Use of Simulation in the Development of Next-generation Measurement Standards for Radiation Dosimetry

R. E. Tosh[1], H. Chen-Mayer[1]

[1]NIST, Gaithersburg, MD, USA

Abstract

Dosimetry measurements needed for quality assurance of radiotherapy beams are currently traceable to NIST through an indirect chain that connects field instruments used in the clinic (principally, ionization chambers) to a primary standard water calorimeter at NIST used in Co-60 gamma radiation. Large differences in beam characteristics (e.g. energy spectra and intensity modulation) between the NIST reference conditions and the clinical setting are often addressed via simulations of radiation transport, often with substantial systematic uncertainties associated with assumptions about how the irradiated medium interacts with the radiation. Whether diffusive modeling of the radiation heating problem could be done with COMSOL Multiphysics® remains to be seen, but the present work summarizes a different sort of simulation effort, directed toward adapting dosimetric calorimetry for dynamic radiation beams typical of stereotactic radiosurgery and, possibly, brachytherapy sources used for treating prostate and breast cancer - work whose success would open the way for next-generation measurement standards for radiation dosimetry.

By contrast, the existing calorimetry method used in primary standards (shown in Figure 1) involves thermistor probes sealed in a glass vessel containing high-purity water. Uniform, static radiation fields, for which that type of instrument was designed, nevertheless evolve highly nonuniform thermal distributions over time (of exposure) whose effects on the desired temperature measurements we model with COMSOL, using conjugate heat transfer physics, for purposes of developing correction factors.[1]

In the case of dynamic beams or small, nonuniform radiation fields, such an approach is eminently unsuitable for standard reference dosimetry, so we have begun to study how remote sensing approaches based ultrasonic and/or optical probes could be used to image the dose field in 3D as a function of time - in effect, by reading out the thermal imprint of ionizing radiation in water.[2] In this regard, the Heat Transfer Module has been used to model radiation-induced Boussinesq convection in an open phantom in order to study apparent "cooling" in a radiation beam (which we have observed with a circular ultrasonic array used for imaging temperature distributions in water), as a design tool for developing Joule heating sources for testing that array (Figure 2), and for assessing the degree to which water is heated by probe radiation from a laser, thereby introducing systematic errors into the calorimetry results we might hope to obtain from that instrument (Figure 3).

Our work is preliminary, in part because the experiments are lagging behind the modeling effort, but the latter has enabled us to obtain quantitative estimates of correction factors for heat transfer (applicable to calorimetry measurements) and, as suggested in Figures 2 and 3, to implement modifications to our ultrasonic array that made it capable of imaging temperature fields arising from a Joule heating source and to model the effect of heating of the water medium by the probe radiation.

Reference

[1] R.E. Tosh, H. H. Chen-Mayer, A Transfer-Function Approach to Characterizing Heat Transport in Water Calorimeters Used in Radiation Dosimetry, Thermal Conductivity 29/Thermal Expansion 17, DEStech Publications, Inc., 499 ff, (2008).

[2] Eugene V Malyarenko, Joseph S Heyman, H Heather Chen-Mayer and Ronald E Tosh, Time-resolved radiation beam profiles in water obtained by ultrasonic tomography, Metrologia 47 208 (2010).

Figures used in the abstract

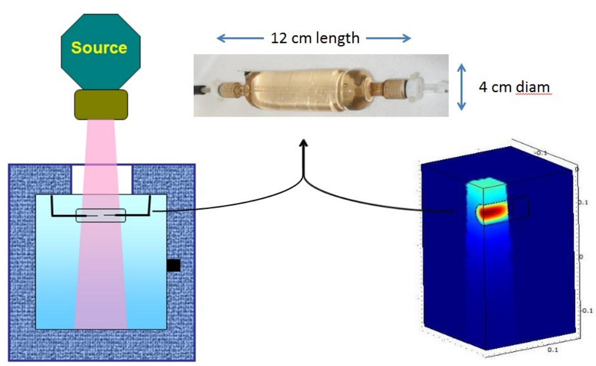

Figure 1: Water calorimeters used in static, flat radiation fields are typified by the instrument shown on the left, in which a sealed glass core containing thermistor probes is used to detect radiation induced heating. Modeling of heat transfer within the irradiated core, needed for correcting experimental results, is shown to the right.

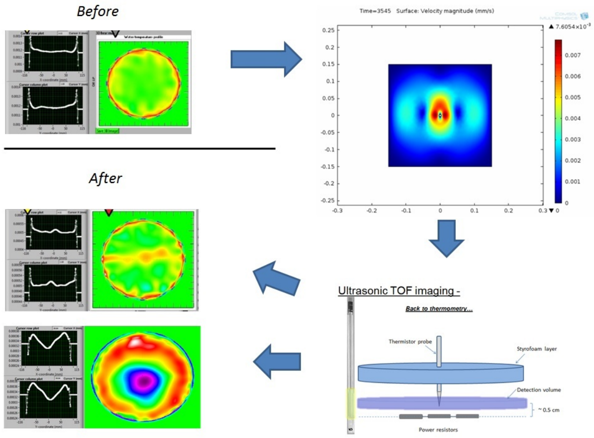

Figure 2: Chronology of our use of the Heat Transfer Module to identify thresholds for convection that guided design modifications to our ultrasonic imaging system, thereby vastly improving its ability to resolve milliKelvin-level heating by our test system (immersed power resistors, above) and, subsequently, a radiotherapy beam of high-energy electrons (below).

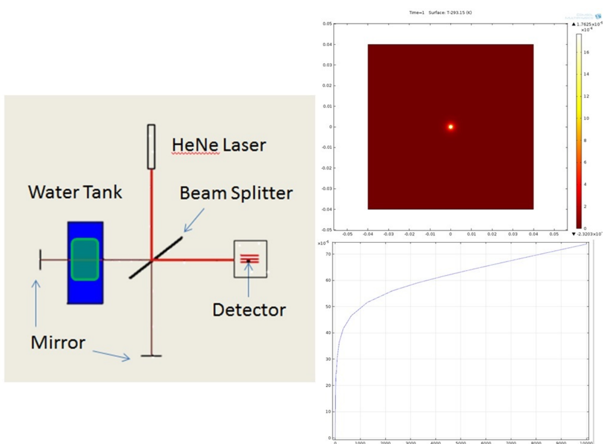

Figure 3: Modeling of heating of water by a probe laser beam (HeNe, 633 nm wavelength) showing a small but significant background signal (temperature rise over time) that must be subtracted from associated calorimeter measurements done in the corresponding interferometer setup (green rectangle in the water tank indicates radiation-beam penumbra).