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ANALYSIS OF MATERIAL CHARACTERISTICS FOR THE CONSTRUCTION OF ENERGY DEGRADING AND SCATTERING PLATES FOR ELECTRON BEAM SKIN RADIOTHERAPY

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ABSTRACT

There are many radiosensitive diseases associated to the skin such as mycosis fungoids and the syndrome of Sézary that are part of a sub-group of cutaneous diseases type T-cell lymphoma. Several studies indicate the eradication of the disease when treated with linear accelerators emitting electron beams with energies between 4 to 10 MeV. However, this treatment technique presents innumerable technical challenges since the disease in general reaches all patient´s body, becoming necessary a very large field size radiation beam, and also, it should deliver superficial doses limited to the skin depth.
To reach the uniformity in the dose distribution, many techniques had already been developed. Based on these previous studies and guided by the report nr. 23 of the AAPM (American Association of Physicists in Medicine), the present study will develop an energy scattering and degrading plates, supplying subsidies for a future installation for skin treatment at the "Serviço de Radioterapia do Hospital das Clínicas de São Paulo.
As part of the plates design, first of all, the energy spectrum of the 6 MeV electron beam of the VARIAN 2100C accelerator was reconstructed through Monte Carlo simulations using the MCNP4C code and based on experimental data. Once the spectrum is built the design of the plates has been performed analyzing several materials, shapes and dimensions most adequate on the basis of radial and axial dose distribution, production of rays-x and dose attenuation. The simulations will be validated with experimental measurements using copper and aluminum.

1. INTRODUCTION

Mycosis fungoides and the syndrome of Sézary are part of a sub-group cutaneous lymphoma type T disease, related to the lymph-proliferative clutters that occur when lymphocytes in charge for the skin defense become malignant, causing abnormalities in the skin. The disease mainly affects people aged between 45 and 69 years. It can reach internal organs and lead to death in less than a year [1].

Among the various techniques of treatment, the whole body irradiation with electrons beam known as Total Skin Electron Therapy (TSeT) is considered one of the most effective [2].

This technique involves the irradiation of patients with a large electron beam field, with energies between 4-10 MeV, that deliver superficial dose, limited to skin depth. The report nr. 23 [3] of the AAPM (American Association of Physicists in Medicine) defines relevant parameters, such as uniformity of the beam, percentage depth dose and x-ray contamination.

This treatment technique presents innumerable technical challenges[4], several treatment techniques have been developed to meet these requirements, like to Stanford technique involving one or several [5] fields and the rotation or translation [6] of the patient.

The present work aims to assist the implementation of this treatment technique in the “Serviço de Radioterapia do Hospital das Clínicas da Universidade de São Paulo” given the specifications of TG23, developing energy degrading and scattering plates through the experimental measurements and simulations using the software MCNP4C based on the Monte Carlo method. These plates will be placed between the accelerator and the patient producing a uniform field with 200x80 cm^2 with a low x-ray contamination.

2. MATERIALS AND METHODS

2.1. Monte Carlo

Monte Carlo method simulates the radiation transport through a stochastic process based on physical and statistical principles of radiation transport and interaction of particles. The processors and code evolution has caused the appearance of many software based on Monte Carlo method to be used in planning treatment for patients in hospitals [7].

The software MCNP4C based on the Monte Carlo code is used in this work to simulate the linear accelerator Varian Clinac 2100C of the “Serviço de Radioterapia do Hospital das Clínicas da Universidade de São Paulo”. The 6 MeV energy spectrum was reconstructed from experimental measurements of PDD (Percentage Depth Dose) and profiles. A point source of electrons used in the simulation shows the angular distribution between 0° and 11.5 ° and the energy spectrum show in Figure 1.

Several simulations were performed using this spectrum and a water phantoms sub-divided in small radial and axial ellipsoids, defining the regions for dose calculation.

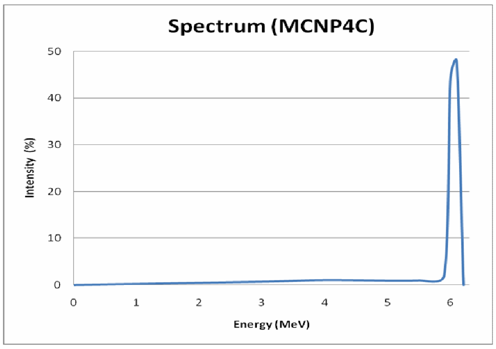

Figure 1. Linear accelerator simulated energy spectrum

The results of the simulation depend on the spectrum used, geometric details and the number of particles simulated, simulations with complex geometry, involving long distances or different materials require a great amount of particle simulations, increasing the processing time that in some cases can reach some weeks or more depending on the CPU capacity. For example on a simple plate simulation with 2.5 m SSD, it takes approximately 3 weeks, to obtain an uncertainty of less than 2%.

In the MCNP software there are several mathematical techniques for reducing variance, in this work we used the geometric splitting [8] that causes particles to split in multiple particles whenever it enters in an important region of the geometry pre-defined by the user. Energy deposition by photons and electrons has been calculated by MCNP *F8 tally. Also the F6 tally has been used to calculate the energy deposition by photons only for the estimation of x-ray contribution to the total dose. Another feature used to reduce the simulation time was the energy cut off, it makes the particles to lose all their energy whenever it reaches a energy value defined in the input data. This value is defined based on the mean free path of a particle for a particular energy. In most cases, this value was 0.5 MeV, defined according to the ellipsoids volume, which delimiter the region of our interest. These reducing variance techniques reduce the simulation time by 90%.

2.2. Experimental Procedure

The experimental measurements were made using the linear accelerator Varian Clinac 2100C, with the energy of 6 MeV with maximum field opening and high-dose rate conditions for the realization of the technique of TSeT treatment. The measures of PDD and profile were performed on an automated water phantom routinely used for dosimetric calibrations (Figure 3) produced by wellhofer, with parallel plates and pin-point ionization chambers.

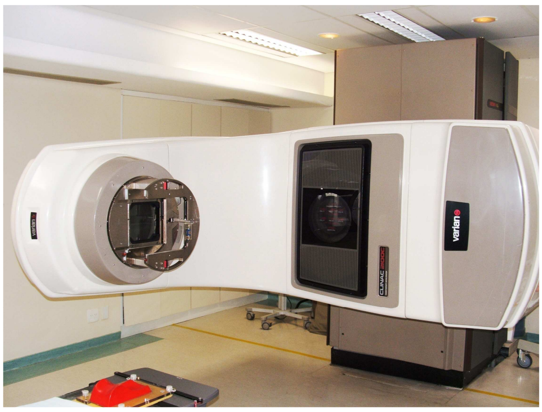

Figure 2. Linear accelerator Varian Clinac 2100C.

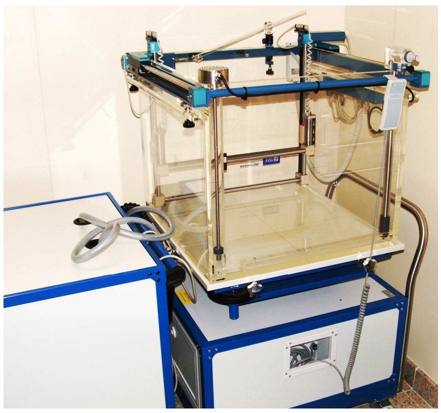

Figure 3. Water phantom (Wellhofer).

The PDD and profile results obtained for different SSD allowed the construction and validation of the spectrum, allowing also the validation of the simulations performed with different materials.

3. RESULTS AND DISCUSSION

3.1 Reconstruction of the Spectrum

The spectrum of the 6 MeV electron beam of the linear accelerator Varian Clinac 2100C was characterized by experimental measurements and simulations, using the Monte Carlo Code MCNP4C to simulate PDD and dose profiles in an water phantom. The comparison between the results obtained can be seen in Figures 4 and 5.

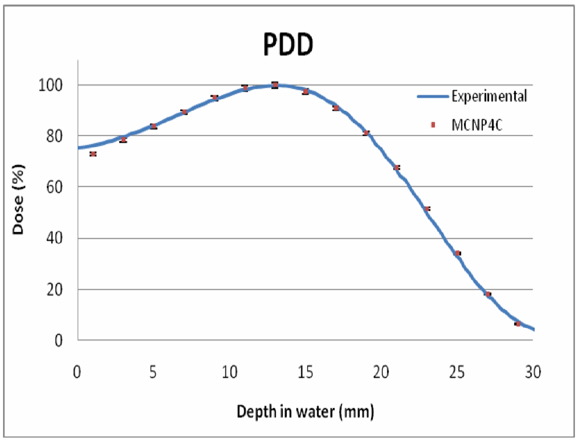

Figure 4. PDD in water phantom (SSD 70cm).

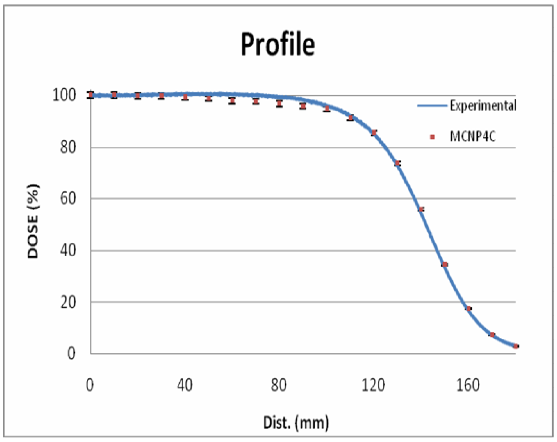

Figure 5. PDD in water phantom (SSD 70cm).

Measurements were made at the 70 cm SSD, in an automated phantom (wellhofer), using parallel plates and pin-point ionization chambers. In addition, measurements of profiles at different depths were carried out, and at 100 cm of SSD. In all cases the error less than 2%.

The maximum distance between the patient and the accelerator in the treatment room of the Hospital das Clínicas is 2.5 m, however treatments with single-field are usually made at 7m away [1]. In order to obtain the desired field size in a relatively small distance, various materials such as copper, aluminum, titanium, zinc, spear, acrylic, beryllium and others, were analyzed through PDD and profiles simulations to determine aspects, such as x-ray production and beam scattering and attenuation. The simulations materials were validated through experimental measurements. Those experiments were done by positioning flat copper and aluminum plates with different thicknesses at the accelerator exit, the results of PDD and profile can be seen in Figures 6 to 11.

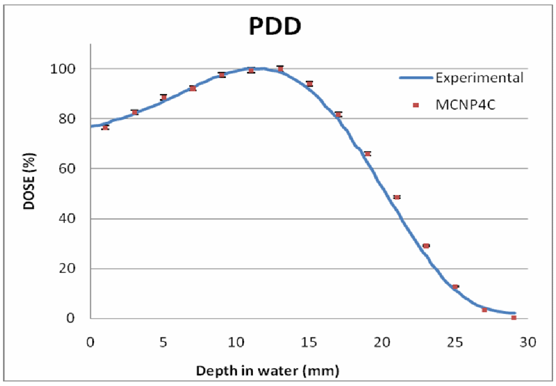

Figure 6. PDD with the aluminum plate ($20x20cm^2$; 1mm thickness)

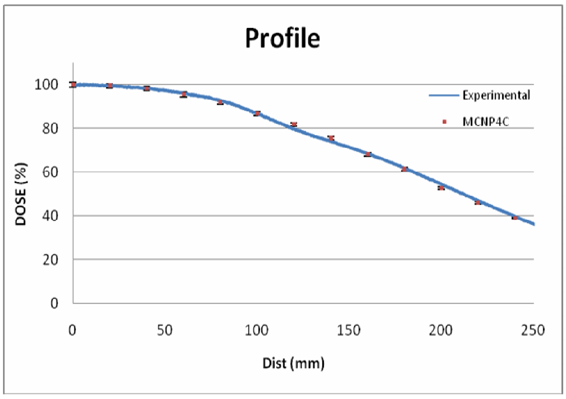

Figure 7. Profile (11 mm depth) with aluminum plate ($20x20cm^2$; 1mm thickness)

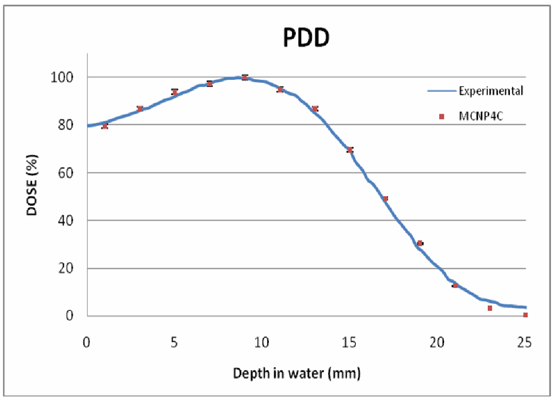

Figure 8. PDD with the aluminum plate ($20x20cm^2$; 3mm thickness)

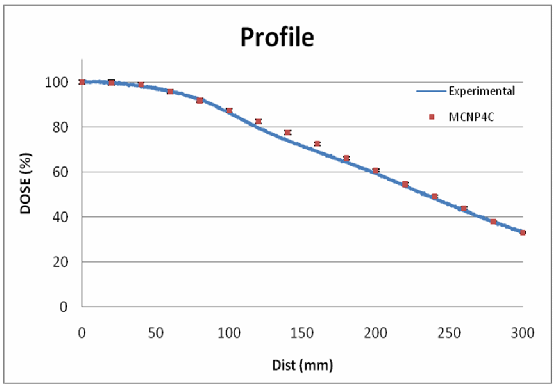

Figure 9. Profile (11 mm depth) with aluminum plate ($20x20cm^2$; 3mm thickness)

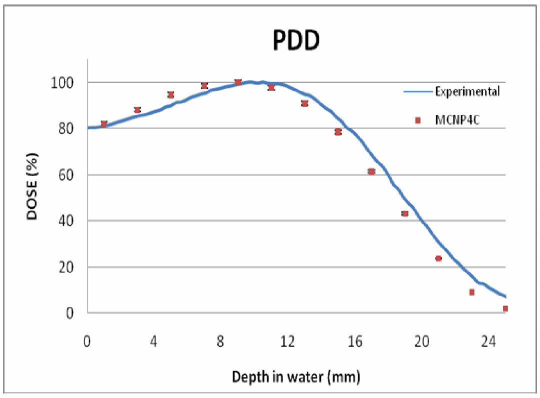

Figure 10. PDD with the cooper plate ($20x20cm^2$; 0,8mm thickness)

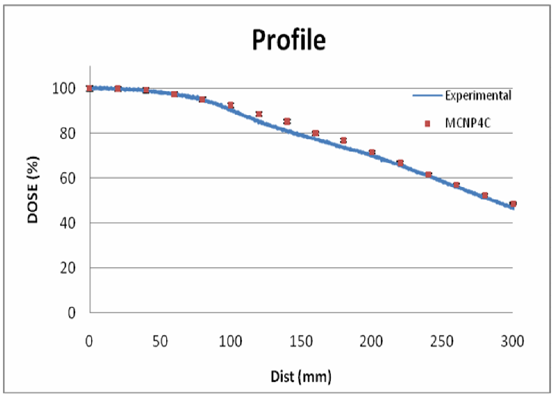

Figure 11. Profile (11 mm depth) with the cooper plate ($20x20cm^2$; 0,8mm thickness)

Based on the material analysis and bibliographical study, scatter copper plates with various forms were simulated positioned close to the accelerator exit, these scatter plates consist of ellipsoids of different sizes and thicknesses. Simulation results did not meet the requirements of TG23 which establishes a minimum uniform field in the central region (160x60 cm^2) of 8% in vertical direction and 4% in horizontal direction.

To achieve the required uniformity, acrylic plates were added. One ellipsoidal plate was added just below the copper plate and two rectangular plates about 1 cm thick positioned at 100 cm from the exit accelerator. The copper plates were replaced by plates of zinc, maintaining the same configuration, the results of profile simulations can be seen in Figures 12 and 13

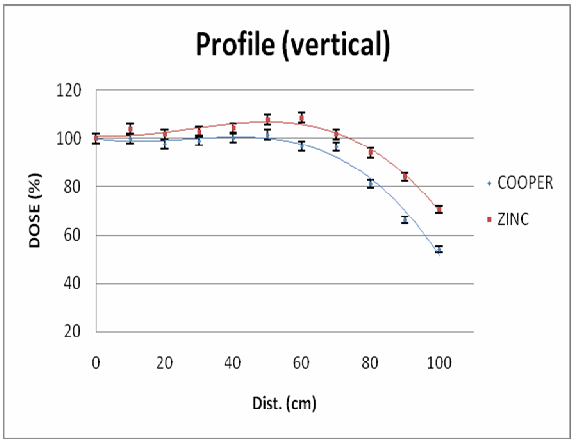

Figure 12. Profile with the cooper and zinc energy scattering and degrading plate SSD 2.5m (vertical direction)

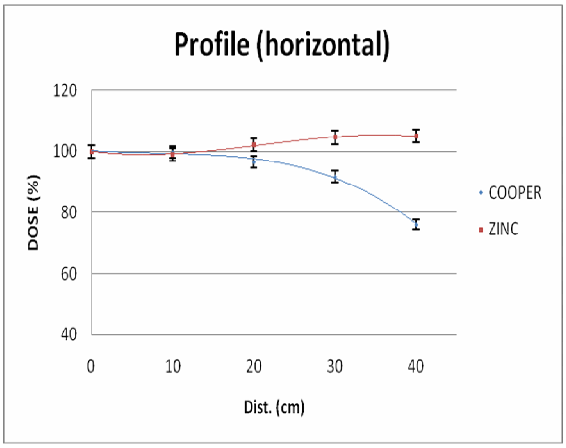

Figure 13. Profile with the cooper and zinc energy scattering and degrading plate SSD 2.5m (horizontal direction)

The simulation results using copper and zinc plates have shown in the central region (140 cm in vertical direction and 60 cm in horizontal direction a field uniformity with maximum variations of approximately 4% in the horizontal direction but a field uniformity with variations greater than 8% in the vertical direction. We expect to reduce this variation with adjustments in the spectrum which presents values slightly below the experimental measurements in the field extremities and small adjustments in the geometry of the plates[9].

The treatment region depth varies from 5 mm to 15 mm or more depending on the disease severity. Different plates will be developed to meet these clinical needs. The depth of treatment region using cooper and zinc plates can be seen from PDD (Figure 14).

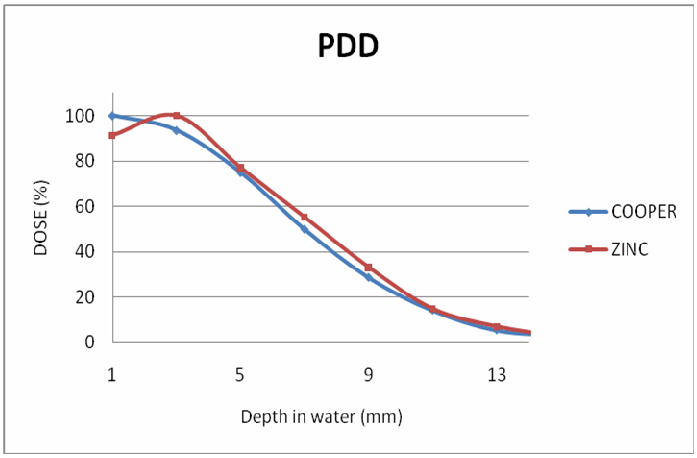

Figure 14. PDD with the cooper and zinc energy scattering and degrading plate SSD 2.5m.

The x-ray contamination due to distance and the material placed between the accelerator and the patient is approximately 4%, according to the specifications limit the TG23, making necessary the use of filters on certain conditions.

4. CONCLUSION

The results obtained by simulation with the code MCNP4C to distances of 2.5 m from the source (position where the treatments will be performed) are close to parameters specified by TG23, these simulations will be validated by experimental measurements in terms of treatment.
The simulations will be repeated with different materials to establish composition which gives the best results, producing plates with different characteristics, allowing treatment of various conditions, considering the clinical needs and feasibility of construction of the plates.
We believe that with minor adjustments in the electron beam spectrum and geometric correction in the acrylic plates the TG23 requirements will be fulfilled.

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