Simulation of Radiation Dose Response in Phantom for CT

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Abstract

X-ray CT is widely used in diagnostics medical imaging. The radiation dose produced by the scanner to the patient is conventionally referenced to measurements performed by an ionization chamber in a phantom of tissue equivalent characteristics. On a fundamental level, the radiation absorbed dose, J/kg, can also be determined directly by the temperature rise in the absorbing material. We have performed preliminary measurements using this calorimetric method to determine the CT dose at a point in a high density polyethylene (HDPE) phantom as a medium. The expected temperature rise in PE is about 0.6 mK per Gy. A typical CT scan delivers a dose of 10s of mGy. Measurements were performed in a 16-slice medical CT scanner at 120 kVp. For the purpose of this study, an elevated dose is delivered by using twenty consecutive axial scans at 250 mA, which delivers a nominal total dose of 705 mGy in 50 s.

Use of COMSOL Multiphysics: To help understand and verify the measurement results, a model of polyethylene block with axial symmetry was studied using the module governing heat transfer in solids with a transient response. The x-ray beam in a CT machine which rotates at 2.8 s per complete cycle was simulated using a planar heat source having the 2.8 s on/off cycle. The sensing thermistors were also modeled using glass and metal materials. A time waveforms of the temperature rise at a given point in the phantom was obtained from the solution. The simulation was first performed with a pure PE phantom. A relatively smooth temperature waveform was obtained (Figure 1, lowest curve) that has a final temperature rise only about ¼ of that measured (highest curve), with a much lower contrast for the beam on/off transitions after each 2.8 s cycle. To simulate the measured temperature waveform, the glass and wire materials were added according to the dimensions and estimated compositions into the model. The result (middle curve) resembles more of the experimental data, but the final magnitude is still too low, possibly from underestimating the input CT beam power, and will be further investigated. However, the oscillatory response of each cycle is clearly shown, indicating that the contribution to that part of the measured temperature rise mainly came from the glass/wire component of this device. The ultimate goal of this work is to lead to a PE calorimeter for CT dosimetry. While the measurements can be performed in one spatial location per sensor at a time, the simulation can provide an entire temperature distribution in the whole phantom, which essentially gives the dose map in 3D. However, this calculation must be verified by measurement, and in turn the measurement data has to be corrected for the response due to non-phantom material, which in this case is non-trivial. The preliminary study presented here shows that the calorimetry approach is feasible, and can provide complementary information to the current practice in CT dosimetry based on ionization

measurements and Monte Carlo calculations.

Figures used in the abstract

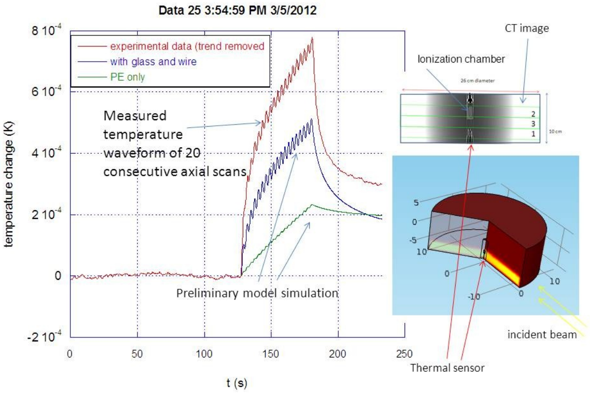

Figure 1: COMSOL model and transient temperature response for a polyethylene phantom with axial symmetry and with a spatially restricted heat source simulating a time averaged rotating CT beam with 20 periodic cycles (2.8 s per rotation). The green curve is the COMSOL output obtained with the PE phantom without incorporating the sensing thermistors into the model. The blue curve is the output with certain amount of glass and metal added to simulate the thermistors and wire, and the red curve is the experimentally measured data.