Dose reduction effect using thermoplastic bolus on the exit-depth-dose accumulation due to electron return effect: A Monte Carlo simulation study

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INTRODUCTION

In magnetic resonance guided radiotherapy, electron return effect is a phenomenon caused by magnetic field which enhances dose at interfaces with large density-difference which is from higher-to-lower density mediums, cf (Figure 1).

According to A.J. E Raaijmakers et al. [1], during irradiation without magnetic field (Figure 2.left), free electrons are generated that travel through the medium. This process causes a constant flux of electrons in a predominantly downstream direction. Dose deposition arises from these electrons losing energy along their path. At the exit-depth of the medium, the electrons enter the underlying space which is air medium and cause no more damage in the medium.

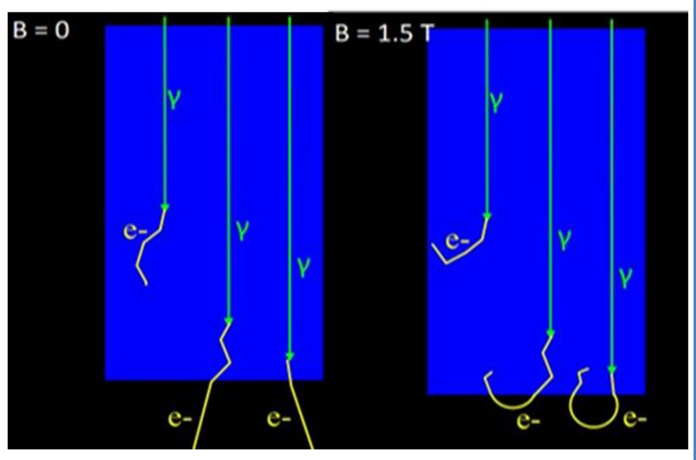

Figure 2: Schematic trajectory of a secondary electron traveling in (L) zero and (R) finite magnetic field [1].

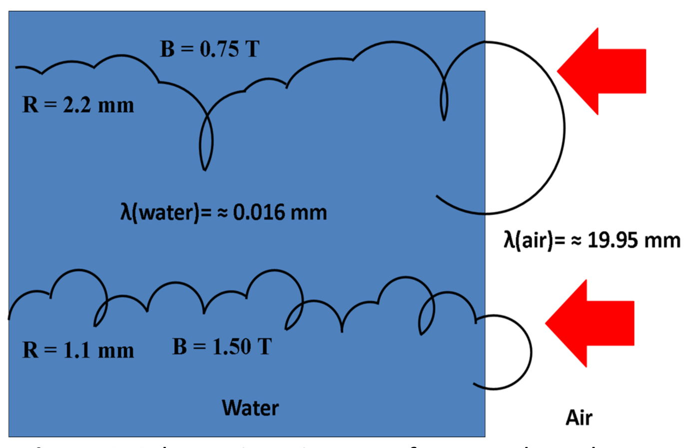

Figure 1: Schematic trajectory of a secondary electron traveling in different strength of magnetic field.

In the presence of a magnetic field (Figure 2.right), the trajectories of the electrons will be bent, describing a helix. Their mean free path length in the medium is short compared to their helical radius, thus, electrons will scatter from interaction to interaction, with curved trajectories in between. However, as soon as the electrons leave the medium and enter air, their mean free path length will be long and moves in a curved trajectories with less interactions such that it will re-enter the medium and effectively continue scattering at the opposite direction to accumulate high exit-depth dose.

MOTIVATION

Figure 3: Thermoplastic bolus

Attaching bolus at the exit-skin depth and applying MRgRT

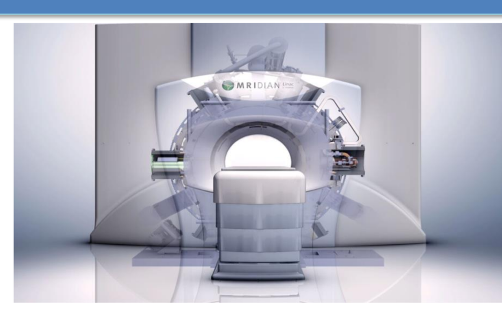

Figure 4: Magnetic resonance guided radiotherapy (MRgRT)

In realistic approach, human body skin is an interface between human tissue and air environment which is a low density medium. When applying magnetic resonance guided radiotherapy on the patient, the skin dose at the exit-depth of the patient's body will receive an heightened amount of dose build-up due to the electron return effect phenomenon. With this problem, the researchers come up with the solution which is to use thermoplastic bolus attached to the exit-skin interface of the patient's body in order to absorb the build up of dose.

MATERIALS AND METHODS

- **Monte Carlo Simulation**
  - Geant4 Application for Tomographic Emission (**GATE** version 8.0)
  - Dose actor for dose profile graphing
- **Target Phantom simulation Set-up**
  - **Tissue Phantom** (Phantom1) enclosed in air environment, cf. Figure 5.
    - Transverse magnetic field at (+y) direction.
  - **Tissue Phantom with thermoplastic LDPE/PTFE and ULDPE bolus** embedded at the exit-depth where ERE occurs, cf. Figure 5.
    - Thermoplastic boluses has thickness of 2 mm - 20 mm.
    - Transverse magnetic field at (+y) direction.
  - **Tissue-Bone-Skin Phantom** (Phantom2) enclosed in air environment
    - (0-91) mm is Tissue medium, (91-98) mm is Bone medium, and (98-100) mm is Skin medium.
    - Transverse magnetic field at (+y) direction.
  - **Tissue-Bone-Skin Phantom with thermoplastic LDPE/PTFE and ULDPE bolus** embedded at the exit-depth where ERE occurs.
    - Thermoplastic bolus has varied thickness of (2 mm - 20 mm)
    - Transverse magnetic field at (+y) direction.

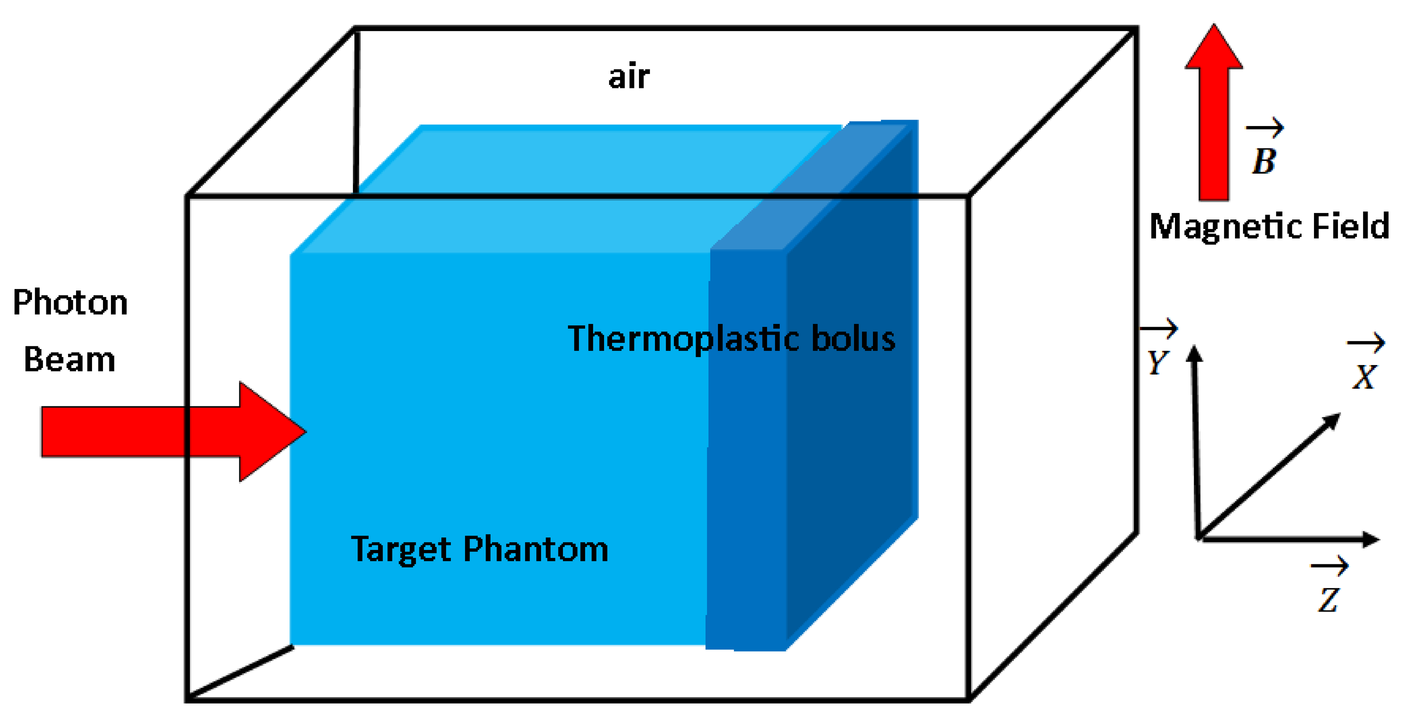

Figure 5: Target phantom embedded with thermoplastic bolus at the exit depth.

Simulation Process

- Figure 8 shows the simulation process on Tissue phantom and Tissue-Bone-Skin Phantom with and without thermoplastic LDPE/PTFE and ULDPE boluses.
- Each simulation has 200 million number of events and resulting root files are used to get histogram of depth-dose distributions using C++ codes via Root.
- Also, calculation of percent dose difference was done to confirm the dose reduction effect of thermoplastic boluses.

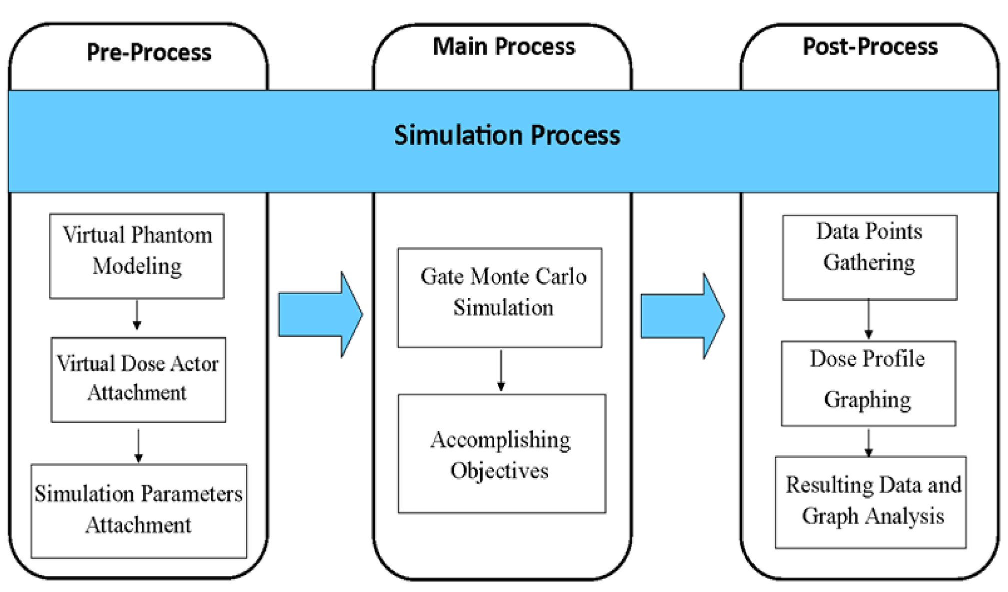

Figure 8: Simulation process

OBJECTIVE

- This research aim to investigate the used of thermoplastic bolus with different thickness and density at the exit skin-interface to reduce the dose deposition accumulated on the exit-skin interface where ERE occurs due to the transition of medium to air environment. The dose reduction effect of this thermoplastic bolus on the accumulation of dose was investigated using Monte Carlo simulation via the GATE toolkit.

RESULTS

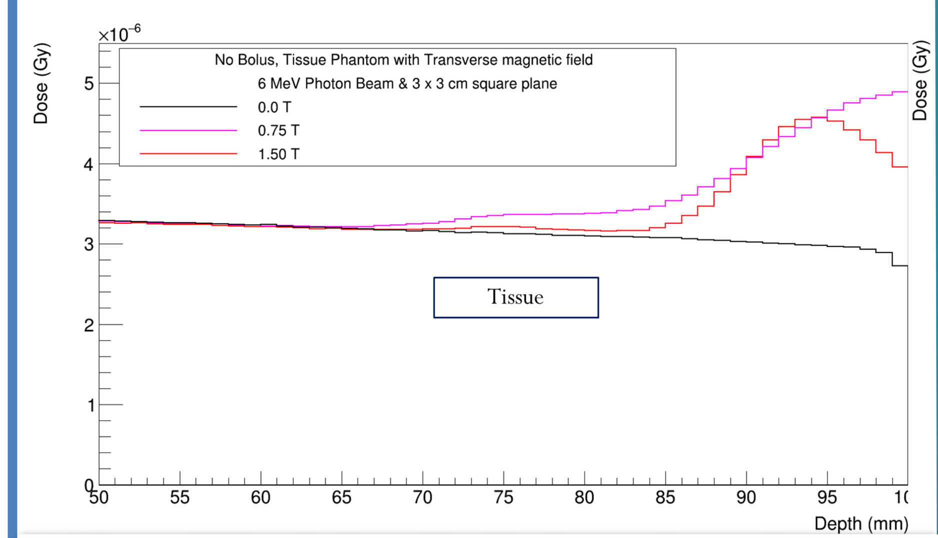

Figure 7:Depth-dose distribution at tissue phantom with the presence of transverse 0.75 and 1.5 T magnetic field.

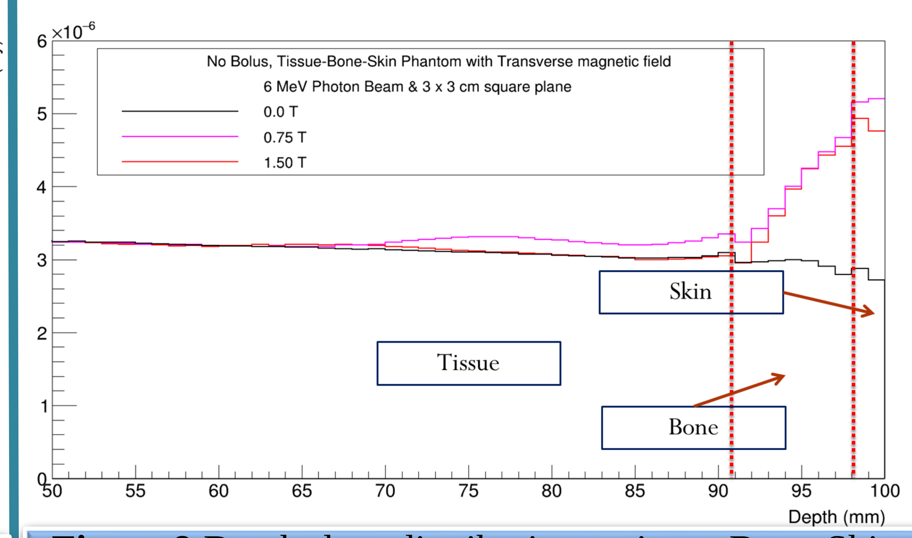

Figure 8:Depth-dose distribution at tissue-Bone-Skin phantom with the presence of transverse 0.75 and 1.5 T magnetic field.

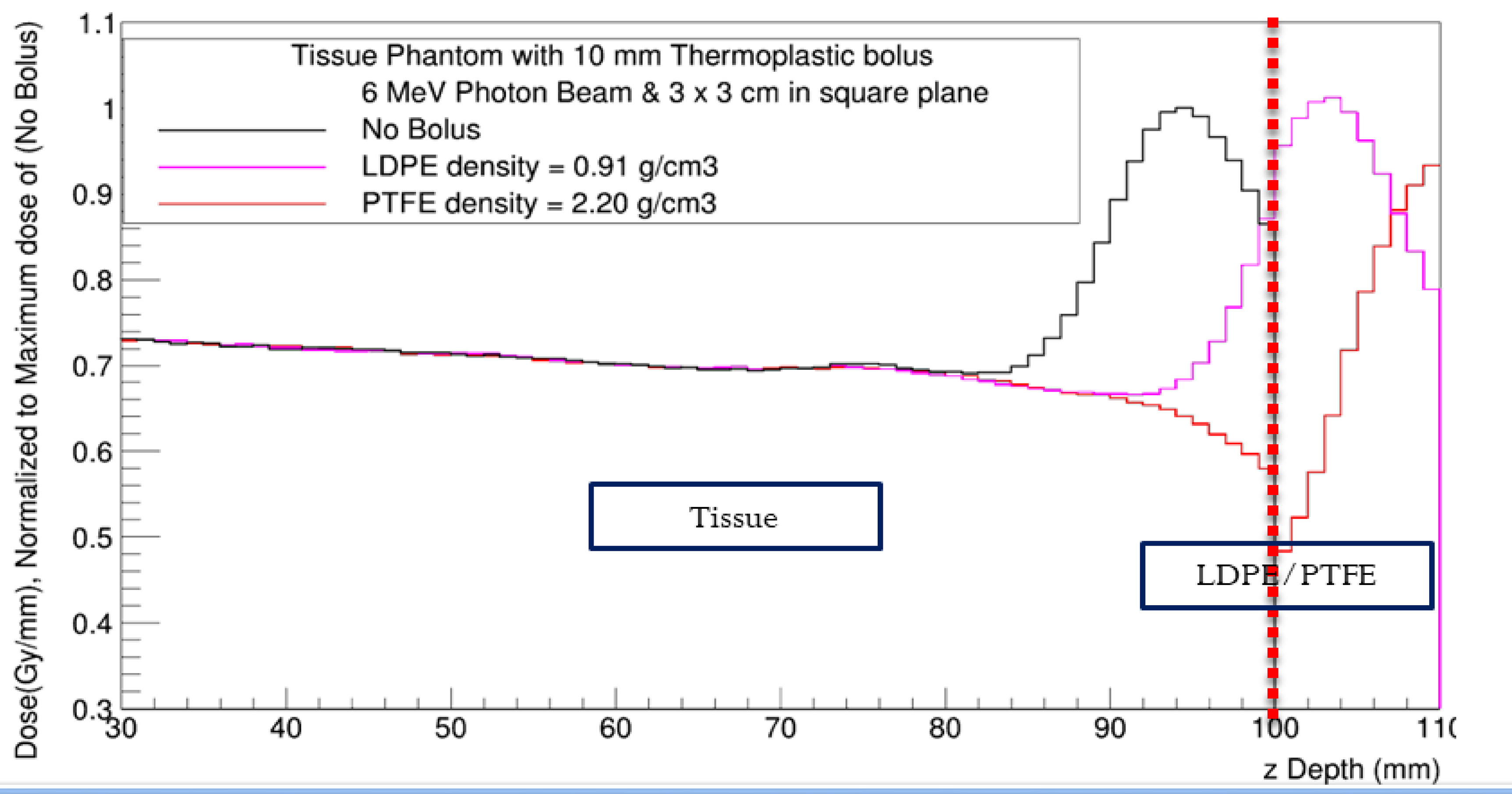

Figure 9:Depth-Dose Profiles at Tissue phantom embedded with LDPE/PTFE thermoplastic bolus with 10 mm thickness at the exit-depth with the presence of transverse 1.5 T magnetic field.

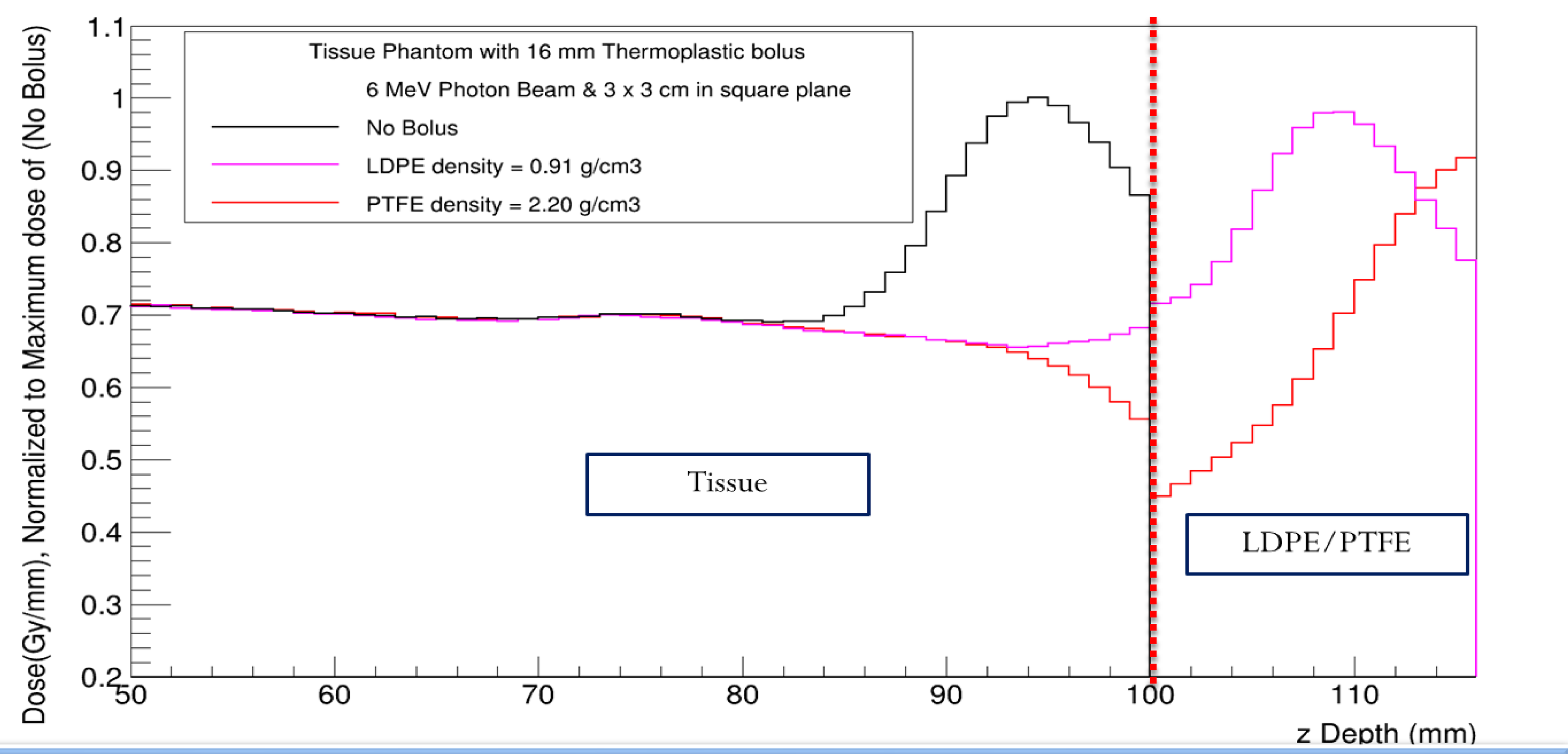

Figure 9:Depth-Dose Profiles at Tissue phantom embedded with LDPE/PTFE thermoplastic bolus with 16 mm thickness at the exit-depth with the presence of transverse 1.5 T magnetic field.

Bolus' thickness	Dose Difference (DD)	PDD	Total Absorbed Dose
10 mm, LDPE	1.28×10^{-5} Gy	75.77%	4.27×10^{-5} Gy
10 mm, PTFE	1.71×10^{-5} Gy	101.36%	3.33×10^{-5} Gy
16 mm, LDPE	1.57×10^{-5} Gy	92.76%	6.28×10^{-5} Gy
16 mm, PTFE	1.71×10^{-5} Gy	101.50%	4.84×10^{-5} Gy

Table 1: Dose Difference (DD)/PDD over total accumulated dose and Total absorbed dose of LDPE/PTFE using 1.5T at Tissue phantom.

Bolus' thickness	Reduced by Factor dose of	Reduced by Factor dose percentage of	Total Absorbed Dose
10 mm, LDPE	9.44×10^{-6} Gy	87.45%	4.56×10^{-5} Gy
10 mm, PTFE	1.25×10^{-5} Gy	115.45%	3.43×10^{-5} Gy
16 mm, LDPE	1.15×10^{-5} Gy	106.12%	6.55×10^{-5} Gy
16 mm, PTFE	1.27×10^{-5} Gy	117.37%	4.93×10^{-5} Gy

Table 2: Dose Difference (DD)/PDD over total accumulated dose and Total absorbed dose of LDPE/PTFE using 1.5T at Tissue-Bone-Skin phantom.

CONCLUSION

We were able to investigate the dose reduction effect of a low density thermoplastic bolus: Low Density Polyethylene, LDPE and high density thermoplastic bolus: Polytetraflorouethylene, PTFE at two different phantoms which are Tissue phantom and Tissue-Bone-Skin phantom with transverse magnetic field. The PDR and Dose profiles show that LDPE and PTFE thermoplastic bolus at Tissue phantom with 1.50 T reduce the exit-depth dose accumulation at 92% of 16 mm LPDE and 101% of 10 mm PTFE; Also, LDPE and PTFE thermoplastic bolus at Tissue-Bone-Skin phantom with 1.5 T reduce the exit-depth dose accumulation at 106% of 16 mm LPDE and 115% of 10 mm PTFE.

ACKNOWLEDGEMENT AND REFERENCE

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[1] Raaijmakers, A.J.E., Raaymakers, B.W. and Lagendijk, J.J.W. (January 2008). Magnetic-field-induced dose effects in MR-guided radiotherapy systems: dependence on the magnetic field strength. Phys. Med. Biol. 53 (2008) 909-923.