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Comparison of measured and Monte Carlo calculated electron beam central axis depth dose in water

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BACKGROUND: *The Monte Carlo method is the most accurate means of predicting dose distributions in radiation treatment of patients. Owing to rapid development of computer technology the use of this method is now not restricted only to big research centers. A Monte Carlo simulation of medical linear accelerator head and central axis depth dose calculation for electron beams are presented in this work.*

METHODS: *Calculation of central axis depth dose distributions for 6, 9 and 12 MeV electron beams from medical linear accelerator Varian 2100C was performed with program FOTELP on personal computer. FOTELP is a general purpose Monte Carlo code for simulation of coupled transport of photons, electrons and positrons. The results of calculations were compared with experimental data. Measurement of electron central axis depth dose distributions was performed with automatic field analyzer in water.*

RESULTS: *Good agreement between calculated and measured data is demonstrated for depths from surface of water phantom to depth on which dose falls to about 50% of maximum dose on central axis. Systematic discrepancies between measured and calculated data exist under depth of 50% dose. Simplification of geometrical model of accelerator head is supposed to be the main reason for these discrepancies.*

CONCLUSION: *Because of limited computer power (333MHz Celeron processor) it was necessary to simplify geometric model of accelerator head and to follow relatively modest number of electron histories. In this sense the results of calculations could be estimated as very good. In order to achieve better agreement between calculated and measured data or to perform more complex calculations a much more powerful hardware is needed.*

KEY WORDS: *Monte Carlo Method; Phantoms, Imaging; Software; Radiotherapy Dosage*

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INTRODUCTION

The Monte Carlo simulation of radiation transport is the most accurate means of predicting dose distributions and other quantities of interest in radiation treatment of patients (1). Due mainly to long computational times, Monte Carlo techniques are mainly used for investigational purposes. However, owing to rapid development of computer technology and algorithms the use of this method is now not restricted only to big research centers. It appears that we are rapidly approaching a time when Monte Carlo simulations will be part of everyday practice in radiotherapy departments.

The aim of this work was to calculate electron central axis depth dose data in water using general purpose Monte Carlo code FOTELP (2-4) and to compare calculated and measured distributions in water phantom. Calculation was done for 6, 9 and 12 MeV electron beams from medical linear accelerator Varian 2100C (Varian, Paolo Alto, USA). Simulation of particle transport through accelerator head and water phantom was done on a personal computer with 333 MHz Celeron processor and 64MB RAM. The geometrical model of accelerator head was made according to schemes, specially prepared by the manufacturer for purposes of Monte Carlo simulations (Monte Carlo Project No. 73). Experimental determination of depth dose distribution was performed with automatic field analyzer RTD (Multidata, St. Louise,

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USA).

The motivation for this work was not only the increasing importance of Monte Carlo simulation in external beam radiotherapy, but also the possibility to use domestic program FOTELP, which can be easily installed on personal computers. Program FOTELP is a general purpose Monte Carlo code for the simulation of the coupled transport of electrons, positrons and photons. For purposes of external beam radiotherapy calculations this program was specially adjusted by its author Dr. R. Ilić. Some of its capabilities, which make this program well suited for accelerator head modeling will be only briefly mentioned in this work. Attention will be paid mainly to the evaluation of results of central axis depth dose distributions simulation. Good agreement between simulated and measured data, which is demonstrated in this work, shows that program FOTELP is a valuable tool for radiotherapy calculations.

MATERIALS AND METHODS

Software package FOTELP

Software package FOTELP (2-4) is a general purpose Monte Carlo code to simulate the coupled transport of photons, electrons and positrons by the Monte Carlo method for numerical experiments in dosimetry, radiation shielding, radiotherapy, for evaluating the efficiency of detectors, and counters, for computing the absorbed energy in the layers of microelectronics components, for estimating radiation damage of materials, and other numerical experiments concerning the mentioned particles. Codes from this package perform calculations in 3D geometry with random spectra of particles having energy in the range from 1 keV to 100 MeV, and material region for which geometry can be described by planes and surfaces of the second order. FOTELP codes apply transition probabilities from the previous to the following state of phase space, which are prepared by FEPDAT code.

Software package FOTELP, as other well-known programs, for instance BEAM (5) and PEREGRINE (6), PENELOPE (7,8), is adjusted to meet the special requirements of external beam radiotherapy calculations. This means that the code produces a phase-space output of the beam at any specified plane in the model (i.e. position, energy, direction and type for each particle crossing this plane).This phase-space file can be reused by the program FOTELP as an input for simulation of particle transport in water phantom or can be analyzed to obtain beam characteristics.

The FOTELP code user prepares three input files in the text editor (2). The geometrical model of accelerator head and water phantom is described in file Rfg.inp. The physical and chemical characteristic of all materials included in the model as well as data for the creation of an energetic scale are contained in file Fepdat.inp. The geometry and spectral characteristics of source, number of simulated particles from source and dimension of elementary volumes (voxel) in which the absorbed dose is scored are recorded in file FOTELP.inp.

Geometrical model and calculation details

The simplified model of Varian 2100C accelerator is shown in Figure 1. After leaving accelerator tube (1), narrow electron beam (2) travels through focusing coil system (3), bending chamber (4), vacuum window (5)(6), upper scattering foil (7), primary collimator opening (8), lower scattering foil (9), ionization chamber (10), mirror (11), movable collimator jaws (12) and finally, through electron applicator (13). Description of construction and role of these parts are beyond the scope of this work, for more details reader should consult reference (9).

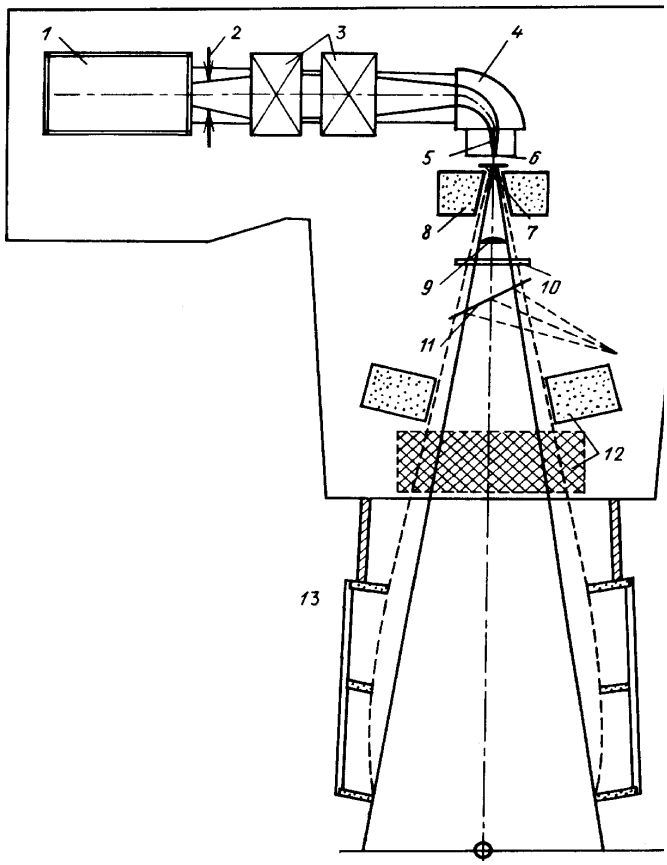

Figure 1. The simplified model of medical linear accelerator treatment head. See text for explanation

The geometrical model of accelerator head used for simulation in this work is presented in Figure 2. In order to achieve reasonable calculation times the model is simplified comparing with the manufacturer's blueprints. Following the terms of use, these blueprints and materials and the dimensions of accelerator head elements are not presented. The model consists of upper (I) and lower (III, V) scattering foils, movable collimator jaws (VIII) and finally water phantom beneath the accelerator head (X). Air layers between the

elements of the accelerator head (II, IV, VI, VII) and between the head and water phantom (IX) are also presented. The symmetry axis of the model is Z-axis, coincident with the beam axis. Geometrical surfaces (D1 - D11) are also marked in Figure 1. Intersections of geometrical surfaces are denoted with numbers 14-23.

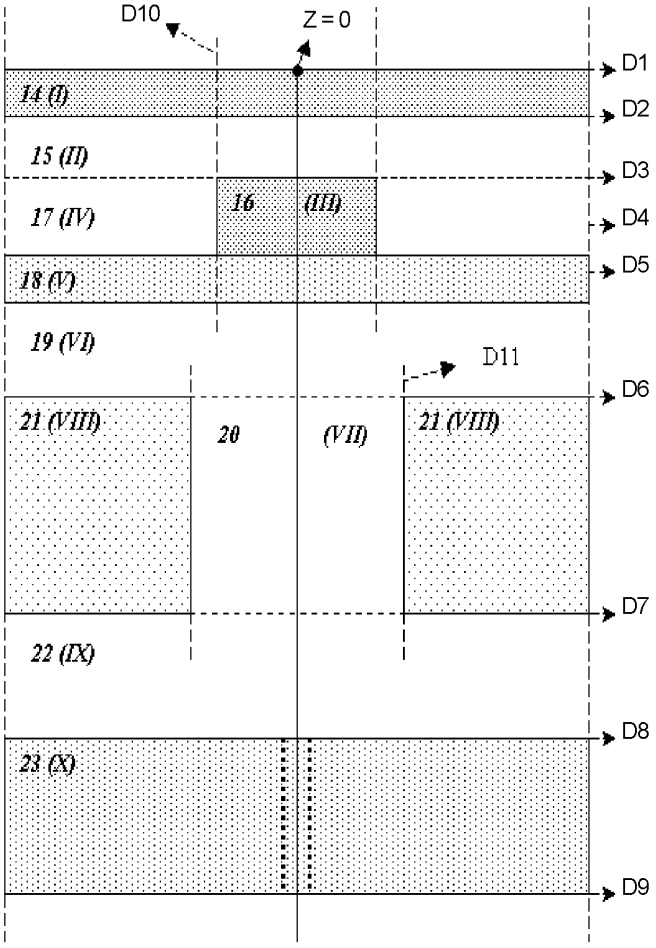

Figure 2. Geometrical model of accelerator head used in FOTELP code . See text for explanation

The main simplification of the model, omitting of electron applicator, was done according to previous Monte Carlo calculations (5) which shows that electrons scattered from the applicator and collimator jaws contribute only about 10% to the surface dose. Electrons from the applicator are the least penetrating since some of them go through applicator scarpers. The segment ionization chamber and mirror are not included in the model because they are very thin in the direction of beam propagation.

The primary electron beam entering the upper scattering foil (point Z=0 in Figure 1.) was supposed to be monoenergetic, because of a lack of adequate information on its spectral characteristics (10). The energy of this beam was adjusted to match the depth at which the dose falls to 50% of dose maximum on the measured central-axis depth-dose curve in water phantom. The number of electrons in the primary beam was set to $2x10^8$.

The absorbed dose was scored in quadratic volumes (voxel) centered on the central axis of beam in water. The dimensions of voxel was 2x2x2mm.

The cutoff energies of electrons, photons and positrons were set to 500keV (10). Particles with energies under off-off value are locally absorbed, i.e. their transport is interrupted and energy is absorbed at a point.

Another interruption of particle transport and local energy absorption is performed in collimator jaws. The program calculates the relationship between particle position and energy in jaws. If the particle has insufficient energy to leave the jaws, its transport is interrupted. As in the case of all other simplification, the reason for transport interruption is a reduction of computation times.

RESULTS AND DISCUSSION

The results of the calculation and measurements of 6, 9 and 12MeV electron central axis depth dose distributions in water are shown in Figures 3 - 5.

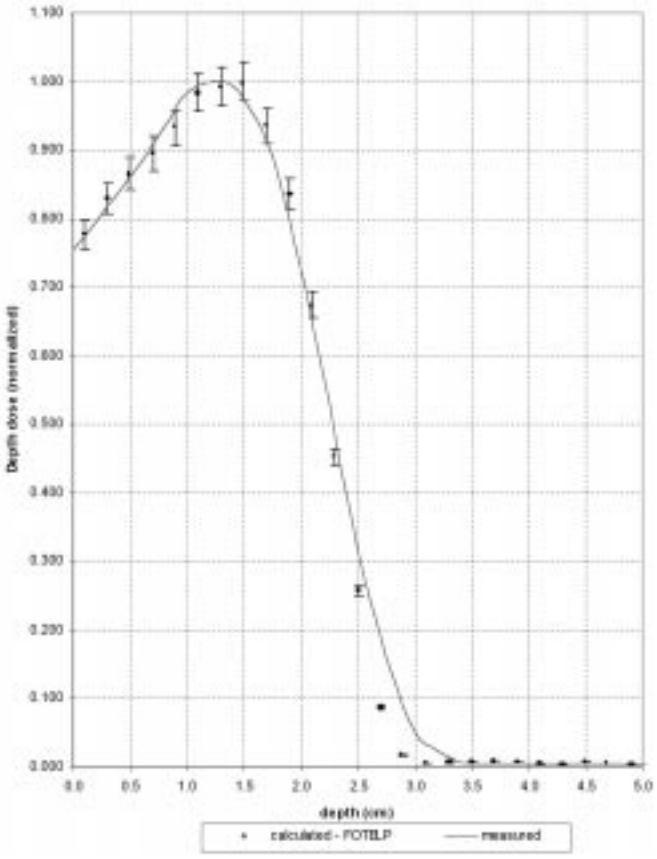

Figure 3. Calculated and measured 6MeV electron beam central axis depth dose distribution

In depth range from surface to depth, at which the dose falls to about 50% of the maximum dose, the agreement between calculated and measured values is very good . In this depth range the statistical precision of simulation is about 3% (on 1ó level) and results coincidence within this range.

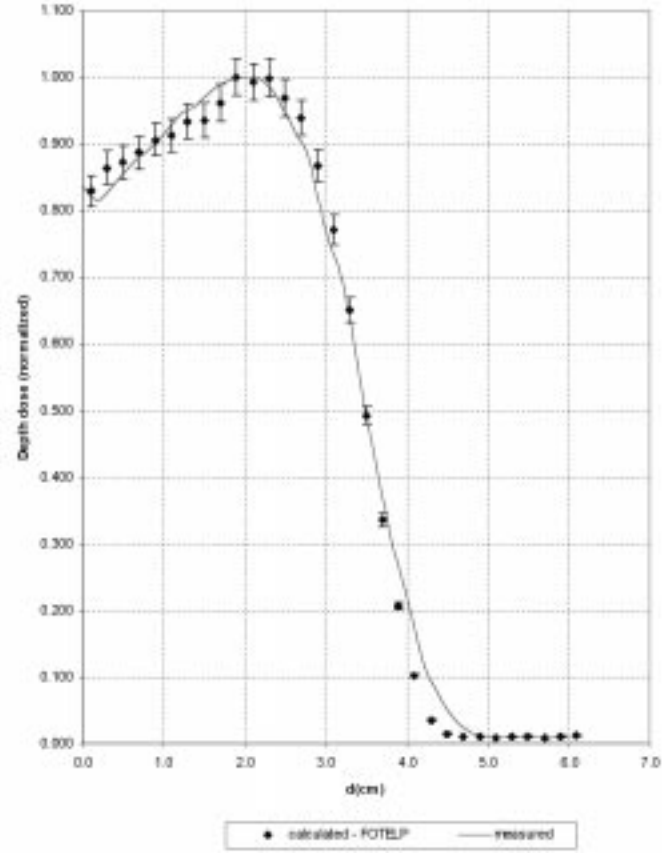

Figure 4. Calculated and measured 9MeV electron beam central axis depth dose distribution

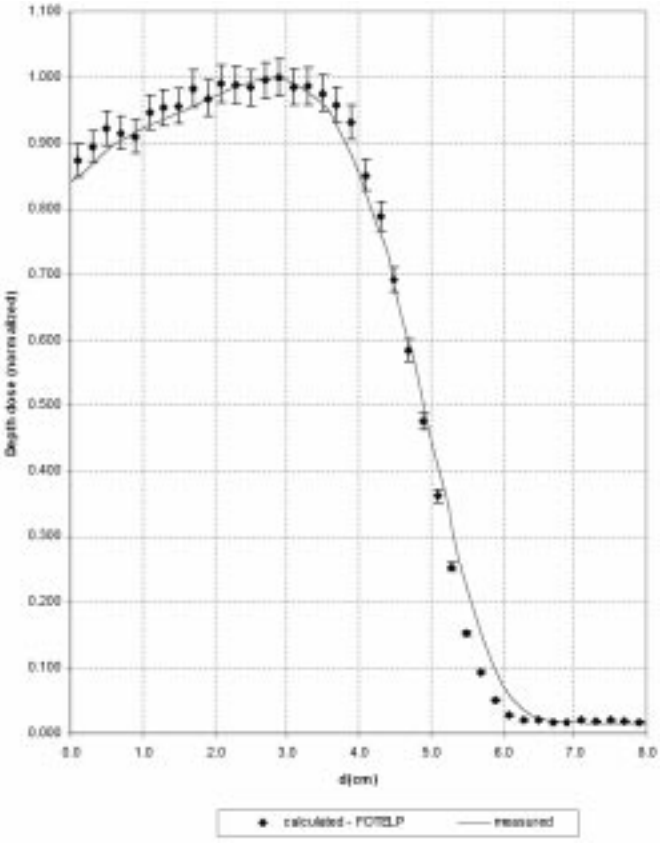

Figure 5. Calculated and measured 12MeV electron beam central axis depth dose distribution

Discrepancies between the calculated and measured dose exist for depths beneath the depth of 50% dose - calculated values are lower than measured. The precision of simulation in this depth range is also lower and is about 5%.

Discrepancies between calculated and measured values can be partially explained by a lack of bremsstrahlung photons. The reason for this is an interruption of particle transport in collimator jaws; some of the absorbed electrons would otherwise produce bremsstrahlung photons. Another reason could be the difference between the stated and the actual scattering foil thickness. It is well known that most of bremsstrahlung photons are produced in scattering foils, so small differences in thickness can result in wrong predictions about bremsstrahlung photon production. (10). Finally, it should be mentioned that the low precision of simulation could also contribute to discrepancies between calculated and measured data.

The depth range where the agreement between the results of simulation and measurement is good is very important for electron radiotherapy. It is obvious that program FOTELP with the simplified model of accelerator head can correctly calculate the so-called therapeutic range of beam (important in treatment planning) and a depth of 50% dose. The latter quantity is very important in electron beam dosimetry.

The calculation time is a very important characteristic of every Monte Carlo simulation. Unfortunately, due to problems with GETTIME routine in Fortran Power Station Compiler (Microsoft, USA) it was not possible to measure calculation times exactly. Problems appeared on several computers. Calculation times for simulation of $2x10^8$ electron histories were about 50 - 90 hours. Routine GETTIME was not able to register so long time periods. For the same reason it was not possible to check some important relationships between the number of simulated electron histories, calculation times and statistical precision of simulation (11-13).

CONCLUSION

This work presents an initial step in radiotherapy calculations with FOTELP code. Two main field of interest are covered: radiotherapy treatment unit simulation (5,7,8) and dose distribution calculation based upon voxelized geometry of medium (14-16). Obtained results are encouraging for further investigations in the field of radiotherapy Monte Carlo simulations.

In order to compute correctly the central axis depth dose distribution in the whole depth range, it will be necessary to include all relevant elements of the accelerator head in the geometrical model and to increase the number of simulated particles. In this case it would be possible to carry on a more complex calculations. This task can be realized only on much more powerful hardware. For instance, program Peregrine runs on a system of 24

Pentium II processors, 300MHz each. This configuration permits the transport of about $2x10^8$ particles through a grid of 2x2x2mm voxel in only one hour. On such a system it is possible to achieve statistical precision of order 1.5% within few hours.

REFERENCES

1. Jette D. Electron beam dose calculations. In Physics of radiation therapy. Berlin: Springer Verlag; 1994.
2. Ilic RD. Instructions for use of FOTELP software package, version G2k. Beograd, 2000.
3. Ilic RD. Monte Carlo techniques in the transport of particles. Belgrade: Naucna knjiga; 1991.
4. Ilic RD. Computer simulation of transport of electrons through substance. Elektron- 100 godina od otkrica. Vol. 6. Belgrade: SANU; 1997.
5. Rogers DWO, Fadegong BA, Ding GX, MA M and Mackie TR. Beam: A Monte Carlo code to simulate radiotherapy treatment units. Medical Physics 1995;22:503-24.
6. Hartmann Siantar CL, Bergstrom PM, Chandler WP, Chase L, Cox LJ, Daly TP et al. Lawrence Livermore National Laboratory's Peregrine project. UCRL-JC-126732 . Livermore; 1997.
7. Mazurier J, Salvat F, Chauvenet B, Barthe J. Simulation of photon beams from Saturn 43 accelerator using the code PENELOPE. Phys Med 1999;XV(3).
8. Sempau J, Sánchez-Reyes A, Salvat F, Oulad ben Tahar H , Jiang SB, Fernández-Varea JM. Monte Carlo simulation of electron beams from an accelerator head using PENELOPE. Phys Med Biol 2001;46(4).
9. International commission on radiation units and measurements (ICRU), Radiation dosimetry: Electron beams with energy between 1 and 50 MeV, ICRU 35, 1984.
10. Ding GX and Rogers DWO. Energy spectra, angular spread and dose distributions of electron beams from various accelerators used in radiotherapy. National Research Council of Canada 1995; Report PIRS 439.
11. Briesmeister JF (editor). MCNP - A general Monte Carlo N-particle transport code. Manual LA-12625. Los Alamos; 1997.
12. Bielajew AF, Efficiency, statistics and sampling, NRC Reports, PIRS-0395, 1996.
13. Bielajew AF, Rogers DWO, Variance reduction techniques, NRC Reports, PIRS-0396 1996.
14. du Plessis FCP, Willemse CA, Lötter MG, Goedhals L. Comparison of the Batho, ETAR and Monte Carlo dose calculation methods in CT based patient models. Med Phys 2001;28(4).
15. Schneider W, Bortfeld T and Schlegel W, Correlation between CT numbers and tissue parameters needed for Mont Carlo simulations of clinical dose distributions. Phys Med Biol 2000;45.
16. Schneider W, Bortfeld T, Schlegel W. Vergleich von CT-basierten 3D Monte Carlo Simulationen und semiempirischen Verfahren bei Elektronenbestrahlungen. In: Leitner H, Stucklschweiger G, eds. Medizinische Physik '96. Graz: DGMP; 1996.