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The SOF detectors in pulsed neutron measurements

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Abstract

The time decay of the pulsed thermal neutron flux has been measured with quasi-point SOF detectors (scintillator with the optical fiber). The detectors have been placed at three positions in a 12 cm cube of polyethylene. The time decay constants of the fundamental exponential mode of the thermal neutron flux have been determined and compared with results of a reference measurement using ^{3}He neutron detectors at the cube surface and with a theoretical result from the thermal neutron diffusion theory.

1. Introduction

The SOF detector (Scintillator with the Optical Fiber) consists of a small amount of a scintillator tightly connected to the tip of an optical fiber. The other tip is optically coupled with a small photomultiplier. Mori et al. [1, 2] are the authors of the idea of this construction. In our case the scintillator on the tip of the fiber is ZnS(Ag) mixed with LiF enriched with ^{6}Li up to 99.9% and transparent adhesive material (with the volume ratio of 1:1:1). Another type of the scintillator, like a plastic one, may be used as well as another type of the thermal neutron converter, e.g. boron. The scintillator and the fiber are covered with a lightproof screen. We use the thermal neutron SOF detector based on a plastic fiber with diameter 2 mm and the lenght 2.1 m. The thickness of the scintillator is about 1.5 mm. The reactions between ^{6}Li nuclei and thermal neutrons emit alpha particles and tritons which produce scintillations as a result of interacting with ZnS(Ag). The emission spectrum of ZnS(Ag) has a maximum at 450 nm [2] and well matches the Hamamatsu type R1635 photomultiplier with the bialkali photocatode which diameter is 8 mm. We use a bunch of three SOF detectors connected to one photomultiplier. Details of the construction were described in our Report [3].

It was found [3] that the SOF detector may be successfully used instead of the ^{3}He proportional detector. The experiments, described below, are concentrated on the study how the thermal neutron flux φ(t) decays in time in the small sample depends of the position inside the sample's volume. For this three positions of the SOF detectors in the sample are selected.

2. The experimental set-up

The experimental set-up consists of the investigated sample (polyethylene) of the fixed size (cube 12 cm), covered with a cadmium shield. The system is irradiated by bursts of 14 MeV neutrons. The duration of the neutron burst has been equal to 100 μs and the repetition time has been 1.8 ms. The neutrons slow down in the system and form the thermal neutron field decaying in time. The die-away rate of escaping thermal neutrons is measured with a thermal neutron detector [4, 5]. In the experiment, the time decay constant λ of the fundamental exponential mode, $e^{-\lambda t}$, is found.

The theoretical λ value for the sample is calculated according to the formula:

$$\lambda = v\Sigma_a + D_0B^2 - CB^4 \qquad (1)$$

where the neutron parameters for polyethylene of the density ρ = 0.9057 g cm^{-3} are [4,6,7]:

$v\Sigma_a$ = 6005 s^{-1} – the thermal neutron absorption rate,

D_0 = 25 695 cm^2 s^{-1} – the diffusion constant,

C = 1958 cm^4 s^{-1} – the diffusion cooling coefficient,

and B^2 is the geometric buckling which is a parameter depending on the geometrical shape and size of the sample [9].

The decay constant λ, calculated for the 12 cm cube of polyethylene is 10 825 s^{-1}.

First, two detection lines with ^{3}He detectors were used for verification of the experiment (Table 1). A scheme of the arrangement is shown in Fig. 1.

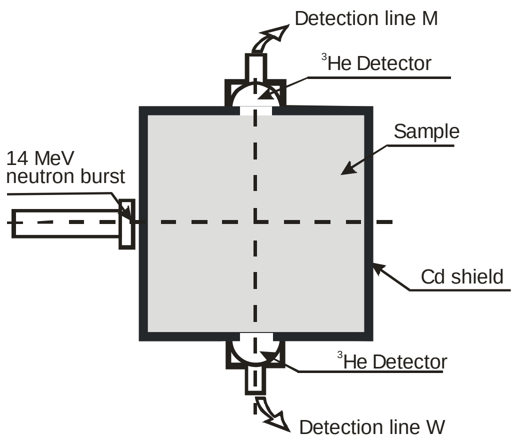

Fig. 1. Experimental set-up with ^{3}He detectors at the fast neutron generator.

The measurements were done with a good counting statistics (about 2 200 000 counts in the defined region of analysis) and acquisition time about 3 hours.

The experiments with a bunch of the three SOF detectors were done with one detection line only. In order to obtain a good counting statistic, a much higher neutron flux has to be used. It caused overloading of the ^{3}He detector so this line was not used. A simplified diagram of the measuring system is shown in Fig 2. The detection line consists of three SOF detectors connected to the photomultiplier, preamplifier, amplifier and HV power supply. Measured pulses were delivered to the input of the multiscaler.

The polyethylene cube was prepared with a hollow to place the SOF detectors in three positions: at the upper surface of the cube (Geometry I), 1 cm below the surface (Geometry

II), and in the centre of the sample (Geometry III).

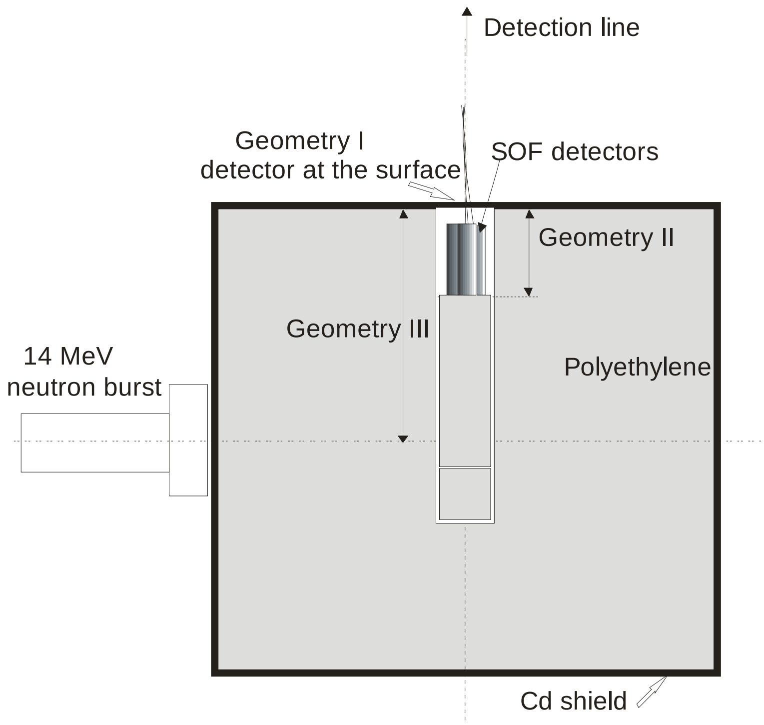

Fig 2. Three types of geometry in the experiments with the SOF detectors.

The die-away curves of thermal neutrons have been registered in the multiscaler which has had the dwell time equal to 2 μs. For the SOF detectors the time of the acquisitions were about 6 hours and the counting statistics (in the same region of analysis as while using ^{3}He detectors) was less then 100 000 counts, which results from the small dimensions of the SOF detectors (diameter about 2 mm, the sensitive volume is 46 750 times less then of the helium detector). So, it needs longer measurements for a good assign of the measured time decay constants λ of the thermal neutron flux in polyethylene in each measurement.

3. Results

The values of the measured thermal decay constant λ, by the ^3He and SOF detectors, are listed in Tables 1 and 2, where $\sigma(\lambda)$ is the standard deviation of the determined value λ.

Table 1. Reference time decay constants λ of the thermal neutron flux in the polyethylene sample (measured with the ^3He detectors).

No.	λ $\sigma(\lambda)$ $[s^{-1}]$	Lab. code
1	10 814 31 10 898 59	m02001 w02001
2	10 745 37 10 878 29	m02002 w02002

The counting statistics in the single measurement with the SOF detectors is insufficient to determine the decay constant with a high accuracy. Therefore, the experiments were repeated a few times for each position of the detector. The final value of the decay constant for each case was achieved as a weighted average of results of individual short measurements, similarly as described in [9]. In Table 3 the experimental results for helium and SOF detectors are compared.

Table 2. Measured time decay constants λ of the thermal neutron flux in the polyethylene sample (SOF detectors).

Geometry I

No	λ σ(λ) [s^{-1}]	Lab. code
1	11 013 120	02003
2	10 701 96	02014
3	10 893 137	02015
4	10 913 122	02016
5	10 855 113	02017
6	10 880 336	02018
7	10 880 107	02019
8	10 773 152	02020
9	10 982 94	02021
10	10 891 111	02022
11	10 987 167	02023
12	10 944 112	02024
13	10 725 122	02025

Geometry II

No	λ σ(λ) [s^{-1}]	Lab. code
1	10 787 87	02006
2	10 823 139	02007
3	10 849 111	02008
4	10 793 108	02009
5	10 938 72	02010
6	10 802 124	02011
7	10 750 72	02012
8	10 827 169	02013

Geometry III

No	λ σ(λ) [s^{-1}]	Lab. code
1	11 001 120	02004
2	11 089 98	02005
3	10 986 95	02026
4	10 932 46	02027
5	10 974 52	02028
6	10 974 79	02029
7	11 003 50	02030
8	10 965 90	02031
9	10 918 74	02032

Table 3. Comparison of the obtained time decay constants λ ± σ(λ) [s^{-1}] of the thermal neutron flux in the polyethylene sample.

^{3}He detectors	Geometry I SOF Detectors at the surface of the sample	Geometry II SOF Detectors 1cm below the top of the sample	Geometry III SOF Detectors at the centre of the sample	Theory
10829 ± 18	10 865 ± 35	10 825 ±35	10 972 ± 22	10 825

Conclusions

It was found that the measured time decay constant λ of the thermal neutron flux in the Geometry I and II is consistent with results of the neutron diffusion theory and measurements with use of the ^{3}He detectors. Let us notice that neutron data employed in the neutron diffusion theory, Eq.(1), are obtained from measurements at the surface of the samples.

In the case of Geometry III, the SOF detectors in the centre of the sample, the decay constant of the thermal neutron flux is a little higher. Probably it is a result of a lower escape of thermal neutrons in the centre (cf. Eq.1) but more precise experiments are required for investigation of this problem.

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