Establishing Absorbed Dose Thresholds for Nonlinearities in Water Calorimetry

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Abstract

The technique of water calorimetry for primary-standard dosimetry of radiotherapy-level ionizing radiation is well established at national metrology institutes around the world, where such a direct realization of absorbed dose establishes the basis for calibrating instruments used for dosimetry in medical settings. The typical calorimeter system uses miniature thermistor beads to measure temperature changes in water, which are assumed to be proportional to the energy deposited by the radiation beam, or absorbed dose. Ensuring linear response to radiation heating is thus essential to obtaining accurate estimates of absorbed dose from these instruments, and considerable effort is expended in designing both instrument and experimental conditions so that this is achieved. The widespread use of conformal therapies involving scanned beams of variable geometry and/or energy have raised concerns within the metrology community over whether the classical setting for calibrating field instruments, in which a static, flat radiation field with minimal variation over the active detection region (of instruments being calibrated), offers a valid, reliable basis for accurate dosimetry in treatment settings. Among the research efforts addressing this problem are computational modeling of dose deposition in pencil beams and development of detectors with the spatial granularity and response time needed to characterize dynamically changing beams. New ideas for primary standards, such as ultrasonic imaging of absorbed dose within a water phantom [1,2], are also being developed that might contribute significantly to assuring accuracy of dose measurements in dynamically changing beams. However, successful realization of such new approaches would require a more thoroughgoing physical understanding of the nonlinearities of dose response due to radiolytic chemistry in high-purity water and natural convection due to nonuniformities of the dose distributions. The work presented here summarizes our efforts to characterize thresholds for onset of nonlinearities in heat generation and transport within an open phantom subject to irradiation from treatment beam models, so that we can begin to develop corrections for spurious effects and systematically design the instrument to minimize their impact. Initial work with finite-element models has targeted the onset of natural convection, and preliminary results, oscillations exhibited in Figure 1 and variations in thermal transfer functions in Figure 2, suggest that the thresholds are sufficiently high that the effect would be negligible. The preliminary models involve overly simplified geometry, and thus significant refinements are envisioned for future calculations, after which attention will turn to modeling of the heat defect due to radiolytic chemistry.

Reference

1. 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 3 (2010).
2. R.E. Tosh, F.B. Bateman, H. H. Chen-Mayer, E.V. Malyarenko, Ultrasonic Imaging of Dose to Water From a 1.5 MeV Electron Beam, 54th Annual Meeting of the American Association of Physicists in Medicine, July 28 - Aug 2, 2012.

Figures used in the abstract

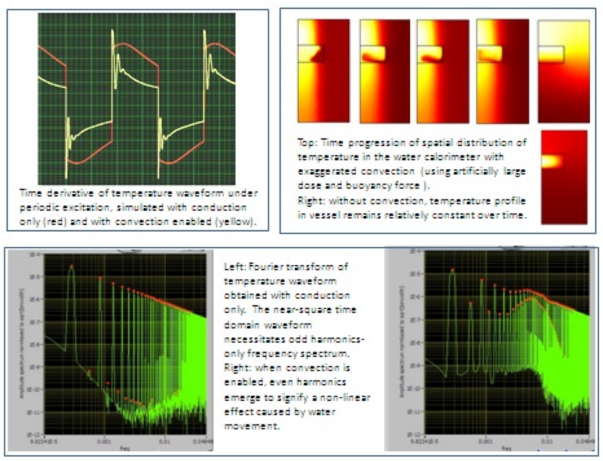

Figure 1

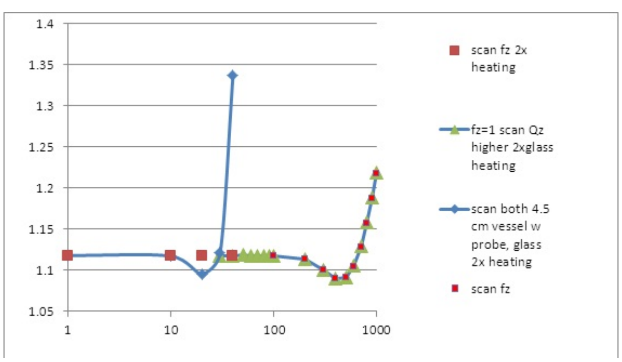

Figure 2