Monte Carlo simulations for the in-beam PETITION PET scanner

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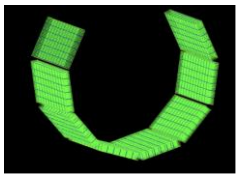
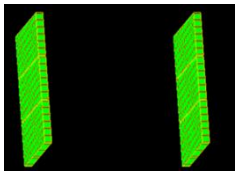
Background: In the context of the PETITION (PET for InTensive care units and Innovative protON therapy) project, a PET scanner is being developed for range verification and online hypoxia guided proton therapy for Gantry 2 at PSI (Paul Scherrer Institute). It is designed as a table mounted system with an opening for proton irradiation and can rotate in steps of 90º to allow treatment from multiple directions. This simulation-based work investigates the PETITION open-ring geometry (Fig 1a) in comparison to the conventionally used two panel geometries (Fig 1b) for in-beam imaging.

Material and Methods: The GATE Monte Carlo (MC) [1] toolkit was used to simulate a point Na^{22} (radius = 0.3 mm) source embedded in a plastic cube (1 cm^3) filled with 1 MBq of activity. Absolute sensitivity and spatial resolution (FWHM) of the two scanner geometries were determined for comparison. Furthermore, the proton beam activation within a head phantom was recorded using the FRED MC code [2]. The activation was simulated using GATE with the PETITION open ring configuration and the image was reconstructed to assess the scanner performance. SSIM (Structure Similarity Index Measure) was computed to compare the reconstructed image of the activation to the expected image.

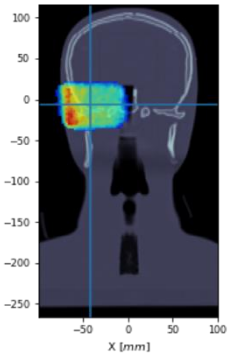
Results: Absolute sensitivity at the center of the Field of View (FOV) is 1.48 % for the open ring configuration compared to 1.08 % for the conventional dual panel configuration. Spatial resolution is in the order of 2.5 mm FWHM for the open ring geometry as compared to 3 mm FWHM for dual panel configuration at the center of the FOV. The expected improvement in the sensitivity and spatial resolution over conventional scanner configurations is essential for improving the reconstructed image quality with limited statistics during online range verification. SSIM between the reconstructed and expected phantom activation from the proton beam is estimated to be 0.77. Reconstructed and expected images have some differences as indicated by the SSIM metric which primarily come from the artefacts due to the opening. The simultaneous reconstruction from the four possible scanner orientation corrects for this artefact, thereby, restoring the SSIM to 0.92. Furthermore, we have to take into account that the expected image indicates an ideal image without any noise modelling.



a. PETITION open ring configuration



b. Dual panel configuration



c. Reconstructed head phantom activation using the PETITION open ring configuration

Fig 1. PET scanner geometries used for the simulations as visualized in GATE and the reconstructed activation image.

References:

[1] S Jan et al. (2004) Phys. Med. Biol. **49:** 4543

[2] A Schiavi et al. (2017) Phys. Med. Biol. **62**: 7482–7504