Simulation of Radiation Dose from Diagnostic X-ray Beams

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Introduction: This work started as developing a calorimetric standard for the direct realization of absorbed dose for x-ray diagnostic beams (such as x-ray CT). The CT dose standard is a simple cylinder of PMMA (current CTDI standard) or high density polyethylene (proposed AAPM TG200 standard). The present study is to compare the heat properties of water and polyethylene in a simple geometry to simulated human tissues in a more realistic human phantom in a CT beam setting. This serves the purpose of relating the measurements performed in a simple geometry to the much more difficult determination of in-vivo dose.

Computational Methods: Time dependent teat transfer in solids based on

$$\rho C_p \frac{\partial T}{\partial t} - \nabla \cdot (k \nabla T) = Q$$

was simulated in water, polyethylene, and a human chest phantom created using CT DICOM data available on the public image archive and ScanIP (Simpleware) software. The heat source term was simulated based on radiation energy transfer (taking into account both attenuation and absorption). Materials radiation and thermal properties were obtained from the NIST XCOM data base and the ITIS human tissue thermal data base (Table 1). For the energy conversion to radiation dose, we assume $D=\Phi E\mu_{en}/\rho$, where Φ is the photon fluence, E the photon energy (60 keV is used for this study), μ_{en}/ρ the mass energy-absorption coefficient, yielding a quantity of Gy (J/kg).

Table 1. Thermal and radiation properties

	Cp (J/kg/deg)	k (W/m/deg)	density (kg/m3)	mu/rho 60keV	mu_en/rho 60 keV
lung	3886	0.39	394	2.05E-01	3.28E-02
muscle	3421	0.49	1090	2.05E-01	3.26E-02
bone	1313	0.32	1908	3.15E-01	1.40E-01
water	4180	0.6	1000	2.06E-01	3.19E-02
PE	1900	0.38	930	1.97E-01	2.24E-02

Results: For convenience, a 1 Gy/min dose rate in water (much higher than real CT use) was assumed, following the timing structure of a rotating fan beam with an opening angle of 57 deg, at 2 s rotating cycles and sampling at 0.1 s intervals. Fig. 1 shows the temperature distribution in a uniform water cylinder (26 cm diameter) after 10 s of total irradiation. For visualization purposes, the fan angle was reduced to 15 deg to show the spatial distribution. Fig. 2 is the corresponding temperature distribution in the chest model.

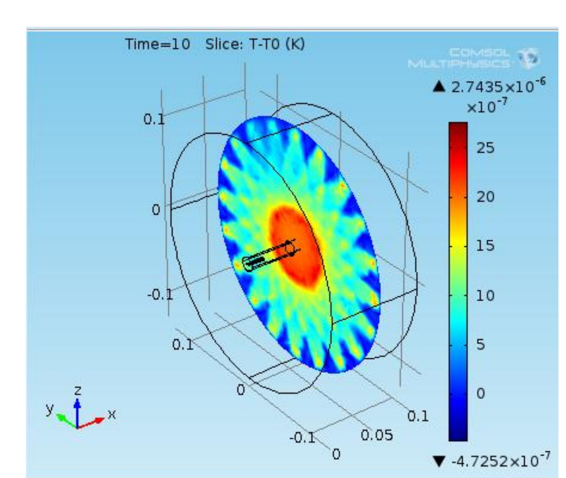

Figure 1. Simulated temperature profile in a cylinder of water or polyethylene.

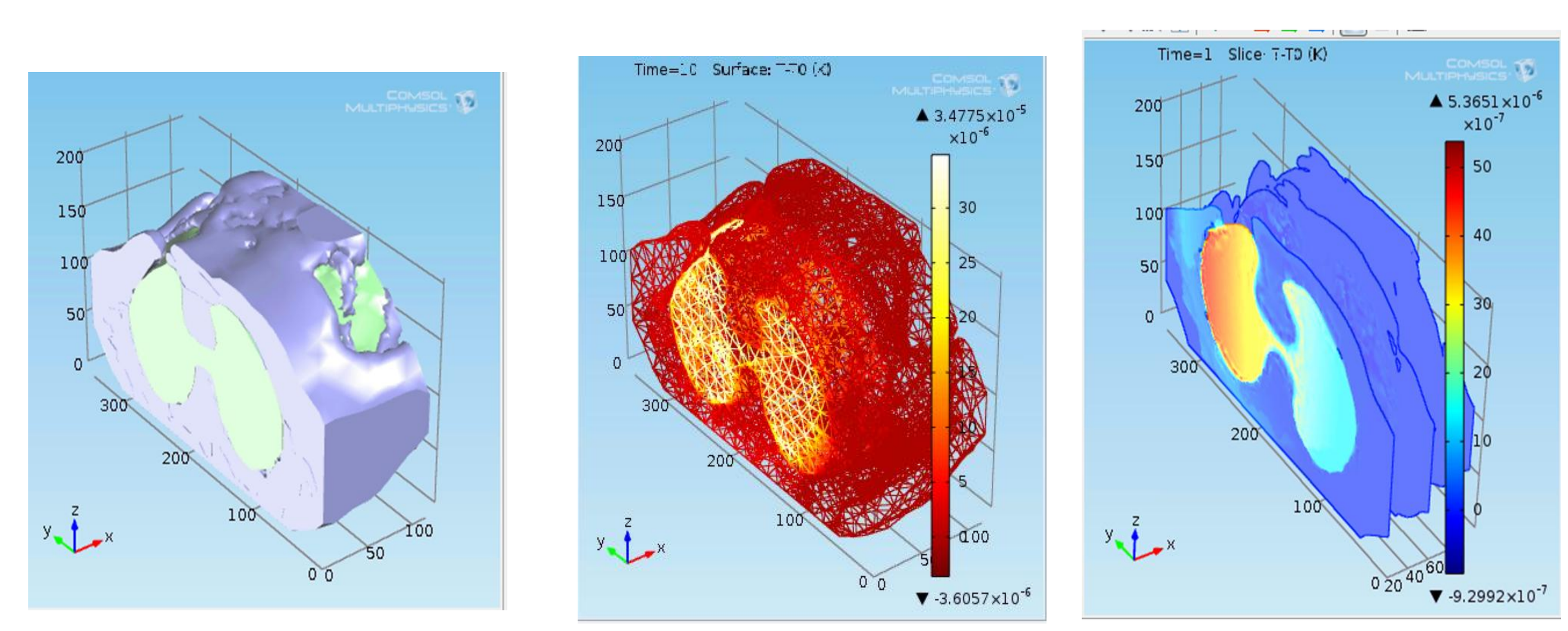

Figure 2. A human chest model (mesh size 5 mm) segmented into lung, chest wall, and bone domains and the temperature response in the same CT beam.

Conclusions: The thermal response was assessed for a simple standard geometry to a more complex human phantom. The simulated beam that produced a temperature rise of 4.0 μK/s in water and 6.2 μK/s in PE resulted in the lung region of about 2 μK/s. More accurate boundary conditions need to be applied in the next step of modeling.

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