Applications of the Monte Carlo Code for Radiation Transport Simulation for Use in Radiotherapy

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Abstract
The simulation of electron beam transport by the Monte Carlo method in arbitrary, user-defined, complex geometries made of any chemical element or material was used to examine an influence of a beam forming system on absorbed dose distributions for electron beams from medical accelerators. The typical beam defining system consists of scattering foils, adjustable collimators and electron applicators. The scattering metal foils flatten the radiation fields of medical accelerators. The adjustable collimators shield a patient from secondary radiation. The electron applicator produces radiation fields with demanded shapes and protects surrounding healthy tissues. The SHOWME Monte Carlo code, a modified GEANT3 code version, was used to calculate the absorbed dose distributions for an 18 MeV primary electron pencil beam.

1. INTRODUCTION

One of the most developing methods in radiation treatment is an externally applied beam of electrons produced by use of linear accelerator with energies up to 20 MeV. To prepare an optimal radiotherapy planning it is necessary to have a detailed information about a distribution of a dose delivered to a patient. An important tool to deal with this problem is the application of Monte Carlo methods for electron and photon transport in matter. The aim of the presented calculations was to look for characteristic features of absorbed dose distributions and their dependence on beam defining system elements by use of the Monte Carlo code.

2. THE MONTE CARLO SIMULATION

The essence of the Monte Carlo techniques is to simulate the transport of different particles in arbitrary, user-defined, complex geometries made of any chemical element or material.

On one hand, with this method a large number of particles' life histories could be followed from the source to the end using elementary probabilities at each stage. On the other hand, the Monte Carlo techniques allow to obtain some average quantities, e.g. bremsstrahlung efficiency and energy [1].

Simulating a process means:
1. evaluation of the probability of occurrence of the process, by sampling the total cross section,
2. generation of the final state after interaction, by sampling the differential cross section of the process,
3. computation of the mean value of some quantities which characterize the (quasi) continuous processes.

The SHOWME code, a modified version of the GEANT3 code [2], is used to simulate the transport of different particles in arbitrary, user-defined, complex geometries made of any element or material. It considers the dominant processes which can occur in the energy range from 10 keV up to 10 TeV.

All processes which are important in the energy range interesting for medical use are implemented in the code:
1. processes involving photons: (e^-, e^+) pair production, Compton collision, photoelectric effect, photofission of heavy elements,
2. processes involving electrons and positrons: multiple scattering, ionization and delta rays production, bremsstrahlung, annihilation of a positron.

The transport of electrons, positrons and photons is followed until either a particle leaves an experimental setup or its kinetic energy becomes lower than 10 keV for electrons and positrons and 100 keV for photons (these values are parameters in calculations).

The calculations were performed on a CONVEX C-3210 computer at the Soltan Institute for Nuclear Studies at Świerk. One million histories were simulated in calculations. The average calculation time taken per one incident electron depended on the setup geometry. For all presented cases it was less than 0.024 seconds.

The Monte Carlo simulation allows us to see the effects of different parts of the beam defining system on the final dose distribution. The simulation geometry is shown in Figure 1. The 18 MeV monoenergetic, monodirectional electron beam (so called "pencil beam") is perpendicularly incident on the water phantom. The full simulation includes all components of the beam defining system which either cross the beam or are used to define its edge. Parts of the supporting assembly which came close to the geometric edge of the beam were not included. Some of

the details of the beam defining system are given in the text.

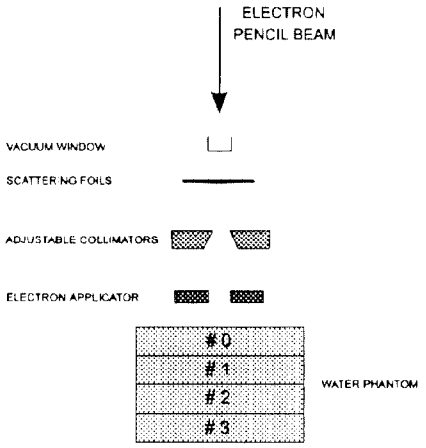

Figure 1. The schematic diagram of geometry used in calculations

The main phenomena involved in the process of electron beam collimation are: an appreciable air scattering of electrons with energies up to 20 MeV, a production of scattered electrons by collimator walls and bremsstrahlung produced in collimators or apertures.

The pencil beams really start at the vacuum window of the accelerator. They are usually broadened by one or two scattering foils and thus after leaving the foils at the final collimator and applicator they are no longer narrow.

The Monte Carlo method for generating electron dose distributions, used for a pencil beam, appears to be one of the most promising models, due to the inclusion of physics of electron multiple scattering [3].

The beam reaching a patient should be widely distributed in energy and direction. To flatten radiation fields of medical electron linear accelerators scattering foils are inserted into the electron beam. There are, however, also other scattering materials in the beam, e.g. an accelerator tube window, transmission chambers and air. Electrons are also spread from the walls of the collimator into the central beam. The complete scattering system influences the shape of depth dose distributions, the maximum absorbed dose rate at a treatment distance and the flattening of treatment fields. The collimation of a beam is necessary to limit its size and to protect surrounding healthy tissues.

The applicators with square or circular openings, made of low atomic number materials to minimize the brems-strahlung production, are the most often used electron collimators. Recently a multi-leaf collimator consisting of a number of bars made of low atomic number materials is used in the electron collimator design. They are mounted in a frame and can be moved individually to generate irradiated fields with irregular shapes.

3. Calculation Details and Results

In Figure 2 the radial distributions of the absorbed dose for an 18 MeV electron pencil beam are shown for a beam defining system which consists of a copper scattering foil and a fixed aluminum collimator. The copper scattering foil is shaped as a 0.0085 cm high cone with 1.4 cm and 7.0 cm diameters. The aluminum collimator is a tube which is 2.5 cm high, with an inside radius of 3.25 cm and an outside radius of 18 cm. The distance between a vacuum window and a water phantom is 100 cm. The radial distributions of the absorbed dose are calculated for the 1 cm thick water layers. The range calculated for 18 MeV electrons in water is equal to 9 cm. The dose distributions for the 1 cm thick water layer lying 4 cm below the phantom surface are shown for three simulation geometries: 1. the 18 MeV electron pencil beam is perpendicularly and directly incident on the water phantom (without foil, without collimator); 2. the electron pencil beam is passing through the scattering foil placed 20 cm from the vacuum window (with foil, without collimator); 3. additionally, the aluminum collimator is placed 65 cm from the vacuum window (with foil, with collimator). The profiled scattering foil creates the expected decreasing of the dose values for small radii. The collimator reduces the dose outside and the level of 1 % of the dose in the center is reached for the radius of 8.8 cm.

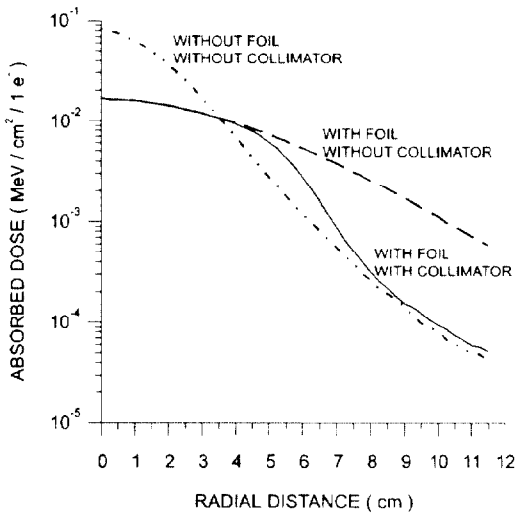

Figure 2. The radial distributions of the absorbed dose for an 18 MeV electron beam for a collimation system consisting of a copper scattering foil and aluminum collimator for the 1 cm thick water layer lying 4 cm below the phantom surface

In Figure 3 the radial distributions of the absorbed dose for an 18 MeV electron beam for the described above beam defining system which consists of a copper scattering foil and an aluminum collimator are shown for six 1 cm thick water layers: the first water layer (#0) and layers lying 1 cm (#1), 2 cm (#2), 3 cm (#3), 4 cm (#4) and 9 cm (#9) below the water phantom surface.

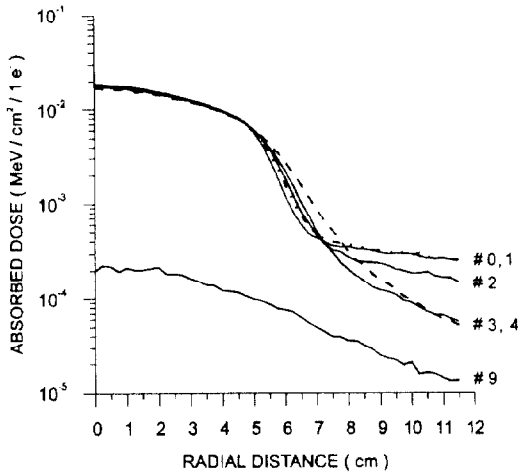

Figure 3. The radial distributions of the absorbed dose for an 18 MeV electron beam for a beam defining system consisting of a copper scattering foil and an aluminum collimator for 1 cm thick layers lying on different depths in the water phantom

For layers lying deeper in the phantom an influence of water on broadening of the depth dose distributions could be seen. Of course, for the specified shapes of the beam defining system elements the final dose distributions also depend on the distance between the collimator and vacuum window, which was equal to 65 cm in the presented calculations.

In Figure 4 the Monte Carlo calculated relative isodose contours for an 18 MeV electron pencil beam in water are shown for the tube aluminum applicator with a cut-out in a shape of letter I which is 12 cm high, with bottom and top parts 9 cm long and 4 cm thick. The electron applicator height is 2.5 cm. The isodose contours are calculated for a setup consisting of the scattering foil and electron applicator, both described above. The scattering foil is placed 30 cm from a vacuum window and the applicator - 90 cm from it. The distance between the vacuum window and the water phantom surface is 96 cm. The shown isodoses are for the fourth 1 cm thick layer lying 4 cm below the water phantom surface. The calculated isodoses follow the shape of the electron applicator.

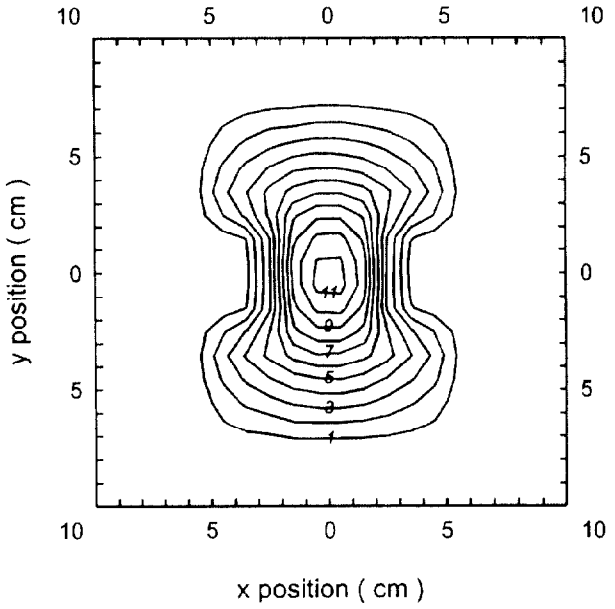

Figure 4. The Monte Carlo calculated relative isodose contours for an 18 MeV electron pencil beam for a beam defining system consisting of a copper scattering foil and an electron applicator for the fourth layer lying 4 cm below the water phantom surface

The Monte Carlo calculations presented in this paper are helpful in better understanding of phenomena occurring when the electron beam passes through the matter and they could be used for designing of beam defining systems.

4. REFERENCES

[1] "Monte Carlo Transport of Electrons and Photons" ed. by T.M. Jenkins, W.R. Nelson and A. Rindi, New York and London, Plenum Press, 1988

[2] R. Brun, F. Bruyant, M. Maire, A.C. McPherson and P. Zanarini, "GEANT3-User's Guide", CERN DD/EE/84-1

[3] W.T. Scott, "The Theory of Small-Angle Multiple Scattering of Fast Charged Particles", Rev. of Mod. Phys., vol. 35, no 2, pp. 231-313, April 1963