The effects of high atomic material in photon beams at the interface

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Abstract. The effect of Z-material on the dose distribution of 6, and 15 MV photon beams was studied. The calculated central percentage depth dose distributions, with and without the material were compared. The percentage depth dose values at the interface below the prosthesis were lower for all energies by as much as 5% compared with percentage depth dose values without the materials. For each radiation beam, the dose enhancement factors (DEFs) at the distal interface were calculated. To verify the DEFs calculated at the interface, the Thermoluminescence dosimeters (TLDs) were used for comparison. The DEF values agree well within 1.5%. The results revealed that the DEF calculated at the interface increased with increasing the photon beam energy as well as increasing material thickness.

1. Introduction

The effect of radiation near a media interface has long been a subject of investigation [1], [2], [3], [4], [5], [6]. If two media of different atomic numbers (Z) in contact geometry are irradiated by a photon beam, there exists a region in which the electron fluence is composed of electrons generated in both media [7]. The region may extend from the interface to a few millimetres or centimetres depending on the energy of the photon beam [8]. Different densities and atomic numbers of materials relative to water yield challenges for accurate radiotherapy dose calculation when photon beams pass through these structures [8]. Several authors have quantitatively calculated or measured the effect of materials on dose distributions [9], [10], [11].

Klein and Kuske [12] measured the changes in the photon dose distributions due to the material. The TLD chips were placed between the implants and a bolus layer representing the subcutaneous muscle flap. A 6 MV photon beam of 10×10 cm^2 field size with a 45 wedge was used. Their results showed no significant alteration of depth doses 5 cm away from the implant with minor interface perturbations for all their implants. They concluded that radiation does affect the material to some degree. Based on the known principles of interaction of radiation with matter, the transport of energy can be modelled and calculated using Monte Carlo (MC) algorithms [13]. The purpose of this study is to compare the photon dose distributions in the presence of a various materials using Monte Carlo calculations and to the dose distribution in water without the Z-materials.

2. Method and Materials

2.1 Accelerator model:

The geometry of an accelerator head is illustrated in figure 1. Various components of the head relevant in Monte Carlo calculations are mentioned. To verify the validity of the radiation source, the calculated PDDs and profiles for both 6 MV and 15 MV for various field sizes (3×3, 6×6, 10×10, 15×15 and 20×20) at SSD of 100 cm were compared with the measured data. The differences were within 2% for PDDs and 3% for profiles.

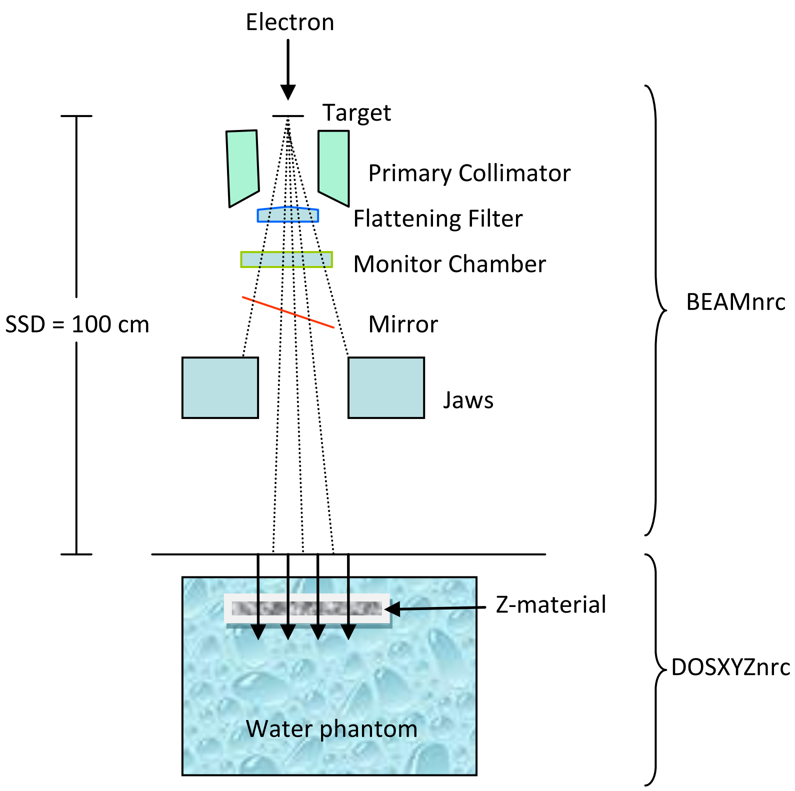

Figure 1. Varian linear accelerator head.

The geometrical input data for the 6 and 15 MV photon beams were based on specifications provided by the manufacturer [14]. The origin of the coordinate system (x, y, z) = (0, 0, 0) was at the front surface of the target where the electrons are incident. The isocenter of the machine was defined at (x, y, z) = (0, 0, 100) cm. Dose enhancement factor (DEF) was defined as the ratio of the dose at a depth with the material in place and the dose at the same depth in water without the material. Thus a dose enhancement is obtained if DEF > 1.0, while a dose reduction is observed if DEF < 1.0.

2.2 Monte Carlo simulation code

Monte Carlo simulations take into account the physics of particle interactions using experimental cross-section data. Monte Carlo EGSnrc code [15], [16] was used in this study. The code breaks the simulation of the beam into two. Firstly the accelerator head components were simulated by using BEAMnrc user-code [17]. Secondly, the dose in the water phantom was calculated using DOSXYZnrc user-code [18]. The BEAMDP code [19] was used for phase space data processing.

The parameters for simulation were AE = 0.7 MeV, AP = 0.01 MeV, ECUT = 0.7 MeV, PCUT = 0.01 MeV. During simulations, ESTEPE was set to zero so that the PRESTA defaults are used.

2.3 Construction of water phantom

The water phantom geometry was defined as a rectilinear volume with voxels ($2 \times 2 \times 0.5$ mm^3) along the axis at a right-handed coordinate system. The materials used in the phantom were chosen from PEGS4 cross sectional data file. The 700icru.pegs4dat was used throughout the calculations. The phantom was modelled as $50 \times 50 \times 50$ cm^3.

3. Results and Discussion

The following sections summarize the results for 6 and 15 MV Varian Clinac 2100C accelerator model. For 6 MV simulations, a total of 5×10^7 electrons were sampled. For 15 MV simulations, a total of 3×10^7 electrons were sampled.

3.1 PDD Curves

All the results in this study showed the effects of the material on photon beam at the distal interface. Figure 2 shows the comparison of central depth dose distributions with and without the materials in the water phantom. The solid lines represent the percentage depth dose in water without the material, while symbols indicate the percentage depth dose in water with the beam having passed through the prosthesis.

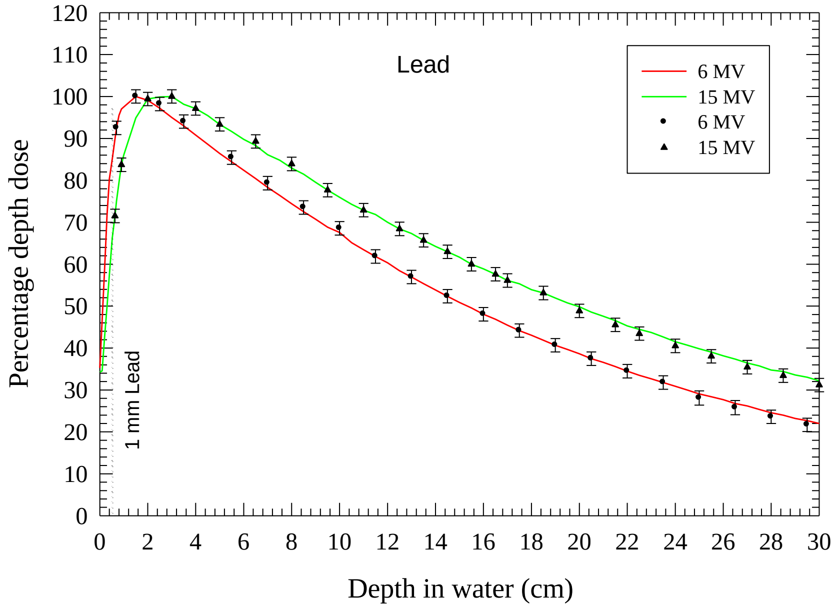

Figure 2**:** Depth dose distribution curves with and without 1 mm Lead material in a water phantom for 6 and 15 MV beams with 10×10 cm^2 field size.

Immediately behind the lead material, the dose is less than that without the material, with maximum percentage difference of 2.4% and 1.7 % for 6 MV and 15 MV beams respectively. This is due to photons being attenuated just after passing through the material. Similar results were observed by [11].

3.2 DEF within 5 mm distance.

Figures 3(a) and (b) represent the dose enhancement factors as a function of distance from the material within the material-water interface.

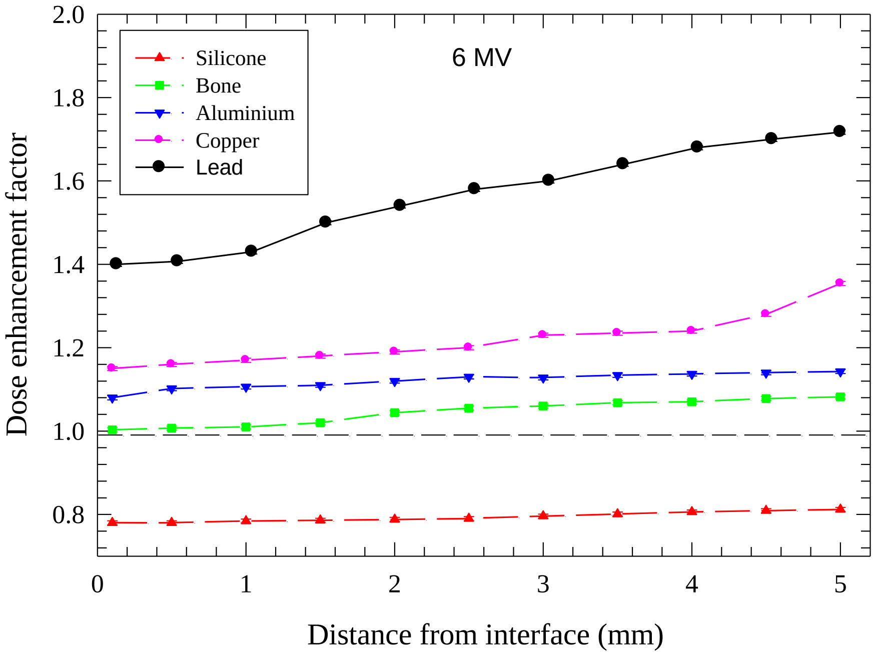

Figure 3(a): Dose enhancement factor as a function of distance from the interface calculated for 6 MV photon beam with 10 × 10 cm^2 field size defined at 100 cm SSD. The line at 1.0 is drawn to reflect the dose enhancement (DEF>1) and dose reduction (DEF<1).

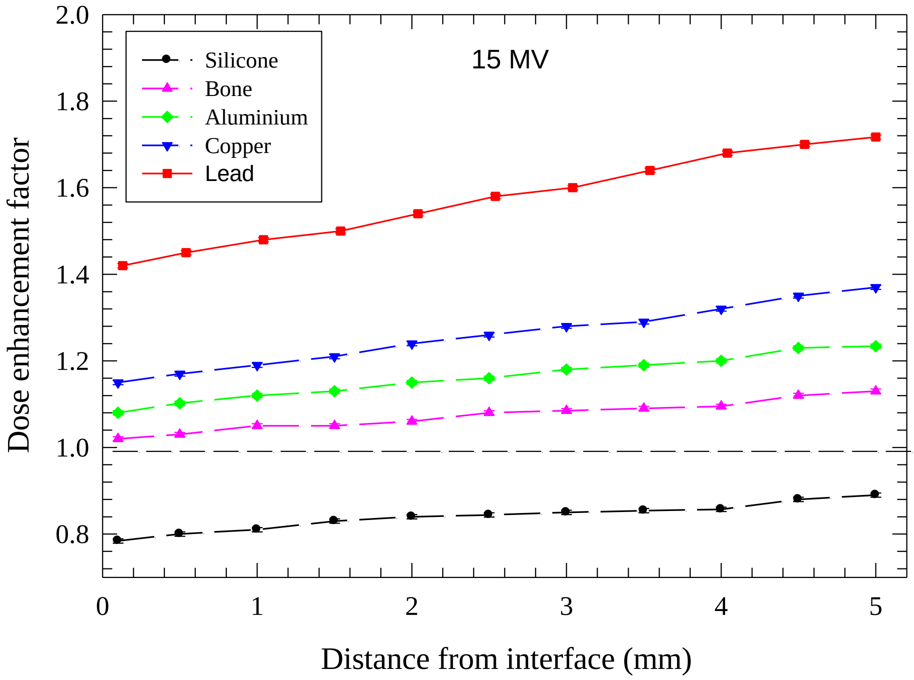

Figure 3(b): Dose enhancement factor as a function of distance from the interface calculated for 15 MV photon beam with 10 × 10 cm^2 field size defined at 100 cm SSD. The line at 1.0 is drawn to reflect the dose enhancement (DEF>1) and dose reduction (DEF<1).

3.3 Dependence of DEF on material thickness

Eight different materials with thickness ranging from 1.0 mm to 8.0 mm were used in this study. The same material was irradiated with both 6, and 15 MV photon beams. Figure 4 shows DEF calculated for silicone gel, bone, aluminium, copper and lead materials. It can be seen from the curves that for a given photon energy, there is a slight increase in DEFs with the increase in material thicknesses. A slight increase in dose was observed as the thickness of the material was increased. This is due to a change in the scattered photon contribution with the change in the thickness of the material. Similar results were observed by Li *et al* [10]. It is observed that materials with higher atomic number enhance the dose.

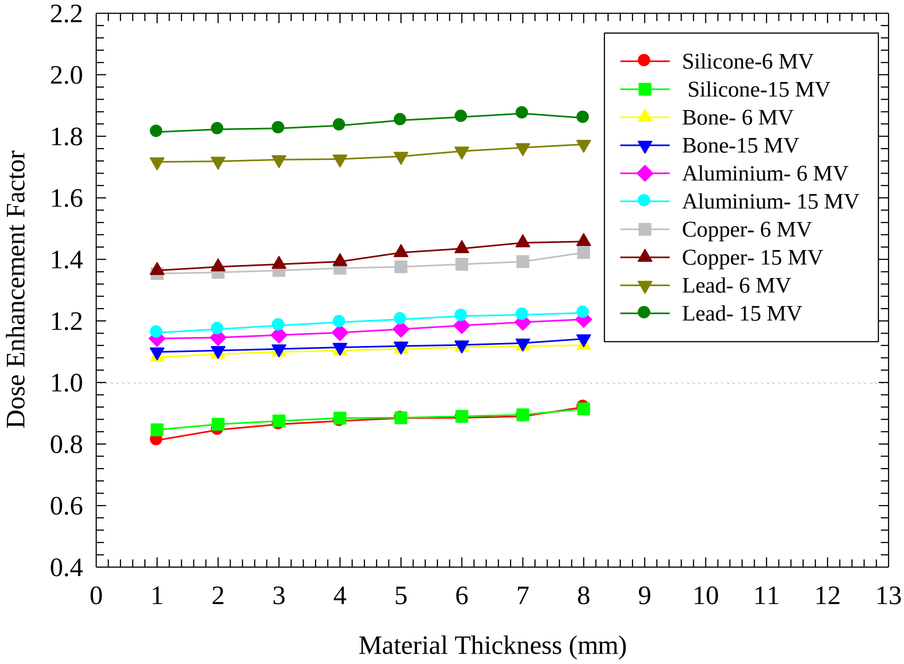

Figure 4: Calculated DEF at the interface as a function of material thickness for 6 and 15 MV beams. The line at 1.0 is drawn to reflect the dose enhancement (DEF>1) and dose reduction (DEF<1).

3.4 Validation of results.

For verification of results, TLDs were used. Table 1 shows a comparison between the dose enhancement values for 6 and 15 MV photon beams calculated in water and within a TLD at the material interface. DEF (water) indicates the dose enhancement values calculated in water, while DEF (TLD) indicates dose enhancement values calculated using a TLD placed at the same point in the water phantom. It can be seen from table 1 that the dose enhancement factors for both energies are slightly higher than those calculated within TLDs. The DEF values agree well within 1.5%.

Table 1. DEF calculated at 5 mm within the interface for 6 and 15 MV beams for 1 mm thickness.

Material	6 MV			15 MV		
	DEF (Water)	DEF (TLDs)	% Diff	DEF (Water)	DEF (Water)	% Diff
Silicone gel	0.976	0.962	1.4	0.991	0.976	1.5
Bone	1.082	1.076	0.6	1.093	1.084	0.8
Aluminium	1.143	1.139	0.3	1.150	1.144	0.5
Copper	1.354	1.344	0.7	1.362	1.350	0.9
Lead	1.717	1.702	0.9	1.734	1.728	0.3

4. Conclusion

The Monte Carlo model, which was based on the EGSnrc code was built, tested and validated against experimental data. The Monte Carlo model was tested against PDDs and profile data which proved to replicate data within about 2%. The PDD distributions with and without the material were compared. In the region immediately distal to the material, the dose was less than dose without the material. This was due to fewer electrons produced by the material. This is believed to be due to a discontinuity in the photons producing electron fluence at this location. The DEF calculated at the interface increased with increasing photon beam energy as well as increasing material thickness. The accuracy of our model was validated by comparing the dose distribution calculated with TLDs. Good agreement (1.5%) between the DEF calculated in water and within a TLD was achieved. As photon energy increases, the energy of secondary electrons produced from the high-Z material increases. Even a 1.0 mm thick piece of lead may provide dose enhancement.

5. References

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