MATHEMATICAL SIMULATION OF THE NEUTRON INTERACTION WITH MATTER

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The application of neutron beams is important for some fundamental problems in nuclear physics, for fission and fusion reactors, future safety of atomic energy, neutron radioactivation analysis, neutron radiography etc. Solving of such problems is connected with huge material and financial expenses, so the mathematical simulation is widely used. In NSC KIPT GEANT3, GEANT4, our own programs, etc. are used for these purposes. The mathematical models and algorithms of calculation of passage of neutrons with energy up to 14 MeV through homogenous medium with fissionable materials were developed. The simulation of passage of neutrons with energy up to 3 MeV through the plate and cylinder was considered. The obtained results were compared with existing literature data.

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During last years neutrons became widely used in different scientific and applied problems, so more neutron sources are required for these purposes. Such main branches are:

– nuclear constants measurement;
– fundamental researches in nuclear physics;
– researches in physics of condensed media;
– neutron optics;
– neutron- activation analysis;
– producing of radioactive isotopes;
– neutron beams usage for medical purposes;
– neutron radiography;
– geologic exploring, mineralogy;
– studying of material behavior in neutron fields, particularly, for thermonuclear reactors;
– studying and using of neutron processes in the secure nuclear power.

For most of the above-mentioned tasks it is important to study neutron passing through matter. It is a difficult problem and it is not always possible to solve it with the methods of pilot experiment. It is connected with development of expensive experimental equipment.

Mathematical simulation methods allow to choose optimal conditions of experimental researches and technologies in which neutrons are used.

Most of the above-mentioned branches may be used in our institute, including neutron radiography.

Neutron radiography method consists in the following: collimated neutron beam is passing through the object to be studied and is simultaneously registered by the detector of flux distribution after this object (usually in the plane normal to the beam direction).

Technical proposal on creation of neutron radiography set based on the linac was developed at NSC KIPT during last years. Technical requirements for such a setting were also developed and different variants of its realization were considered. The neutron-radiography set includes: charged particle accelerator, neutron target, system for neutron field forming and beam diagnostics, image visualization system. While development and exploitation of such a set different problems connected with generation of γ-quanta and neutrons and their interaction with the matter can appear.

For simulation of such processes we used such program packages as GEANT3, GEANT4, etc., and also programs of our own development.

Let us consider some obtained results of simulation of neutron passing through the matter.

1. We considered a neutron passing through the plane polyethylene layer. This material was chosen because, firstly, it is widely used as a moderator in radiation protection and neutron dosimeters. Secondly, data about neutron passing through polyethylene can be found in the literature and it allows one to compare the results with existing data.

In fig.1 the results of simulation of neutron passing through the polyethylene layer are shown. Initial neutron energy was 2 MeV, plate thickness δ=5 cm.

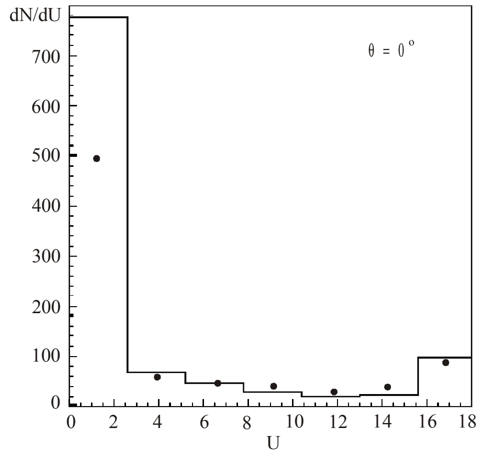

Fig. 1. *Neutron spectrum after passing through the polyethylene plane with thickness 5 cm (initial energy E_0=2 MeV, angle θ=0°, u – lethargy). • – [3]*

Parallel neutron beam was normal to the plane (θ=0°). The horizontal axis is the lethargy, i.e. logarithm of a ratio of the neutron energy after passing through the plane to the thermal energy (E_{out}/E_{th}). The vertical axis is the number of neutrons in the interval. We considered 4096 events. The points are the results from [3], the histogram is the simulation result.

2. In fig.2 the results of the simulation of distribution of thermal neutron sources are shown as a function of the plane depth for the initial energy 2 MeV and the angle θ equals to 0°. The thermal neutron source is the point of the last neutron interaction before it becomes thermal, i.e. with the energy 10^{-7} MeV (0.1 eV). The points are the results from [3], the histogram is the simulation result. We considered 4096 events.

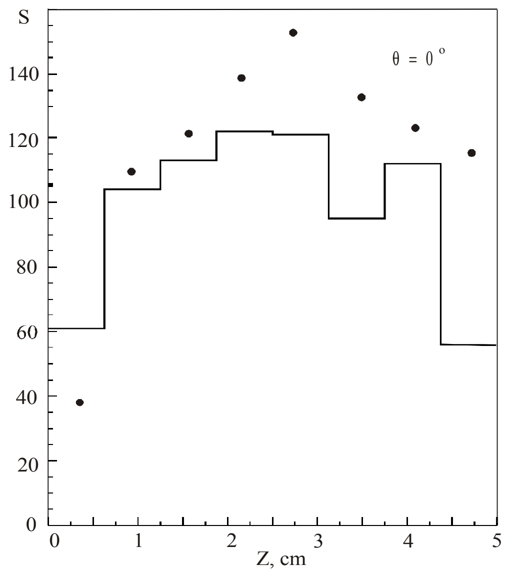

Fig. 2. *Thermal neutron sources distribution S as function of plane depth Z for initial energy 2 MeV and angles θ equal 0. • – [3]*

3. Albedo is one of the fundamental values. Without knowing this value it is impossible to calculate the parameters of defense shields, to optimize the system of neutron beam forming in the set for neutron radiography etc. Fermi was the first who introduced this value for characteristics of neutron passing from one media to another under the condition that in the reflecting media there are no neutron sources and neutrons are reflected diffusely.

Albedo is determined as a ratio of the number of reflected neutrons to the number of initial neutrons.

We considered a parallel neutron beam with energies 0.3, 1 and 2 MeV falling at different angles to the plate. In fig.3,a,b the simulation results of reflection of this beam from the plate with thickness 5 and 15 cm are shown. You can see that albedo increases with energy decreasing. Albedo also increases with plate thickness increasing.

4. Polyethylene hollow cylinders are used in biological protection and in neutron dosimeters. So, it is useful to know neutron behavior inside the hollow cylinders of different diameters and with different thickness of their walls.

In fig.4,a,b the simulation results of a neutron spectrum inside the cylinders with outer diameter 120 cm (wall thickness 9 cm) and 5.5 cm (wall thickness 1 cm) are shown.

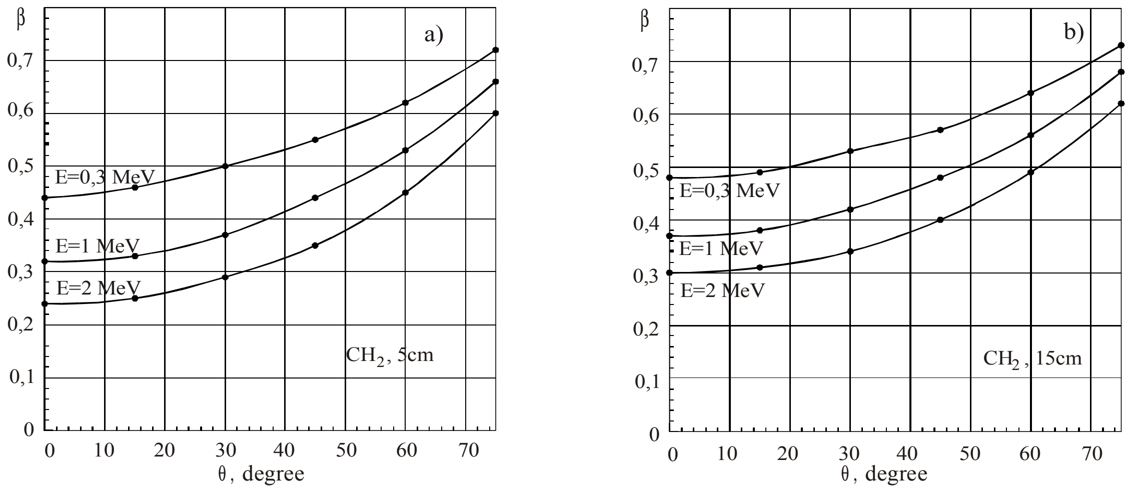

Fig. 3. *Albedo for neutrons with energy 0.3, 1, 2 MeV for the plane with thickness a) 5 cm и б) 15 cm*

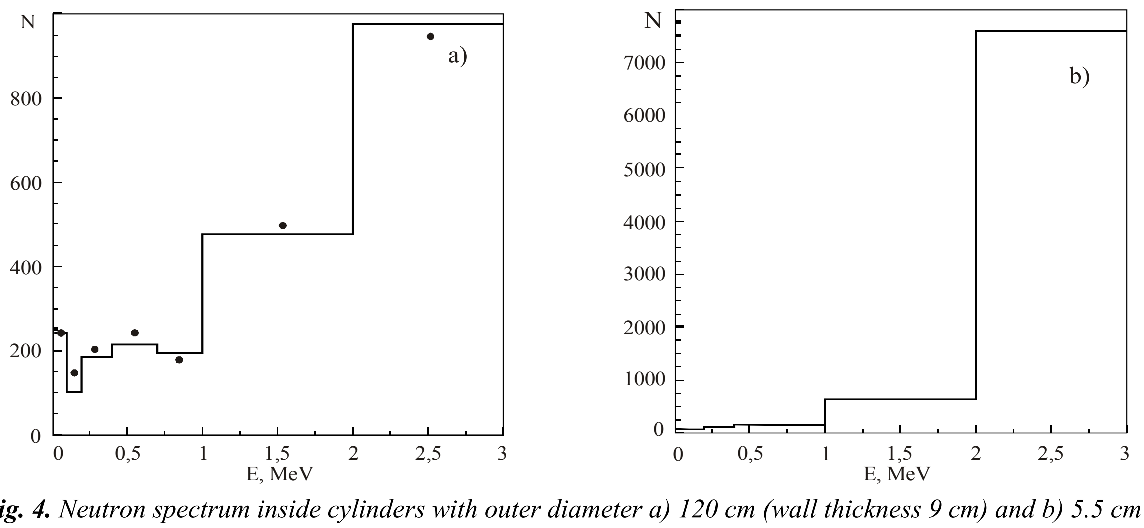

Fig. 4. *Neutron spectrum inside cylinders with outer diameter a) 120 cm (wall thickness 9 cm) and b) 5.5 cm (wall thickness 1 cm). Initial energy E_0=3 MeV. • – [4]*

The horizontal axis is the neutron energy and the vertical axis is the number of neutrons inside the cylinder. The histogram presents our results, and points are results of [4]. Number of events is 10000. Comparison of simulation results for cylinders of different diameters shows the necessity of taking into account not only the cylinder thickness but the cylinder diameter too.

5. In fig.5 the preliminary results of simulation of a parallel neutron beam passing through the graphite plate with thickness 0.5 and 8 cm are shown. To describe the spectrum of neutrons which falls normal to the plate we used the expression $dN/dE = e^{-E} sh(2E)^{1/2}$, where E is the neutron energy, MeV.

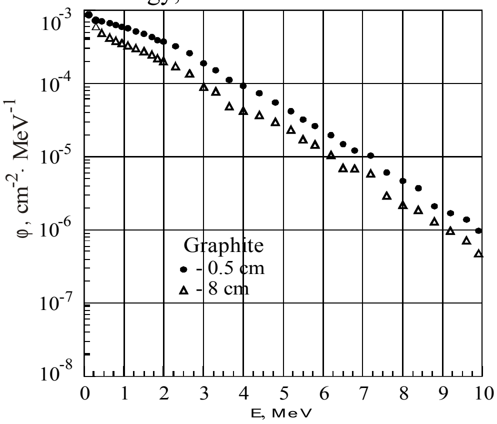

Fig. 5. *Neutron spectrum after graphite plate*

First this expression was obtained by Watt B.E. [5] when he investigated the spectrum of neutrons, originating at ^{235}U fission with thermal neutrons. It is well agreed with the observed spectrum up to the energy of escaped neutrons up to 17 MeV. Fig.5 shows that neutron fluence φ of such a spectrum (neutron number per area unit, per unit energy interval and per neutron originated from the source) after passing the plate decreases with the plate thickness increasing. From fig.5 it also follows that at such statistics ($5 \cdot 10^6$ events) and very wide energy intervals in the neutron spectrum after the graphite plate there are no minima at energies, corresponding to maxima in the total cross-section of neutron interaction with carbon. Such effect also can be found in simulation results of neutron passing through graphite [6].

Given data show that the programs created describe the neutron interaction with the matter and can be used as a base for simulation of complex physical and technological settings.

So, mathematical simulation allows one to solve different physical problems, but in the realization of such tasks there are some difficulties connected with deficiency of mathematical methods properly describing physical processes, databases of physical constants and also computer techniques and highly qualified specialists.

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МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ВЗАИМОДЕЙСТВИЯ НЕЙТРОННОГО ИЗЛУЧЕНИЯ С ВЕЩЕСТВОМ

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Применение нейтронных пучков актуально для решения ряда фундаментальных задач ядерной физики, ядерных и термоядерных реакторов, будущей безопасной ядерной энергетики, нейтронно-активационного анализа, нейтронной радиографии и т.д. Решение таких задач связано с огромными материальными затратами, поэтому широко используются методы математического моделирования. Для моделирования прохождения нейтронов с энергией до 14 МэВ через однородную среду и через среду с делящимся материалом были разработаны математические модели и алгоритмы программ. В представленной работе рассмотрены результаты расчета прохождения нейтронов спектра деления через графит и нейтронов с энергией до 3 МэВ через плоский и цилиндрический слои полиэтилена.

МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ ВЗАЄМОДІЇ НЕЙТРОННОГО ВИПРОМІНЮВАННЯ З РЕЧОВИНОЮ

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Застосування нейтронних пучків є актуальним для вирішення ряду фундаментальних задач ядерної фізики, ядерних та термоядерних реакторів, майбутньої безпечної ядерної енергетики, нейтронно-активаційного аналізу, нейтронної радіографії і т.п. Вирішення таких задач пов'язане с великими матеріальними затратами, тому широко використовуються методи математичного моделювання. Для моделювання проходження нейтронів з енергією до 14 МеВ крізь однорідне середовище та через середовище з матеріалом, що ділиться, були розроблені математичні моделі та алгоритми програм. В цій роботі розглянуті результати розрахунків проходження

нейтронів спектра поділу крізь графіт та нейтронів з енергією до 3 МеВ крізь плоский та циліндричний шари поліетилену.