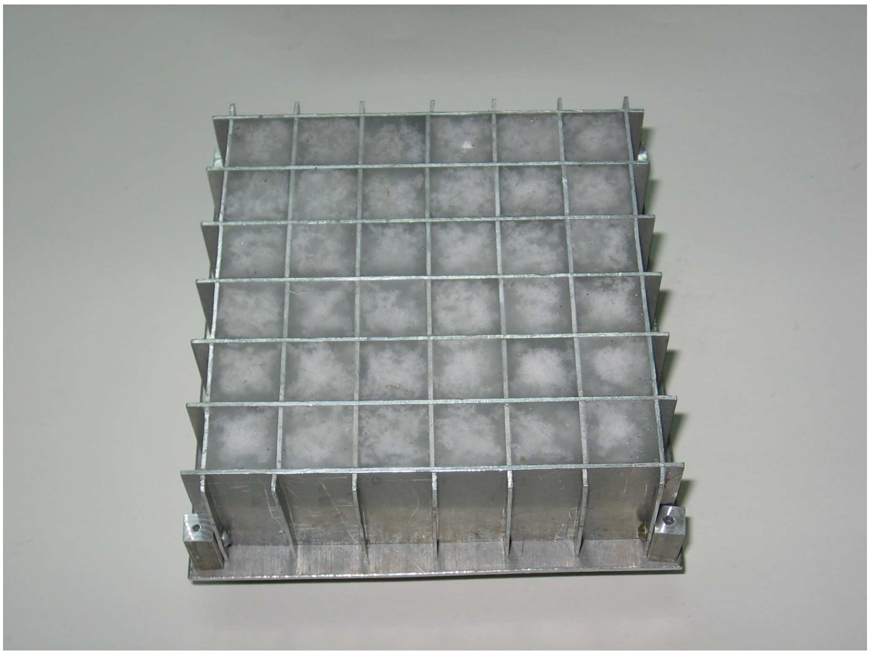

Fig.1. View of the constructed moderator array.

3. Test measurements with the pulsed thermal neutron source

Measurements of the time-decay constant λ have been carried out in the temperature of 20^0C, at various experimental conditions on the experimental set-up. The moderator array has been placed at the end of accelerator tube and shielded (on the surface at the target) by a 2 mm cadmium layer. This shield prevents entering thermal neutrons from the surrounding into the moderator array, but makes possible fast neutrons transport from 14 MeV neutron source.

The time decay of the thermal neutron flux in different parts of the moderator array has been observed. First, the neutron detector has been placed at the centre of the moderator array. The 2 mm cadmium layer with a window (∅ = 3 cm) for the detector covered the surface of the moderator array (Case a in Fig.2). In the second experiment, two detectors have been installed in the opposite corners of the moderator array (Case b in Fig.2) at the windows in the 2 mm cadmium shield. An example of the recorded time distribution of the counted pulses is shown in Fig.3. The decay constant λ of the fundamental mode of the thermal neutron flux $\phi(t)$ has been determined in the same way as always in our pulsed experiments (Drozdowicz *et al.* 1993). Detailed parameters and results of the experiments are given in Tables 1 and 2, where I_p is the average intensity of the measured thermal neutron pulses.

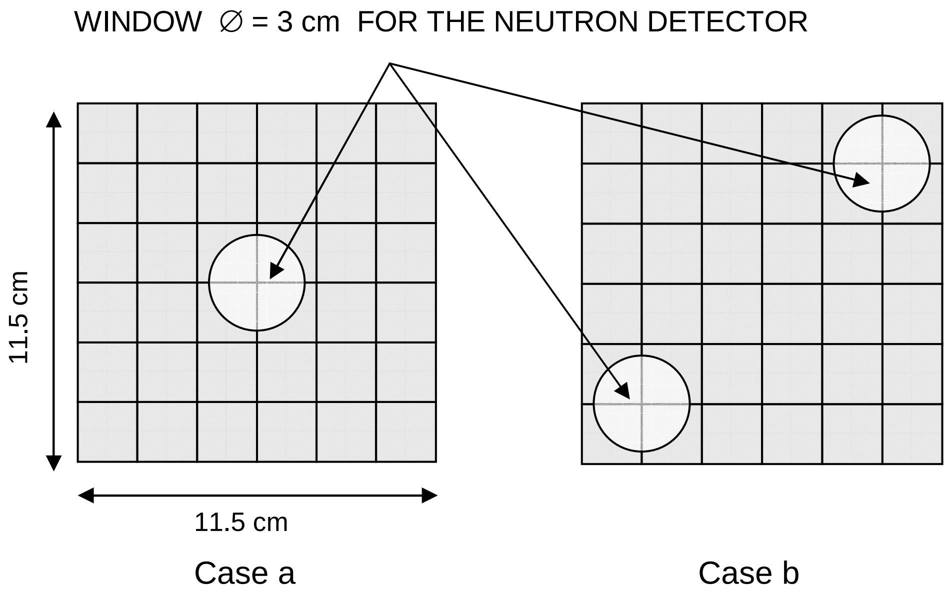

Fig.2. Two locations of the detectors at the moderator array.

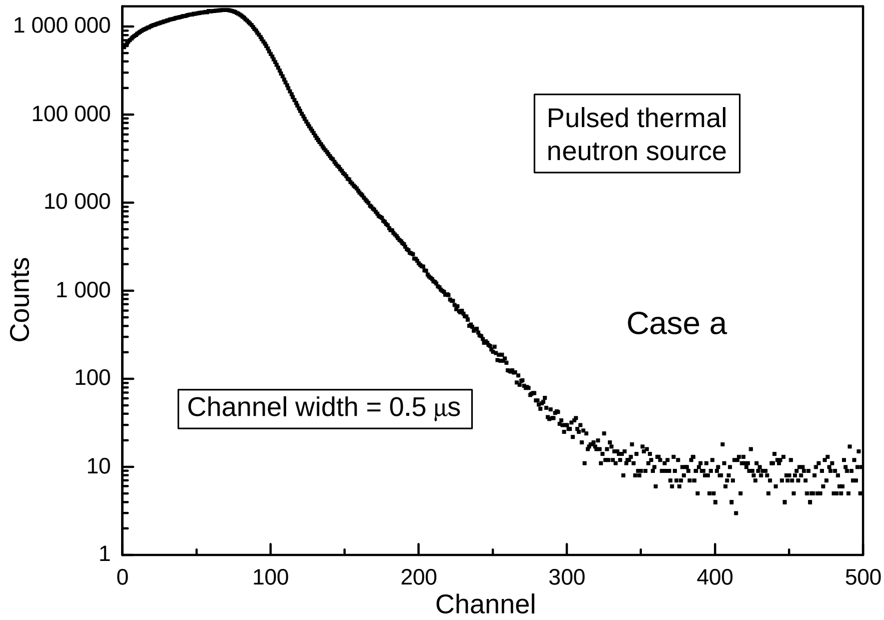

Fig.3. Example of the recorded time distribution of the counted pulses.

Table 1. Parameters and results of neutron experiments with the pulsed thermal neutron source, **Case a.**

Measurement No.	Primary neutron source		Secondary neutron source			
	Duration of the neutron burst T_{imp} [μs]	Repetition time of the neutron burst T_{rep} [ms]	Average intensity I_p [s^{-1}]	Time analyser channel width Δt [μs]	Number of channels N	Time decay constant $\lambda \pm \sigma(\lambda)$ [s^{-1}]
1	40	0.4	1 000	0.25	1024	92 250 ± 723
2	40	0.4	1 500	0.5	512	92 837 ± 418
3	40	0.4	3 000	0.5	512	92 282 ± 212

The time decay of the thermal neutron flux is very rapid. The values of λ are within the statistical accuracy the same on the whole surface of the moderator array. They are slightly different from those expected from the Monte Carlo simulations.

Table 2. Parameters and results of neutron experiments with the pulsed thermal neutron source, **Case b.**

Primary neutron source		Secondary neutron source				
Duration of the neutron burst T_{imp} [μs]	Repetition time of the neutron burst T_{rep} [ms]	Average intensity I_p [s^{-1}]	Time analyser channel width Δt [μs]	Number of channels N	Detector No.	Time decay constant $\lambda \pm \sigma(\lambda)$ [s^{-1}]
90	1.1	2000	1	512	1	93 373 ± 851
					2	91 933 ± 1238

The next series of two experiments has been performed in order to investigate whether the observed decay constant of the neutron flux from the moderator array influences measurements of the thermal neutron decay in samples. A cubic (7 cm) polyethylene sample has been used. Polyethylene as a good neutron moderator makes possible to perform the experiments directly at the 14 MeV neutron source.

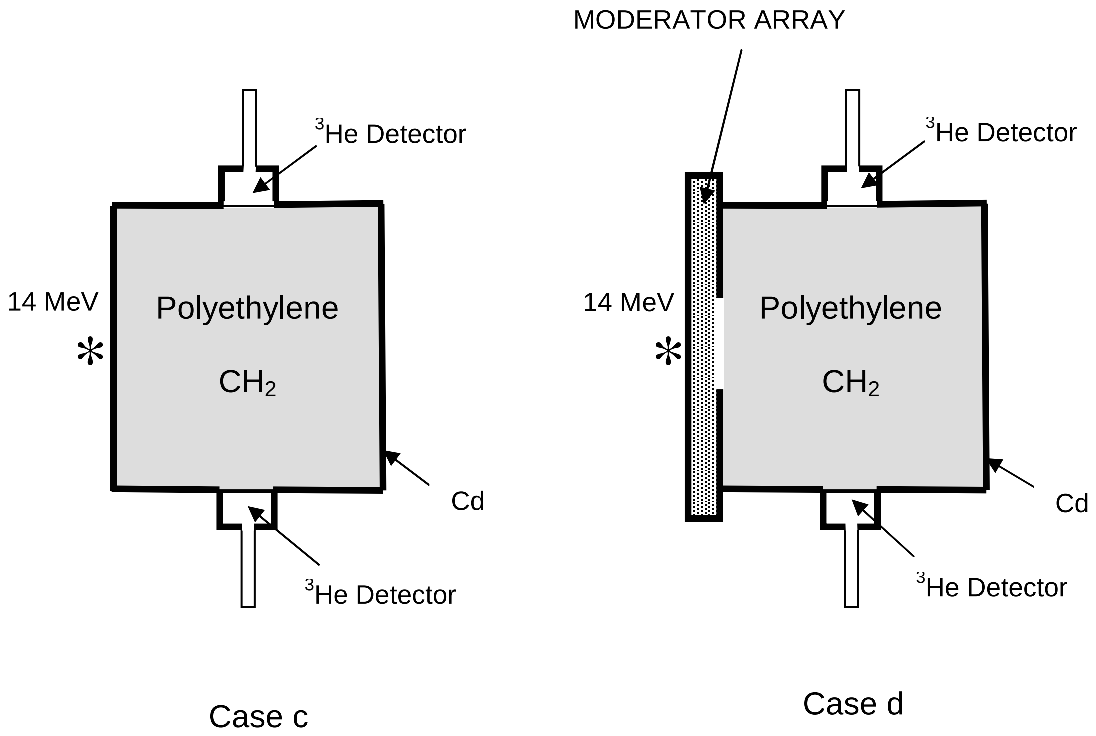

Fig.4. Experimental set-up to measure the time decay constant for the sample.

Two neutron detectors in a symmetrical position counted thermal neutrons (Case c in Fig. 4). The results are presented in the Table 3.

In the next experiment (Case d in Fig.4) the moderator array has been inserted between the target of the accelerator and the sample on the experimental position (Fig.3). The moderator array have been shielded with a 2 mm Cd cadmium layer on the whole surface, except the window between the array and the sample. A corresponding window has been made in the cadmium covering the polyethylene sample.

The results from both experiments and both detector lines fluctuate only statistically. Average values are λ =19 434 s^{-1} in Case c and λ =19 419 s^{-1} in Case d.

Table 3. Decay constants in polyethylene cube measured without (Case c) and with (Case d) a presence of the moderator array.

Case	Primary neutron source		Secondary neutron source				
	Duration of neutron the burst T_{imp} [μs]	Repetition time of the neutron burst T_{rep} [ms]	Average intensity I_p [s^{-1}]	Time analyser channel width Δt [μs]	Number of channels N	Detector No.	Time decay constant $\lambda \pm \sigma(\lambda)$ [s^{-1}]
c	90	1.1	2000	1	512	1	19 422 ± 104
						2	19 466 ± 41
d	90	1.1	2000	1	512	1	19 465 ± 103
						2	19 373 ± 39

5. Conclusions

The pulsed thermal neutron source of the very large time-decay constant has been built. The moderator array, which provides the most effective moderation of 14 MeV neutrons has been selected. The time-decay constant of the entire arrangement has been verified experimentally and the obtained value of λ is nearby expected. It is fully satisfactory for the thermal neutron pulsed experiments. The decay of the thermal neutron flux $\phi(t)$ is considerable rapid comparing to the decaying flux in the investigated sample. The comparison is presented in Fig.5.

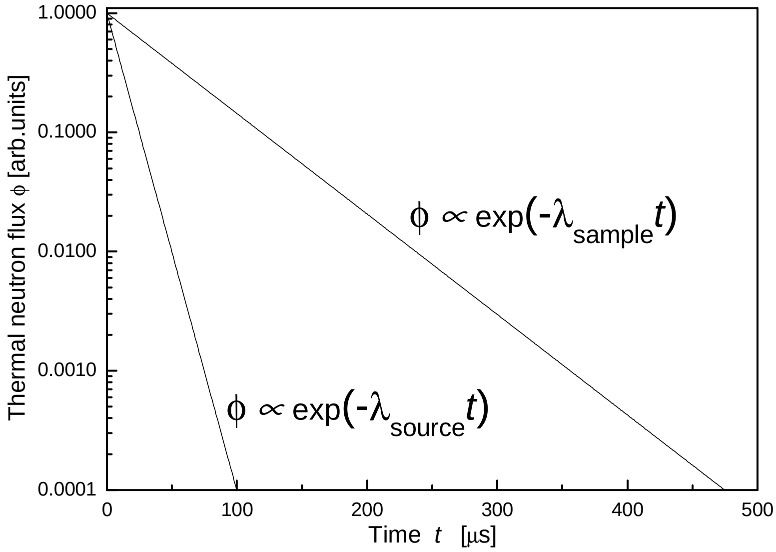

Fig.5. Comparison of the thermal neutron decay $\phi(t)$ in the moderator array and in a sample of polyethylene.

The performed experiments has also proved that the use of the moderator array does not disturb the experimental conditions for the measured sample.

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