

STUDY OF A 3D DOSIMETRY SYSTEM RESPONSE – ARCCHECK[®]

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ABSTRACT

Ionizing radiation therapies have improved over the years, becoming more specific for each patient. Thereby as the treatment planning system (TPS) complexities increases, the quality assurance (QA) methods have to be in a constant evolution. One of the techniques that demand great complexity is the Volumetric Modulated Arc Therapy (VMAT). One possible way to VMAT commissioning is using 3D dosimetry systems and recently a new 3D dosimetry system called ArcCheck had been developed and commercialized mainly for VMAT quality assurance. It is water-equivalent and composed by an array of 1386 diodes arranged in a spiral pattern. Since simulation methods, like Monte Carlo method, ensure highly accurate results, MCNP (A General Monte Carlo N-Particle Transport Code System) is totally reliable for problems that involve radiation transport. This work presents a preliminary study of the 3D dosimetry system ArcCheck by developing two computational models in MCNP6. In addition, experimental measures were acquired using the ArcCheck in a Linear Accelerator and then these values were compared with the results obtained by simulations of both models. The comparisons showed good reproducibility.

1. INTRODUCTION

Over the years, ionizing radiation therapies, as Radiotherapy, have largely improved the machines and equipments as well as the daily procedures, becoming more complex and specific the treatment planning system (TPS) for each patient. Thereby as the TPS complexities increases, the Quality Assurance (QA) methods have to be in a constant evolution to ensure the proper functioning of the dose delivery system [1]. One of the techniques that demand great complexity and attention in QA is the Intensity Modulated Radiation Therapy (IMRT) associated with dynamic rotation, which is called Volumetric Modulated Arc Therapy (VMAT). The VMAT is a technique that attempts to optimize the 3D dose distribution by modulation of beam intensity, in one or various rotations, using any arc length around the patient [2], in order to try to save significantly the adjacent healthy tissues in an extremely fast treatment [3].

This technique attempts to be as close as possible to an exact treatment due to a planning algorithm which varies simultaneously three parameters during treatment [3]. Since it is quite complex, there are not official reports of commissioning procedures of machines VMAT mode yet. One possible way to VMAT commissioning is planar dose verification by the use of films or a matrix detector between a simulator object, where all parameters of the

treatment are varied at the same time - the machine rotation velocity, the use of multileaf collimator and the dose rate released -, simulating the treatment irradiation of the patient in this simulator object [4]. It is also possible commissioning VMAT machines using three-dimensional (3D) dosimetry systems since their implementation is more feasible and their use improves the accuracy in QA procedures when compared to a two-dimensional system. In order to investigate more appropriate QA procedures, some studies with 3D dosimetry systems have been carried out by several authors [1].

Recently a new 3D dosimetry system called ArcCheck (Sun Nuclear Corporation) had been developed and commercialized mainly for VMAT quality assurance. It is water-equivalent and composed by an array of 1386 fixed SunPoint[®] diodes (size 0.8 x 0.8 mm) arranged in a helical pattern inside a cylindrical structure, forming a helical detector mesh (Figure 1.b). The central cavity (Figure 1.a) is designed to insert several accessories, like a homogeneous solid core as well as a dosimetry core with ionization chambers [5]. Actually, this system has been object of dosimetry studies for routine use in QA procedures of Radiotherapy clinics. With the purpose of performing dosimetry studies for commissioning and implementation of a dosimetry system, it is possible to create a virtual model that represents the real system, by the use of the tools of some software.

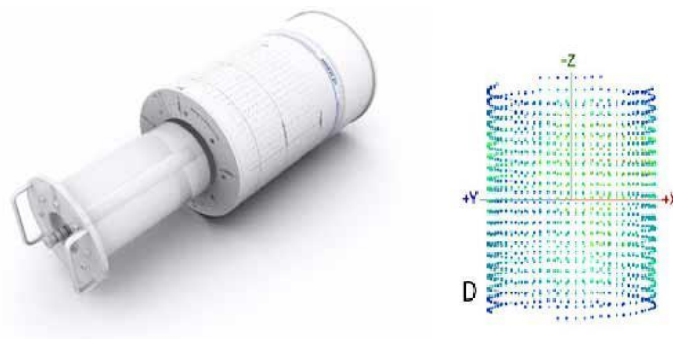


Figure 1: At left, ArcCheck with a solid acrylic inserted, water-equivalent [5]. At right, diodes arrangement inside ArcCheck [1].

Monte Carlo method (MCM) is a widely used tool to solve problems involving stochastic processes. Since simulation methods like this ensure highly accurate results, their use is totally reliable for many knowledge areas [6]. MCNP (A General Monte Carlo N-Particle Transport Code System) is a general-purpose code based on Monte Carlo method and designed especially to represent systems that involve radiation transport. The version 6 of MCNP (MCNP6) is much more than the merger of previous versions capabilities (MCNP5 and MCNPX). Among other tools, MCNP6 allows the user to generate or read mesh geometries, for example, and also allows obtaining track-length tally over 3D mesh [7].

This work is a project in progress and it presents a preliminary study of the 3D dosimetry system ArcCheck by developing two computational models for simulation using MCNP6. Then it will be able to contribute to dosimetry studies for QA in Radiation Therapy mainly in therapies that use volumetric dynamic arc (VMAT).

2. METHODS

It was lead using MCNP6 - the code based on Monte Carlo method - to develop two computational model of the ArcCheck to simulate dose values, named FMESH Model and Spheres Model. In addition, experimental measures were acquired using the ArcCheck in a Linear Accelerator (LINAC) of the Radiotherapy department at “Beneficência Portuguesa” of São Paulo hospital and then these values were compared with the results obtained by simulations of both models. So, with all comparisons, it was possible to infer about the results, in order to provide subsidies for the elaboration of more appropriate Quality Assurance procedures.

In both models, a phase-space file of the Varian Clinac 600C Linear Accelerator was used as the radiation source, which was originally recorded in a plane with a 10x10 cm² radiation filed and an energy of 5.88 MeV [8]. In simulation input, the plane was positioned so that it represented the accelerator head with a fixed angle of 0°.

2.1. FMESH Model: A Simple Model

The first one is a simple computational model of the system developed using the FMESH Tally of MCNP6, which considers electronic equilibrium of the system and uses the track-length of the particles to calculate dose. First, to define the effective mass volume of ArcCheck in the input for simulation, the real measures of the dosimetry system were used. In general, a cylindrical shell equivalent to water, of internal radius equal to 7.5 cm and external beyond 13.3 cm, was defined. Then the central cavity present in the system was also filled with water, simulating as if it were with its solid core accessory.

In this model, the FMESH tool – more specifically *FMESH4 – was used to create a cylindrical three-dimensional mesh tally within the distance of the ArcCheck diodes (10.45 cm). This mesh was divided into 1386 volume units so that each unit represented the volume occupied by each diode and its surroundings. The FMESH card was requested to the software in such a way that it resulted in a dose value for each bin, just as each diode results experimentally. Figure 2 shows a plot of the longitudinal section of this model, where it is possible to check the mesh representation in blue color.

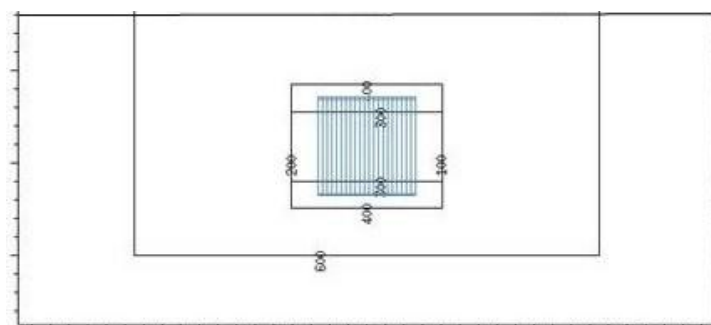


Figure 2: Xming plot of FMESH Model - Plane XZ.

2.2. Spheres Model: A More Realistic Model

In the same way as in the FMESH Model, in the input of the Spheres Model, the cylindrical shell equivalent to water was defined and was also filled with water, representing ArcCheck with a solid core. The difference of this model resides in the substitution of the generic mesh tally by 1386 spheres positioned exactly in the locations of each diode inside the ArcCheck, in a spiral way. Thus, it is possible to obtain dose values from each sphere. Both the external structure of the virtual dosimetry system (3.a) and the spheres representing some of the diodes (3.b) are shown in the plots of Figure 3. It is important to emphasize that the spheres have a radius much greater than the real diodes, as a way of approximation.

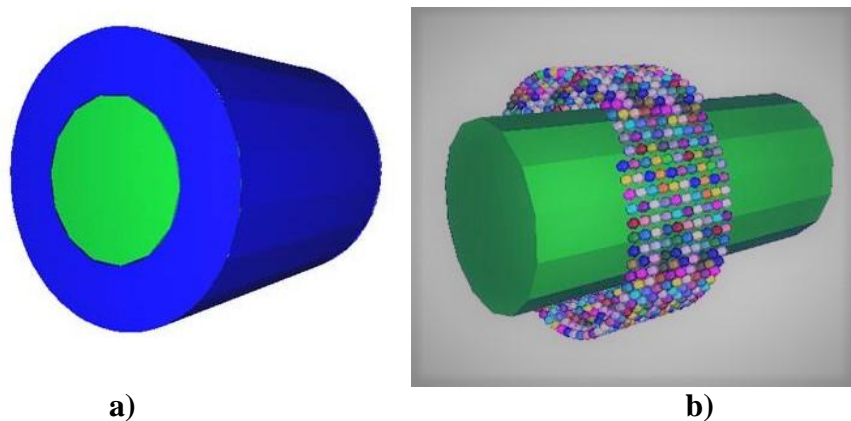


Figure 3: a) 3D Vised plot of external structure of ArcCheck. b) 3D Vised plot of the spiral arrangement of the spheres inside ArcCheck, $r=0.456$ cm. Both are from Spheres Model.

At first, for this model, it was requested to MCNP6 results of dose values from the F6 Tally, a tool that considers electronic equilibrium of the system and uses track-length of the particles for the calculation of the dose. In a second moment, the *F8 Tally was used to obtain the dose values, which actually considers the energy deposited in the cell of the problem and considers that there is no electronic equilibrium in the system.

3. RESULTS AND DISCUSSION

For both the FMESH Model and the Spheres Model using F6 Tally, a number of particle histories (nps) of 10^8 was chosen. For the Spheres Model using *F8 Tally, an nps equal to 10^9 was used. These values were chosen from so that the results of the simulations always generated relative errors less than 1% for all points requested. After the simulations, the MATLAB software was then used to process the outputs of the models and generate dose map images of the results (dose unit given in MeV/g). This was also done for the experimental data obtained in VMAT with ArcCheck, under the same conditions of the simulations – 6 MeV, 10×10 cm² field. Doses were normalized and the points with doses less than 10% of the maximum dose were denied.

3.1. FMESH Model Results

In this model, due to the three-dimensional mesh tally, a data output was requested containing only the dose values along the height of the mesh (21 bins) and radially (66 bins), totaling 1386 units that formed the two-dimensional dose map, as shown in Figure 4.a. The same dose map was also generated from the experimental data taken at the hospital, resulting in Figure 4.b.

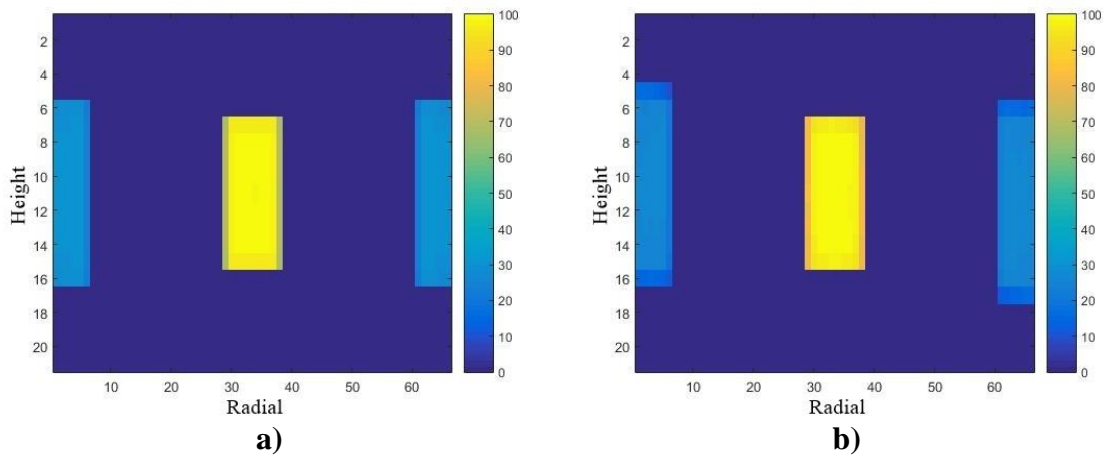


Figure 4: a) Dose map of the simulation using FMESH. b) Dose map of the experimental data of ArcCheck. Both are normalized.

From these images, if each dose map is considered to be in fact an open cylindrical shell, the large amount of dose deposited mainly in the area of the irradiation field is visible, as well as a considerable dose in the lower part of the system, also in the direction of the field area. Then, with both dose results, it was possible to make a comparison between the experimental and the simulated data. In generating the image of this difference, Figure 5 was obtained. It is possible to infer that, despite being a satisfactory model, given its simplicity, it is not totally correct mainly because it does not consider the spiral sequence of the real diodes. The main apparent dose differences are due to this.

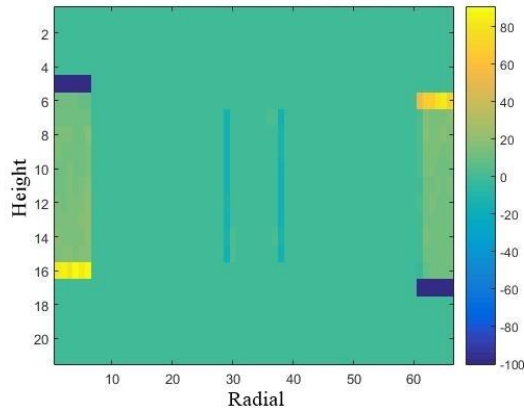


Figure 5: Difference between FMESH simulation dose data and the experimental dose data.

3.2. Spheres Model Results

As previously mentioned, this model was used in two different simulations, varying the Tally, in order to observe if there was great relevance in the results according to the way in which the software obtained the dose values.

3.2.1. Spheres model using F6 tally

The simulation using F6 Tally also resulted in a behaviour similar to the experimental results, as it is possible to observe in Figure 6.a. The theoretical result was also compared with the same experimental data used in FMESH Model. With respect to the other model, it is visible in Figure 6.b that the differences between simulated and experimental data of this model are lower.

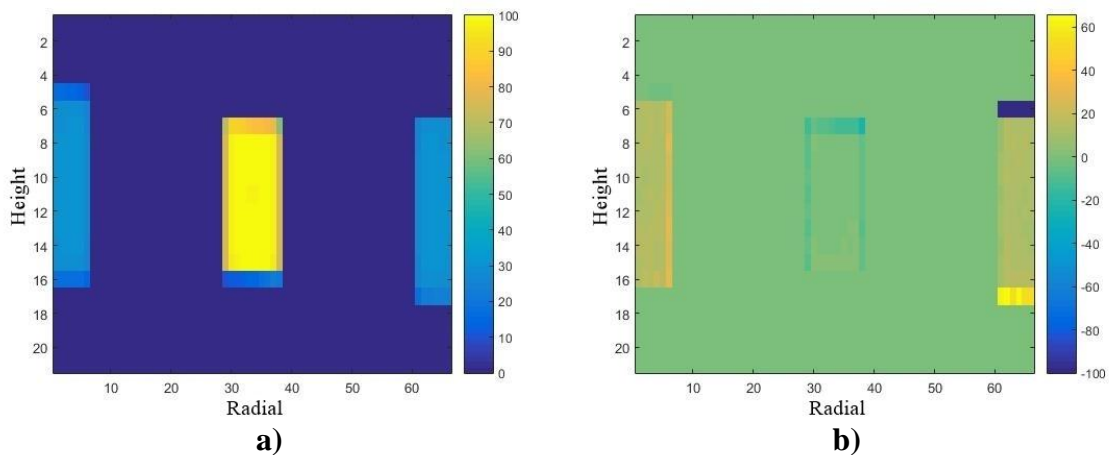


Figure 6: a) Dose map of the simulation using F6 Tally. b) The difference between F6 simulation dose data and the experimental dose data.

3.2.2. Spheres model using *F8 tally

The simulation using *F8 Tally, shown in Figure 7.a, was also compared with the experimental data, resulting in a dose map of the difference, shown in Figure 7.b. In this result, the differences are also lower if compared to the FMESH Model, since this is quite similar to that obtained from F6 simulation. Since the Tally used considers that there is no electronic equilibrium, it may be more realistic if compared with the other results, especially if there is the intention to reduce the size of the spheres in the future, to a size closer to that of the real diodes.

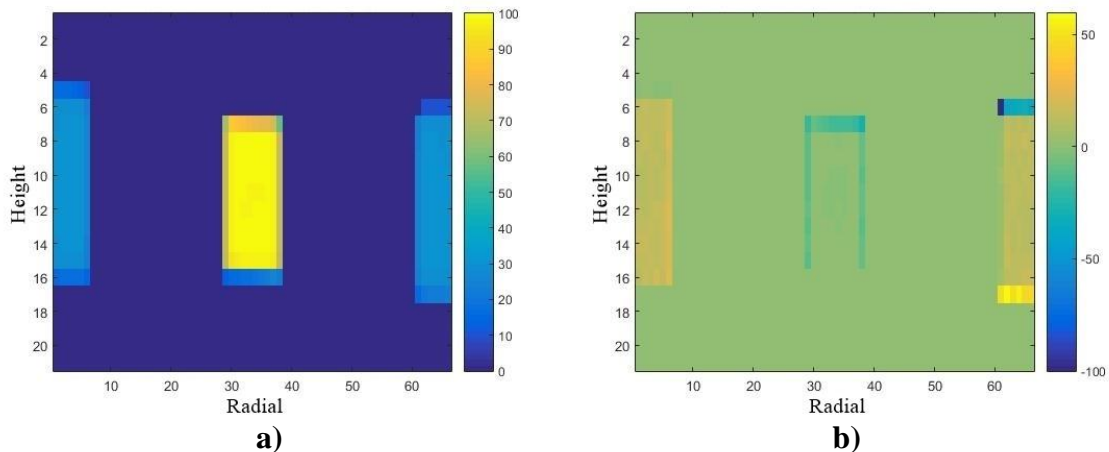


Figure 7: a) Dose map of the simulation using *F8 Tally. b) Difference between *F8 simulation dose data and the experimental dose data.

It is possible to infer that this model, both with F6 and with * F8 tallies, generated good results and is more satisfactory than the FMESH Model. Also, it is possible to verify that there is a subtle difference between F6 and *F8 simulations more due to calculation form of each tally – by track-length or energy deposition. The large errors obtained, visible in the difference maps, may be due to lack of detection in the ineffective spaces between the ArcCheck diodes, obtained from experimental data. And this may be interfering with dose detection, causing differences mainly at the edges of the irradiation field.

4. CONCLUSIONS

It can be affirmed that the work developed has computational models that have generated good results, mainly the Spheres Model. Subsequently, it is intended to adjust some parameters to reach a more accurate model. At this moment, the comparisons showed good reproducibility, which will make this work contribute to a characterization of ArcCheck aiming to establish more accurate VMAT quality assurance methods in the future.

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