Simulation of Radiation Dose From Diagnostic X-ray Beams

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Abstract

The use of calorimetry for the direct realization of absorbed dose from radiotherapy beams is widely known and forms the basis of national primary standards throughout the world. For beams used in diagnostic procedures such as x-ray CT, however, the doses and associated thermal effects are much smaller, posing significant technical challenges for successful implementation of a calorimetric standard.

The present study is to address the radiation-induced chemical reactions in previous work1 involving the AAPM TG200 high-density polyethylene (HDPE) phantom by replacing the small sensor core with polystyrene which has no heat defect in low-energy x-rays. As this work builds upon the earlier approach, employing two small thermistors as temperature sensors (wired into a Wheatstone bridge and monitored via lock-in detection), embedded in a removable "core" element (1.5 cm dia. x 2 cm cylinder) that exactly fits into a small cavity milled into the base of a cylindrical HDPE phantom (26 cm dia. X 10 cm) along the axis (Fig. 1). The thermistors in the PS core are about 0.3 mm dia., much smaller than the ones in the PE core. Two cores were used interchangeably under identical configurations.

Measurements were conducted with each core element under identical beam settings in a Philips Gemini-TF clinical PET-CT scanner, a16-slice CT scanner with a 120 kV, 250 mA beam at 16x1.5 mm collimation. Consecutive 30 axial cycles were recorded at a nominal dose of 17 mGy/cycle, as determined by a calibrated ionization chamber (Radcal CT Reference Class). Representative experimental traces from the lock-in amplifier obtained for runs conducted with PE and PS cores are shown in Fig.2. The chamber and calorimeter traces exhibit pulses associated with the ~2.8 s gating of the CT beam, closer inspection of which reveals a complicated time structure that cannot be easily analyzed for shot-to-shot dose estimates. Aggregate doses accumulated over the pulse sequence are obtained as the difference between the final tail of each trace and the pre-irradiation drift segment; the PS data exhibit a thermal response much closer to that of the chamber. The higher PE response is a combination of greater excess heat from the larger amounts of thermistor materials in addition to the expected heat defect.

The non-reproducibility evident in the calorimeter traces (for each core) is believed to be a consequence of uncontrolled heat transfer. The timing structure observed within each cycle needs further investigation in order to extract shot-to-shot doses delivered by the machine, at

which point the defect in PE can be evaluated. COMSOL Multiphysics® simulation was previously carried out for the PE core, showing significantly lower thermal response than that measured experimentally. Remodeling using polystyrene is being planned.

Figures used in the abstract

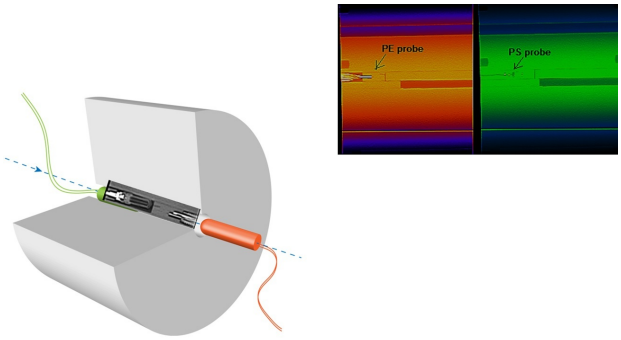

Figure 1: Left: thermistor and ion chamber insert inside of the HDPE phantom. Righ: CT images of thermistor probes embedded in different materials inserted in the phantom.

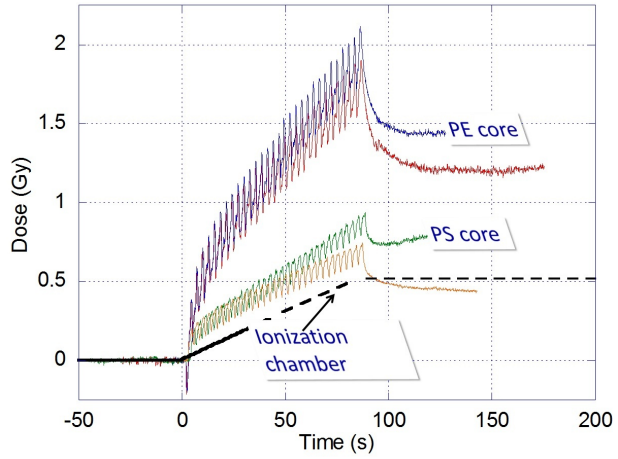

Figure 2: Time dependence of dose as determined by the temperature rise in the material, during the 30 cycle axial scans. The change in temperature caused by the CT beam is in the range of 20 to 30 microK per cycle, depending on the heat capacity of the material. The pre-irradiation trends due to temperature drift were subtracted for all curves. The ionization chamber measurement was conducted for 15 cycles, and the extrapolated value for 30 cycles is plotted as the nominal dose for these measurements.