Monte Carlo Modelling of Small Field Dosimetry: Non-ideal Detectors, Electronic Disequilibrium and Source Occlusion.

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Small photon fields are used to deliver two important modern radiotherapy techniques, stereotaxy and intensity modulated radiotherapy. Accurate characterisation of small-field dosimetry requires measurements with precisely aligned specialised detectors and is thus time-consuming and error-prone. At field sizes below 3 cm, electronic equilibrium may not be established on central axis so the profiles will be peaked. The fluence perturbations caused by finite detector size and any measurement geometry inaccuracies are more significant, and new phenomena, such as occlusion of the photon source edges by the linac jaws, will be apparent.

A Monte Carlo model of a 15 MV photon beam was validated against precise large-field measurements and then used to predict small-field dosimetry. The sensitivity of small-field dosimetry to a wide range of parameters including measurement misalignments and variation of focal spot width was investigated with the Monte Carlo model. The effects of detector geometry, atomic composition and physical density on dosimetric measurements were also evaluated.

Due to their small sensitive cross-sections, unshielded diodes were expected to produce some of the most useful data. The Monte Carlo model correctly predicted diode-measured PDDs and profiles for field sizes down to 0.5 cm. Whilst the agreement between modelled and measured output factors is good over the range 1 to 10 cm there is a significant discrepancy for very small fields. The variation with depth or field size of both the silicon:water mass stopping power ratio and mass energy absorption coefficient ratio is minimal. Monte Carlo modelling shows that the overall response of the unshielded diode is constant with field size between 1 and 10 cm. However, a correction of 3% is needed for a field size of 0.5 cm. Analogous correction factors have been calculated for diamond and air detectors.

The output factor for very small fields is shown to be extremely sensitive to focal spot width, mainly due to the influence of source occlusion however the small-field phantom scatter factor also changes with extreme variations of spot width.

Thus, while Monte Carlo models based exclusively on large-field data can quite accurately predict small-field profiles and PDDs, in the absence of experimental methods of determining initial electronbeam profile it will remain necessary to measure small-field output factors, fine-tuning modelled spot sizes to ensure good matching between the Monte Carlo and measured output factors.

Finally while both the silicon:water mass stopping power ratio and mass energy absorption coefficient ratio do vary slightly with field size and depth, the more significant cause of error when using small detectors is the non-water like density. The distortion of the electron fluence (compared to that of the undisturbed medium) by the dense silicon diode not only increases the measured small-field output factor but also artificially slightly narrows the profile as the integral dose remains constant, making it hard to correct for. This distortion is much greater for either air or diamond so the silicon diode remains the optimum choice of detector.

Papers resulting from this work

1. **Scott AJD,** Nahum AE and Fenwick JD 2008 Using a Monte Carlo model to predict dosimetric properties of small radiation fields. *Med. Phys.* **35** 4671-4684
2. **Scott AJD**, Nahum AE and Fenwick JD 2009 Monte Carlo modeling of small photon fields: quantifying the impact of focal spot size on source occlusion and output factors, and exploring miniphantom design for small-field measurements. *Med. Phys.* **36** 3132-3144
3. **Scott AJD**, Nahum AE and Fenwick JD, The density dependence of detector response to non-equilibrium small photon fields, submitted to *Radiother. Oncol.*