Monte Carlo modelling of a VARIAN 2300C/D photon accelerator

Yassine Toufique[1], Othmane Bouhali[1,2]

[1]Texas A&M University at Qatar
[2]Qatar Computing Research Institute, Hamad Bin Khalifa University

Abstract

Clinical beam accelerators are widely used in radiation therapy facilities to provide the adequate beams for treatment. The success of the treatment depends on the accuracy of the dose calculated and radiation administered. In this work we conduct a comprehensive modelling of the Varian Clinac 2300C/D from electron beam generation to target response, using GATE simulation toolkit. To validate our numerical model, Gamma Index parameter is used to compare the simulation results against the experimental measurements. Results from Percent Depth Dose and Dose Profile are presented and discussed. This Monte Carlo model and the accuracy of these results can be extended to accurately calculate the dose distribution in real treatment planning systems.

1. Introduction

Clinical linear accelerators (LINACS) allow the production of electrons or photons with energy of several MeV, commonly used for the treatment of cancer. These LINACS are based on the principle of acceleration of electrons by high frequency electromagnetic waves. The LINAC delivers the highest possible dose of radiation to the tumour volume while limiting the irradiation of surrounding healthy tissues to reduce the risk of complications.

The success of the treatment depends on the accuracy of the dose calculation and on the accuracy of the irradiation. A precise method to achieve this, is through Monte Carlo (MC) simulation of the transport and interactions of particles individually in the material. MC techniques achieve an excellent level of accuracy in calculating the absorbed dose during a treatment planning process. They differ from the analytical algorithms present in commercial software by their ability to realistically consider both the mechanical and geometrical characteristics of the radiation source, and the tissue heterogeneities in the patient's body.

Several Monte Carlo simulation software have been developed for applications in medical physics, nuclear medicine or internal dosimetry

In this work we perform a complete Monte Carlo modelling of a Varian Clinac 2300C/D accelerator benefiting from the computational power capabilities offered by the university. The parallel calculation method has been chosen to reduce significantly the simulation CPU time consumed. The model of the accelerator is validated through a series of parameters specific to the quality of the photon beam delivered. These parameters, obtained after simulations of shots in water, are compared with the experimental measurements resulting from quality checks routinely performed in the radiotherapy department.

With the accuracy achieved, this model can be used to accurately calculate the dose

administered to the patient and its distribution in a homogenous system.

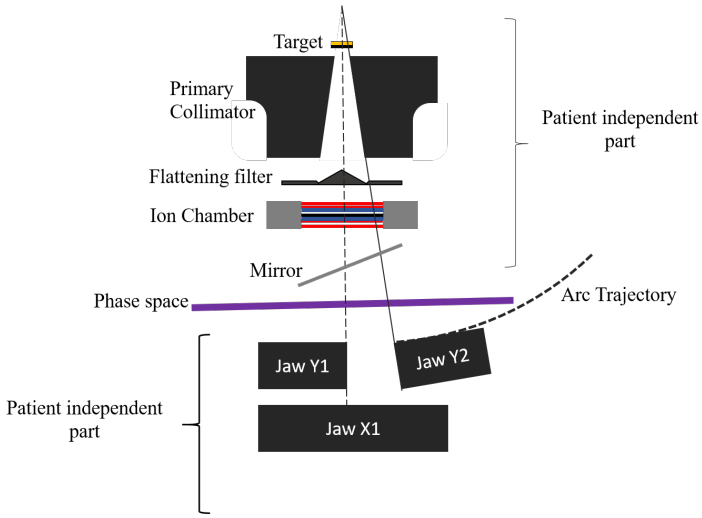

Figure 1 *schematic view showing the different elements of the clinical LINAC simulated in this work.*

2. Simulation setup

The simulation is based on GATE (Geant4 Applied for Tomographic Emission) [1]. It is a simulation tool that draws on many potentialities offered by GEANT4 [2]: complete set of validated physical models, description of complex geometries, generation and monitoring of particles and visualization of volumes and particle trajectories.

In this study, a recent LINAC called Varian Clinac 2300C/D (Varian Medical Systems,Palo Alto, CA, USA) was modelled. Varian Clinac 2300C/D systems are used to generate high photon energies of 6 -20 MV as well as electron beam energies between 4 and 22 MeV. This LINAC is composed of different elements as shown in Figure 1. These elements are:

- Target: X-rays are generated by Bremsstrahlung effect from a high energy electron beam (between 6 and 23 MeV) striking a metal target made of high-Z material (Tungsten) coupled with a copper (Cu) layer
- Primary collimator: To guide the X-ray field, a Tungsten collimator is placed after the target. It consists of a cylinder with a conical Air gap.
- Flattening filter: is composed of a set of conical metal slices with different depths and aligned with the central axis
- Jaws (X and Y): made of Tungsten-Alloy they are used to limit the treatment field size and provide a uniform attenuation of the radiation beam outside the treatment field.

To validate the model, we have compared the estimated dose distribution (Percent depth doses (PDD) and dose profiles (D)) with experimental measurements taken with a water phantom in a hospital. The experimental setup consists of a water tank of 30x30x30 cm^3, equipped with a motorized and remotely controlled arm to move an ionization chamber of 5x5x5 mm^3 of dimension.

3. Results, discussion and future work

In this work we have compared the calculated dose distribution PDD and dose profiles (D) with experimental measurements using the Gamma Index (GI) metric [3]. It allows to express the difference between two dose distribution images in a given point in space. It is based on two other criteria: Dose-To-Agreement (DTA) (presented in mm), and Dose-Difference (DD) (presented in %).

An electron spot with FWHM of 0.9 mm and an average mean energy of 5.2 MeV with a sigma of 0.16MeV was used and found to agree with measurements in 6MV photon mode as can be seen from the results below.

3.1. Speeding up the simulation

Simulating a complete LINAC system with all physics processes involved is a cumbersome operation that is computationally expensive. Simulating 10^{10} electron beam takes around 3600 hours on a single core machine. In order to alleviate this problem, we adapted our code to run on a parallel architecture where thousands of jobs are split to run simultaneously on many processing cores. For this, we used the Raad2 supercomputer facility available at Texas A&M University at Qatar [4].

As can be seen from figure 2, the speedup factor is drastically improved and can reduce the simulation time by up to a factor of 200, depending on the number of cores used.

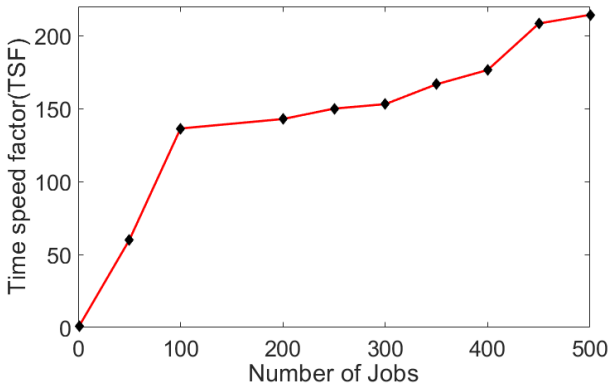

***Figure 2**: Speed factor achieved when splitting a radiotherapy simulation task of 10^{10} primary electrons into several jobs that run simultaneously at 100 cores.*

3.2. Dose profile results

Figure 3 left presents the calculated results of PDD for a 10x10 cm^2 field size showing to be in good agreement with experimental measurement with a GI parameter of (2%/ 2mm). This indicates that 97.7% of the calculated data points are in good agreement with the measurements for GI < 1and 86.5% for GI < 0.5.

Similarly figure 2 right shows that the calculated D profiles agree well with the measurements. These results indicate that 95.2% of the calculated data points are in good agreement with the measures for GI <1 and 81.2% for GI < 0.5.

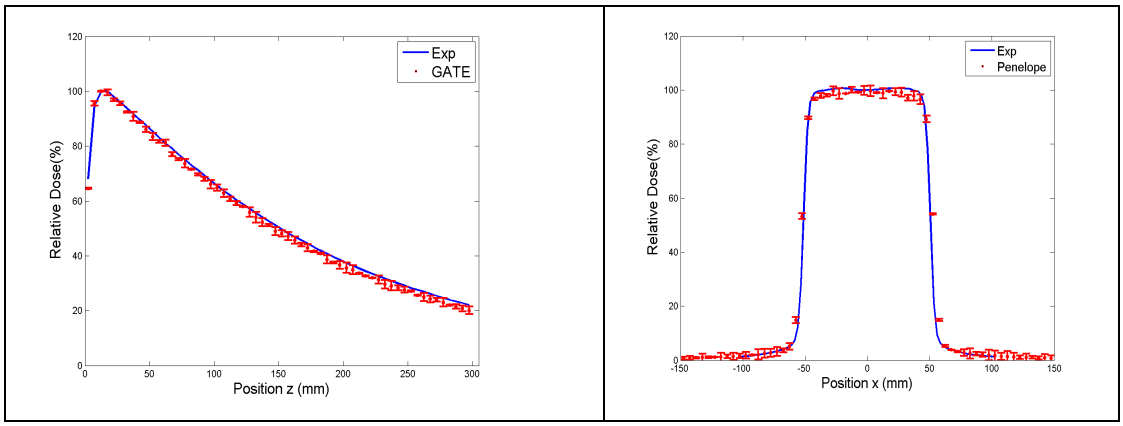

Figure 3: *modelling results of the Percent Depth Doses (PDD)(left) and dose profiles (D) (right) compared to experimental measurements.*

3.3. Future work

These results give high confident in the numerical modelled developed here. As a next step, we are working on two directions that will be presented in the full version of the paper.

First, we have a better understand the influence of the electromagnetic process provided by GATE, we are working on comparing the three common models: Standard Model, Livermore and Peneloppe.

Second, with the accuracy achieved, this model is being used to accurately calculate the dose administered to the patient and its distribution in a homogenous system. Currently, in clinical applications, the estimation of dose is done using the Anisotropic Analytical Algorithm (AAA). In order to simulate the heterogenous nature of the human body, we are using phantoms that emulate the four substances: water, tissues, tumour and bones.

4. References

[1] D. Sarrut et al., A review of the use and potential of the gate monte carlo simulation code for radiation therapy and dosimetry applications, Medical Physics 41 (6Part1) (2014) 064301.

[2] J. Allison et al., Geant4 developments and applications, IEEE Transactions on Nuclear Science 53 (1) (2006) 270-278.

[3] D. A. Low et al., A technique for the quantitative evaluation of dose distributions, Medical Physics 25 (5) (1998)

[4] Raad2 supercomputer, TAMUQ Research Computing, https://www.qatar.tamu.edu/researchcomputing/