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PROTON AND ELECTRON DEEP DOSE PROFILES FOR RETINOBLASTOMA BASED ON GEANT 4 CODE

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ABSTRACT

Herein, the dosimetry responses to a retinoblastoma proton and electron radiation therapy were investigated. The computational tool applied to this simulation was the Geant4 code, version 4.9.1. The code allows simulating the charge particle interaction with eyeball tissue. In the present simulation, a box of 4 cm side water filled had represented the human eye. The simulation was performed considering mono energetic beams of protons and electrons with spectra of 57 to 70 MeV for protons and 2 to 8 MeV for electrons. The simulation was guide by the advanced hadron therapy example distributed with the Geant4 code. The phantom was divided in voxels with 0.2 mm side. The energy deposited in each voxel was evaluated taken the direct beam at one face. The simulation results show the delivery energy and therefore the dose deposited in each voxel. The deep dose profiles to proton and electron were plotted. The well known Bragg peak was reproduced for protons. The maximum delivered dose defined the position at the proton stopped. However, to electrons, the absorbed energies were delivered along its path producing a more continuous distribution following the water depth, but also being stopped in the end of its path.

1. INTRODUCTION

Geant4 code is a toolkit for computational simulation, based on tools that can be used to simulate transport of particle through the matter. It has advantage to be of free distribution. The Geant 4 permits the user simulate a radiotherapy treatment and produce of electron and proton energy distribution profiles in a specific medium [1].

The proton therapy is a treatment based on the specific properties of dose deposition at depth dependent on the proton energy. The proton deliveries great part of his energy in a specific point that is called Bragg peak. The proton therapy has became a gold standard treatment for many neoplasms, since it provides high doses of ionizing radiation without exceeding the tolerance dose to sensitive surrounding structures, such as the retinoblastoma radiation therapy [2].

The use of electron beams in radiotherapy consists in applying an external beam produced by linear particle accelerators (LINAC). In ocular tumors such as retinoblastoma, the beam is directed to the orbit looking for the ideal direction in order to minimize the deleterious effects on the lens, cornea and optic nerve that is no longer possible to avoid all the time [3].

The retinoblastoma is a malignant intraocular tumor, which happens usually in childhood. It represents about 30% of all ocular tumors. The major emphasis in the treatment of retinoblastoma is not only a cure but also to preserve the affected eye [4].

In this paper, through simulation we want to make a comparative analysis between the rate of dose deposition of two beams - proton and electrons, for irradiation of retinoblastoma.

2. EXPERIMENTAL

The computational code Geant 4 has been installed and checked for the simulations. Monoenergetic beams of protons and electrons were set up for the dosimetric simulations. To the representative geometry of the human eye, a water phantom was considered, made of a box of 4 cm side, with slices covering the sensitive area of the transverse model. In total, 200 voxels with 0.2 mm each were used inside the phantom in order to provide adequate resolution of the power distribution in depth. A water phantom with a density of 1 g/cm^3, that is similar to the tissue density, was assumed to represent the eyes ball and the retinoblastoma.

The monoenergy of the proton beam applied on the simulation has been assumed at the range of 57 MeV to 70 MeV. A special emphasis was given to the beam at energy of 63.5 MeV since it is the energy used in standard proton treatments for retinoblastoma.

For the simulations with electron beams, the beams energy range was from 2 MeV to 8 MeV. The energy of 6 MeV is the electron standard pattern for the retinoblastoma treatment.

Six simulations were performed using the Geant4 code, version 4.9.1 in order to calculate the deep dose deposition for proton and electron beams in a water phantom, representative of the human eye. The simulations were based on advanced hadrontherapy example, which simulates a room treatment and the direct proton pathway toward the phantom as shown in Figure 1. The example was changed in order to permit also simulating an electron beam [5, 6].

More details about the simulations, including the processing time and platform description are discussed by Braga, 2008 [7].

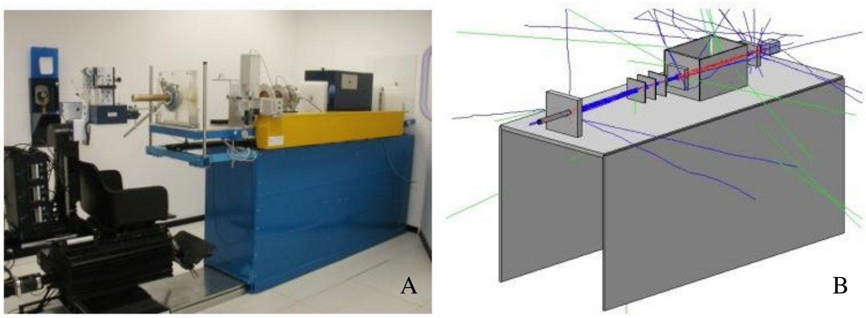

Figure 1: A) The real equipment for proton therapy, installed in Laboratory Nazionale del Sud Institute of Physics nucleare in Nazionale di Catania, (B) simulated equipment used for the present simulation [6].

The main objective of this study was to compare the differences between absorbed dose generated by electrons and protons beams. It is aimed to determine to the protons beam the position of the Bragg peak, the point which the highest energy deposition occurs and the region where there would be a more effective dose. The same was done for electron beams in order to make a comparison.

3. RESULTS AND DISCUSSION

The following Figures show the results from the simulations were depicted for the proton and electron beams, respectively. The graph profiles are presented on depth (voxel position) versus Energy (MeV), in which each voxel represent 0.2 mm.

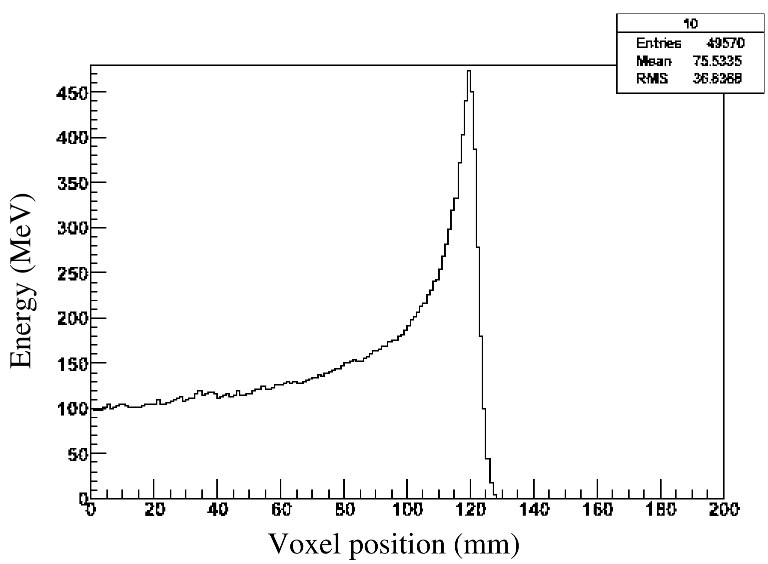

Figure 2: Deep profile of the energy deposited in a water phantom for a monoenergetic proton beam with average energy of 57 MeV.

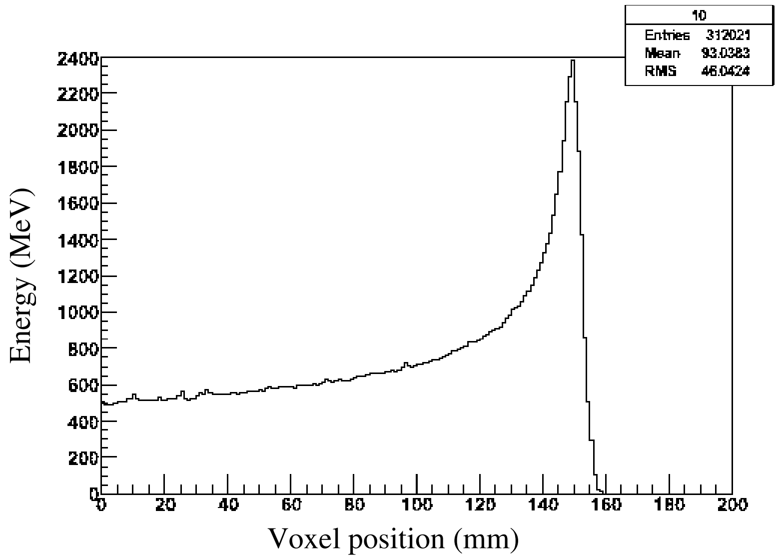

Figure 3: Deep profile of the energy deposited in a water phantom for a monoenergetic proton beam with average energy of 63.5 MeV.

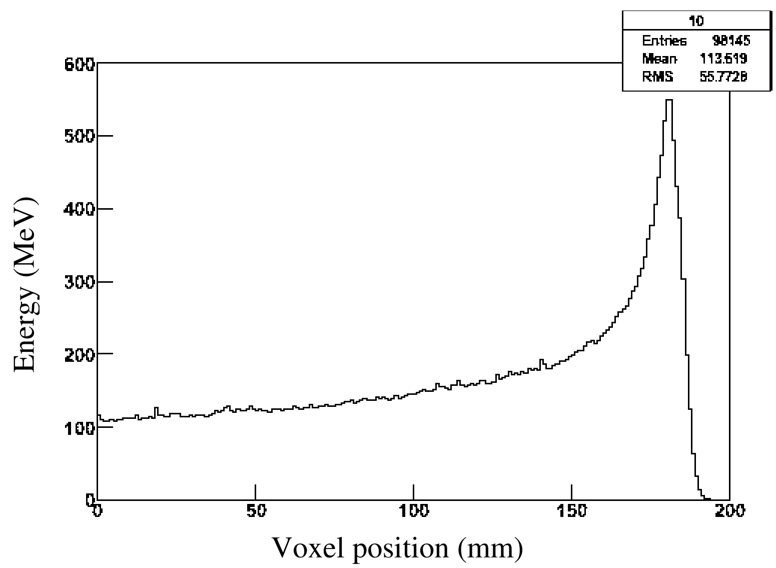

Figure 4: Deep profile of the energy deposited in a water phantom for a monoenergetic proton beam with average energy of 70 MeV.

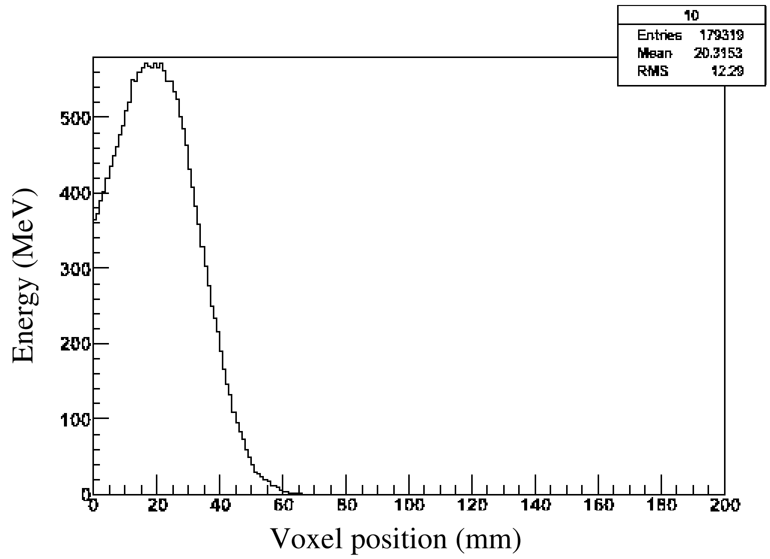

Figure 5: Deep profile of the energy deposited in a water phantom for a monoenergetic electron beam with average energy of 2 MeV.

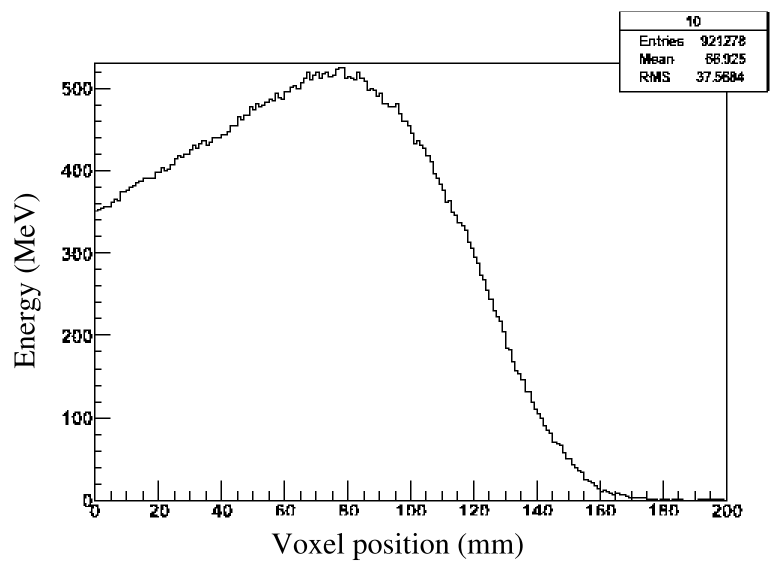

Figure 6: Deep profile of the energy deposited in a water phantom for a monoenergetic electron beam with average energy of 6 MeV.

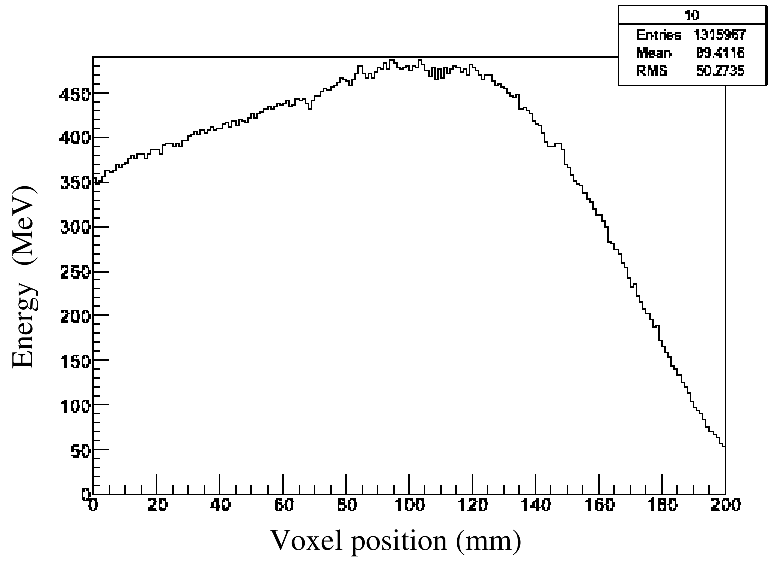

Figure 7: Deep profile of the energy deposited in a water phantom for a monoenergetic electron beam with average energy of 8 MeV.

The results shows that the deep profiles for the proton beams have a fixed position for the maximum deposition of energy, known as the Bragg peak. Just after this region, the deposition of energy drops to zero quickly. It does not occur the same for electron beams. The deep deposited energy profile for electrons has almost a constant deposition of energy along its path (increasing slowing) and after a platoon is decreasing until zero. This deep profile makes the energy deposition ineffective in the treatment. Indeed, it increases the risk of exceeding the permissible maximum dose on the normal surrounding, as crystalline, sclera, optical nerve etc.

Analyzing the graphs, one can observe that to the profile associated to 63.5 MeV proton incident energy the maximum energy deposition occurs at 3 cm depth, ideal to irradiate the bottom of the eye. Unlike the protons, electrons do not have a high energy deposition on a fixed position, spreading its energy along its path.

In order to present the results in units of dose (Gy) the values obtained by the simulation were converted, using a factor (K). To get the conversion factor (K) following transformations were applied:

$$Gy = \frac{J}{Kg} \tag{3.1}$$

The unit of energy in MeV was converted to Joule:

$$1MeV = 1.602 \times 10^{-13} J \tag{3.2}$$

The phantom was divided into 200 voxels of 0.2 mm each. To obtain the total volume of one voxel, the volume irradiated was divided by the number of voxel:

$$Volume\ (voxel) = \frac{1\ cm^3}{200} = 5\times10^{-3}\,cm^3 \qquad (3.3)$$

so the mass of the voxel is defined by:

$$m = d\times v = 1\frac{g}{cm^3}\times5\times10^{-3}\,cm^3 = 5\times10^{-3}\,g = 5\times10^{-6}\,Kg \qquad (3.4)$$

In order to convert the energy absorbed on the phantom, calculated by the code, to absorbed dose, the following expression was applied:

$$\frac{MeV}{Kg} = \frac{1.602\times10^{-13}\,J}{5.000\times10^{-6}\,Kg} = 3.200\times10^{-11}\,\frac{J}{Kg} = 3.204\times10^{-8}\,Gy \qquad (3.5)$$

Thus, to generate the absorbed dose, multiply the energy deposited (y) by the conversion factor (K).

$$K = 3.204\times10^{-8}\,Gy \qquad Dose = y\times K \qquad (3.6)$$

Tables 1 and 2 present the absorbed dose on Gray (Gy) for various beam simulations. The maximum values of the deposited energy, its position, and the entrance energy were considered. Dose depositions were evaluated dividing those by the water mass on the voxel. Thus, for each monoenergetic beam, the following data are shown: depth (position) of the higher energy deposition; the entrance particle energy, energy deposited on the higher (Bragg peak); and the absorbed dose per particle at the entrance and the Bragg peak.

Table 1: Monoenergetic proton beams, position of greater power in depth, the deposited energies at the entrance and at the Bragg in the phantom, and the absorbed dose at the same position, respectively, normalized per particle.

Protons					
Energy (MeV)	Depth (cm)	Total Energy at entrance (MeV)	Total Energy at Bragg Peak (MeV)	Entrance dose/próton (Gy)	Bragg Peak/proton (Gy)
50.00	1.80	100.00	430.00	$3.20x10^{-10}$	$1.37x10^{-9}$
57.00	2.40	100.00	470.00	$3.20x10^{-10}$	$1.50x10^{-9}$
63.50	3.00	500.00	2400.00	$3.20x10^{-10}$	$1.54x10^{-9}$
70.00	3.70	100.00	550.00	$3.20x10^{-10}$	$1.76x10^{-9}$
50.00	1.80	100.00	430.00	$3.20x10^{-10}$	$1.37x10^{-9}$

Table 2 Monoenergetic electron beams, position of greater power in depth (average), deposited energy at the entrance and the average energy in the phantom, the entrance dose and also dose at the area of higher deposition normalized per particle.

Electrons					
Energy (MeV)	Depth (cm)	Total energy value at entrance (MeV)	Maximum Energy Value on depth (MeV)	Entrance Dose/elétron (Gy)	Maximum dose in depth/elétron (Gy)
2.00	0.40	350.00	530.00	$1.12x10^{-9}$	$1.69x10^{-9}$
6.00	1.60	350.00	520.00	$1.12x10^{-9}$	$1.66x10^{-9}$
8.00	2.00	350.00	480.00	$1.12x10^{-9}$	$1.53x10^{-9}$
10.00	2.60	350.00	460.00	$1.12x10^{-9}$	$1.47x10^{-9}$

In this study, the irradiation using proton beams shows to be a superior technique compared to the irradiation by electron beams. Irradiation with protons was shown to be able to deliver a higher dose in a specific area. Therefore, there may be a decrease in dose delivery on the adjacent normal structures.

In this work, the beam entrance energies tested were able to irradiate the back of the eye. The dose delivery at 3 cm of the phantom comprises the situation of interest.

4. CONCLUSIONS

An advance on radiotherapy techniques means an ideal therapy which provides the same dose control on the whole target volume minimizing the dose on the surrounding tissues. Our results showed that proton irradiation is close to this ideal condition. The proton technique has advantage over electron irradiation. Indeed, the proton therapy has the ability to provide a dose deposition in specific volumes. This is because these particles interaction processes possess unique characteristics such as the formation of the Bragg´s peak.

This study shows that the proton beams can deposit at specific depths higher doses superior to the entrance doses deposited at the surface of the phantom. The region of interest is close to 3 cm, representing the back of eye ball where retinoblastoma tumor grows. Protons with energy of 63.5 MeV deposit most of their energy at 3 cm depth, the required region for the retinoblastoma irradiation. We believe that these particles may deposit dose without damaging sensitive normal structures. While the electron irradiation provide a delivered dose spread over all the eyes ball, including the normal tissue, thus the irradiation makes impossible preserve the eyes function.

We had the purpose of providing a comparison between the depth dose profiles of electrons versus protons in a water phantom. We hope that these results show the superiority of the proton irradiation in detriment of electrons, limited to the domain of the simulation. There are international guide which supports the use of protons on retinoblastoma. The authors encourage the implementation of this technique in Brazil, especially for childhood eyes tumors, such as the retinoblastoma. Despite of the superior responses of protons, clinical studies are essential to determine the true benefit of this type of radiation especially in view of the cost of this treatment modality.

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