

Impact of Thick Range Shifters on Neutron Dose in Conformal Proton FLASH Therapy

Anna Becker^{1,6}, Lara Dippel^{2,6}, Kim Giebenhain^{2,6}, Kilian-Simon Baumann^{1,3,4,6}, Hans-Georg Zaunick^{2,6}, Kai-Thomas Brinkmann^{2,6}, Klemens Zink^{1,4,6}, Uli Weber^{1,5,6}

¹University of Applied Sciences Mittelhessen (THM), Giessen

²Justus Liebig University, Giessen

³University Hospital Giessen-Marburg, Clinic for Radiation Oncology, Marburg

⁴Marburg Ion Beam Therapy Center, Marburg

⁵GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt

⁶LOEWE Research Cluster Advanced Medical Physics in Imaging and Therapy (ADMIT), University of Applied Sciences Mittelhessen, Giessen

Introduction

FLASH radiotherapy employing ultra-high dose rates (UHDR) has shown significant healthy tissue sparing while maintaining tumor control comparable to conventional dose rates [1]. Achieving UHDR with protons typically requires cyclotrons operating at maximum energy without a degrading system. To produce conformal depth-dose distributions under these conditions, 3D range modulators (3DRM) can be used in combination with thick range shifters [2, 3]. However, introducing these additional beamline components near the patient increases secondary neutron production and thereby elevate the risk of secondary malignancies [4]. This study examines how neutron production is affected by thick range shifters through comprehensive Monte Carlo (MC) simulations. A preliminary experimental benchmarking was performed with a commercial neutron rem counter detector.

Material and Methods

MC simulations were performed with TOPAS v3.9. Using the Marburg Ion Beam Therapy Center (MIT) as a real-world reference, the MC model incorporated a full implementation of the MIT nozzle and treatment room walls to facilitate experimental comparison. A proton pencil-beam of maximal machine energy (222.7 MeV) was directed at a water phantom placed at isocenter, with the range shifter placed upstream (Fig. 1). Various thicknesses of Aluminum (5, 10, 14 cm) and PMMA (9.3, 18.6, 26 cm) were modelled and compared. Neutron spectral fluence was scored at four out-of-field positions at 0°, 45°, 90°, and 225° relative to the beamline. Scoring filters were applied to determine component-specific contributions to neutron production. Neutron ambient dose equivalent $H^*(10)$ was calculated from the spectra using ICRP-74 [5] conversion factors, and simulation results were compared to $H^*(10)$ measurements performed at MIT with a Berthold LB6411 neutron rem counter for all investigated setups.

Results

Range shifters substantially increased neutron dose, with enhancement factors of 1.2–6.1 for PMMA and 1.2–10.5 for Aluminum depending on range and detector position (Fig. 2). Neutron-origin analysis identified the range shifter as the dominant source, followed by the water phantom. Room-scattered neutrons accounted for 8–25% of the total, indicating that

room modeling must not be neglected. Measured and simulated $H^*(10)$ values showed acceptable agreement across all investigated setups.

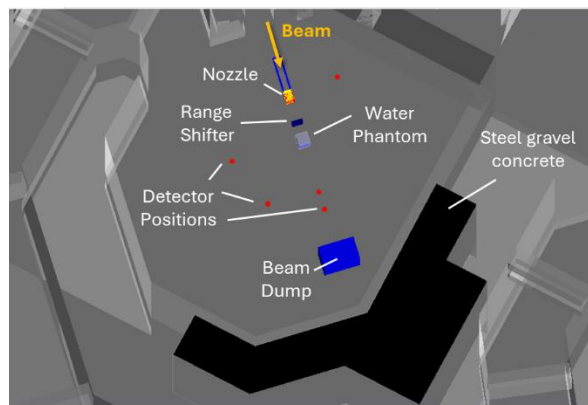


Fig. 1: Simulation geometry in TOPAS.

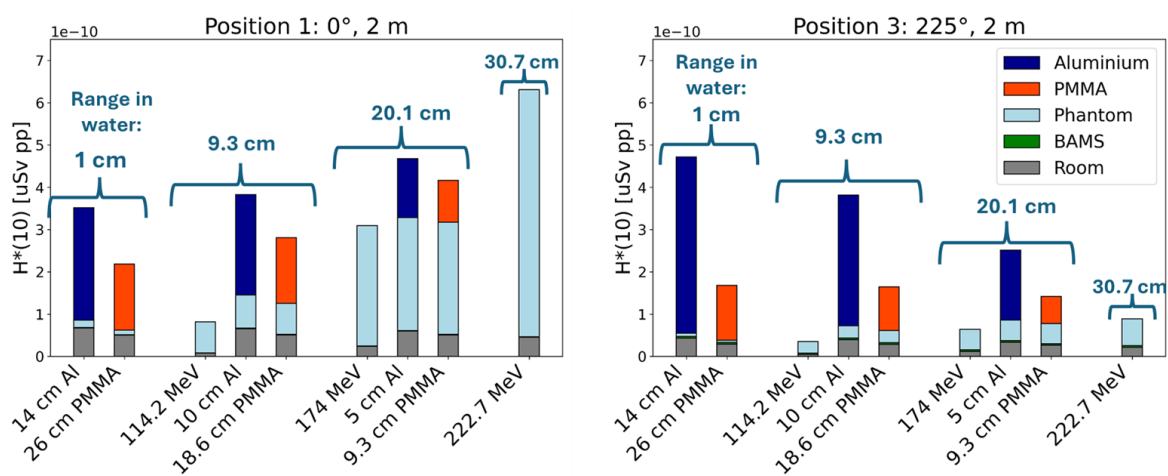


Fig. 2: Neutron ambient dose equivalent $H^*(10)$ for setups with and without range shifter.

References

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