Dose calculation in patients with PENELOPE/PENGEOM

E García, J Jiménez and J Puimedón
Laboratorio de Física Nuclear, Facultad de Ciencias, Universidad de Zaragoza, Spain

E-mail: puimedon@unizar.es

Abstract. The freeware code PENELOPE/PENGEOM (version 2003) was used for the calculation of the dose delivered to a patient in external beam radiotherapy. A specific subroutine (STEPVX) for particle transport through voxels of heterogeneous media was developed and tested. We compared simulations between homogeneous and heterogeneous media and we found that STEPVX increased the CPU time only with 10%. As a byproduct of the work, PENGEOM efficiency at handling the approximate geometry of a double-focused multileaf collimator was verified.

1. Introduction

The Monte Carlo method will possibly become a standard technique to achieve more precise radiotherapy treatment plans, overcoming the inherent difficulties of deterministic algorithms in calculating the dose delivered to a very heterogeneous media as the human body. The main objective of this work was to estimate the dose delivered to a patient using the freeware code PENELOPE/PENGEOM [1,2] (version 2003) while making it in the most user-friendly mode possible. For this purpose, a specific subroutine (STEPVX) for transport of electrons and photons through voxels of heterogeneous media was developed. As PENELOPE is a general purpose code where a set of subroutines have to be linked to the main programs written by the user, we needed our own routines to accomplish the objective. This software covered three parts: the first one was dedicated to the calculation of the phase space file (PSF) on the bottom plane of the input geometry, which could include the upper and lower jaws or replace the latter with a multileaf collimator (MLC); the second one utilized the PSF to compute the percentage depth dose and lateral dose profiles in water or any other homogeneous material and the third one calculated the delivered dose by the PSF to a patient or a heterogeneous body.

2. Methods and results

2.1. Treatment head geometry and phase space file

The model of the radiation field is the phase space file. This file contains, for each particle, its position and momentum coordinates, the particle type and its statistical weight as well as the identification number of the primary electron which generated it. The latter allows us to obtain the dose per primary electron impinging on the accelerator target although we do not utilize all the particles of the PSF. The phase space file was calculated with PENELOPE/PENGEOM using an approximate geometry

---

(c) The structure of a user's main program can be found in the distribution package of PENELOPE/PENGEOM (tutorial.pdf).
(figure 1) of the head of a PRIMUS SIEMENS linac working at 6 MV. The energy of the linac was adjusted by an iterative fit of the measured relative central axis depth dose in a water phantom; in spite of that, we still observed some discrepancies in the lateral dose profiles between the Monte Carlo results and the experimental data because we do not know the exact geometry of the treatment head. These differences, which are very common if the manufacturer does not provide a detailed description of the head geometry and materials, will be smaller when the phase spaces of commercial linacs become freely available [3] at the IAEA web site.

Figure 1. Approximate geometry of the treatment head, which was used to calculate the phase space file.

Conformal radiotherapy using multileaf collimators is currently considered as a standard clinical practice. We wrote the code that handles the double-focused leaves of the MLC in an approximation which did not take into account the leaf gaps: we simulated 27 inner leaf pairs projecting a shadow width of 1 cm at the isocenter plane and 2 outer pairs projecting a shadow of 6.5 cm. This is a tedious task, but the user can define the MLC apertures as free geometry parameters and write them only once. We calculated the PSF when the upper and lower jaws open a 40x40 cm$^2$ field and the analogous PSF but with the MLC in the place of the lower jaws; we found that MLC implementation increased slightly the CPU time with 5%.

2.2. Transport of particles inside patient CT image
The basic parts of the PENGEOM package are the so called bodies (space volumes limited by quadric surfaces and filled with an homogeneous material(b)) and the subroutine STEP(c), which moves particles a distance previously sampled and takes into account the crossed boundaries and the changes of the material. The computed tomography (CT) image of a patient consists of a large number of voxels of different electronic density and the definition of every voxel as a body is, though a straightforward solution, cumbersome and in our case inapplicable because PENGEOM (version 2003) admits up to 250 surfaces and 125 bodies(d). To solve this problem we defined a body homogeneously filled with water representing the whole CT image (CT-body) and we converted the CT image to water voxels of different mass density with a piecewise linear function [4]. Therefore the cross sections and stopping powers used by PENELOPE are those of water and when the particle is

(b) See reference [1], page 160.
(c) See reference [1], page 167.
(d) See reference [1], page 170.
inside CT-body we switch off the STEP subroutine and switch on our new subroutine, STEPVX, which moves the particles through the voxels taking into account their different mass densities. Note that, in the sake of simplicity, we did not use the three material intervals suggested in [4], although we will include them in an improved version of the subroutine.

STEVPX works in a similar way as STEP, with the same arguments and is compatible with the subroutines and algorithms of PENELOPE. The subroutine is fully transparent for the user and it treats every voxel in the same way that STEP treats a body. It returns the control to the main program after each track segment within the current voxel or if the particle leaves the voxel or the CT-body. The user must do only three small modifications in the structure of the main program provided with the distribution package of PENELOPE:

a) supply the number assigned by PENGEOM to the body representing the CT-body
b) supply a COMMON block with the characteristics (number and size of voxels, matrix of densities) of the CT-body
c) call STEPVX instead of STEP when a particle is in the CT-body.

The subroutine should be fast enough to be useful in the simulation of clinical plans. We ran two simulations to calculate, without any variance reduction, the deposited dose delivered by a 40x40 cm$^2$ field defined by two pairs of jaws in a homogeneous water phantom of 60x60x30 cm$^3$. In the first simulation we used the standard procedure of PENELOPE, i.e. with the subroutine STEP tracking the particles in the whole volume of the phantom; in the second one we built the CT image of the phantom divided in 0.5x0.5x0.5 cm$^3$ voxels of density 1 g/cm$^3$ and we used STEPVX to track the particles in every voxel. In both simulations the percentage depth dose and lateral dose profiles at 10 and 20 cm were equal within the statistical uncertainty, and we found that in the second case the CPU time required increased with 10%. This is the effect of STEPVX because the only difference between both simulations was the tracking subroutine used. We found similar results in CPU times using patient CT files instead of the voxels of the same density. Once the efficiency of the new subroutine was evaluated, the full simulation package (including the subroutine STEPVX and the replacement of the lower jaws with our approximation of the MLC) was applied to real patient’s CT files. As an example, figure 2 shows a fictitious case of a radiotherapy treatment and dose delivered to a patient.

Figure 2. Example of patient irradiated by a field delimited with a multileaf collimator. Graphs with PCRT, Radiotherapy Treatment Planning System, Copyright © 2005, Técnicas Radiofísicas S. L.
3. Conclusions
The freeware code PENELOPE/PENGEOM could be efficiently extended with STEPVX to calculate the dose distribution in very heterogeneous media as a CT image; we found that the CPU time increased with 10% with respect to homogeneous media. As a by-product of the work we saw that PENGEOM is very efficient in handling an approximate geometry of a double-focused MLC; the CPU time increased with 5% when we calculated a PSF with the MLC instead of the lower jaws. Users have to do easy and few changes in their main programs to incorporate STEPVX to PENELOPE. Since STEPVX is a tracking subroutine, it could be applied to treatments delivered with gamma or electron beams, either in the phase space approach or in the source model approach.

Acknowledgements
This research work was financed by Tècnicas Radiofísicas, S.L.

References
[1] Salvat F, Fernández-Varea J M, Acosta E and Sempau J 2003 PENELOPE, A Code System for Monte Carlo Simulation of Electron and Photon Transport (OECD Nuclear Energy Agency, Issy-les-Moulineaux, France)
[2] Sempau J, Fernández-Varea J M, Acosta E and Salvat F 2003 Experimental benchmarks of the Monte Carlo code PENELOPE Nucl. Instr. and Meth. in Phys. Res. B 207 107-23
[3] Capote R 2007 these proceedings
[4] Ma C-M, Li J S, Pawlicki T, Jiang S B, Deng J, Lee M C, Koumrian T, Luxton M and Brain S 2002 A Monte Carlo dose calculation tool for radiotherapy treatment planning Phys. Med. Biol. 47 1671-89