

MONTE CARLO MODELING OF THE ELEKTA PRECISE LINEAR ACCELERATOR: VALIDATION OF DOSE DISTRIBUTION IN A HETEROGENEOUS WATER PHANTOM

B. Juste, M.E. Mota, R. Miró, S. Gallardo, G. Verdú

Chemical and Nuclear Engineering Department.

Polytechnic University of Valencia.

Camí de Vera, s/n. 46022 València, Spain.

bejusvi@iqn.upv.es; mamomo2@etsii.upv.es; rmiro@iqn.upv.es; sergalbe@iqn.upv.es;
gverdu@iqn.upv.es

ABSTRACT

The present work is devoted to develop a computational model using the Monte Carlo code MCNP5 (Monte Carlo N-Particle) for the simulation of a 6 MV photon beam given by Elekta Precise medical linear accelerator treatment head. The model includes the major components of the multileaf accelerator head and a cube-shaped water tank. Calculations were performed for a photon beam with 10 cm x 10 cm irradiation field at 100 cm distance from source. The simulation is able to predict the absorbed dose distribution within the water tank using the F8 or FMESH4 tally and the achieved results have been validated by comparison with experimental values measured at the Hospital Provincial de Castelló. Dosimetric parameters calculated at the phantom show a good agreement with the measured ones. Moreover, the parallelization of the MCNP5 code demonstrates that this simulation is not only an accurate tool to predict the energy deposition but also a fast way to obtain satisfactory results.

Key Words: Biomedical applications of radiation, MCNP5 Monte Carlo code, SL linacs, Multileaf collimator.

1. INTRODUCTION

Monte Carlo particle transport algorithms simulate the physics processes of radiation energy deposition in tissues. These algorithms are recognized among the most accurate and fast dose calculation methods. Nevertheless, the clinical application of these techniques has been limited by their associated long calculation times. Consequently, Monte Carlo simulations have only been used for some relative dose comparisons with experimental data. However, as computing power continues to decrease in cost while increasing in speed, it becomes increasingly feasible to use Monte Carlo for radiotherapy treatment planning.

According to this, the present work develops a methodology using MCNP5 [1] to simulate the Elekta Precise medical linear accelerator treatment head, with the aim of calculating the 3D dose distribution in a water phantom keeping the accuracy of results in a calculation time within the permissible ranks to consider its clinical application.

The first step of the work is focused on the modelization of the Elekta Precise geometry and the rest of parameters defining the simulation, such as physics particle transport, source characteristics, material properties and selected tally (*f8 or FMESH).

On the other hand, the second main goal of this work is to accelerate the calculation without compromising the results accuracy. To that, the MCNP5 code has been parallelized in an SGI Altix 3700, using the MPI parallel protocol with 16 processors, and we have increased MCNP5 calculation speed by recompiling the code using the -O2 optimization option of the Intel Fortran Compiler 9.0 on the Linux parallel computing machine, which enables optimizations for speed [2]. Moreover, the advantages of the new feature in Version 5 of MCNP, called FMESH, “Superimposed Mesh Tally”, have been also used in this simulation.

Calculated results by these models have been compared with experimental data obtained at the *Hospital Clínic Universitari de València*

2. MATERIALS AND METHODS

Nowadays the *Elekta Precise* radiotherapy unit is employed in many radiotherapy treatments [3]. To simulate the transport of electrons and photons that travel through the unit, from the source up to the detectors located at the water phantom, we have realistically modelled the geometry of all the components. The specification of the source and some physics aspects of the particle transport have been also necessary to carry out this simulation using MCNP5. This irradiation treatment head have been modelled to obtain space phase files at the end of the collimator. Particles gathered at this surface have been re-used to calculate depth dose curves.

The successful efficiency of the MCNP5 code has been demonstrated in a previous study using radiation transport calculations in a cobalt therapy unit [4].

In this work, an Elekta Precise linear accelerator head was represented in MCNP5 by the target disc, primary collimators and flattening filter, with the dimensions and materials specified by the manufacturer. The X-ray energy spectrum used was obtained after a 6 MV monoenergetic electrons hit with the tungsten target located at the target block [5]. The main difficulty to simulate the photon beams from linacs is that the energy of the electrons at the target is unknown. The value given by manufacturer (Elekta) is 6 MeV for 6 MV initial electron beam, with a fwhm (full width at half maximum) of 0.5 MeV.

Figure 1 shows the photon energy spectra used in the simulation to define source characteristics.

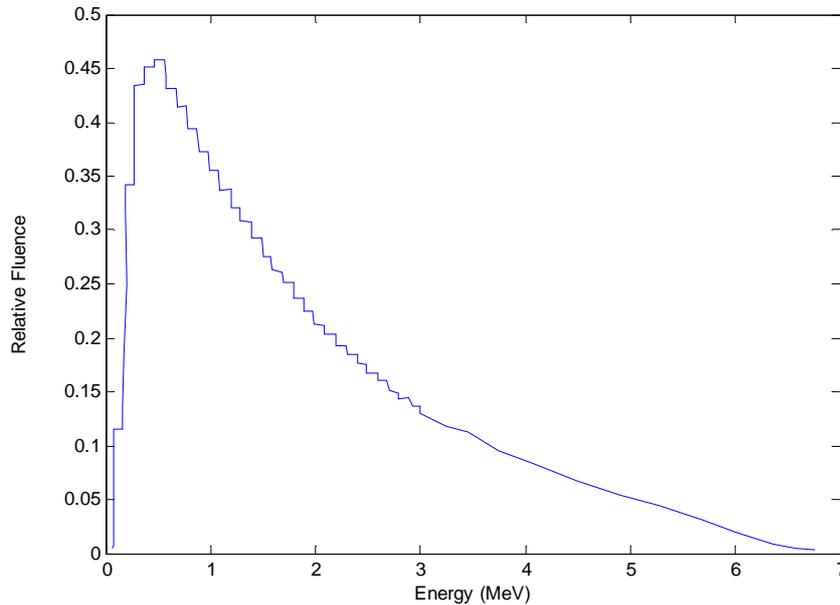


Figure 1. Photon energy spectra. 6 MVbeam.

The energy cut-off for photons was 0.001 MeV (the default value of MCNP5). However, since simulating electron tracks requires large computation time, in order to reduce it, an energy cut-off of 0.01 MeV has been selected in electron transport.

The photon source was assumed to originate isotropically from a point with a total divergence angle of 14° in the $x-z$ and $x-y$ planes. The source was positioned at a distance of 100 cm from a water phantom whose volume was $50\text{ cm} \times 50\text{ cm} \times 50\text{ cm}$.

The variation of relative dose with phantom depth was obtained from tally results. We used the *F8 tally, in this case, the tally utilized is the energy deposition in units of MeV per *voxel* and subsequently converted to relative dose. In MCNP, this tally is the pulse-height distribution in the detectors modified to energy units (designated as *F8:E). On the other hand, we used the FMESH (tally 4) associated with its respective flux-to-dose conversion factors (NIST) at the depth of maximum dose (1.5 cm) for a 6 MeV $10\text{ cm} \times 10\text{ cm}$ field.

2.1. Characteristics radiotherapy unit.

The accelerator model (Elekta Precise) was defined according to the manufacturer specifications. Figure 1 represents the schematic diagram of the upper head configuration view of the MCNP5 geometric model, for a typical low-energy photon beam configuration. It can be observed in the figure the X-ray target block, the primary tungsten alloy, the primary collimator with the low-energy port, the ion chamber assembly and the autowedge assembly which includes the wedge and the backscatter plate.

The ion chamber assembly consisting of a ceramic motherboard, three signal plates and three polarizing plates, separated by spacers made of aluminum have been also included in the model, as well as all the collimation section, which was modeled in detail including the multileaf collimation system and diaphragms.

The FMESH tally card used in the simulation allows to define a mesh tally superimposed over the water tank geometry and to obtain the track length estimation of the particle flux from the surface to the bottom. The registration of particles allows us to see how the energy deposition varies inside the water phantom and to develop the 3D dose distribution map.

On the other hand, results using the traditional *F8 tally card by means of dividing the cube phantom in small 0.5 cm x 0.5 cm x 0.5 cm *voxels*, have been also used are results are compared with those obtained previously and experimental data.

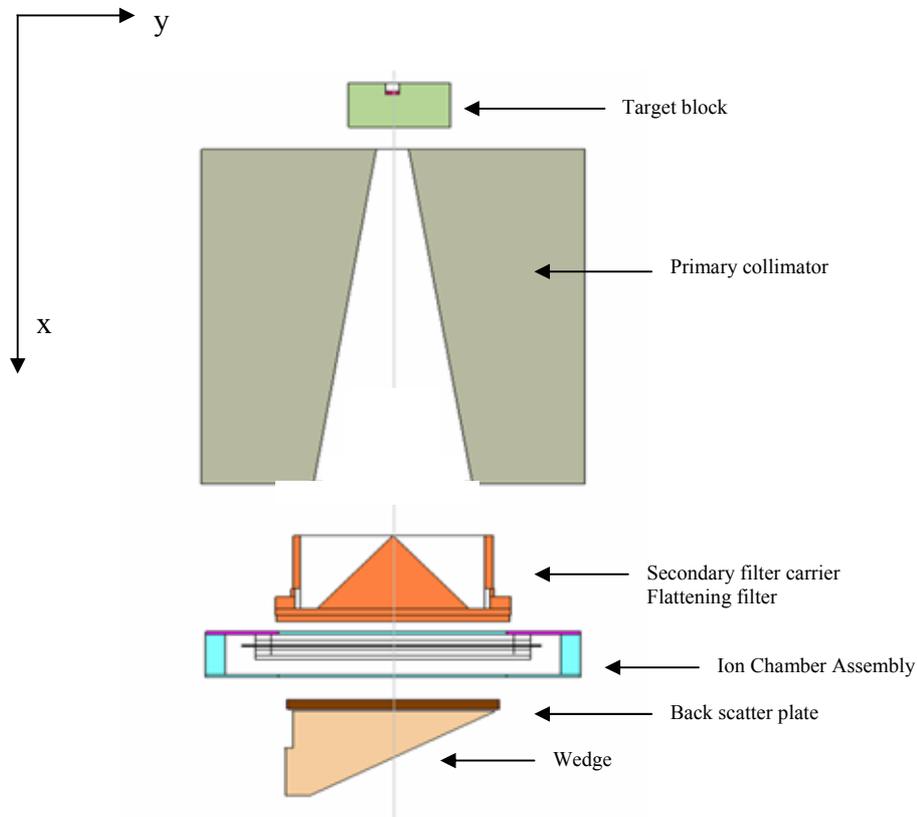


Figure 2. Schematic view of the simulated geometry of the Elekta linac upper head for 6 MeV X-ray beams.

2.1. Experimental data.

Experimental central axis percentage depth dose curves in a water phantom are obtained for a 6 MeV photon beam using a 10 cm x 10 cm irradiation field being the water surface of the tank at 100 cm far from the target.

Dose measurements were performed using a FC65-P *Scanditronix Wellhoffer* cylindrical ionization chamber with a 0.65 cm³ sensitive volume inserted into the cube-shaped phantom (“*RFA-300 Water Phantom*”).

A view of the Elekta Precise and the water phantom used in the experimental part of this project is shown in Figure 2.



Figure 3. View of the Elekta linac upper head for 6 MeV X-ray beams and the water phantom.

3. VALIDATION

To validate the dosimetric parameters obtained with the simulation we have compared them with the experimental data measured at the Elekta Precise therapy unit at *Hospital Clínic Universitari de València*.

Figure 3 and 4 show the comparison of experimental and calculated dose values, first using the *F8 tally and then the FMESH tally.

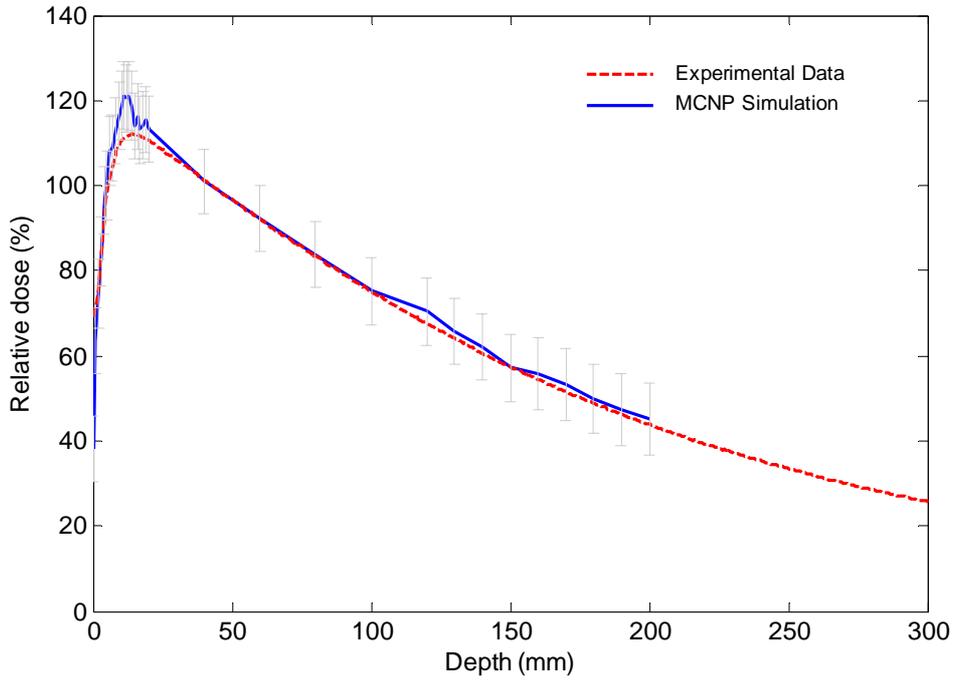


Fig. 4. Comparison of the relative central axis depth doses of water phantom, for a 10 cm x 10 cm field size beam using *F8 tally

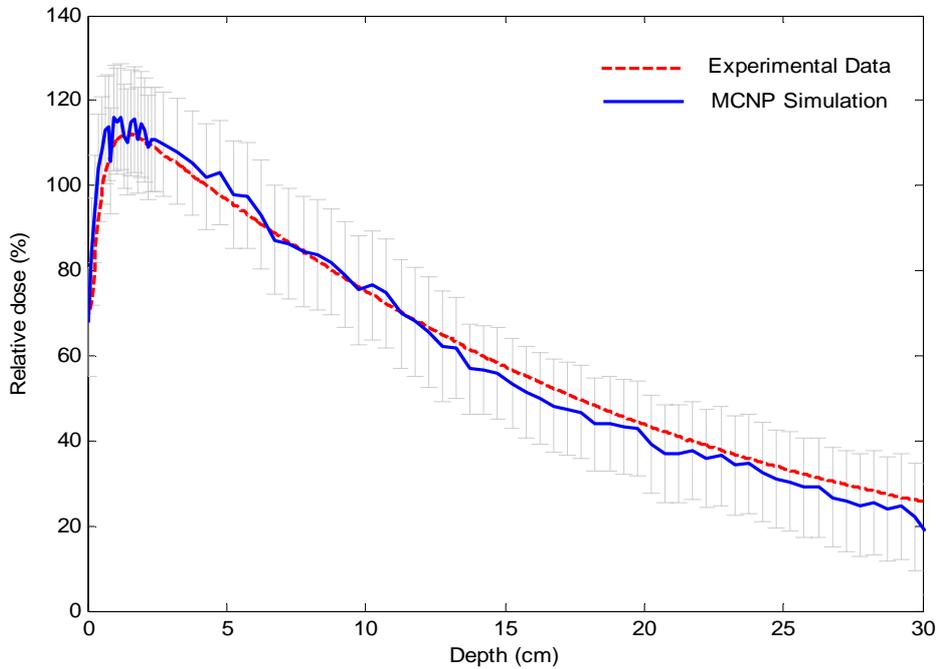


Fig. 5. Comparison of the relative central axis depth doses of water phantom, for a 10x10 cm² field size beam using FMESH tally.

As it can be seen, a good agreement between experimental and calculated results is achieved in both simulations; being the maximum percentage difference between measured and calculated dose less than 5% in all evaluated points.

Both models fit accurately the central axis depth dose experimental curve in the homogeneous phantom, although the model including the FMESH reproduces better the build up effect.

Moreover, as Table I shows, the associated computational time selecting FMESH is highly shorter than the one needed using the *F8 simulation, concluding that that the use of the FMESH4 tally offers an extraordinary fast simulation to obtain the 3D dose mapping using the Monte Carlo method.

Table I. Computation time.

Model	CPU time (16 CPU's)
FMESH	7381.37 minutes
*F8	491.53 minutes

4. CONCLUSIONS

The Monte Carlo method has been successfully applied to the simulation of an Elekta Precise radiotherapy unit model irradiating a water phantom.

Comparing deep dose curves calculated in the phantom using the *F8 and FMESH4 tally to those obtained from the experimental measurements, we can state that MCNP5 code is able to simulate a clinical linac treatment head simulation and therefore to predict accurately the 3D dose deposition using a considerably short computational time confirms the goodness of the computer model, demonstrating the efficiency of such a method for radiotherapy treatment planning, predicting the energy deposition.

ACKNOWLEDGMENTS

We would like to thank the “*Hospital Clínic Universitari de València*” for the given help, as well as the financial support of the Generalitat Valenciana under the contract no. GV06/127.SPT-Radioterapia, and the project VID/PP/2005/5700, funded by the Polytechnic University of Valencia. We wish to thank also Elekta Limited for the given information.

REFERENCES

1. X-5 Monte Carlo Team, *MCNP- A General Monte Carlo N-Particle Transport Code*, Version 5, LA-UR-03-1987, Los Alamos National Laboratory (2003).
2. J. Cheatham and F Brown, "Increasing MCNP5 calculation speed by compiler optimization", LA-UR-05-5950, Los Álamos Nacional Laboratory, August 2005.
3. J Van de Walle *et al*, "Monte Carlo model of the Elekta SLiplus accelerator: validation of a new MLC component module in BEAM for a 6 MV beam," *Medical Physics Biology*, Vol. 48, 371-385 (2003).
4. Miró R., Juste B., Gallardo S., Santos A., Verdú G. "Cobalt Therapy Dosimetric Calculations Over a Voxelized Heterogeneous Phantom: Validation of Different Monte Carlo Models and Methodologies Against Experimental Data" *IEEE Transactions on Nuclear Science*. Dec. 2006. Volume: 53, Issue: 6, Part 2. pp.3808-3817. ISSN: 0018-9499
5. C. BramoullÉ, F. Husson, J.P. Manens, "Monte Carlo (PENELOPE code) study of the x-ray beams from SL linacs (Elekta)," *Physica Medica*, Vol. XVI, n.3 (2000).