SENSITIVITY ANALYSIS OF PARAMETERS AFFECTING OPTICAL PHOTON TRANSPORT IN PLASTIC SCINTILLATING FIBRES USING GEANT4

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Introduction: We have developed a novel x-ray detector prototype comprising a plastic scintillating fibre array (PSA) for imaging and dosimetry in radiotherapy [1]. To inform the development of an optimised next-generation detector, a Monte Carlo (MC) model of the prototype was created [2]. The aim of this study was to investigate the sensitivity of the MC model to changes in optical transport parameters unspecified by the prototype manufacturer.

Materials and methods: A MC model of our prototype was developed with Geant4 (v10.2) using the electromagnetic and optical physics modules. The geometry consisted of a PSA coupled to the photodiode array of an electronic portal imaging device (EPID). The PSA comprised polystyrene fibres with a PMMA cladding and extra-mural absorber (EMA) to prevent optical cross-talk. The EMA optical attenuation properties were unspecified by the manufacturer, as was the nature of the boundary between the fibre core and cladding. Sensitivity of the detective quantum efficiency (DQE) to variations in these parameters was quantifed with *G4OpticalSurfaces* to manipulate optical reflection/attenuation at these boundaries. The fraction of photons attenuated by the EMA was varied between 10-100% and the core/cladding interface was simulated as a polished or ground surface with specular spike, specular lobe or diffuse lobe reflection properties.

Results: Figure 1 shows how the different mechanisms of optical reflection at the fibre core/cladding boundary affected photon trajectories and the distribution of photons detected upon exiting the fibres. Specular spike, specular lobe and diffuse lobe reflection processes introduced additional noise into the MC model that significantly decreased the calculated DQE relative to that of an ideal, polished boundary (Figure 2). The best fit between MC-calculated and measured DQE (DQE(0) ~3%) was obtained by simulating specular spike or lobe reflection at the fibre core/cladding boundary with an imperfect EMA attenuating 50% of incident optical photons and thereby introducing optical cross-talk. When considering the ideal case of 100% EMA absorption and a polished core/cladding boundary, DQE(0) was increased to ~8%. In all cases, the PSA-EPID DQE exceeded that of a standard commercial EPID.

Conclusions: Geant4's *G4OpticalSurfaces* are valuable tools for simulating optical processes at the material boundaries within plastic scintillating fibres. The PSA-EPID model was sensitive to variations in both EMA attenuation and roughness of the fibre core/cladding boundaries, with increases in these parameters decreasing the MC-calculated DQE.

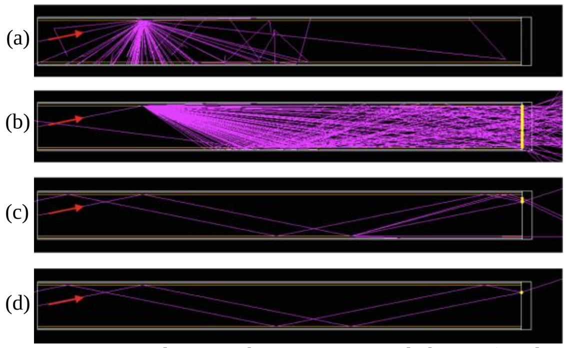

Figure 1. Visualisations showing 100 optical photons (incident from the red arrow) propagating along a single fibre when simulating the core/cladding boundary as a: (a) polished reflector; (b) specular spike reflector; (c) specular lobe reflector; and (d) diffuse lobe reflector. Detected photons are indicated as yellow dots.

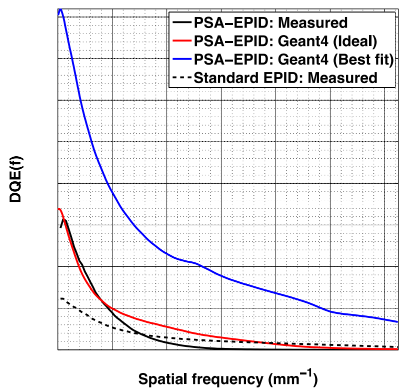

Figure 2. DQE measured with the prototype PSA-EPID and simulated using the Geant4 model. Simulation results were generated using ideal values for the uncertain parameters as well as values that best fit the measured data. The DQE measured using a standard commercial EPID is also shown for comparison.

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References:

1. S. Blake et al. *Med. Phys.* **40**, 091902 (2013).
2. S. Blake et al. *Phys. Med.* **32**, 1819-26 (2016).
3. Geant4 Collaboration (S. Agostinelli et al.), *Nucl. Instrum. Meth. Phys. Res*. A **506**, 250-303 (2003).