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AUTHENTICATION OF A 6 MV VARIAN CLINAC 2100 USING THE MONTE CARLO SIMULATION PLATFORM GATE/GEANT4

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ABSTRACT

Dose assessment in radiotherapy is a critical step in cancer treatment planning, hence the importance in the simulation of cancer treatment to have a model that is well suited to the reality of the accelerator head. In this study, the components of Varian Clinac 2100 were modeled by Monte Carlo code GATE, the source was determined and adjusted for a 6MV photon. The standard reduction variance techniques and some filters have been used to speed up computer time and to ameliorate the efficiency of the Monte Carlo method. The dose distribution ending was evaluated in the 50 x 50 x 50 cm^2 water tank voxelized by 4 x 4 x 4 mm^3 voxels. The dose profiles, depth dose (PDD), and isodoses of the 10 x 10 cm^2, 20 x 20 cm^2, 30 x 30 cm^2, 40 x 40 cm^2 fields obtained by simulation were compared to the measured data. The result of this comparison was assessed using the gamma index, which was above 98% and 95%respectively for the dose profiles and PDD, and a deviation percentage below 2% for 98% of the coordinates. These results show an agreement of the simulated and measured dosimetric data allowing to have a model granting a simulation of treatment plans in radiotherapy using photons of 6MV close to that planning in radiotherapy services.

Keywords: *Monte Carlo, GATE/GEANT4, Linear accelerator, 6 MV photon beam, Dosimetry, Dose profile, Depth-dose.*

1 INTRODUCTION

In radiotherapy precision is the main goal to irradiate the tumor while sparing healthy tissue, it shows that the dose calculation algorithm has a crucial influence on the good control of tumor tissue.

The Monte Carlo algorithm showed the accuracy of electron and photon transport in matter. This algorithm simulates the particles, follows the interactions produced, and calculates the dose. The greater the number of events, the calculation is more accurate and the statistical certainty decreases except that the calculation time increases.

In radiotherapy, several Monte Carlo codes are used and classified according to their programming language C++ and Fortran respectively as follows EGS4, EGSnrc, Monte Carlo N-Particle (MCNP), PENELOPE, GEANT3 are programmed in FORTRAN but GEANT4 and GATE wrote in C++.

GATE uses the GEANT4 libraries to perform a simulation. It was designed specifically for applications in medical physics, initially developed for simulation at the diagnostic level, and then developed for therapeutic simulations. GATE allowed a very maneuverable geometric manipulation allowing an agreement very close to reality. As a strong point in favor of this code, it is adequate for dose calculations [1].

This article presents the method used for the simulation of the Varian Clinac 2100 accelerator head for a photon energy of 6 MV, using theGATE/GEANT4 form, followed by dosimetric evaluation of dose profiles and deep doses and isodose curves for 10 x 10 cm^2, 20 x 20 cm^2, 30 x 30 cm^2, 40 x 40 cm^2. And also geometric verification of these.The main purpose is the validation of these results based on a comparison of the curves obtained by simulation and this obtained by experiment, using the criteria used in quality assurance in radiotherapy is at the commissioning of the machine. This validation will subsequently provide a ready-to-use model for the simulation of radiotherapy treatment plans[2,3].

2 METHODS AND MATERIALS

2.1 Modeling of the Source

The creation of X-rays is done by the interaction of electrons that have a high velocity with a metal target of very high atomic number. This source is essentially defined by two parameters the energy and the size of the spot [4,5]. In the previous study, the energy of the source is 6 MeV with a spot size bounded between 1 mm and 3 mm for the four fields this is defined from the literature which concluded that FWHM ranges from 0.7 to 3.3 mm [6] and from 0 to 4 mm [7].

2.2 Simulated Geometry

In this study, the VarianClinac 2100 accelerator head was simulated with the GATE Monte-Carlo code (version 8.2) compatible with the GEANT4.10.04.p02 version. The calculation was performed within a remotely accessible high-performance computing (HPC) infrastructure within the MARWAN Computing Center (CNRST). All the components of the accelerator head were modeled taking into consideration the construction adopted by the manufacturer VARIAN. The spatial position, materials, and composition density of each part (target, primary collimator, flattening filter, ionization chamber, collimators, a multi-leaf collimator (MLC)) were taken into consideration. For the necessary measurements, a 50 x 50 x 50 cm^{3}voxelized water tank with 4 x 4 x 4 mm^3 voxels where also simulated Figure 1. This tank has been placed at a source to surface distance (SSD) is 100 cm at the center of the beam for the four fields 10 x10 cm^2, 20 x 20 cm^2, 30 x 30 cm^2, 40 x 40 cm^2 and with the MLC fully open.

2.3 Physics Frame

In GATE since version 6, there are several types of models for electromagnetic physics [8,9]. In this study, *PhysicsListElectroMagnetic Standard Option*

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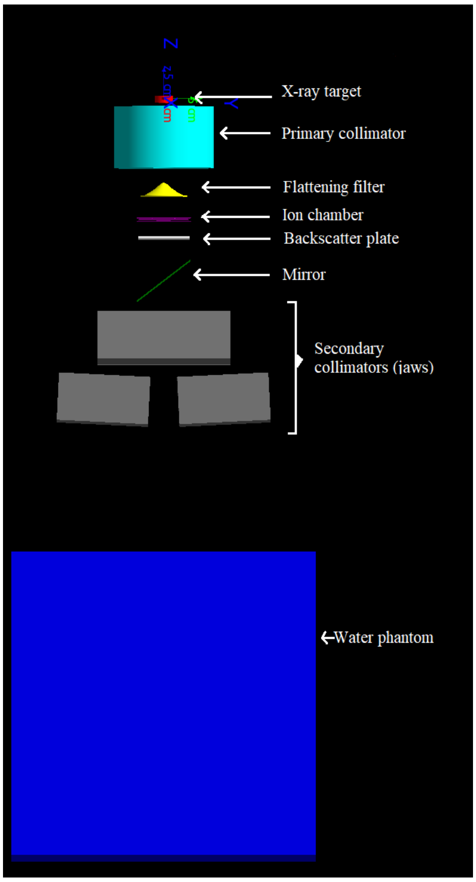
3 models have been chosen, the latter for medical applications that are at the origin of a *PhysicsList* combine several processes and parameters created by the GEANT4 collaboration. We also used the actor *DoseActor* attached to a water tank with a resolution of 125 x 125 x 125 knowing that we chose a voxel of 4 mm where the dose calculation will be carried out. The choice of 4 mm was not random but knowing that the internal diameter of the chamber was 3,04 mm this last one is not a number that will allow having a number of resolution integer of the blow we rounded so to have 4 mm that allowed us to have the number aimed of the resolution if we had not chosen this volume the code during the calculation will round automatically. *DoseActor* is the actor chosen to calculate the absolute dose in a 3D matrix attached to our water tank and adjust on the fact of storing the information along that is to say from *Pre-step* to *Post-step* this actor automatically calls classes already implemented in GEANT4. In the code, we also implemented other actors, filters, and selective bremsstrahlung splitting (SBS) to speed up the calculation time[10]. the variance reduction technique proposed by Gate, more precisely SBS was used with a factor of 100, in other words when a primary electron arrives at the target and creates braking radiation, the splitting technique samples 100 photons at a time with a weight of 1/100 each.

2.4 Reference Measured Dose

Figure 1: 2D view of the Varian Clinac 2100 operating in photon beam at 6MV on the ZX plane generated by the code GATE (the image is not to scale).



Baseline measurements were taken during the monthly Quality Assurance (QA) at Center Mohammed VI for Treatment of Cancer, Ibn Rochd University Hospital, Casablanca, Morocco. These measurements are taken as recommended by TRS398 (IAEA) [11] for 10 x 10 cm^2 field and SSD = 100 cm using 50 x 50 x 50 cm^3 water tank as phantom and the linac head positioned at 0°. Dose profiles and depth dose for 20 x 20 cm^2, 30 x 30 cm^2, 40 x 40 cm^2 fields were also evaluated. These measurements were made with a cylindrical ionization chamber model 30013 PTW, Freiburg, Germany in internal diameter and of 3.05 mm. The latter was important for the simulation of the dimensions of the *dosel* calculations.

2.5 Evaluation Parameters

Accelerator head validation is performed by evaluating the dose overlay for the percentage depth dose curve (PDD) and the dose profiles according to the x-axis (cross-plane) and y-axis (in-plane) by checking the homogeneity and symmetry of the latter. In this study, ScanDoseMatch software [12] was used to evaluate gamma index, which calculates gamma index by superimposing two curves,

the one obtained by simulation and the one measured. A change in the extension of the simulation results was made so that the software can read the coordinates of each measurement according to each voxel. Gamma parameter validation according to TRS 430 (IAEA)) [13] and 99% for PDD and 97% for the profiles. The percentage deviation of the calculated results from those calculated is also checked using equation 1. All this evaluation allowed a dose modeling later very adequate to reality.

$$Déviation = \left(\frac{\left|V_m - V_{exp}\right|}{V_{exp}}\right) x\ 100\% \qquad (1)$$

Where :
V_m : value simulated in GATE in the profil and PDD.
V_{exp} :experimental value obtained in QA.

3 RESULTS AND INTERPRETATION

3.1 Dose profiles and PDD

The dose profiles obtained by simulation showed good beam targeting symmetry and showed homogeneity for the four fields, as well as a correlation with the experimental results figure2.The lateral distance between the point at 80 % and the point at 20% of the dose on the beam axis. This distance also called penumbra increases in-depth (that is to say according to the z-axis) this can be seen in the figure 3of the field 10 x 10 cm^2 for example. Figure 4 shows the homogeneity of the distribution of doses of the 10 x 10 cm^2 field, 100% of doses standardized on the beam objective, by superimposing these results it was also obtained for the 20 x 20 cm^2 fields, 30 x 30 cm^2, 40 x 40 cm^2.

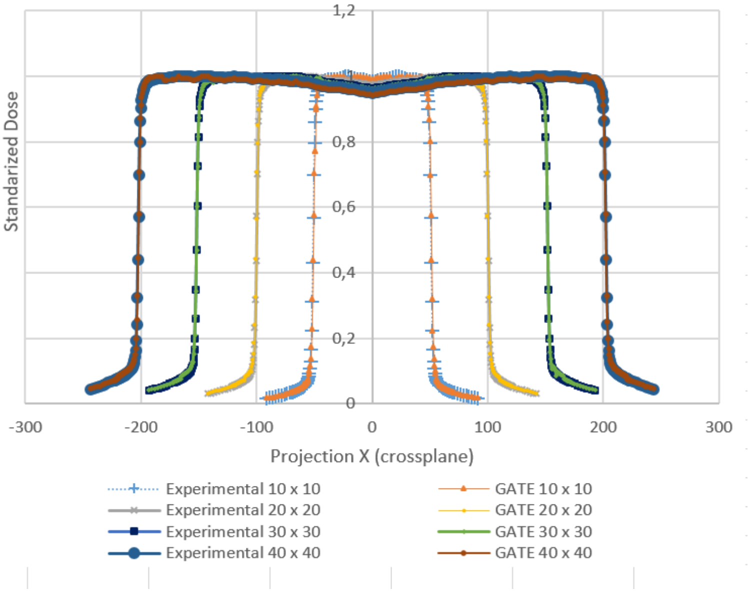


Figure 2: Field dose profiles (crossplane) of 10 x10 cm^2, 20 x 20 cm^2, 30 x 30 cm^2, 40 x 40 cm^2 for a depth of 1,5cm.

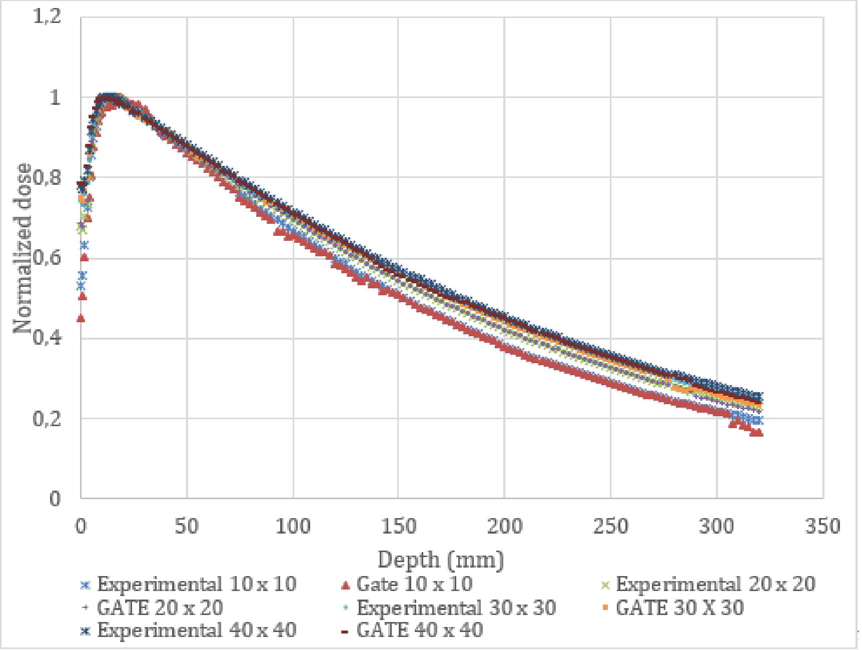


Figure 3: The PDD of 10 x 10 cm^2, 20 x 20 cm^2, 30 x 30 cm^2, 40 x 40 cm^2 for the depth 5 cm.

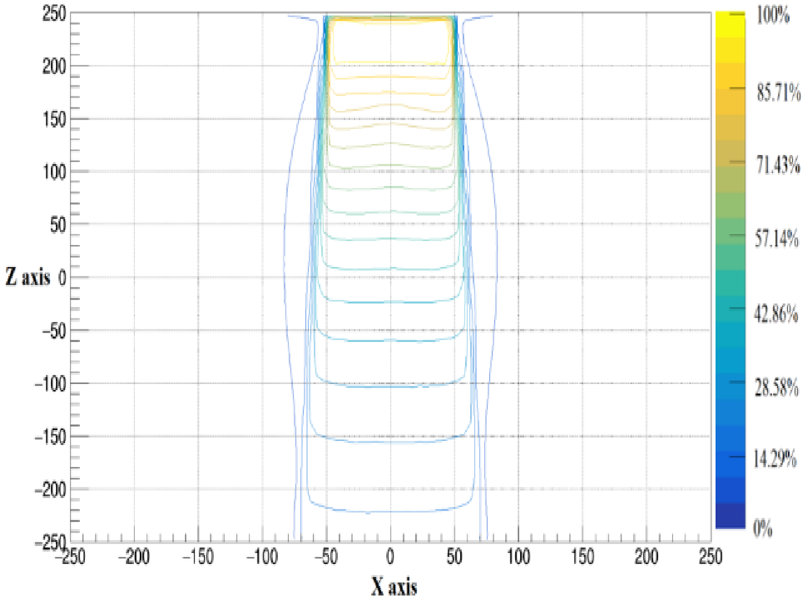


Figure 4: Field 10 x 10 cm^2 isodoses according to the ZX projection.

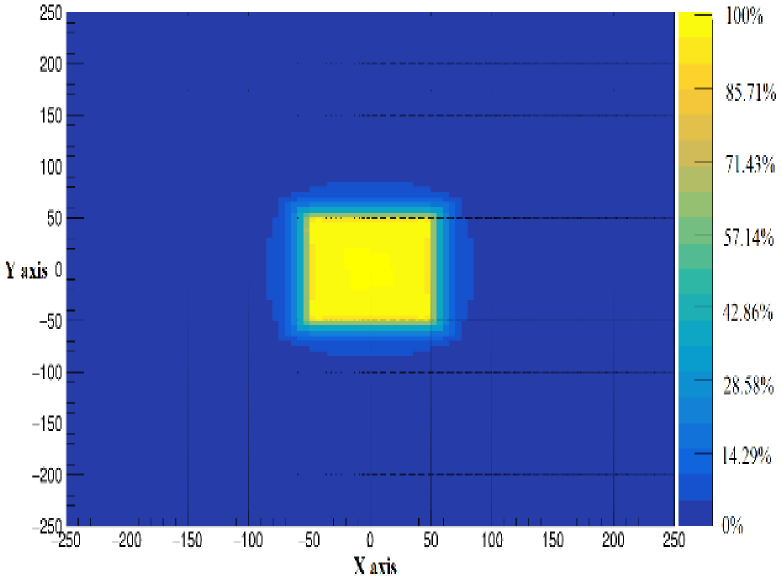


Figure 5:Field 10 x 10 cm^2 isodoses according to the YX plan.

The figure 5 shows during the PDD matching that the results obtained by the simulation are almost superimposed on the experimental data. The dose at equilibrium dose of the four fields obtained by the simulation is about 0.542%, 0.539%, 0.543%, 0.544% lower respectively of the fields 10 x 10 cm^2, 20 x 20 cm^2, 30 x 30 cm^2, 40 x 40 cm^2 which shows a very small shift.

3.2 Gamma index and Deviation

Validation of the gamma index values was below than 98% and 91% respectively for the dose profiles (figures6) and PDD (figure7) using 2% as the pass rate. The percentage deviation calculated between the measured and simulated curves was less than 2% for 98% of the coordinates.

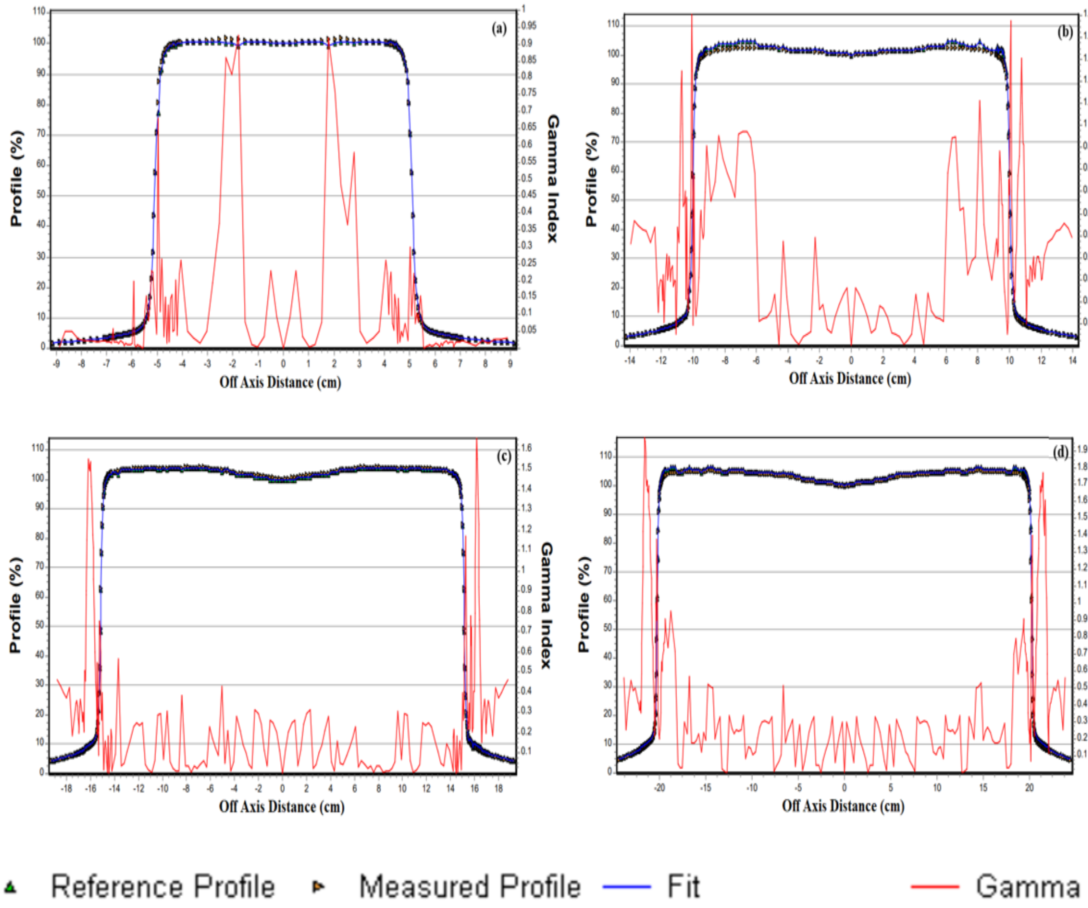


Figure 6: Gamma analysis between results of the simulation and experimental measurements for dose profiles, considering a field of: (a) 10 x 10 cm^2, (b)20 x 20 cm^2, (c) 30 x 30 cm^2, (d) 40 x 40 cm^2.

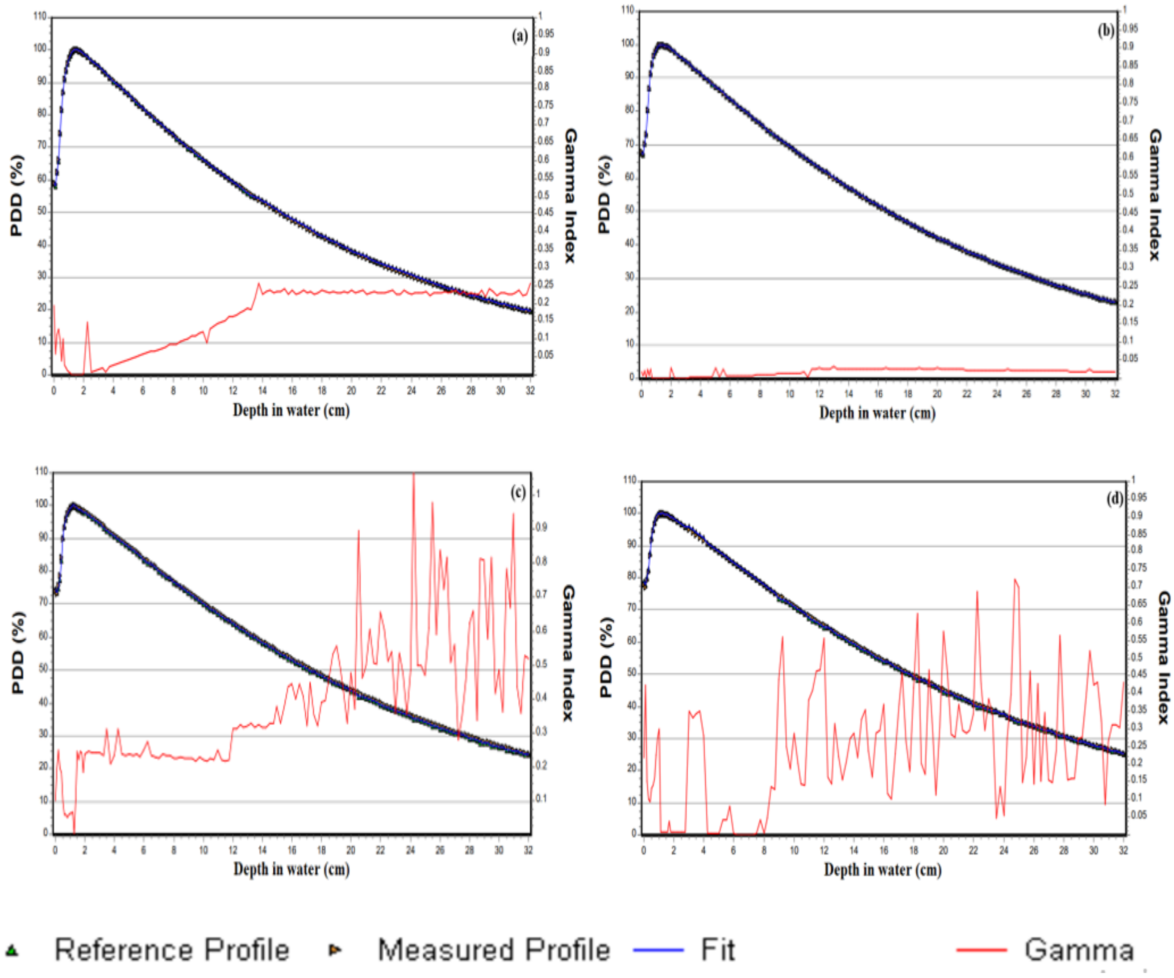


Figure 7: Gamma analysis between results of the simulation and experimental measurements for PDD, considering a field of:(a) 10 x 10 cm^2, (b) 20 x 20 cm^2, (c) 30 x 30 cm^2, (d) 40 x 40 cm^2.

4 CONCLUSIONS

In this work, the adaptation of the simulation of the accelerator head Varian Clinac 2100 for the energy of 6 MV showed conformity of the results, through the consideration during the simulation of the geometry and the physics that lurks behind the head of the accelerator, and also, by having compared the results obtained in simulation with the experimental results. This allows the possibility of using this validation as a reference or model for other radiotherapy treatment planning work by Monte Carlo simulation whilebeing sure that the results obtained are realistic in terms of dosimetric precision.

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