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MONTE CARLO CALCULATION OF THE SLOW NEUTRON BACKGROUND IN THE NEUTRON-NEUTRON SCATTERING EXPERIMENT AT THE PULSE REACTOR **BIGR**

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Расчёт методом Монте Карло фона медленных нейтронов в эксперименте по нейтрон-нейтронному рассеянию на реакторе БИГР

Проведены расчёты методом Монте Карло ожидаемого фона медленных нейтронов в планируемом прямом эксперименте по измерению сечения нейтрон-нейтронного рассеяния на импульсном реакторе БИГР. Исходные энергетические и пространственные распределения медленных нейтронов на поверхности замедлителя были рассчитаны с помощью программы MCNP исходя из реалистичной физической модели геометрии реактора, защиты, замедлителя и коллиматоров. При расчёте транспорта медленных нейтронов в коллимирующей системе учитывалось не более двух актов упругого рассеяния в поверхностном слое внутреннего кадмиевого покрытия коллиматоров. Вычисленный фон медленных нейтронов более чем на порядок ниже ожидаемого эффекта от нейтрон-нейтронного рассеяния при номинальных импульсах реактора БИГР.

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Monte Carlo Calculation of the Slow Neutron Background in the Neutron-Neutron Scattering Experiment at the Pulse Reactor BIGR

Slow neutron background calculations were performed for the proposed geometry of the neutron-neutron scattering experiment at the BIGR pulse reactor. The incoming slow neutron space and spectral distributions on the moderator surface were calculated with the MCNP program starting from the exact physical model of the reactor fuel and moderator and shielding geometry. Two elastic scatterings of slow neutrons from the neutron absorbing cover (Cd) inside the collimating and shielding system were taken into account. The calculated thermal neutron background is significantly lower than the estimated *n–n* scattering effect.

The investigation has been performed at the Frank Laboratory of Neutron Physics, JINR.

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1 Introduction

Direct measurement of the neutron-neutron scattering cross section has never been performed before[1]. The BIGR pulse reactor [2] has record neutron pulse flux-power parameters, convenient for performing such an experiment: the neutron fluence on the surface of the reactor jacket is $\sim 10^{15} n/cm^2$, pulse width $2ms$. The reactor is located in the center of the $10 \times 10m^2$ reactor hall, allowing a vacuum neutron-neutron collision cavity to be built in the vicinity of the reactor jacket surface. This cavity is surrounded with the moderators, necessary collimation system and a neutron guide through the hole in the wall of the reactor hall to the coordinate thermal neutron detector.

The character of the experiment requires the preliminary calculation of the possible background of slow and fast neutrons in the complicated geometry of moderators, collimators and shielding. In this paper we describe the method and present the results of the Monte Carlo calculations of the slow neutron ($E_N < 200meV$) background for several similar collimation geometries.

2 Geometry of the experiment and the method of calculations

The geometry of the n-n scattering experiment is shown in figures 1 and 2. Near the BIGR reactor inside the aluminium alloy vacuum jacket a moderating system, consisting of four polyethylene sheets which form the n-n collision chamber, is placed. The thermal neutron detector "sees" the n-n collision cavity through a special collimator which maximally suppresses the probability of neutron penetration the detector from any site except the internal region of the n-n collision cavity. The entire internal surface of the collimating system is covered with sheets of cadmium absorbing slow neutrons. The only source of slow neutrons in this case is the surface of polyethylene moderator.

The moderator surface and spectral distribution of slow neutrons (up to 0.2 eV) were calculated with the MCNP program [3], outgoing from the exact geometry of the reactor fuel and construction, and geometry of moderators and shielding. The spectrum of slow neutrons averaged over the surface of the moderator is shown in the fig.3. Angular distribution of slow neutrons with respect to moderator surface normal obeys the cosine law: $\Phi(\theta) \cdot d\Omega \sim cos\theta \cdot d\Omega$. Scattering of slow neutrons inside absorbing walls was considered isotropic and was taken into account in a one collision approximation, due to the small value of the ratio of scattering and capture cross sections for Cd in this energy range.

The probability of slow neutron scattering from the absorbing wall was calculated according to the formula, obtained as a result of integration over infinite wall thickness of elementary isotropic scattering acts:

$$w(\phi, \psi) = \sigma_{sc}/\sigma_t \cdot cos\phi/(cos\phi + cos\psi), \qquad (1)$$

where ϕ and ψ are angles of incoming and scattered neutrons with respect to the surface normal, σ_{sc} and σ_t are the scattering and total cross sections for a given energy of the neutron. Only elastic scattering in Cd was taken into account. This simplification leads to some exaggeration of the calculated background because, for the major part of the spectrum, inelastic scattering lessens the neutron energy, decreasing the ratio of scattering to the capture cross sections. Only two re-scatterings in the collimating system were taken into account (as each subsequent re-scattering diminishes the reflected flux by three orders of magnitude).

Seven types of slow neutron trajectories, by which neutrons outgoing from the moderator's surface, can reach the detector after two rescatterings in the surface layer of the collimating system, are shown in fig.4.

Table I shows nine different configurations of the shielding-collimating system, corresponding to different combinations of the sizes of collimators cross sections.

3 Results of calculations

The results of the calculations are shown in fig.5 and Table II. Fig.5 shows the dependence of the background on the length m of the pyramidal section of the collimator. It can be seen, that for a short collimator, when the possibility opens for a one-scattering neutron trajectory reaching the detector, the background increases drastically. For the "closed" geometries, when one-scattering trajectories are forbidden, the background depends on the length m of the collimator only slightly.

Table II shows the contribution of the different trajectories from fig.4 to the total slow neutron background.

4 Conclusion

The estimation shows that for the maximal BIGR reactor pulse with a total neutron production of 10^{19} neutrons per pulse, the number of registered thermal neutrons from n-n scattering is about $0.5 n/cm^2$ for configuration 1, (Table I). From Table II for this configuration and reactor pulse intensity the total slow neutron background is about $10^{-2} n/cm^2$, which is almost two orders of magnitude lower. This calculations show that the thermal neutron background is not a serious problem in this experiment.

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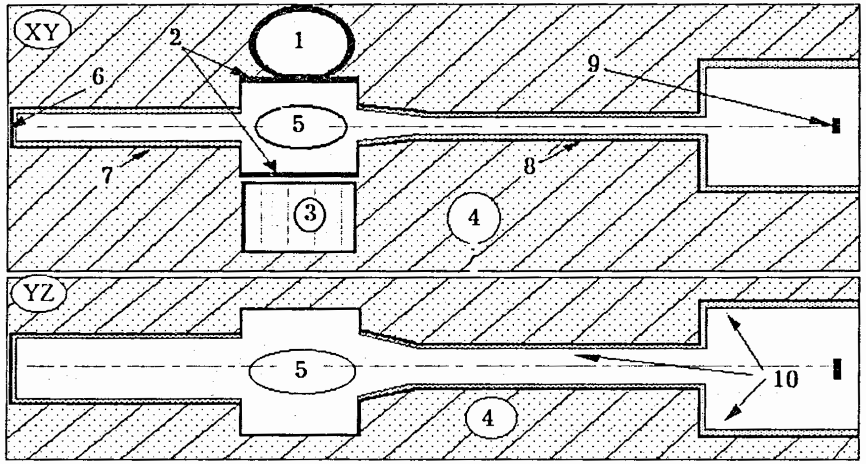

Fig.1 The scheme of the experiment for direct measurement of the neutron- neutron scattering cross section: XY - horizontal section, YZ - vertical section. 1. BIGR pulse reactor, 2. polyethylene moderator, 3. graphite reflector, 4. shielding, 5. n-n collision cavity, 6. back wall, 7. back collimator, 8. forward collimator, 9. neutron detector, 10. *Cd* covering the entire internal surface area of the collimating system.

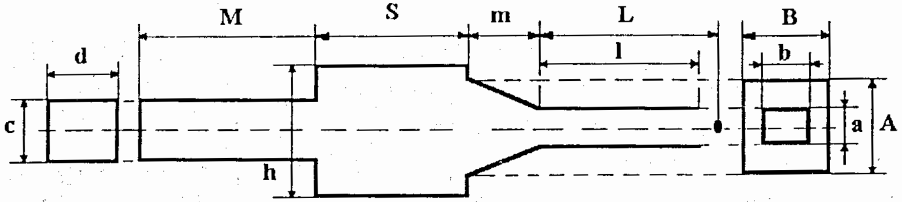

Fig.2 Geometric scheme of the shielding-collimating system: $S = 100cm$, $M = 450cm$, $h = 20cm$, $c = 20cm$, $d = 40cm$, $l = 5m$, $S/2 + m + L = 20m$, the sizes of a, A, b, B, and m were varied according the Table I and fig.5.

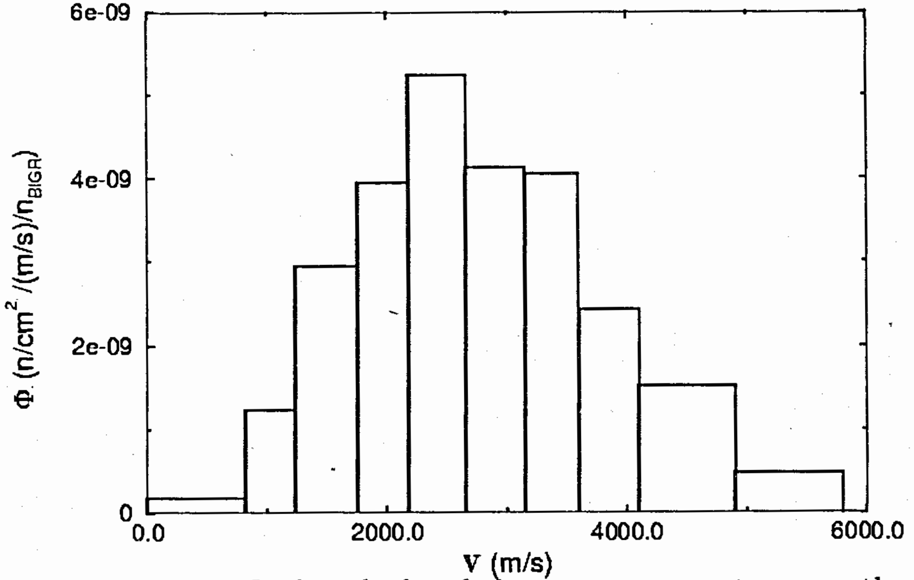

Fig.3 Monte Carlo calculated slow neutron spectrum on the surface of the moderator.

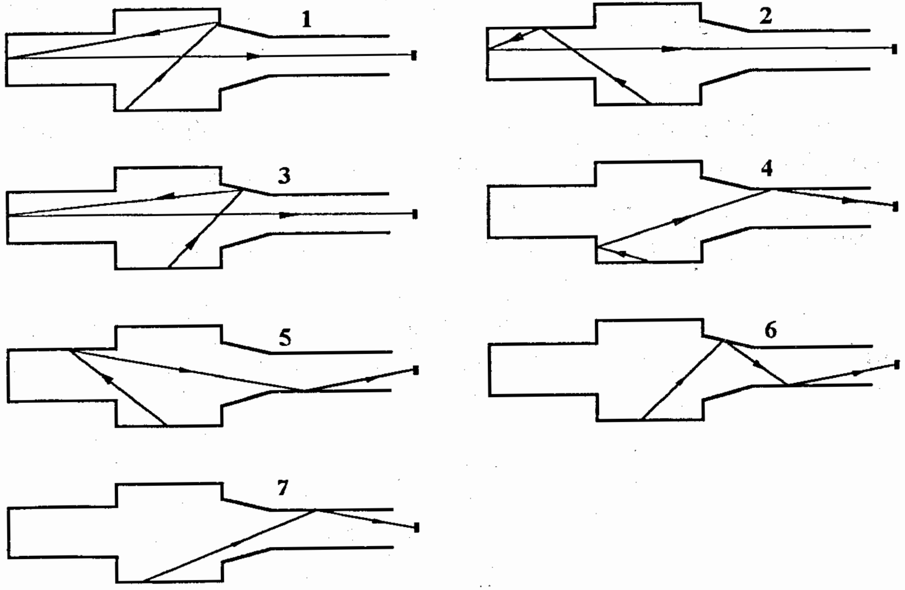

Fig.4 Configurations of background slow neutron trajectories inside the shielding-collimating system.

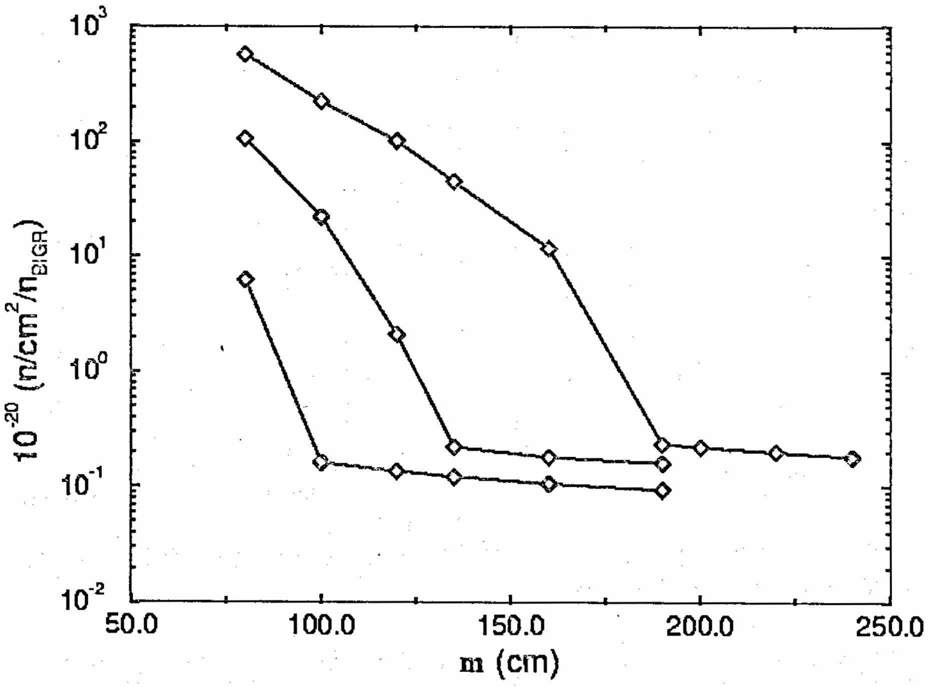

Fig.5 The calculated thermal neutron background in the n-n scattering experiment per one neutron of the reactor for different configurations of the shielding-collimating system, according to Table I, as a function of the length m of the pyramidal section.

Table I. The numbers of geometric configurations of the shielding-collimating system according to sizes a, A, b, and B of collimating section.

a		5	6	7
b		20	24	28
A	B	N_c		
8	33	1	2	3
9	38	4	5	6
11	43	7	8	9

Table II. The contribution of seven different types of slow neutron trajectories N_{tr}, according to the notations of fig.4, to the total slow neutron background for nine geometric configurations N_c according to Table I for $m = 135cm$. The upper row for each of the nine geometric configurations gives the absolute slow neutron background multiplied by 10^{20}, per one neutron of the BIGR reactor, per $1cm^2$ of the detector, located at a distance $S/2 + m + L = 20m$ from the center of the n-n scattering cavity. The lower row gives the relative contribution to the total slow neutron background for each configuration from different neutron trajectories according to fig.4.

N_c N_{tr}	1	2	3	4	5	6	7	$\sum$
1	0.034	0.018	0.012	0.019	0.015	0.023	0.0	0.12
	0.28	0.14	0.10	0.16	0.13	0.19	0.0	1.0
2	0.049	0.026	0.015	0.031	0.025	0.047	0.0	0.19
	0.25	0.13	0.08	0.16	0.13	0.24	0.0	1.0
3	0.066	0.035	0.015	0.045	0.037	0.083	0.0	0.28
	0.24	0.12	0.05	0.16	0.13	0.30	0.0	1.0
4	0.026	0.018	0.018	0.031	0.015	0.027	0.0	0.14
	0.19	0.13	0.13	0.23	0.11	0.20	0.0	1.0
5	0.037	0.025	0.023	0.050	0.025	0.054	0.0	0.21
	0.17	0.12	0.10	0.23	0.12	0.25	0.0	1.0
6	0.051	0.034	0.025	0.074	0.037	0.099	0.0	0.32
	0.16	0.11	0.08	0.23	0.12	0.31	0.0	1.0
7	0.009	0.018	0.031	0.040	0.015	0.033	4.8	5.0
	0.002	0.004	0.006	0.008	0.003	0.007	0.97	1.0
8	0.013	0.026	0.039	0.070	0.025	0.068	20.7	20.9
	0.0006	0.001	0.002	0.003	0.001	0.003	0.99	1.0
9	0.022	0.034	0.044	0.10	0.037	0.13	44.4	44.8
	0.0005	0.0008	0.001	0.002	0.0008	0.003	0.99	1.0

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