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Out-of-field Dosimetry and Microdosimetry in Clinical and FLASH Proton Therapy

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In this work, a method for enhanced detection and imaging of the radiation field generated in pencil beam scanning (PBS) proton therapy delivered at conventional and ultra-high-dose rates (UHDR) is presented. This work specifically aims to quantify the dose, flux and linear energy-transfer spectra (LET) of the stray radiation measured outside the target volume including contribution from thermal neutrons.
A semiconductor pixel detector Timepix3 with silicon sensor in miniaturized electronics [1] was used to image particles including thermal neutron fields produced in a water phantom. The experiments were carried out at the Proton Therapy Center Czech (PTC), Prague, Czech Republic, using clinical proton beams and at the University Proton Therapy Dresden, Germany, using UHDR proton beams both produced by IBA isochronous cyclotrons. The detector equipped with a neutron converter attached to a part of the sensor (Fig. 1b) was prior calibrated at reference radiation fields at the Czech Metrology Institute, Prague, Czech Republic [2], including the thermal neutrons. Interactions of various types of particles were recognized and discriminated using pattern recognition and artificial intelligence algorithms and compared to Monte Carlo (MC) simulations. The 2D visualization of the integrated mixed radiation field outside the target volume in the region marked on Figure 1e at a depth of 15 cm in water is displayed in Figure 2. An example of particle discrimination of thermal neutron interactions from mixed field is shown in Figure 2c. The flux of stray particles including protons, heavier ions, thermal neutrons, photons and electrons was measured and compared to MC simulations. Furthermore, the flux of thermal neutrons from Figure 3 is converted into equivalent dose [2]. Results of dose rate measurements in conventional and UHDR proton beams were provided for individual classes of particles. The thermal neutron field in the mixed-radiation stray fields of PBS proton therapy can be measured with high discrimination by the Timepix3 detector. Such detailed spatial mapping of thermal neutrons has an application in, for example, out-of-field dosimetry and research in Neutron Capture Enhanced Particle Therapy [3]. Besides thermal neutrons and protons a large flux of electrons and gamma rays was also measured. Moreover, in the plateau region of the Bragg curve, secondary ions were identified. These findings underscore the importance of comprehensive radiation characterization for optimizing therapeutic outcomes and ensuring patient safety.

Reference:

[1] Oancea, et al. (2023) Out-of-field measurements and simulations of a proton pencil beam in a wide range of dose rates using a Timepix3 detector: Dose rate, flux and LET. Physica Medica, 106, 102529. https://doi.org/10.1016/J.EJMP.2023.102529
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