Update on the NIST Second-Generation Room-Temperature Water Calorimeter

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The NIST is in the process of improving our primary standard for absorbed dose to water in ^{60}Co and high-energy photon beams. Based upon the original design of Steve Domen, in which thermistors are used in a calorimeter vessel to sense radiation heating of water, the new instrument incorporates lock-in detection and computer automation to facilitate extracting the desired signals in the presence of electrical and thermal noise. The computer system is used both for control of the experiment and for real-time- and post-processing of voltage waveforms from the calorimeter. The flexibility afforded by the computer system can be further exploited to address the need for accurate dose measurements under adverse conditions such as in the presence of conduction and convection cooling and excess heat from non-water materials. We are developing data-acquisition and analysis techniques that can extract the correct signal from data that contain apparent distortions resulting from heat transfer.

We have focused on using digital filtering and Fourier analysis of time-domain waveforms to extract radiation-heating signals and to characterize the frequency-domain behavior of heat-transfer artifacts. This frequency-domain response is represented as a system transfer function, depicting the apparent dependence of the measured dose on the duration of the irradiation. This transfer function, $H(\omega)$, has been determined experimentally and also numerically by simplified 2D finite-element modeling, as shown in Fig. 1. In our system, where the external water is stirred, $H(\omega)$ depends mainly on the vessel geometry. Using the results from two vessels, with radii of 16.5 cm and of 22.5 cm, we have shown qualitatively that the system transfer function has a maximum value at a given irradiation time that increases with increased vessel radius.

In order for this systematic approach to produce useful corrections to the absorbed dose as a function of irradiation time, we have been pursuing lowering thermal and electrical noise in the measurement system. We have also investigated thermistor self-heating and convection effects using the frequency-domain technique. An interesting signature of convection emerges in the Fourier spectrum of the temperature signal, which shows the effects of modulation by the velocity field of the water, set in motion by buoyant forces whose time dependence mirrors that of the applied radiation. For the case of 50 % duty-cycle (square wave) chopping of the radiation beam, the effect is marked by the appearance of forbidden even harmonics in the Fourier spectrum. Such modulation products have been observed experimentally and verified by model simulation. Our preliminary theoretical understanding of the effect suggests that they are a necessary product of convection, and, hence, their absence from the Fourier spectrum would imply that convection was negligible. Such criteria are valuable for identifying causes of, and corrective measures for, convection at room temperature.

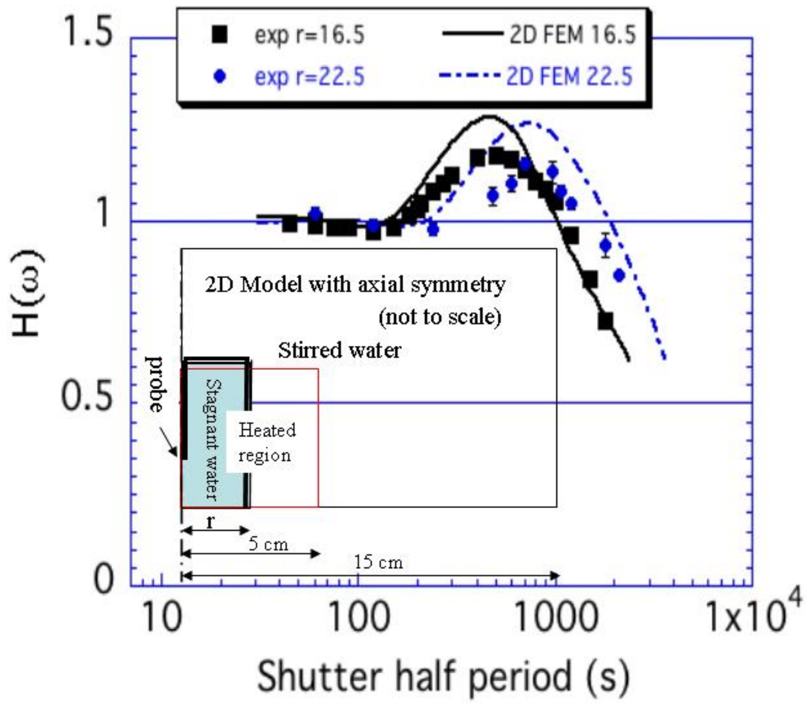

Figure 1. Comparison of FEM generated transfer function to the experimental data for the two vessel sizes. The 2D model is illustrated in the inset. The error bars represent one-sigma random uncertainty.

A second line of calorimetry research, now in phase II of a Small Business Innovation Research grant to Luna Innovations, is directed toward developing an ultrasonic technology for measuring temperature rise in water, and might thereby result in a new type of water calorimeter that features non-contact temperature sensing. We have received a research prototype ultrasonic sensor system that uses pulsed, phase-locked loop (PPLL) technology to derive temperature measurements within a water phantom with tens of µK resolution, and have tested it in ^{60}Co radiation with simultaneous temperature monitoring using a thermistor. With modulated radiation pulses, we have investigated the effect of radiation-induced convection in the open-water phantom where the ultrasound path traverses. In addition, this project has progressed toward developing an ultrasonic tomographic system, based on digital PPLL technology, and has demonstrated a 3-dimensional temperature-profile measurement in water under incandescent heating. This system could eventually allow rapid 3-dimensional absorbed-dose profiling in water and possibly other media.