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Monte Carlo investigation of prostate cancer ion – therapy by using SOBP technique in the GEANT4 toolkit and MCNPX code

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Abstract

Regarding the useful results concerned with an external radio-therapy in treatment of tumors, we consider in this paper a standard model of the human prostate phantom based on MIRD phantom for the Monte Carlo simulation in GEANT4 toolkit and also on MCNPX code for a prostate cancer treatment. We calculate the lateral as well as the dose profiles in the tumor region for both proton and alpha beams in a similar range, and finally having implemented the SOBP technique, we compare the results of the two beams in the corresponding codes used in this analysis.

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Introduction

Nowadays the external radio-therapy particularly the proton-therapy has a big impact on the prostate cancer treatment. This is due to the fact that the ion beams with a very small dissipative energy are penetrating deep into the corresponding tissue, and by colliding with the target surface they accumulate most of their energy on the so called 'Bragg –peak', at the end of their trajectories[1]. However, due to the exponential reduction with energy of the Bragg-peak , after distinguishing the required energies in the tumor vicinity, we must end up to a monotonous Bragg-peak by applying a convenient weighting factor .This is the so called the SOBP (spread out Bragg peak) [2] is shown in figure 1.

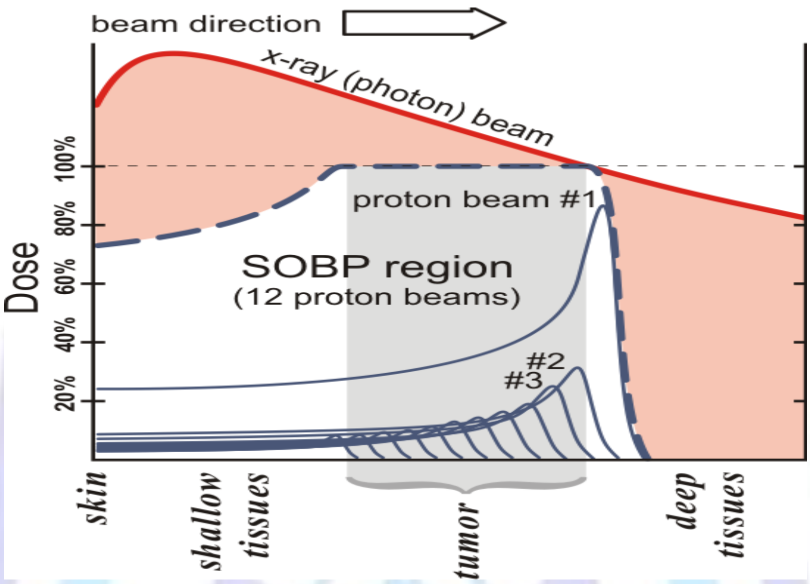

Figure 1.The SOBP absorption dose sample in tumor region for proton beams[3].

In this paper the geometry of the human prostate which is distracted from the standard Phantom MIRD, in MCNPX code and GEANT4 toolkit has been simulated. We have calculated the lateral and depth dose profiles in the tumor region by using the sources of proton and Alfa pencil like beams .Having displayed the SOBP technique to make a monotonous dose in tumor region , we have investigated and compared the obtained distributions with each other.

Method of research work

The simulated prostate Phantom extracted from MIRD Phantom is as a sphere with a 2.2 cm in radius and with a weight of 46.4 grams made from a soft tissue with an average density of $1.04\, gr/cm^2$ placed under vesica and above testicles[4]. While using the proton therapy equipment, the range of energy and also the range of the proton beam movement is completely specified, in order not to damage the lateral sensitive tissues particularly those of vesica and testicles. Thus, the dimensions and positions of the above organs inside the stomach ishighly consistent with the MIRD Phantom(see figure 2). The tumor tissue as part of the Phantom is considered in a depth of 11.2 to 13 cm inside the prostate and the required energies , depth and lateral doses are calculated in these regions.

In this research work, we consider the sources as a single beam energy with a radius of 2mm.placed on the left of stomach in y direction, and the distance between the beginning of the source to the beginning of the stomach is 5 cm. The values of the absorption doses for proton and Alfa beams are cited in table 1 for a few incoming energies.

For the dose calculation we have used the mesh detector withgratings of 5 mm in width for the deep dose profile and 16 mm in width for the lateral dose profile. The direction for detector division is the y axis for the deep dose and the x axis for the lateral dose. The program was run for the Alfa and proton sources in MCNPX and GEANT4 codes for 2 million shootings. The obtained outputs in all figures are for one single particle only. The standard deviation in the last entrance of the deep dose profile is also calculated. These values play akey role in the quality of widening the distributionof the dose in depth.Paying attention to the magnitude and place of the target , in order to spread out the Bragg peak around the total volume it is possible to determine the appropriate energy range, and thus reaching to the values of half width for both the lateral and depth dose profiles, and finally to a monotonous dose distribution in the volume of the target. The width of thelateral as well as the dose profiles depend on the incoming beam. Therefore, the depth and width displacement of the beam depends on the beam energy, in other words such displacements depend on theposition of the Bragg peak. The peaks with the least and with the most rangesare placed inside the stomach in a depth of 11.2 cm and 13 cm (beginning and end of the tumor)respectively. In doing calculations, the weight factor for each single depth dose profile is determined in order to create a monotonous SOBP, deep inside tumor. This factor is then taken into account in the calculation code. The mean energy for the proton beam is equal to 72.1 MeV and for the Alfa beam is equal to 278 MeV. In these energies the Bragg peak is placed in the tumor centre, that is in $y = 12.1\,cm$.

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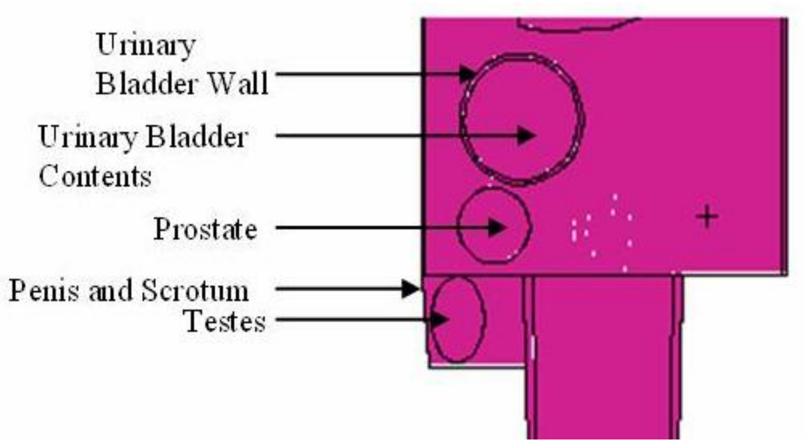

Figure 2.The lateral profile for ORNL MIRD Phantom in the vicinity of the pelvis together with the prostate [4].

Results and discussions

Figures 3 and 4 show the SOAP depth dose profile for proton and Alfa beams. We see from the figure that by entering into the MCNPX and GEANT4 codes the equal weighting factor for proton and Alfa particles(which are different in energy), does not change the surface of the SOBP considerably.

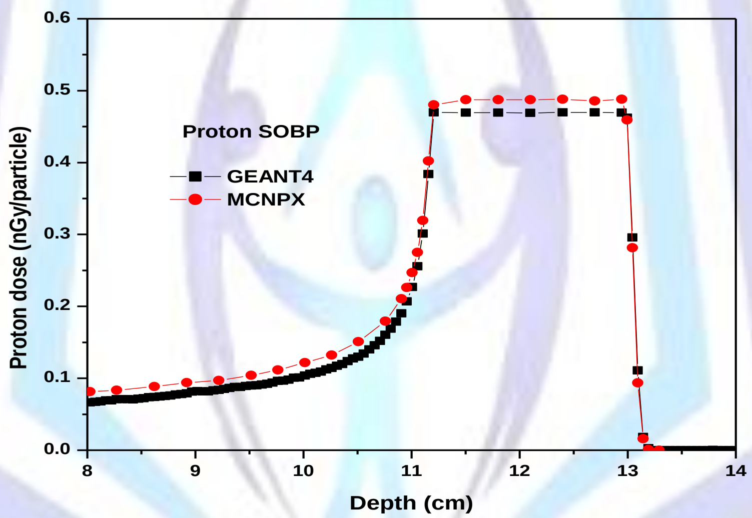

Figure 3.The absorption dose SOAP in tumor region for proton beams.

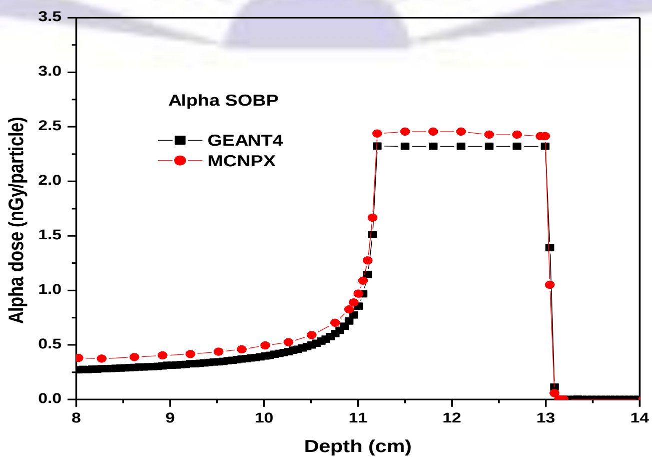

Figure 4. The absorption dose SOAP in tumor region for Alpha beams.

We have calculated in figure 5 the accumulation profile of the lateral energy for proton with two different energies of 62.93 and 80.26 MeV. These values are for the corresponding Bragg peaks for each energy in the two codes. The decrease of the amplitude with energy is perceptible, but half width lateral does not show a considerable change, it increases with a very small variation. This is clearly noticeable in table 1. The same is also shown in figure 6 for the lateral absorption dose with Alpha beams.

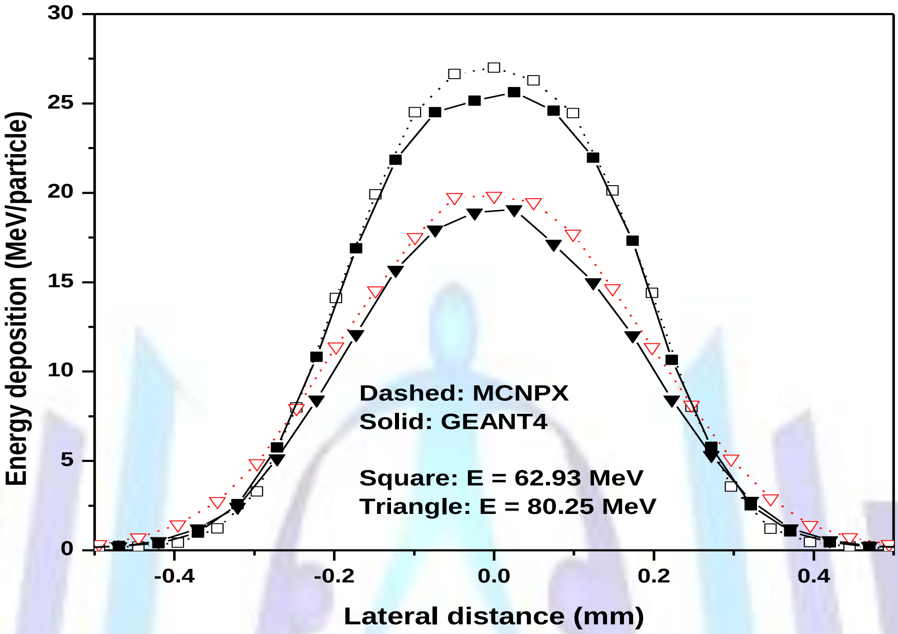

Figure 5 The accumulation profile of the lateral energy at the beginning and also at the end of the tumor in the position of corresponding Bragg peak for proton beam.

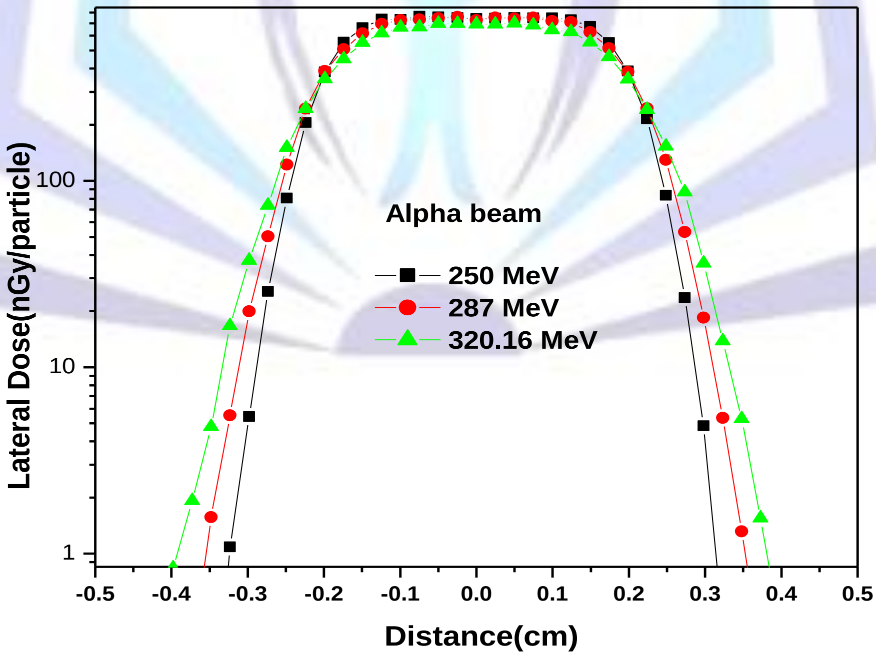

Figure 6. The lateral dose profile from the beginning to the end of the tumor for Alpha beams

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Table 1.The values of absorption dose next to both SOBP and half width (FWHM) for proton and Alfa beams in different incoming energies.

Proton energy (MeV)	SOBP Dose (nGy)	FWHM (mm)	Alpha energy (MeV)	SOBP Dose (nGy)	FWHM (mm)
MCNPX: 62.93	0.480	3.03	**250.24**	2.437	1.41
GEANT4: 62.93	0.469	3.09	**250.24**	2.322	1.50
MCNPX: 66.1	0.487	3.10	**262.09**	2.456	1.45
GEANT4: 66.1	0.469	3.15	**262.09**	2.321	1.48
MCNPX: 69.16	0.487	3.40	**275.1**	2.456	1.50
GEANT4: 69.16	0.469	3.45	**275.1**	2.321	1.55
MCNPX: 72.1	0.487	3.50	**287**	2.456	1.55
GEANT4: 72.1	0.469	3.56	**287**	2.320	1.59
MCNPX: 74.9	0.488	3.60	**298.4**	2.424	1.58
GEANT4: 74.9	0.468	3.55	**298.4**	2.321	1.61
MCNPX: 77.65	0.485	3.90	**309.5**	2.426	1.61
GEANT4: 77.65	0.467	3.93	**309.5**	2.320	1.63
MCNPX: 80.25	0.488	3.70	**320.16**	2.413	1.61
GEANT4: 80.25	0.467	3.71	**320.16**	2.321	1.60

Figure 7 shows the lateral dose in different depth of the proton beam for a specified energy at the centre of the tumor(72.1 MeV). At the beginning of the trajectory the lateral dose is high , decreases with increasing the dose depth, increases again in a specified depth and finally attains it's maximum value in a positioncorresponding to the Bragg peak. The reason for such a behavior is that due to a multiple scattering followed by the lateral widening , the number of transit particles through the central cells is reduced with increasing the depth penetration, causing a reduction in the absorption energy. On the other hand, such a behavioris increased with the depth stopping power. This effect compensates, to some extents, the reduced absorption energy caused by the flux reduction. To a specific depth, the energy reduction due to the lateral scattering is leading the increased stopping power , according to which the total absorption energy is reduced. But at this stage onwards the effect of the increasing in stopping power dominates the lateral scattering, and consequently the absorption energy tends to increase and finally gains its maximum at the value corresponding to the Bragg peak. It is obvious that afterwards it will experience a sharp reduction. Such a behavior for the lateral dose can also be generalized to the Alfa beam.

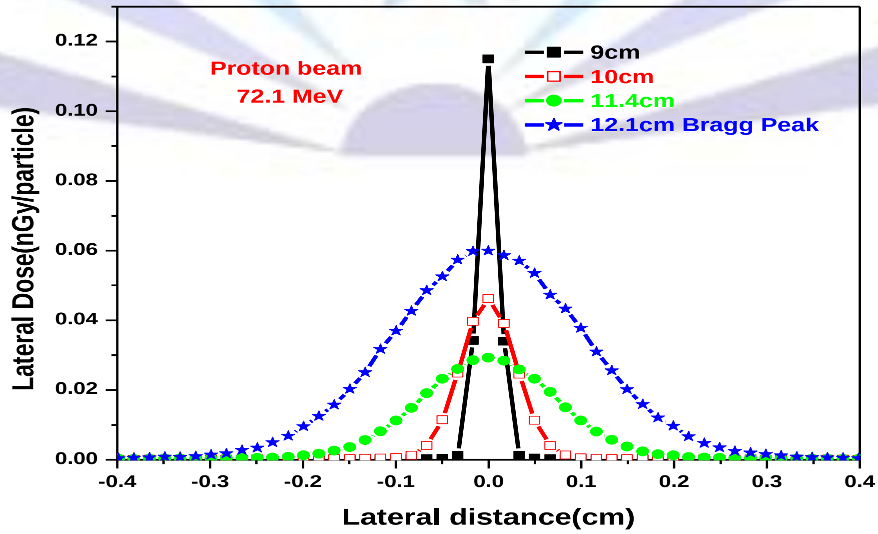

Figure 7 . The lateral dose profile for a proton with an energy of 72.1 MeV from it's arrival to the body up to the Bragg peak position.

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Conclusions

In this paper we have calculated the lateral and depth profiles in the tumor region for proton and Alfa beams in a similar range. We have done this by simulating the human prostate Phantombased on standard Phantom in GEANT4 toolkit and also onMCNP code. Comparison of the results obtained from the two simulation codes used in this analysis shows that they are rather consistent with each other. The slight difference between the results in two different codes is interpreted asthe nature of the Monte-Carlo and also as the different libraries used in two codes .

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