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Comparative analysis of MCNPX and GEANT4 codes for fast-neutron radiation treatment planning

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Abstract

The paper presents a comparative analysis of the MCNPX and GEANT4 simulation tools for the beam therapy fast neutron transport calculation problems. Groups of model experiments are described which compare the absorbed energy calculated values obtained on different types of phantoms and the rate of calculation for both simulation tools is assessed depending on the variation in the phantom and source parameters. The results of the studies can be used as the basis for the fast-neutron treatment radiation planning.

Keywords: Radiation therapy; Radiation treatment planning; Monte Carlo method.

Introduction

Quantitative assessment of the energy absorbed in a substance is employed on a great scale, as the absorbed dose in different organs and body parts of a patient during actual irradiation can be determined from the quantity of this energy. This is the key task at the patient pre-irradiation preparation stage [1].

At present, there are only a number of centers in the world offering fast-neutron beam therapy services. These include three laboratories in the USA, two in Japan, one in Germany and two in Russia [2,3]. In Russia, joint activities with VNIIA are under way at the Obninsk Medical Radiological Scientific Center of the Russian Ministry for Public Health to create a therapeutic facility for therapy by neutrons with the energy of 14 MeV [5]. The key component of this facility is a neutron generator. It operates based on the $^{3}T(d,n)^{4}He$ reaction and generates a monoenergy flux of radiation. This makes the generator superior to the reactor therapeutic facilities, such as FRMII in Germany [6], where, apart from 14MeV neutrons, low-energy neutrons are present, starting from thermal neutrons. Such spectrum limits to a certain extent the range of actual medical applications for the facilities of this type and a great deal of engineering and technical effort is required to make it fit for use.

This study has assessed the action of 14 MeV neutrons on different types of phantoms. Two groups of model experiments were conducted for each of the simulation tools. In experiments of group 1, the results of a calculation on a water voxel phantom of different configurations were compared, including depth and longitudinal isodose distributions and surface effects of the secondary protons formed as the result of the neutron-substance interaction. In group 2, the variation in the calculation rate, depending on the phantom composition, and the change in the source configuration, were compared. As options, a water phantom, a tissue-equivalent phantom and a number of real human phantoms, obtained based on different DICOM-images, were compared. Different parameters of the source are coupled with regard for the impact from the neutron generator as such, and from the medical therapeutic facility comprising the generator and the collimator [7,8].

The requirement for such comparison has emerged from a discrepancy [9] in the experimental data and the calculation model built in the MCNP5 environment. The results of the experiment have led to the need for reassessing the capabilities of the MCNP5 code, which, having a limited range of particles,

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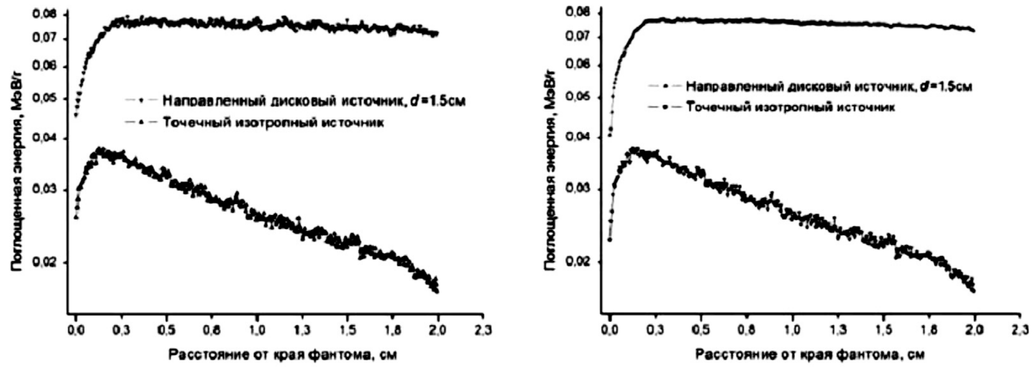
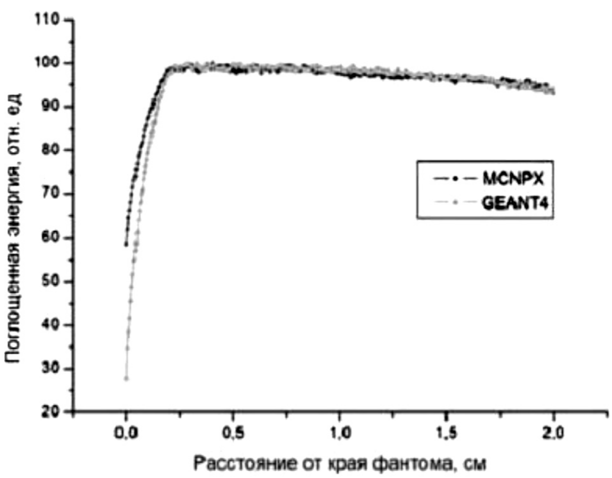


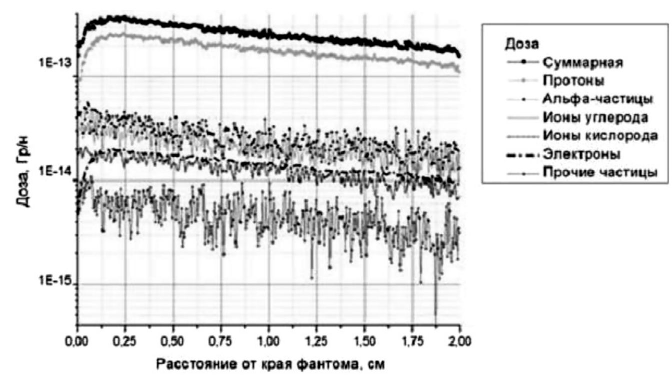
Поглощенная энергия, МэВ/г = Absorbed energy, MeV/g
Направленный дисковый источник, d = 1.5 см = Directed disk source, d = 1.5 cm
Точечный изотропный источник = Point isotropic source
Расстояние от края фантома, см = Distance from phantom edge, cm

Fig. 1. Depth distribution of absorbed energy in the water phantom calculated using MCNPX (left) and GEANT4 (right). The distance from the source is 5 cm. The neutron energy is 14 MeV. The neutron energy flux density is 10^{11} n/s.



Поглощенная энергия, отн. ед. = Absorbed energy, rel. units
Расстояние от края фантома, см = Distance from phantom edge, cm

Fig. 2. A comparative analysis of the total absorbed energy depth distribution (in relative units) in the water phantom. Directed disk source, $d = 1.5$ cm. The neutron energy is 14 MeV.



Доза, Гр/н = Dose, Gy/n
Расстояние от края фантома, см = Distance from phantom edge, cm
Доза = Dose
Суммарная = Total
Протоны = Protons
Альфа-частицы = Alpha particles
Ионы углерода = Carbon ions
Ионы кислорода = Oxygen ions
Электроны = Electrons
Другие частицы = Other particles

Fig. 3. Spectral distribution of absorbed energy from secondary particles.

treats the energy released in a particular cell of the phantom as neutron energy without secondary particles, specifically protons, taken into account. This explains the selection of the MCNPX code which enables energy from secondary protons (being the major contributors) to be counted, and of the GEANT4 code which counts absolutely all types of interactions and does not use kerma approximation.

Tools and methods

The MCNPX v.2.4.5e [10] and GEANT4.9.5-1 [11] software products were used in the problem under consideration.

Monte-Carlo N-Particle Transport Code (MCNP) is a family of codes for simulating the transport of ionizing radiation (neutrons, photons, electrons and others) in material systems using Monte-Carlo methods. MCNPX was developed at Los Alamos National Laboratory in the USA in the ANSI C and FORTRAN programming languages. The code simulates the interaction of particles (neutrons, photons and electrons) with the substance of the system. The scattering and capture reactions, as well as the reaction of nuclei fission by neutrons are considered. It also generates a source of secondary particles formed in nuclear reactions (fission neutrons, photons, electrons). The code is used for problem solving in the fields of nuclear reactor physics, radiation protection and medical radiology [2].

This study used parameters of particles (specified by the phys:x directives) [10] other than default values. In particular, special parameters were set for neutron, photon, electron and proton physics: analog simulation was enabled for all types of particles (that is, use of purely statistical methods for dispersion reduction was disabled), the neutron decay capability was disabled, photonuclear reactions on photons were disabled, and