Development and testing of algorithms for performing computation of detector readings from a pulsed neutron source

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Abstract. To provide the possibility of computation of detector readings from a pulsed neutron source (time dependent readings) the development of algorithms and their realization to upgrade precision Monte Carlo code MCU are considered in this work. New version of the MCU code was tested, which included comparison with experimental results. The experiments were made by Lawrence Livermore National Laboratory in the late sixties. Neutron transport from a pulsed source through layers of various materials was studied in these experiments. The comparison of the MCU calculation results obtained for these experiments with the corresponding MCNP-6 calculations results is also given in this work.

1. Introduction

Precision Monte Carlo code MCU is used for simulation of particle transport in three-dimensional systems. One of the tasks solved with the help of MCU is the computational support of experiments at research reactors and facilities. Detector readings are obtained from a pulsed neutron source at these facilities in particular.

The purpose of this work is to present preliminary results of time-dependent functionals calculations using widely applicable Russian MCU code.

The tallying of such functionals is tested by calculations of the experiments, which were made by Lawrence Livermore National Laboratory in the late sixties [2]. Neutron transport from a pulsed source through layers of various materials was studied in these experiments. The comparison of the MCU calculation results obtained for these experiments with the corresponding MCNP-6 [3] calculations results is also given in this work.

2. MCU description

The MCU code is intended for modeling of transport process of neutrons, photons, electrons, positrons using analogue and non-analogue (weight) Monte Carlo methods based on evaluated nuclear data in three-dimensional systems. For all particles mentioned above heterogeneous transport equation is solved, and for neutrons, the code provides an opportunity to solve homogeneous equation (the problem of critical multiplying systems). Mathematically this means, that kinetic equation with specified boundary conditions, that describes the distribution of particle flux, is solved for this system.

Simulation of the particle transport process is carried out in systems with three-dimensional geometry. The system may consist of a finite number of geometrical zones, bounded by planes or second order surfaces. The parameters of bounding planes and second order surfaces are specified by the user.
Each zone is filled with homogeneous material. Each material is described by the temperature of the material, the set of nuclei, found in the material, and the nuclear density of the nuclei.

MCU code allows modeling of three-dimensional systems with arbitrary geometry using combinative approach, based on the description of complicated three-dimensional shapes with the help of combinations of simple bodies or planes using set-theoretic operations of intersection, complement, and union. There is a set of sample bodies.

3. Experiment description

3.1. General description

The experiments under consideration, performed at Lawrence Livermore National Laboratory in the late sixties, were intended to study nuclear cross sections and verify neutron transport codes. In these experiments, a pulsed neutron source with the energy of about 14 MeV was placed in the centers of spheres-samples. These spheres were made from various materials and had various thicknesses. The neutron flux for a time interval of 2 ns was measured in detectors. These detectors were located at a distance from 752 to 975 cm and at angles to the beam line. The general scheme of the experiments is shown in figure 1 [4].

![Figure 1. Schematic representation of the experiment with the designation of the source, the sphere and detectors.](image)

3.2. Source description

A titanium target with tritium was used as a neutron source. The target was the 1.2 cm diameter disk, which was held by a low mass construction. The reaction T (d,n) ⁴He was used as the neutron production reaction. For this purpose, D+ ions with an energy of 400 keV were sent to the target. In the center-of-mass system, the reaction T (d,n) ⁴He is isotropic. However, under laboratory conditions, the intensity and energy of emitted neutrons in the direction of the beam of deuterium are higher than in the opposite direction.
3.3. **Samples description**

Hard spheres of various materials of various thicknesses were used as the samples under study. Each sphere had a narrow hole into which a target was inserted. For liquid samples, spherical containers with very thin walls were used. A schematic representation of some of the studied samples is shown in figure 2 [2].

![Figure 2. Schematic representation of the studied samples.](image)

3.4. **Received data description**

In the experiments, the neutron flux was recorded for the time interval of 2 ns starting from the beginning of the neutron pulse. Then the data was normalized to the total number of neutrons recorded in the pulse, without any samples. This normalization eliminates the dependence of the results on the intensity of the accelerator.

4. **Description of calculation models**

The possibility to perform computation of detector readings from a pulsed neutron source is tested for aluminum, carbon and iron samples. The composition of the studied samples is shown in table 1. The hole intended for the neutron target is modeled. The view of the modeled sample is shown in figure 3 using the aluminum one as an example. The space outside the sample is defined as the air of standard density 0.001288 g/cm³. The concrete structure of the hall is not modeled due to their insignificant influence.

| Material | Density, g/cm³ | Composition, atomic % |
|----------|---------------|------------------------|
| Aluminum | 2.7           | Al – 100               |
| Carbon   | 1.866         | C – 100                |
| Iron     | 7.87          | Fe – 97.0, C – 1.2, Mn – 1.0, P – 0.7, S – 0.1 |

Table 1. Material composition of the studied samples.
Figure 3. Cross-section of 3D calculation model.

The neutron source is modeled in full accordance with the description of the experiment. Dependence between the flight angle and the energy of the emitted neutron is provided. Energy-dependent detector response function is also implemented.

The neutron flux is recorded in a small volume not using local estimation methods, because only this way of tallying of time-dependent functionals has been implemented at this preliminary stage of work. Due to the fact that the model is symmetrical about the axis passing through the center of the hole the calculations use a ring-shaped tally region rather than a point-detector to speed up the calculation.

The case with the replacement of a solid sphere by air is additionally simulated, since the experimental data were normalized to the total number of neutrons detected without any spheres.

The calculation was performed using a parallel version of the MCU code [5]. This work has been carried out using computing resources of the federal collective usage center Complex for Simulation and Data Processing for Mega-science Facilities at NRC “Kurchatov Institute”, http://ckp.nrcki.ru/ [6].

5. Comparison of the results
The results of calculations using the MCU code are compared with the experimental data and with the MCNP-6 calculations. This comparison is presented in figures 4 – 6 and tables 2 and 3. ENDF/B-VII.0 data is used in MCU and MCNP-6 calculations. The statistical uncertainty (one standard deviation 1 σ) is up to 5 % at each interval for MCU and up to 3 % for MCNP-6. Experimental uncertainty is 7 %.
Figure 4. The neutron flux recorded in the detector as it passes through the aluminum sample.

Figure 5. The neutron flux recorded in the detector as it passes through the carbon sample.
Figure 6. The neutron flux recorded in the detector as it passes through the iron sample.

Table 2. Deviation of MCU results from experiment.

|                  | Aluminum | Carbon | Iron |
|------------------|----------|--------|------|
| Interval with maximum intensity, % | 6        | 8      | -4   |
| Average deviation, %     | 18       | 19     | 30   |

Table 3. Deviation of MCU results from MCNP-6.

|                  | Aluminum | Carbon | Iron |
|------------------|----------|--------|------|
| Interval with maximum intensity, % | 4        | 4      | 2    |
| Average deviation, %     | 16       | 22     | 26   |

The figures show, that dependencies of the registered neutron flux are similar. Moreover, in the interval with the maximum intensity, where the statistical uncertainty is the lowest, the values are close to each other.

6. Conclusion
This article presents preliminary results of calculations of time-dependent functionals using widely applicable Russian MCU code. The validation of this feature is performed using the data of the experiments made by Lawrence Livermore National Laboratory. Comparisons with the experimental data and similar calculations using the MCNP-6 code is made. The maximum observed deviation in the interval with maximum intensity is 8 %, the average deviation reaches 30 %. These results show the efficiency of the method implemented in the MCU. In the future it is planned to continue development
work to provide the possibility of obtaining detector readings from a pulsed neutron source using local estimates.

References
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