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Feasibility study of experimental detection of the hydrogen content in rock material by a pulsed neutron method

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and
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Abstract

Theoretical principles of a pulsed neutron method to measure the water or hydrogen content in a rock material have been tested on the experimental set-up at the fast neutron generator in the INP. The time decay constant of the thermal neutron flux in the samples has been measured as a function of the hydrogen content. Dry crumbled granite has been used as a rock sample. The hydrogen content has varied due to addition of a defined amount of polyethylene (0 to 20 %). A few arrangements (neutron source + sample) have been tried. A dedicated pulsed thermal neutron source has been designed and built. The measuring set-up has been chosen for a final elaboration of the method.

1. Introduction

The thermal neutron pulsed parameters of a material are most often investigated using an experimental set-up at a pulsed fast neutron source. Fast neutrons slow down in the given sample and the thermal neutron flux, decaying in time, is observed. The decay constant λ of the fundamental mode of the flux $\varphi(t)$ is a direct result of such measurement. When specific experimental conditions are fulfilled the λ value can be presented as a function of the thermal neutron diffusion parameters, of the scattering cross-section Σ_s among others. The latter depends on the water content in a sample because, for thermal neutrons, it is strongly influenced by the presence of hydrogen. The effect is meaningful when geological samples are considered. The macroscopic scattering cross-sections Σ_s of main rock components are generally one order smaller than the Σ_s of hydrogen. This difference should make dry and wet rock samples possible to be distinguished in the pulsed neutron measurement. The point in such an experiment is whether a quantitative measurement with a good accuracy is possible.

A preliminary theoretical approach to design an experimental method to measure the cross-section Σ_s and/or the water or hydrogen content in geological samples has been presented in the report by Drozdowicz *et al.* (2002a). As it turned out, a strong dependence of the sought function $\lambda(\Sigma_s)$ on the diffusion cooling effect of the thermal neutron flux in the finite sample investigated is the essential difficulty in a theoretical description of the proposed measurement. Thus, there are two following directions of the relevant research:

1. Numerical and experimental research in order to determine the diffusion cooling coefficients C for the basic rocks (sandstone, dolomite, limestone) and to find a dependence of the coefficient C on the water content in the rock material.
2. Testing measurements with a pulsed neutron source in order to determine possibilities of the experimental set-up and its sensitivity to the water content in rock material.

The first problem was studied and presented by Drozdowicz *et al.* (2002b, 2003a, 2003b). The second one is presented in this report.

2. Selection of samples for the test measurements

A set of samples of a given rock with various water contents should be prepared for the reference measurements. Granite has been chosen as a typical rock material which is characterised with a quite stable mineral and elemental composition and typical thermal

neutron parameters (among main types of geological lithologies). An important advantage of this rock is the low water absorbability. When a crushed material is to be used as the reference sample this feature allows us to avoid a non-controlled changes of the hydrogen content coming from the air humidity. Bulk granite from the Strzegom-Żbik deposit (Poland) has been used in the present experiments.

A preparation of wet samples with a low water content (about few per cent) is technically difficult and can cause heterogeneity of the samples (wet and dry regions in a given sample volume can easily occur). However, the water content in the sample is fully connected to the hydrogen content in it. Thus, in such experiments with thermal neutrons, its is possible to substitute water with another hydrogenous material which is solid, and later only to re-calculate that hydrogen content to an equivalent water content. Polyethylene, $–CH_2–$, has been chosen as the material sufficiently well simulating water, H_2O. Granulated polyethylene has been available as a technical product, Stavrolen™ (Russian production). It has been used to prepare the set of rock samples of different, well-defined hydrogen contents. The dried granulated Stavrolen has been mixed with rock material in required proportions. That technique ensures the homogeneous mixture of materials of the "wet" samples. The important physical and thermal neutron diffusion parameters of water, polyethylene, and granite, are collected in Table 1 where v_0 is the most probable velocity of thermal neutrons, and $\sigma(x)$ here and in all subsequent tables denotes the standard deviation of the x value.

Table 1. Parameters of materials considered for the experiments.

Material	Thermal neutron cross-sections		Solid material density ρ $\sigma(\rho)$ [g cm^{-3}]	Granulation
	Absorption $\Sigma_a(v_0)$ $\sigma(\Sigma_a)$ [cm^{-1}]	Scattering $\Sigma_s(v_0)$ $\sigma(\Sigma_s)$ [cm^{-1}]		
H_2O	0.02224 0.00005	~3.985 0.166	~1	——
$–CH_2–$	0.02726 0.00006	~4.900 0.202	0.9495[P] 0.0015	Spherical grains $2R \approx 3$ mm
Granite A	0.01440 0.00011	0.2503 0.0003	2.6527[S, P] 0.0010	Sieve mesh $2R \approx 2 \div 2.5$ mm
Granite B	0.01083 0.00015	0.2477 0.0003		

[P]) measured in a helium pycnometer
[S]) actual granite (Strzegom deposit)

The thermal neutron diffusion parameters have been calculated by SIGSA code (Drozdowicz and Krynicka, 1995), using a certain approximation for hydrogenous materials (Drozdowicz, 1998a). The typical, average elemental composition of granite used for these calculations is specified in Table 2.

Table 2. Two typical, average elemental compositions of granite (Polański and Smulikowski, 1969).

Element	Granite A [wt. %]	Granite B [wt. %]
O	43.50	48.70
Si	24.00	32.30
Al	8.76	7.70
Fe	8.56	2.70
Ca	6.72	1.58
Mg	4.50	0.56
Na	1.94	2.77
K	0.83	3.34
Ti	0.90	0.23

3. Check test of the thermal neutron diffusion parameters of Stavrolen™

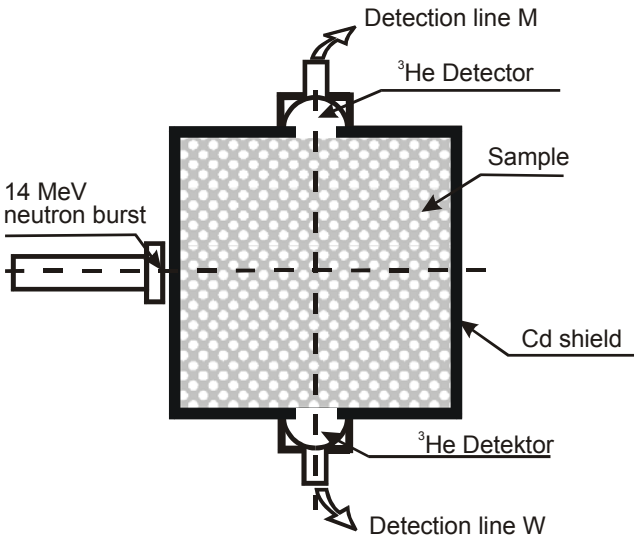

Fig. 1. Experimental set-up at the fast neutron generator.

The time decay constants λ has been measured for given volumes of Stavrolen samples in order to check whether the thermal neutron diffusion parameters of this technical material correspond really to those of pure polyethylene. Two cylindrical samples STAV I and STAV II ($H = 2R = 7.6$ cm and 9.6 cm, respectively) of grained Stavrolen have been prepared. The time decay constants λ have been measured on the pulsed neutron generator experimental set-up (Fig. 1). The obtained experimental results have been

compared to the calculated decay constants for polyethylene, $(CH_2)_n$, samples. The theoretical λ values for these samples have been calculated according to the formula:

$$\lambda = \alpha + D_0 B^2 - CB^4 + FB^6 \ , \qquad (1)$$

where $\alpha \equiv \langle \nu \Sigma_a \rangle$ is the thermal neutron absorption rate, D_0 is the diffusion constant, C is the diffusion cooling coefficient, and B^2 is the geometric buckling of the sample. Small discrepancies between values of the thermal neutron pulsed parameters, reported by different authors for a given hydrogenous material, are usually observed. The problem is especially known for the diffusion cooling coefficient (cf. remarks in the paper by Drozdowicz, 1998b). The same situation is for polyethylene and, therefore, a few variants of the calculation have been performed. The thermal neutron data for polyethylene from different references are collected in Table 3, where C_B denotes the value calculated theoretically within the Beckurts-Granada approach (Granada *et al.* 1987a), and C_D and C_t are the values obtained with the method given by Drozdowicz (1998b, 1999) according to Nelkin's theory (Nelkin, 1960; Williams, 1966). The data are supplemented with the so-called density-removed pulsed neutron parameters, helpful to calculate the real physical parameters at different material density (Granada *et al.*, 1987a; Czubek, 1997; Dąbrowska and Drozdowicz, 2000).

Table 3. Thermal neutron diffusion parameters for polyethylene at 20^0C.

Parameter	Physical, $\rho = 0.92$ g cm^{-3}			Density-removed		
		Set 1	Set 2		Set 1	Set 2
Absorption rate	α [s^{-1}]	5 821[a)]	5 811[b)]	α^M [s^{-1}/(g cm^{-3}]	6 316	6 316
Diffusion constant	D_0 [cm^{2}s^{-1}]	27 133[a)]	26 553[b)]	D_0^M [cm^{2}s^{-1}(g cm^{-3})]	24 962	24 428
Diffusion cooling coefficient	C_B [cm^{4}s^{-1}]	2 422[a)]	2 160[c)]	C_B^M [cm^{4}s^{-1}(g cm^{-3})^3]	1 886	1 682
	C_D+C_t [cm^{4}s^{-1}]	—	2 916[c)]	$(C_D+C_t)^M$ [cm^{4}s^{-1}(g cm^{-3})^3]	—	2 271
Correction	F [cm^{6}s^{-1}]	—	—	F^M [cm^{6}s^{-1}(g cm^{-3})^5]	104[d)]	104[d)]

[a)] Granada *et. al.* (1987b)
[b)] Drozdowicz (1999)
[c)] Drozdowicz and Gillette (1999)
[d)] Dąbrowska and Drozdowicz (2000)

Table 4. Theoretical thermal neutron parameters of the measured Stavrolen samples.

Parameter			Sample	
			STAV I H_2 = 7.6 cm	STAV II H_2 = 9.6 cm
ρ_B		[g cm^{-3}]	0.667	0.648
α		[s^{-1}]	4 213	4 092
based on set 2	D_0	cm^{2}s^{-1}]	36 624	37 698
	C_B	[cm^{4}s^{-1}]	5 668	6 182
	C_D+ C_t	[cm^{4}s^{-1}]	7 653	8 346
based on set 1	D_0	[cm^{2}s^{-1}]	37 424	38 522
	C_B	[cm^{4}s^{-1}]	6 356	6 931
F		[cm^{6}s^{-1}]	788	910

The bulk densities ρ_B of the two samples of grained Stavrolen are, of course, different from the solid material density and are slightly different to each other. The calculated thermal neutron parameters, based on the data from Table 3, are shown in Table 4. The measured and calculated λ values are collected in Table 5. The observed discrepancies between measured and calculated results (maximum ~4 %) allow us to use the basic neutron data for polyethylene in further calculations and discussions when Stavrolen is used. (Note remarks on the neutron parameters of materials at significantly different mass densities in the paper by Dąbrowska and Drozdowicz, 2000.)

Table 5. Measured and calculated time decay constant λ for two cylindrical samples of grained Stavrolen.

Sample	Experiment λ $\sigma(\lambda)$ [s^{-1}]	Analytical calculation, λ [s^{-1}]		
		based on set 2		based on set 1
		$C = C_B$	$C = C_D+C_t$	
STAV I	21 377 72	20 700	20 300	20 900
STAV II	15 802 46	15 300	15 100	15 500

4. Measurements of the time decay constant of the thermal neutron flux in bulk granite+polyethylene samples

The theoretical base for the pulsed measurement of the water content in a rock material of a given thermal neutron macroscopic cross-section Σ_s was given in report by Drozdowicz *et al.* (2002a), and supplemented with the Monte Carlo simulations of the time behaviour of the pulsed thermal neutron flux in such materials (Drozdowicz *et al.* 2002b, 2003a, 2003b). Both the methods (theoretical and numerical) begin the description of the effect from the time moment when the thermal neutron flux exists in the system investigated. The next step is to test the method of measurement and the possibilities of our real experimental set-up (at the pulsed 14 MeV neutron generator), where thermal neutrons are generated in the slowing-down process in the measured sample. In the following subsections, measurements of the decay constant λ of the thermal neutron flux in various granite+polyethylene samples in different geometrical conditions are described.

4.1. Experiments at the pulsed 14 MeV neutron source

The sample of a given regular shape, surrounded by a cadmium shield to fulfill the vacuum boundary conditions for thermal neutrons, is the basic experimental geometry for the pulsed neutron experiment (Geometry I in Fig. 2). Taking into account that the final measurement should be done on samples not too big (about 0.5 ~ 1 dm^3) the cylindrical sample $2R = H = 9.6$ cm has been used. Experiments performed in such geometry have demonstrated that the thermal neutron time decay constant λ can be measured if the content of polyethylene is not less than twenty weight per cent (Table 6). When the hydrogen content in the sample is lower, the number of the neutrons slowed down in the sample is very small. The counting statistics of thermal neutrons is insufficient to observe the thermal neutron decay curve with a good accuracy and to estimate the time decay constant of the fundamental mode of the neutron flux. Even in the case of the 20 % content of polyethylene the λ results are not too much satisfactory. Namely, the decay of the thermal neutron flux after the burst is characterized by a sum of exponential modes. A correct determination of the fundamental decay constant λ is well confirmed if the result obtained from consecutive equal intervals along the decay curve is (statistically) constant, *i.e.* $\lambda(t_d) \approx const.$ where t_d is the variable delay time after the neutron burst. An example of the $\lambda(t_d)$ dependence, which has been typically obtained in the discussed experimental series, is shown in Fig. 3. (The presented result comes from the experiment 2-F, Table 6). An indication of the delay time interval, for

which the λ value remains constant, is impossible. An example of a correct behaviour of the function $\lambda(t_d)$ can be seen later in Fig. 6.

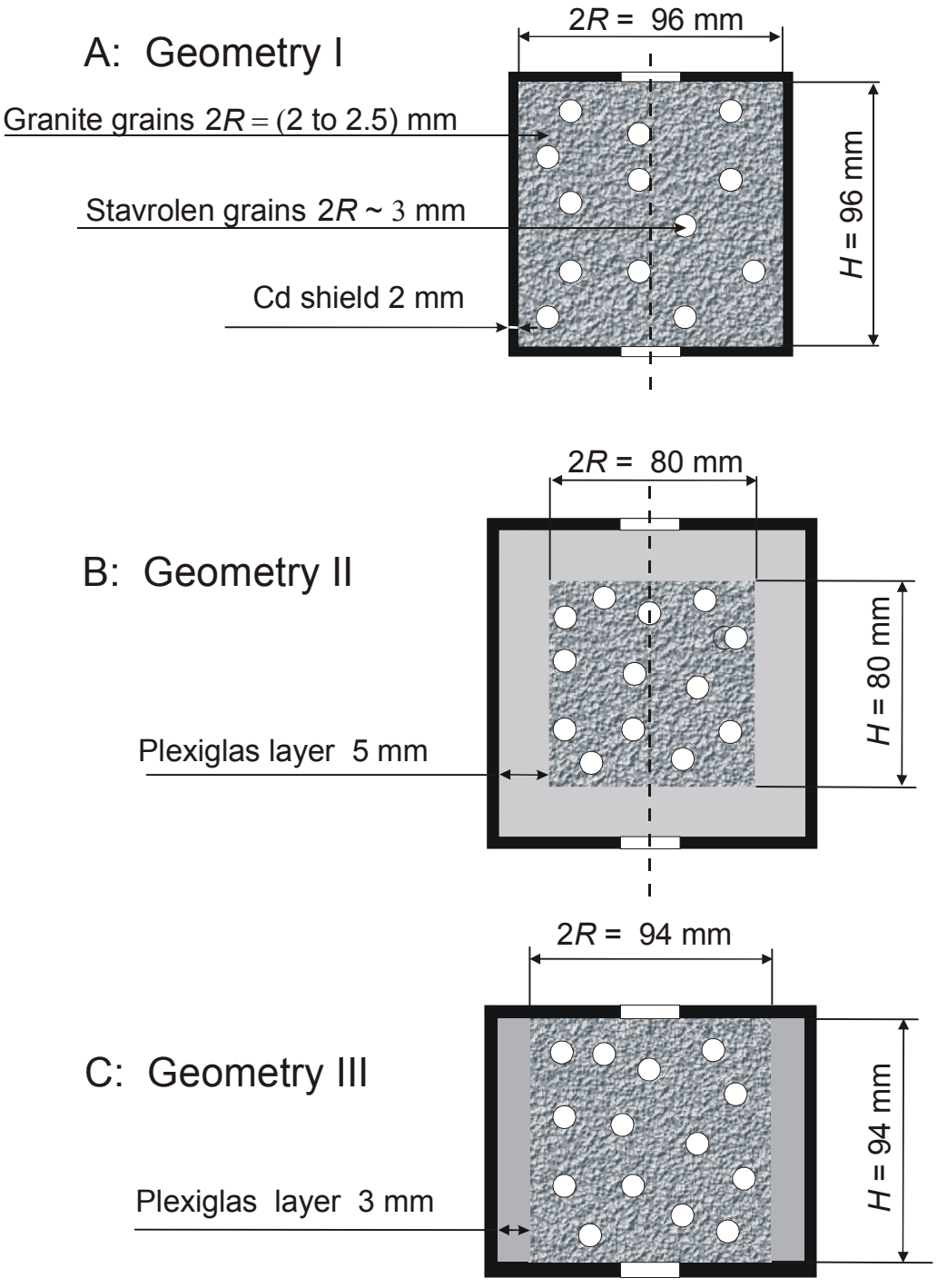

Fig. 2. Three types of the measurement geometry used in the experiments.

Table 6. Measured time decay constants of the thermal neutron flux in granite+polyethylene bulk samples (Fast neutron pulsed source).

No	Geometry type	Polyethylene content [wt. %]	Bulk density ρ_B [g cm^{-3}]	λ $\sigma(\lambda)$ [s^{-1}]	λ/ρ_B $\sigma(\lambda/\rho_B)$ [s^{-1}/(g cm^{-3})]	Lab. code
1-F	I	20	1.0647	25917 309	24342 290	01404
2-F	I	20	1.1651	20391 1022	17502 878	01606
3-F	II	20	1.1004	21099 162	19173 147	01403
4-F	II	15	1.128	21235 161	18825 143	01402
5-F	III	20	1.1346	22287 1225	19643 1079	01607
6-F	III	10	1.3458	24313 380	18063 282	01610

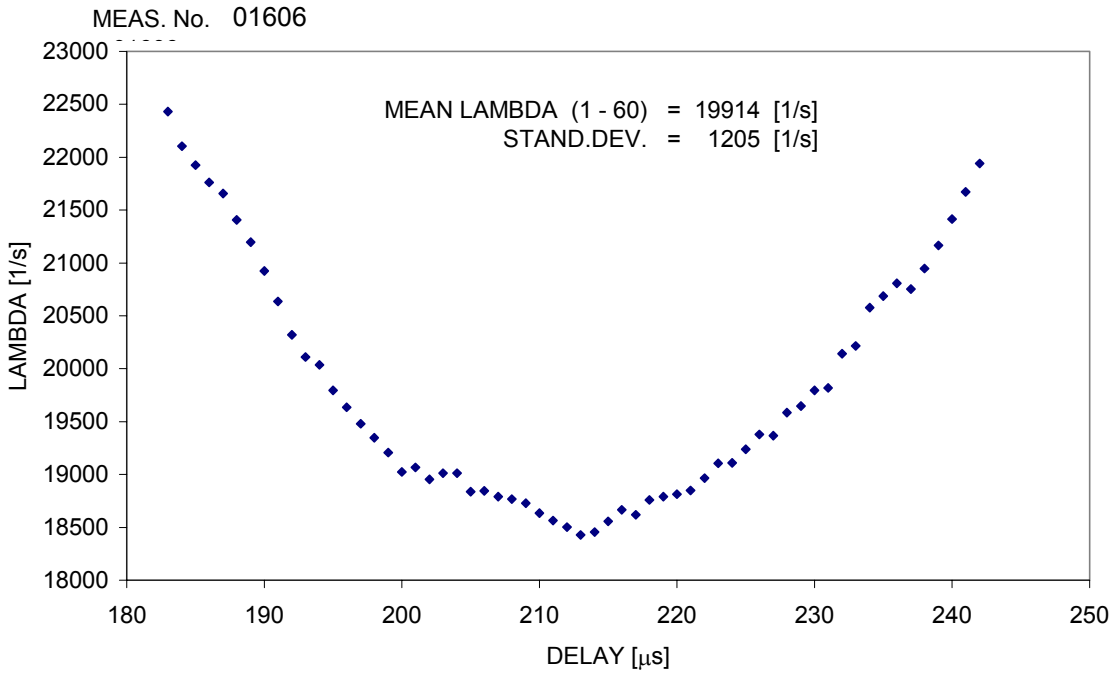

Fig. 3. Decay constant of the thermal neutron flux as a function of the delay time in the case of an insufficient counting statistics.

An improvement of experimental conditions can be achieved using an additional moderator around the investigated sample. The 5 mm Plexiglas layer, surrounding entirely the sample and covered with cadmium ouside, has been used (Geometry II in Fig. 2). The time decay constant λ could be measured at a lower, 15 wt. %, polyethylene content (Table 6). Unfortunately, the measured λ values for samples of two different hydrogen contents are not statistically different. We have concluded that the observed time decay of thermal neutrons is dominated mostly by the decay of neutrons slowed down in Plexiglas.

The last test has been done with a thinner (3 mm) Plexiglas layer surrounding only the sidewalls of the cylindrical sample (Geometry III in Fig. 2). The results obtained for 10 and 20 % content of polyethylene are not promising. The high standard deviation of the measured decay constant λ (*e.g.* result No. 5-F in Table 6) shows that the determination of the fundamental mode flux decay constant from the registered decay curve is very difficult and unreliable.

The main reason of lack of success of the experiment in the proposed set-up is an insufficient number of thermal neutrons which arrive in the sample. The rock materials are weak neutron moderators. Neutrons are moderated mainly only in polyethylene grains and majority of fast neutrons from the 14 MeV source escapes from the sample before the thermalization. Application of the additional layers of moderator (here Plexiglas) causes that mainly the moderator shield determines the observed thermal neutron decay. Moreover, the thermal neutron decay curve contains a big number of higher modes. The isolation of the fundamental mode decay constant is difficult and the accuracy is insufficient. A general low slowing-down power of the sample material creates a low thermal neutron flux in the sample and in the counting statistic, gathered in a reasonable time of the measurement, is very poor. An essential change of the measurement conditions seems to be necessary. The number of thermal neutrons, participating in the diffusion process inside the investigated sample, should be increased.

4.2. Pulsed thermal neutron source

A significant increase of the number of thermal neutrons in the sample can be obtained when the sample is irradiated with a pulsed thermal neutron source. In the case of our equipment (14 MeV neutron source), the best way to gain the thermal neutron flux in the investigated sample is to convert the fast neutron burst into the thermal neutron burst before

neutrons enter the sample. The burst should have a well-defined, short decay time and a high thermal neutron efficiency. The neutron lifetime about 10 μs, several times shorter than the lifetime of thermal neutrons in the irradiated sample (expected about 40 μs to 100 μs) is the main requirement of such source for our experiments.

An idea of the method of slowing-down fast neutrons from the pulsed neutron generator with a good time response was given by Mayer *et al.* (1990, 1992). Here we have proposed a type of the thermal column in the form of a cadmium grid filled with paraffin. The physical principle is shown in Fig. 4. The 14 MeV neutrons from the pulsed source (accelerator target) irradiate the moderating slab which is divided in small cuboids, separated from each other with a cadmium shield. This construction allows almost unperturbed process of slowing-down fast neutrons in the entire volume of the slab. The thermalized neutrons, which would travel from a given cuboid toward the neighbouring one, are absorbed in the cadmium boundaries. Thus, the thermal neutron diffusion is limited only to each separate mesh cell. The resulting time decay of the thermal neutron flux is controlled by the geometric buckling of the single unit and not of the entire slab. When the mesh size is small the geometric buckling of the single cuboid is large and the time decay of the thermal neutron flux is short (cf. Eq.(1)). The quantitative neutron output is, however, a sum of neutrons from the total slab surface.

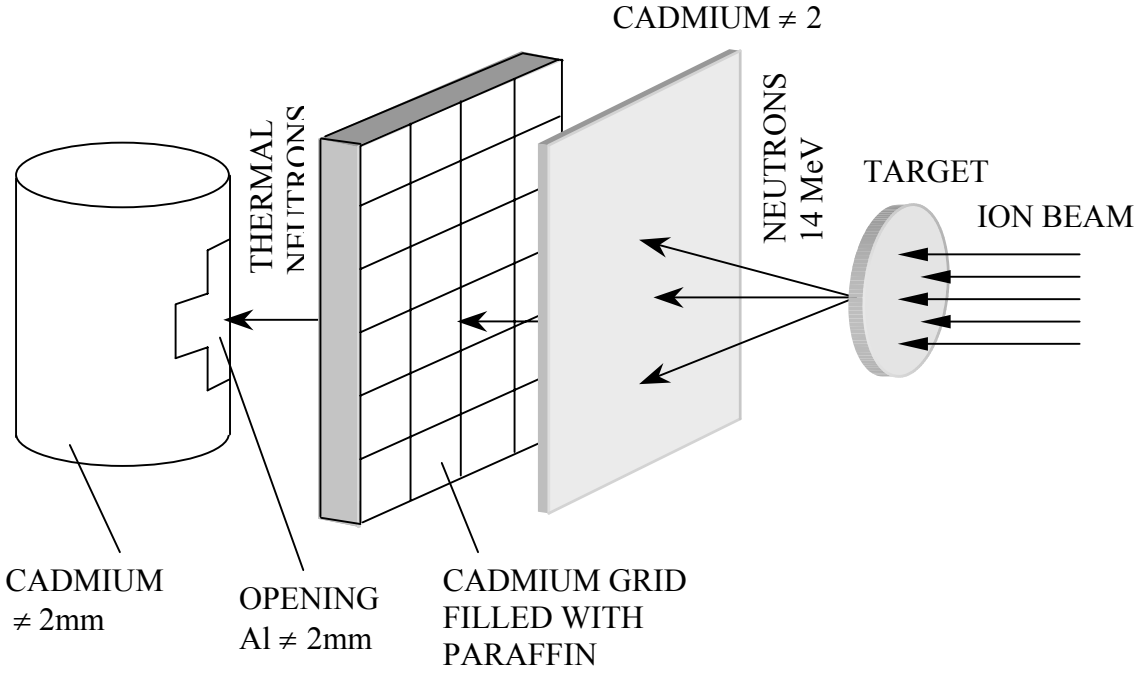

Fig. 4. Principle of the pulsed thermal neutron source.

As it can be clearly noticed, the efficiency of such pulsed thermal neutron source is in a contradiction to the very fast decay of the flux. Several mesh sizes of the moderating grid have been considered to fit the source conditions to the experiment requirements, using paraffin as the moderator.

The fundamental decay constant of the thermal neutron flux in an individual cuboid has been calculated from formula of Eq.(1). Independently, the decay constant has been obtained from Monte Carlo numerical simulations of the time behaviour of the thermal neutron flux in the single cuboid. The total efficiency of the pulsed thermal neutron source has been estimated from other independent MC simulations. The real geometry of different grids in the entire plate has been declared in each calculation. The stationary point source of 14 MeV neutrons has been placed in the centre at the plate surface (8 cm in width × 12 cm in height). The relative thermal neutron flux (E < 1 eV) has been calculated on the opposite surface (window 2.25 cm × 7 cm).

Results of the analytical and numerical estimations are collected in Table 7. Here a supplementary explanation should be made. Namely, in the literature there is no differentiation between the thermal neutron parameters for paraffin and polyethylene (*e.g.* Granada *et al.*, 1987b). This can create certain inconvenience and uncertainty in a more advanced research. Polyethylene can be treated as an infinite chain of CH_2. Paraffin is a closed chain C_nH_{2n+2}, usually with n equal 20 to 40. On the other hand, the nuclear data libraries of the energy- and angle-dependent thermal neutron scattering cross-sections, attached to the MCNP code, contain only the data for hydrogen bound in polyethylene. These data have to be used for both materials. Finally, some of the calculations have been performed for polyethylene, others for paraffin, depending which parameters could be used in particular cases. It is worth to notice that the difference between the decay constants for the 2 × 2 × 3 cm^3 cuboid obtained for paraffins n=20 and n=40 is small (ca. 0.7 %). Much greater discrepancies are observed in the analytical estimations. They come mainly from different methods of calculation of the diffusion cooling coefficient C. Additional uncertainty is introduced by the correction, F, to this coefficient. It is difficult to determine it with a high accuracy (cf. Dąbrowska and Drozdowicz, 2000) and in the case of a small volume of the material (*i.e.* a large geometric buckling) the correction term FB^6 in Eq.(1) becomes significant. The neutron parameters for the presented theoretical calculations have been taken from the set marked as 2 in Tables 3 to 5.

Table. 7. Estimation of the parameters of the pulsed thermal neutron source.

Mesh size $a \times b \times g$ [cm^3]	MCNP simulations			Theoretical calculation (buckling formula)	
	Neutron flux $\varphi(E < 1$ eV) [10^{-6} neutrons per 1 fast neutron]	Theoretical material *)	Decay constant of the thermal neutron flux [s^{-1}] λ $\sigma(\lambda)$	Decay constant λ [s^{-1}]	
				while $C = C_B$	while $C = C_D + C_t$
$2 \times 2 \times 2$	3.451 (±0.7 %)	Polyethylene $\rho = 0.947$ g cm^{-3}	111 217 168	99 812	83 591
$3 \times 3 \times 3$	6.767 (±0.5 %)	Polyethylene $\rho = 0.947$ g cm^{-3}	64 827 385	59 354	55 182
$2 \times 2 \times 3$	6.412 (±0.5 %)	Paraffin n = 20 $\rho = 0.8902$ g cm^{-3}	97 663 175	88 313	75 273
		Paraffin n = 40 $\rho = 0.8902$ g cm^{-3}	98 336 270		
$3 \times 3 \times 2$	3.442 (±0.7 %)	Polyethylene $\rho = 0.8902$ g cm^{-3}	——	74 788	66 335

*) Polyethylene = $-CH_2-$, Paraffin = C_nH_{2n+2}

The 2×2×3 cm^3 mesh was chosen for the experimental verification due to a short decay time and a relatively high thermal neutron flux. The moderating grid containing 24 paraffin cuboids, separated with 2 mm cadmium, has been made (Fig. 5). The plate has been inserted between the fast neutron source (target of the accelerator) and the sample and shielded (on the surface at the target) by the additional 2 mm cadmium shell. This shield preserves entering thermal neutrons from the surrounding into the moderating plate, and is transparent for the fast neutrons from the source. The thermal neutrons emitted from the opposite surface of the moderating grid can reach the cross-shaped opening in the sample shield (Figs. 4 and 5).

A check pulsed experiment has been performed. The time distribution of the thermal neutron flux from the moderating grid has been registered and the fundamental decay constant has been found. It has been also compared to the result of the MCNP simulation of the full thermalization process in a single mesh cell (paraffin, average n=30 used), starting from the 14 MeV neutron source. The results are shown in Table 8. They are in a very good agreement.

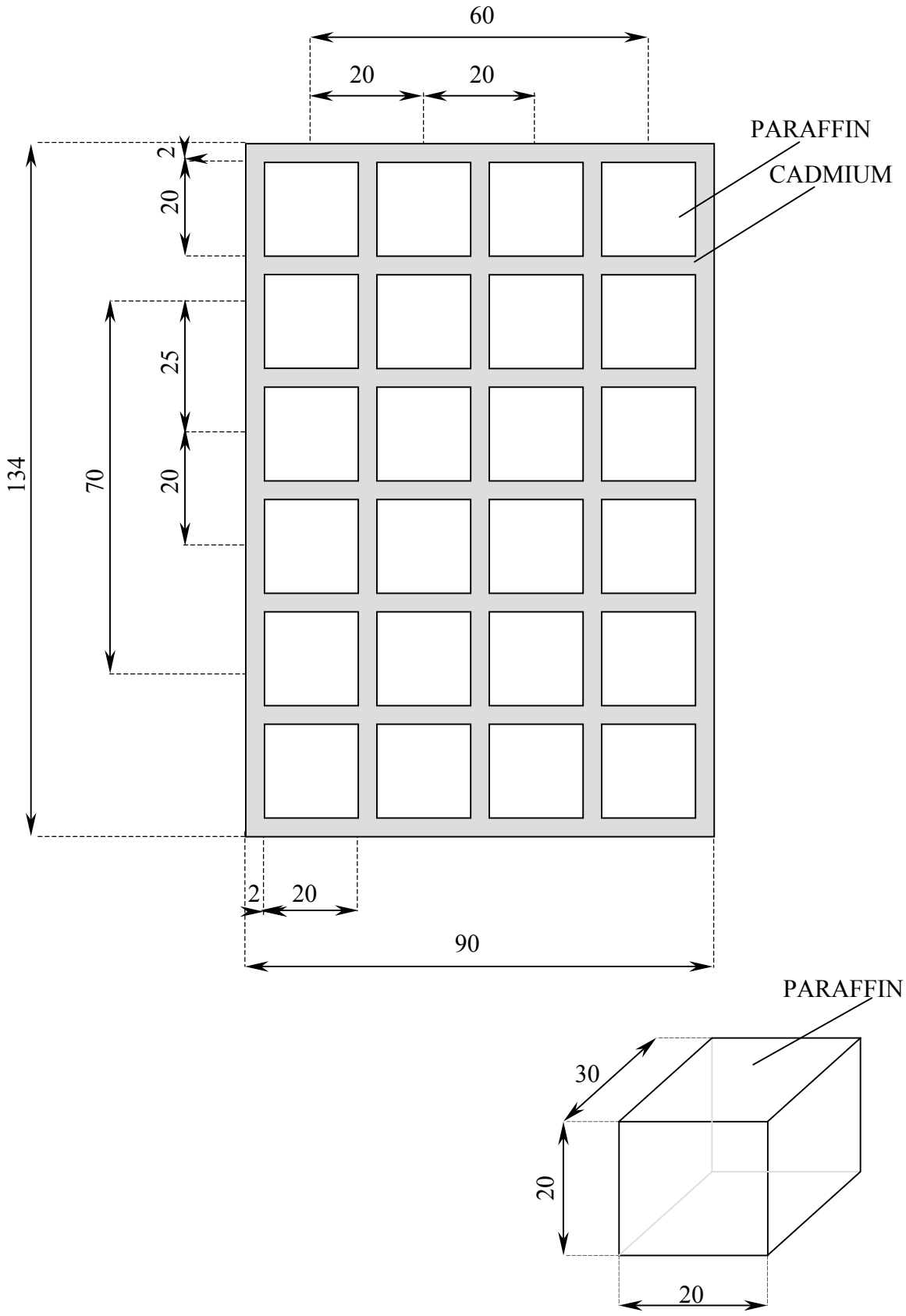

Fig. 5. The designed thermal column.

Table 8. Decay of the thermal neutron flux from the built pulsed source.

Primary neutron source	Pulsed thermal neutron source		
	Material	Decay constant λ [s^{-1}]	
		MCNP simulation	Experiment
14 MeV, pulsed duration: T_{imp} = 30 μs repetition: T_{rep} = 300 μs	Paraffin (n = 30) ρ = 0.8902 g cm^{-3} Mesh: 2×2×3 cm^3	98 900 ± 1 030	~ 98 000 ± 2 000

A comparative measurement (the same sample and the same measurement conditions as in measurement on Sample 2-F, Table 6) has been done. The corresponding $\lambda(t_d)$ dependence is plotted in Fig. 6. That means that the time-decay constant λ found is here stable along the time-decay curve and can be taken as a sure result.

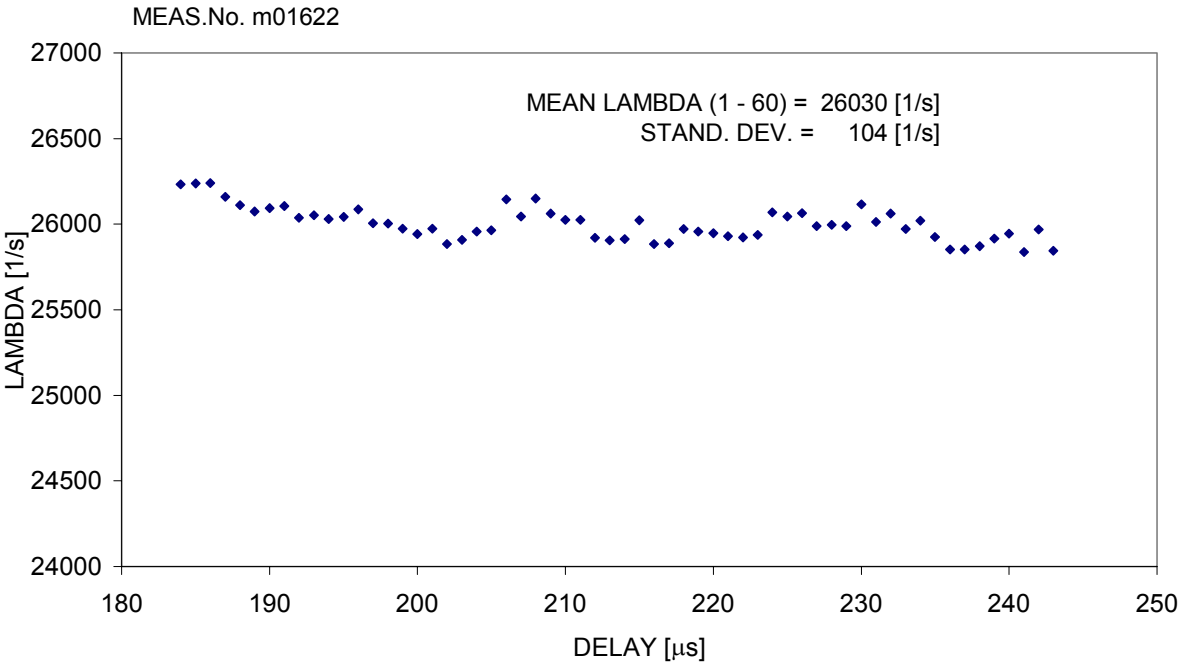

Fig. 6. Decay constant stable as a function of the delay time after the neutron burst.

4.3. Time decay constant λ in granite+polyethylene samples measured with the thermal neutron source set-up

The built pulsed thermal neutron source has been used for the measurements of samples in Geometries I (two sizes) and III, as defined in Fig. 2. The results are collected in Table 9.

Table 9. Measured time decay constants λ of the thermal neutron flux in granite+polyethylene bulk samples (Thermal neutron pulsed source).

No.	Geometry type	Polyethylene content [wt. %]	Bulk density ρ_B [g cm^{-3}]	λ $\sigma(\lambda)$ [s^{-1}]	λ/ρ_B $\sigma(\lambda/\rho_B)$ [s^{-1}/(g cm^{-3})]	Lab. code
1-Th	**I** $H = 2R = 9.6$ cm	20	1.172	25084 74	21403 65	01622
2-Th		20	1.172	25013 58	21342 51	01624
3-Th		20	1.172	24607 103	20996 89	01625
4-Th		5	1.419	30112 803	21221 566	01615
5Th		5	1.419	25202 510	17760 359	01617
6-Th		0	1.479	25286 810	17097 548	01629
7-Th	**I** $2R = H = 16$ cm	5	1.428	17733 80	12418 56	01632
8-Th		3	1.561	17038 208	10915 135	01638
9Th		2	1.554	19929 232	12824 149	01635
10-Th		0	1.44	19665 368	13656 256	01628
11-Th	**III**	10	1.36	22224 205	16341 151	01639
12-Th		5	1.47	20770 494	14129 336	01649
13-Th		3	1.46	21172 260	14501 179	01645
14-Th		2	1.49	21955 321	14735 216	01648
15-Th		0	1.52	20369 366	13401 241	01642

5. Conclusions

A few geometry systems (neutron source + sample) have been tried to investigate the influence of the hydrogen content in the rock sample on the measured signal, *i.e.* the decay constant λ of the thermal neutron flux $\varphi(t)$ in the sample. Conclusions can be drawn from a comparison of all results collected in Tables 6 and 9.

An irradiation of a small bare sample (Geometry I in Fig. 2) with the fast neutron burst does not create the thermal neutron flux sufficient to get a satisfactory counting statistics. An increase of the flux $\varphi(t)$ can be obtained by surrounding the sample with a good neutron moderator. The two variants of such geometry tested (Geometry II and III in Fig. 2) have resulted in the decay constant of the entire sample (granite+polyethylene + surrounding moderator) which is weakly sensitive to the hydrogen content in the rock itself. Finally, these experimental results can be recognized only as non-contradictory with a theoretical prediction.

A use of the pulsed thermal neutron source for samples in Geometry I and for complex samples in Geometry III improves the counting statistics. However, the differences between the decay constants at the polyethylene content changing between 0 and 5 % are not clear (which can result from a possibly non-monotonic behaviour of the function $\lambda(\Sigma_s)$ in this region). Moreover, an amount of the rock material for a bigger sample in Geometry I ($2R = H$ = 16 cm) seems to be too large for a routine measurements. Thus, only Geometry I with a small sample seems in this case to be worth of a further experimental study, probably in an application to samples with a higher hydrogen content.

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