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Matthias Würfl

Towards Offline PET Monitoring at a Cyclotron-Based Proton Therapy Facility

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Matthias Würll
Garching, Germany

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Matthias Würl

Abstract

For the full clinical exploitation of the ballistic advantages of proton beams for radiation therapy, accurate knowledge of the location of dose deposition in tissue is necessary. A dedicated tool for monitoring the dose deposition in-situ and in vivo is positron emission tomography (PET). The implementation of this method requires a detailed Monte Carlo model of the clinical proton beamline for the exact dose calculation and β^+ -activity prediction. For the latter, reliable cross-section data of the β^+ -emitter production channels is needed.

The purpose of this work was therefore to perform two fundamental steps towards the implementation of offline PET monitoring at the Rinecker Proton Therapy Center (RPTC). First, a correct modeling of the proton beam spot scanning and the absolute dose output was established. This included a study of the influence of the low-dose envelope of scanned proton beams on the total dose output. Monoenergetic square fields, as well as homogeneous dose spheres of different sizes were planned with the treatment planning system (TPS) XiO[®], and its predicted dose compared to measurements and simulations. Simulated doses agreed nicely with measurements for all square and sphere sizes, but for small squares and spheres the dose predicted by the TPS significantly differs. For treatment plans including small fields it is therefore recommended to verify planned doses by measurements or MC simulations prior to patient irradiation.

The second step towards offline PET monitoring was to validate an experimental cross-section data set at the RPTC for the most relevant β^+ -production channels. For this purpose, 3 phantom materials (PE, gelatine and PMMA) were irradiated and the proton-induced activity was measured by a full-ring PET/CT scanner. Production yields were extracted from the measured activities and compared to calculated yields from FLUKA MC simulations and data from HIT and GSI. Integral positron emitter yields measured at the RPTC are comparable to simulated yields using experimental cross-sections. Comparison to simulation results using the internal hadronic model of FLUKA for calculating β^+ -emitter yields confirms the findings of previous publications, which recommend to use experimental cross-sections instead. The largest difference to the data from HIT is 18.3%, whereas yields are heavily overestimated at GSI. The scatter correction applied by the

relatively old scanner during PET image reconstruction displaces a significant amount of activity at locations far beyond the proton penetration depth. Therefore, no fine-tuning of the production cross-sections could be performed due to the unreliability of the reconstructed activity spatial distributions for the considered irradiation scenarios.

In order to check the linearity of the PET scanner with the activity level, further irradiations and measurements were performed with different numbers of delivered protons. These data could confirm that due to dead time losses, the scanner underestimates measured activities with increasing level of phantom activation. This resulted in an underestimation of production yields by up to 8% for the PE phantoms. Instead of delivering as much protons as possible for the sake of good statistics in the dynamically evaluated PET images, a trade-off between high count-rate and dead time losses has to be made when performing thick phantom experiments to validate and fine-tune cross-sections for PET monitoring.

Munich, December 2015

Matthias Würfl

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