Neutron-gamma field intensity and absorbed doses simulation at some points of "Romashka" experimental setup

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Introduction

For investigation of the neutron-induced capture and fission reactions on a number of important for basic and applied physics nuclei using gamma-ray multiplicity method, in Frank Laboratory of Neutron Physics (FLNP) a new experimental setup has been commissioned at beam line №4 of IREN neutron time-of-flight (TOF) spectrometer. It consists of lead-shielded gamma-ray spectrometry system of "Romashka" ("Daisy") type (12 NaI(Tl) crystals arranged in a nearly 4π geometry in 2 aluminum containers) and a shield-collimator in front of it.

In this paper the results from the simulation of the setup are reported. The obtained data can be used for evaluation of the radiation environment in the vicinity and inside the gamma-spectrometric system "Romashka".

IREN Facility

The intense resonance neutron source IREN [1] is based on the linear electron accelerator LUE-200 and a non-multiplying tungsten target. Current IREN parameters are listed in the Table 1 below:

Table 1

Parameter	Value
Electron peak current	3 A
Electron energy	35 MeV
Electron pulse duration	100 ns
Pulse repetition rate	25 Hz

Neutrons are produced in the target through a double-stage process. At the first stage accelerated electrons propagating in the target are producing several Bremsstrahlung gamma-quanta. The energy spectrum of the gamma-quanta is limited from above by the maximal energy of the accelerated electrons. At the second stage the gamma-quanta interact with the tungsten nuclei and a number of neutrons are produced. Because of this double-stage process, the experimental setup at the beam-line is exposed to a huge photon burst following the electron pulse and the subsequent neutron flux, which expands to several milliseconds from the latter.

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“Romashka” experimental setup

“Romashka” experimental setup consists of a lead-shielded gamma-ray spectrometry system (Fig. 1) – 2x6 NaI(Tl) detectors in nearly 4π geometry [2] and a composite shield-collimator in front of it (Fig. 2). The collimator (120 cm long and 60 cm wide) narrows the neutron-gamma beam diameter from 16 cm to 4 cm. It is designed as a pack of steel canisters filled with mixtures of granulated polyethylene, boric acid, boric carbide and lead cuttings. At the end of the collimator there is a 10cm-thick lead wall. “Romashka” detectors are placed in a compact composite lead shielding (Fig. 1, Fig. 2) behind the collimator. The collimated beam is supposed to traverse inside a vacuum tube. The scheme of the collimator (Fig. 3) and the properties of the materials filling the canisters are presented in Table 2.

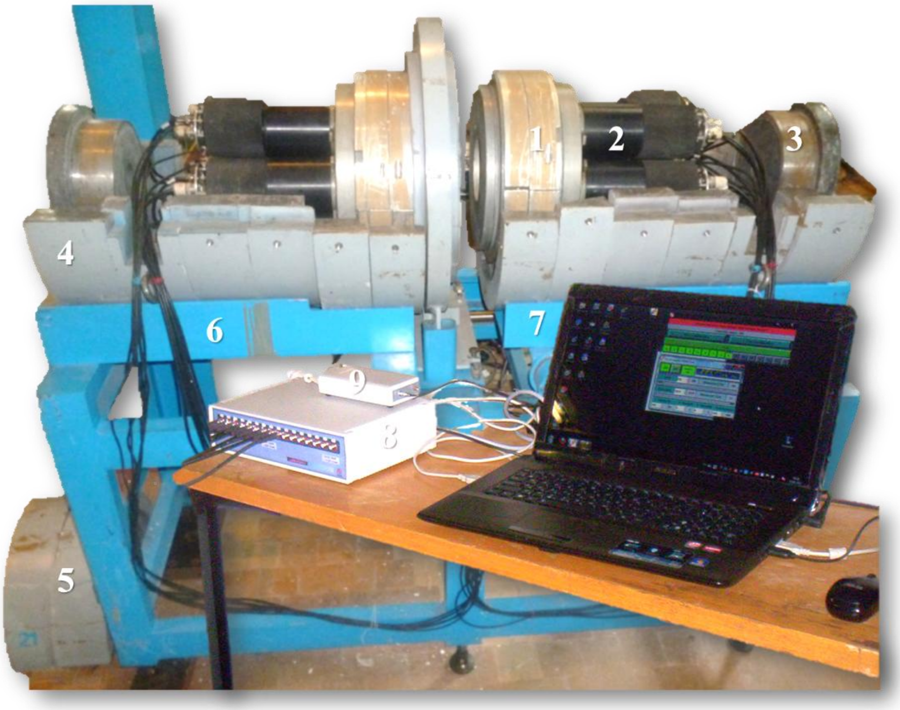

Fig. 1. Twelve crystal gamma-ray spectrometry system "Romashka": 1 – Six NaI(Tl) crystals in a single aluminum cylinder wrapped with aluminum arc-seals, 2 – Photo multiplier tubes FEU-110 and high-voltage divider, 3 – Lead shielding-collimator, 4 and 5 – Lower and upper lead shielding arcs, 6 – Adjustable rigid iron support, 7 – Movable iron trolley, 8 – 16 channels HVSys power supply [3], 9 – Parsek Desktop 8k MCA [4].

Table 2

Material	Weight concentration	Density, g/cm3
Mixture №1	Lead: 0.65022 Boric Carbide: 0.19363 Boric Acid: 0.15615	2.0775
Mixture №2	Lead: 0.66232 Boric Carbide: 0.15722 Boric Acid: 0.18046	2.0456
Mixture №3	Polyethylene: 0.62933 Boric Acid: 0.37067	0.62346

Fig. 2. Collimator canisters filled with different mixtures of materials (left), general view of the complete collimator from behind (middle) and general view of “Romashka” setup at the beam line (right).

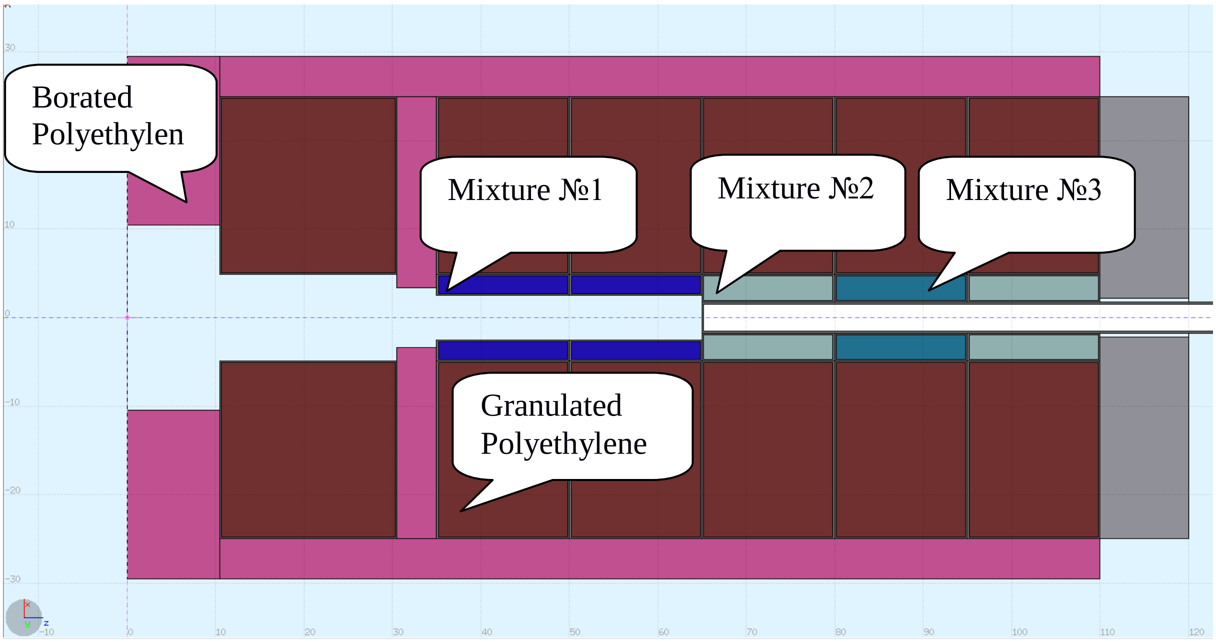

Fig. 3. Scheme of the shielding-collimator.

Monte-Carlo simulation

Due to the neutron scattering and capture in the collimator and shielding as well as in the floor and walls of the experimental hall, the detectors are additionally exposed to these neutrons and gamma-rays. Furthermore, the whole experimental setup as long as it is placed at the beam-line generates secondary particles resulting in dose increase for personnel, which could reside nearby. Because of the setup complexity, in order to estimate the neutron-gamma field intensities and absorbed doses, series of Monte-Carlo simulations using FLUKA code [5] were carried out.

FLUKA is a general purpose tool for calculation of particle transport and interactions with matter and it is used for a large number of applications (shielding design, dosimetry, activation, etc.). It can simulate with high accuracy the interaction and propagation in matter of about 60 different particles with energies from 1keV up to 20TeV. The transport of neutrons with energies lower than 20 MeV is performed by multi-group algorithm, which is faster than point-wise scheme, but lacks the energy resolution in the resolved resonance area due to using group-averaged cross-sections.

FLUKA is written in Fortran77 in double precision, utilizes 64 bit random number generator and available for use under GNU/Linux operating systems. It reads user input from an ASCII file which contains commands describing the problem geometry, definitions of the materials, definition of the particle source, requested estimators etc. Also FLUKA allows user to write own sub-routines for non-standard problems.

To estimate neutron-gamma field intensity and doses there were two simulations made – one with photons and one with neutrons as incident particles. The spectra of incident photons and neutrons for the current IREN parameters and target geometry were simulated by FLUKA beforehand. The simulated spectra were corrected for particle transmission along the non-vacuum neutron guide section using PREPRO code [6] with evaluated data library ENDF/B-VII.I.

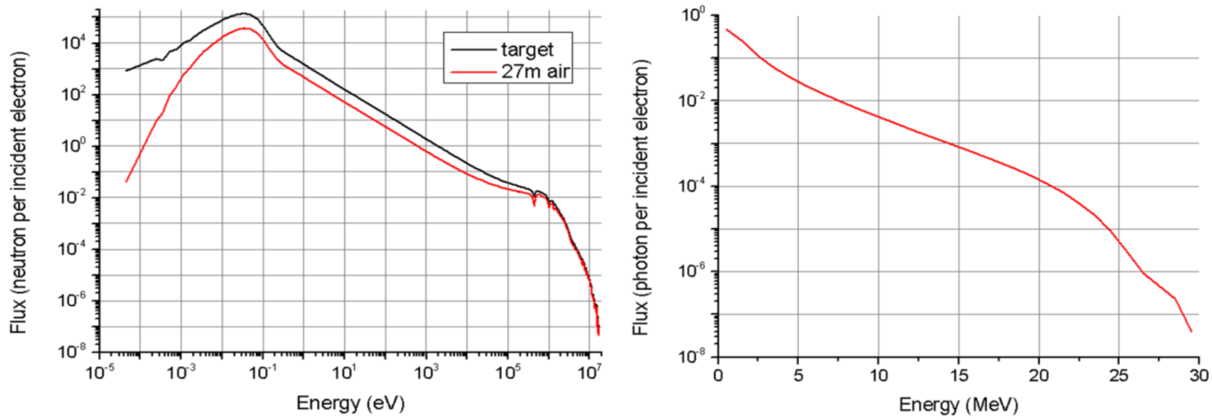

Fig. 4. Simulated IREN differential neutron spectra at the target side and corrected spectra at flight-path 27m (non-vacuum guide) (left) and simulated IREN integral normalized photon spectrum at the target side (right).

FLUKA uses a modification of Combinatorial Geometry package for constructing problem's geometry. It has a number of convex solid bodies (sphere, cylinder, parallelepiped etc.) and "infinite" bodies (infinite cylinders, planes and quadrics). Use of "infinite" bodies is encouraged because they provide more accurate and faster tracking. To construct problem's geometry user should define required bodies and assemble regions out of bodies using Boolean operations (union, subtraction and intersection). The next step is assigning desired materials to the regions.

Model geometry was described as 2 parallelepipeds inside each other (which represents experimental hall), 27 infinite cylinders, 4 truncated cones and 81 infinite planes (which represents collimator, shielding, detector, floor and surrounding walls). All these bodies were "arranged" by Boolean operations in 42 regions with assigned materials. The constructed geometry is close enough to the real one. It was binned with 1cm-step regular spatial mesh for scoring neutron and photon flux (Fig. 5, Fig. 6). Additionally, there were 3 regions filled with tissue equivalent material for scoring the dose at 1m, 3m and 6m (behind the concrete wall) from the detectors (Table 3). All the results shown below are calculated for the current IREN electron beam parameters as shown in Table 1.

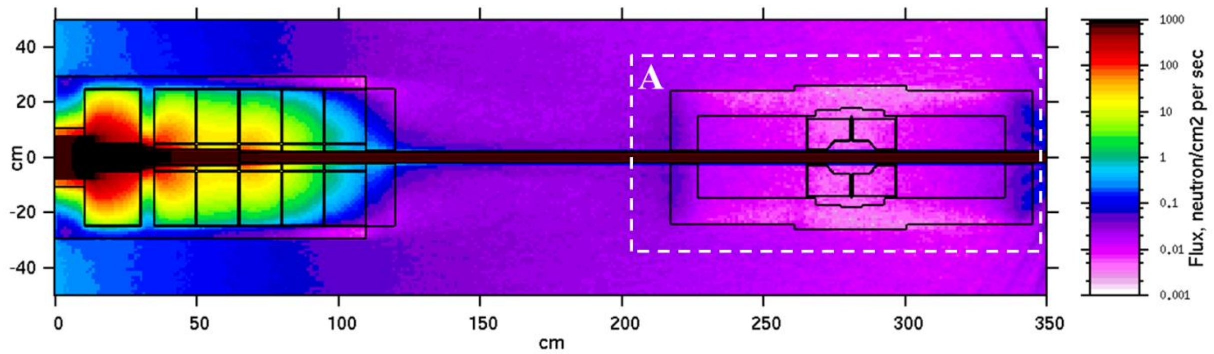

Fig. 5. Spatial distribution (central horizontal slice of the setup) of the neutron flux.

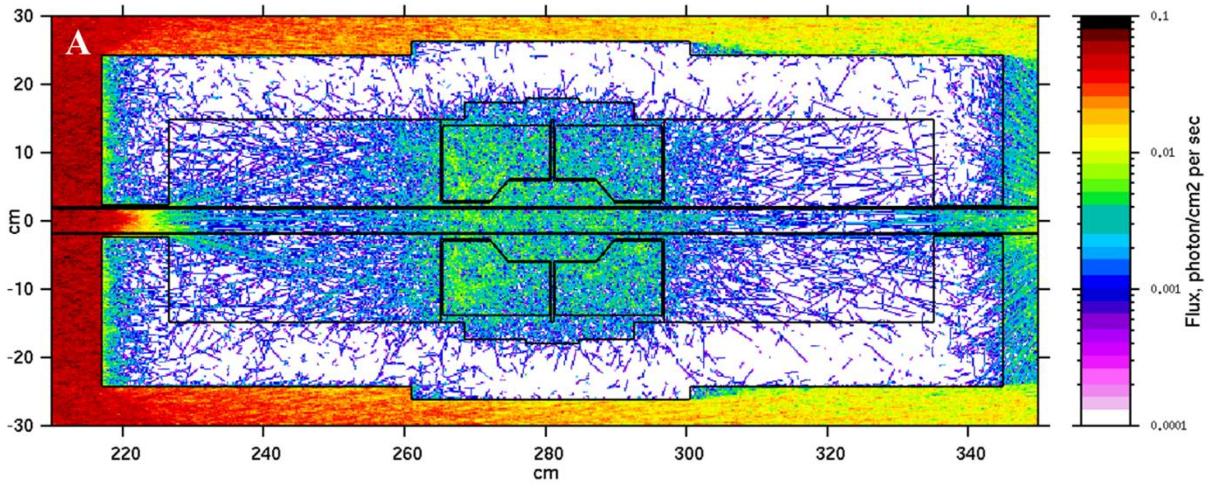

Fig. 6. Spatial distribution (central horizontal slice of the shielded detector) of the photon flux generated by the incident neutron beam.

Table 3

Distance from the center of “Romashka"	Annual dose, Sv
1 m	2.03×10^{-3}
3 m	4.89×10^{-4}
6 m	1.21×10^{-6}

Conclusions

The ratio between the collimated and scattered neutron flux inside the detectors’ shielding was found to be about 5 orders of magnitude. Neutron produced photon flux outside the detectors’ shielding is about 10 times more than inside it. The equivalent dose at 1m distance from the center of the “Romashka” does not exceed the annual dose limit for the group “B” personnel (5 mSv).

References

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