SIMPLIFIED TRANSPORTATION MODEL OF THERMAL NEUTRONS THROUGH THE MATTER

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The effective model providing simulation of thermal neutrons transportation through various matters was scrutinized. Calculation of neutron trajectory is carried out by Monte-Carlo method. The model was tested on the tasks with analytical solutions of diffusion equation. The developed model can be used for the practical important problems of activation analysis and neutron spectrometry etc. due to model simplicity and high speed of code calculations.

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1. INTRODUCTION

The simulation of neutrons transportation through matters configured in elements of installation is the actual task for modern nuclear and radiation physics. Calculation of neutrons field in various environments and volumes is very interesting in designing experimental and industrial installations in which neutrons are used, for example, in installations for the neutron activation analysis, radioisotopes production, neutron spectrometry etc.

The distribution of neutrons, which have slowed down in the non-uniform environments with given geometrical configuration to velocity of thermal balance (thermal neutrons), presents the important aspect of the task. The neutron fields from the neutron sources, which are surrounded by the moderator or the field into studied object, which are also surrounded by moderator, are often of interest. The experimental research methods of such problems are far away from being always fitted within accessible scientific resources while dealing with them and are limited by requirements of personnel safety. The analytical methods use assumptions of uniformity, simplicity and symmetry for interaction domain geometry.

For these reasons the research with the usage of Monte-Carlo simulation methods for the basic processes of neutrons interaction with the matter has advantages. MCNP [1] and GEANT [2] packages are commonly used tools to simulate the given class of tasks.

Authors could not use both widely known simulation package MCNP (Fermi Lab, USA) since its license isn't free, and GEANT 3 one, which due to its bottom energy thresholds limits is out of the thermal neutrons simulation domain. Package GEANT 4, version 4.9.3, already covers the given transportation task of neutrons. However its validity in this energy range is still in the stage of verification. Should be also mentioned that there are non-negligible distinctions between GEANT and MCNP simulation results for the same problems.

The authors point of view is that advantages of the above mentioned software products present significant difficulties in solving of specific tasks in which is required to develop the effective and transparent representation of object. Such advantages are: wide scope of processes on types of interactions and mechanisms, participating particles, combinational opportunities of geometry and physical and chemical properties of materials, the interface of management and processing of results, etc. The development of thermal neutrons effective models is also covered by such class of tasks.

2. DESCRIPTION OF THE MODEL

The simulation of the thermal neutrons interaction with matter has shown that the distributions of neutron velocities and thermal atoms movement are of Maxwell's type. However this task can be considerably simplified. In the present work the following approach to the thermal neutrons field calculation is offered:

- all thermal neutrons move with constant of average for the given temperature velocity;
- the fluctuation of molecules are negligible;
- the elastic neutrons scattering with atoms changes of their initial trajectory but the module of velocity is saved.[1]

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[1]Note, that such neutron transportation simplified model was given in [3]; however one doesn't contain the verification of simplification. Moreover work [3] doesn't analyze the reduction of computer resources consumption by simplified model.

Physical simplicity of the approach reduces probability of mistakes into algorithms. The fact that our model does not consider Maxwell's distribution of neutrons velocity reduces speed of the calculations essentially. The last is very importance when the need calculation time of a task exceeds reasonable limits.

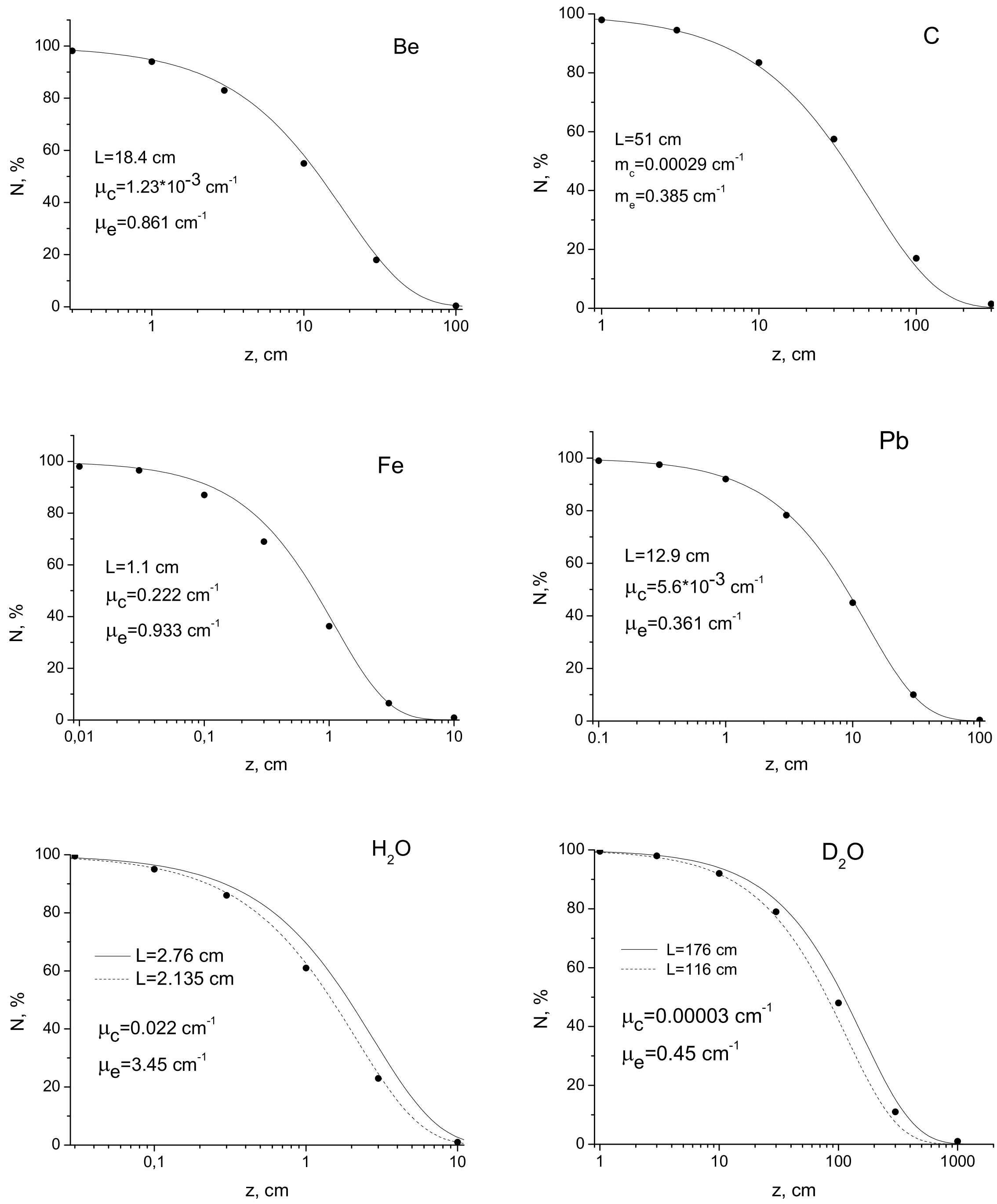

Fig.1. *Transportation of thermal neutrons through plates by various materials, N is the relative output of neutrons, z is a thickness of a plate, L is a length of diffusion. Points are the simulation results, the curves are the analytical calculations (formula (2)), μ_c is macroscopical cross-section of capture, μ_e is macroscopical cross-section of elastic scattering*

By the realization of this approach the method of Monte-Carlo is used. The pseudo-random generators algorithm is applied to support of the basic processes similarly applied in [2]. The spatial step l between events of realization of these processes calculates using formula:

$$l = -\frac{1}{\mu} \cdot \ln(1-\xi), \tag{1}$$

where ξ - the random uniformly distributed number in $[0,1]$, μ - the cross-section, corresponding the mechanism of interaction. By means of formula (1) the steps for each of processes taken into consideration are generated. Then the process with the minimal generated value of step length l is taken out. So as the energy of thermal neutrons is small, the interaction of neutrons with matter take place in two channels only, which are capture and elastic scattering. The cross-sections of these processes are presented in [4] and designated as μ_c, μ_e, accordingly. Thus by means of formula (1) the step for the channel of capture (l_c) and for the channel of scattering (l_e) are generated. The calculation of neutron trajectory stops in the case if the least step length value corresponds to the capture process. The interacting particle has a new pulse direction and neutron continues the motion with velocity of the same absolute value in the case of scattering process The choice of direction of movement after elastic scattering is defined from the solution of collision task for two bodies, one from which is basic (atom - the scattering center). The value of a impact parameter is generated to obtain the new direction of movement. The neutron finding into the given volume during transportation is controlled permanently.

3. RESULTS OF MODELING

In view of assumptions are made in the considered approach, the created model and its program realization should be verified. We'll use for this purpose the analytical calculations describing distribution of thermal neutrons for cases of tasks with simple geometry. Such tasks are: the distribution of neutrons in the plate from a parallel flat source and the distribution of neutrons in a sphere with a point source in its center. The solutions of the diffusion equation for these cases with condition of $\mu_c << \mu_e$ are:

$$N = N_0 \cdot e^{-z/L} \qquad for\, the\, plate, \quad (2)$$

$$N = N_0 \cdot (1/r + 1/L) \cdot e^{-r/L} \qquad for\, the\, sphere, (3)$$

where N is output of neutrons from a plate/sphere, N_0 is number of neutrons gone out from source, z is thickness of plate, r is sphere radius, L is length of diffusion.

Fig.1 shows results of mathematical simulating of neutron distribution in plates from various materials and calculation with formula (2). Simulation and formula (3) distributions of thermal neutrons in spherical volumes of water and heavy water are shown in Fig.2. Each point corresponds to calculation with 10^7 neutrons emitted by source. Two calculated curves are resulted in some graphics as for the same matters value L in reference books [4] and [5] are various. From the presented figures the good accordance of simulation results and analytical calculations is clear. The is an exception for the case of iron, where requirement for analytical calculation approximation $\mu_c << \mu_e$ is not valid. We notice that this requirement is not restriction of the developed model and it is possible to investigate the neutrons transportation through matter with any values μ_c and μ_e. For example, in case of cadmium (for which $\mu_c/\mu_e = 350$) the developed model can be used, however additional testing for similar cases is desirable.

4. THE CONCLUSIONS

The good accordance of simulation results and analytical calculations shows suitability of the developed model for the solution of tasks with more general geometry and non-uniform structure of matters. The reason of this is that the geometry peculiarities and structure heterogeneities of object cannot cancel the correct character of simulating of thermal neutrons interaction with matter.

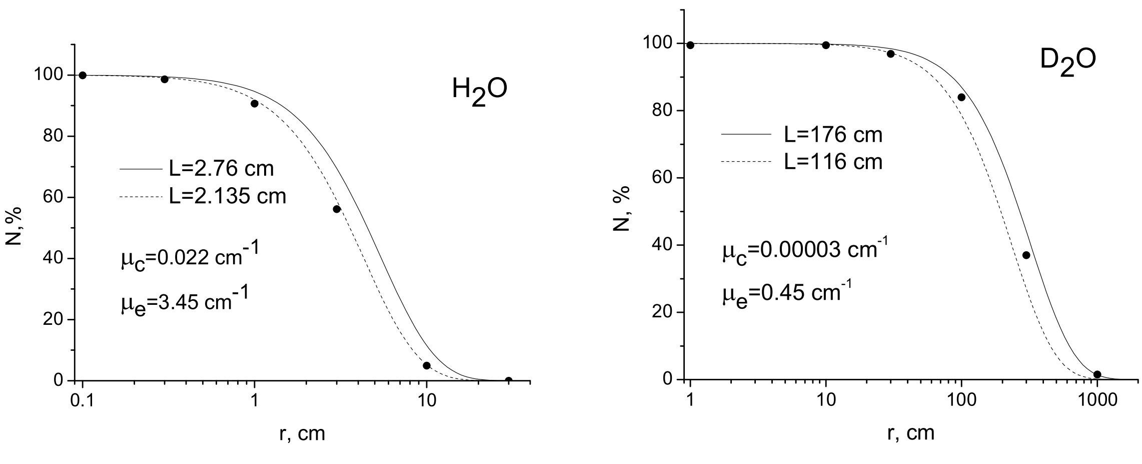

Fig.2. *An output of neutrons from spherical volume. r - radius of sphere, other designations as on Fig.1.*

The program realization for practical application proves that the important advantage of our approach is the increasing of the calculation speed in comparison with standard packages. The most of neutron sources (the gamma-neutron converter, division of nucleus) have the average energy nearby 2 MeV. Therefore our further work will be directed to expansion of a range of simulating neutrons energy up to 10 MeV in order to solve of wider range of tasks in the nuclear and radiation physics.

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In summary authors consider as a pleasant duty express to A.V. Torgovkin gratitude for useful remarks and for the idea that the considered design procedure can be applied not only to thermal neutrons but also for neutrons with energy up to several MeV. [2]

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УПРОЩЁННАЯ МОДЕЛЬ ПРОХОЖДЕНИЯ ТЕПЛОВЫХ НЕЙТРОНОВ ЧЕРЕЗ ВЕЩЕСТВО

А.Ю. Буки, С.А. Каленик, И.Н. Шаповал

Рассмотрена эффективная модель, обеспечивающая симуляцию распространения тепловых нейтронов в различных веществах. Расчет траектории движения нейтрона осуществляется методом Монте-Карло. Модель протестирована на задачах, которые имеют аналитическое решение уравнения диффузии. Разработанная модель, ввиду простоты и высокой скорости счёта её программной реализации, может быть полезной при решении практических задач активационного анализа, спектрометрии нейтронов и т.п.

СПРОЩЕНА МОДЕЛЬ ПРОХОДЖЕННЯ ТЕПЛОВИХ НЕЙТРОНІВ КРІЗЬ РЕЧОВИНУ

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Розглянута ефективна модель, що забезпечує симуляцію розповсюдження теплових нейтронів у різноманітних речовинах. Розрахунок траєкторії руху нейтрона здійснюється методом Монте-Карло. Модель протестована на задачах, які мають аналітичний розв'язок рівняння дифузії. Розроблена модель, з огляду на простоту та високу швидкість розрахунків її програмної реалізації, може бути корисною при розв'язанні практичних задач активаційного аналізу, спектрометрії нейтронів та ін.

[2] It is possible in case when by transportation through matter the neutron energy loss is not great. For example, such case can be realized often in practice the calculation of neutrons transportation through a lead plate with thickness in some centimeters.