“Development of a hybrid alanine-calorimetry absorbed dose standard for linac electron beams”

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Purpose: The NRC primary standard water calorimeter is well-established for measuring dose to water in high-energy linac electron beams but cannot be used for lower-energy electron beams due to practical constraints. This work aims to develop a hybrid absorbed dose standard whereby alanine is calibrated traceable to calorimetry primary standards in high-energy beams and subsequently used to establish absorbed dose in lower-energy beams.

Methods: Irradiations were performed in a water phantom with a horizontal beam setting. The SSD was 100 cm and the field size shaped by a standard applicator was 10 cm × 10 cm at the entrance of the water phantom as prescribed by TG-51 protocol[3] for clinical reference dosimetry of high-energy electron beams. The irradiation set-up is shown in **Figure 1**. Two monitor chambers, also shown in **Figure 1,** were used to track linac drift. Depth-ionization measurements were obtained prior to irradiations to determine R_{50}, the depth at which the absorbed dose falls to 50% of its maximum, and to obtain the reference depth, $d_{ref} = 0.6R_{50} - 0.1$ cm, the depth in water where measurements were made.

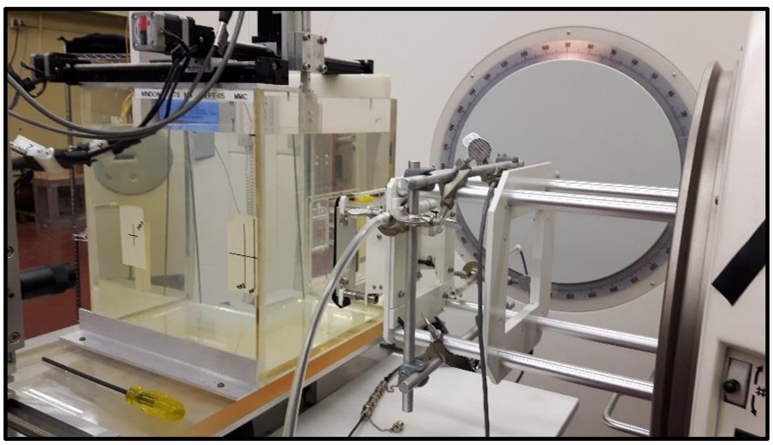
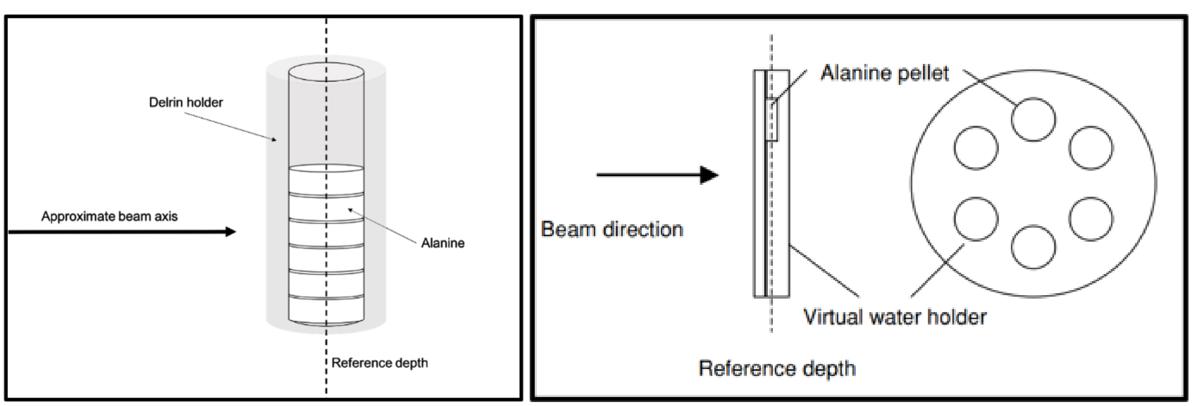


Figure 1. The set-up of an ionization chamber in a water tank in front of the linac.

In **Figure 2**, the holders used for alanine irradiations are depicted. Six alanine (0.48 cm diameter, 0.30 cm thick) pellets are used in a holder for a given irradiation. Ionization chambers and alanine holders are of the same dimensions and are positioned with their points of measurement at the reference depth.



(a) (b)

Figure 2. The holders fabricated at NRC to hold alanine pellets for irradiations, showing the positions of alanine pellets, the approximate axis of the beams and beam direction, and the reference depth. Panel **(a)** shows the cylindrical Delrin holder while panel **(b)** shows the parallel-plate Virtual Water holder.

The intensity of the peak-to-peak alanine signal was read out using a Bruker EPR spectrometer. Alanine pellets were read out individually and were rotated to three cardinal angles to account for any effects of anisotropy.

Alanine dosimeters were calibrated against secondary standard ionization chambers with calibration coefficients traceable to primary standard water calorimeter measurements in high-energy (18 MeV and 22 MeV) electron beams[1,2]. Alanine was then used in low-energy electron beams to determine absorbed dose. This method relies on the alanine signal from the spectrometer being independent of the energy of the electron beam used for irradiations. This assumption was validated using Monte Carlo calculations of the absorbed dose to water and the absorbed dose to alanine for the beam energies used in this work.

The beam quality conversion factor, k_Q, converts the cobalt-60 absorbed dose to water calibration coefficient, $N_{D,w}^{Co}$, with the fully corrected ionization chamber reading, M, in the clinical beam of quality Q to the absorbed dose to water, D_w,

$$\boldsymbol{D_w = M N_{D,w}^{Q} = k_Q M N_{D,w}^{Co}.}$$

The parameter k_Q is central to all linac calibrations that are used to treat cancer patients.

Alanine was used to determine dose to water in electron beams and, with ionization chamber measurements, calibration coefficients for electron beams were obtained. Applying calibration coefficients determined in the cobalt-60 reference beam, k_Q factors for different chamber types were determined with

$$\boldsymbol{k_Q = \frac{N_{D,w}^{Q}}{N_{D,w}^{Co}}.}$$

Results: The results of **Figure 3** demonstrate that absorbed dose energy-dependence is less than 0.2 %. This level of variation allows the use of alanine in low-energy electron beams as an absorbed dose standard traceable to calorimetry measurements in high-energy beams. Measured k_Q factors were obtained for five cylindrical and parallel-plate ionization chambers that are commonly used in clinical practice. **Figure 4** shows the results for one of the cylindrical ionization chambers investigated. Results for all of the ionization chambers investigated are in good agreement (within ~1 %) with literature data.

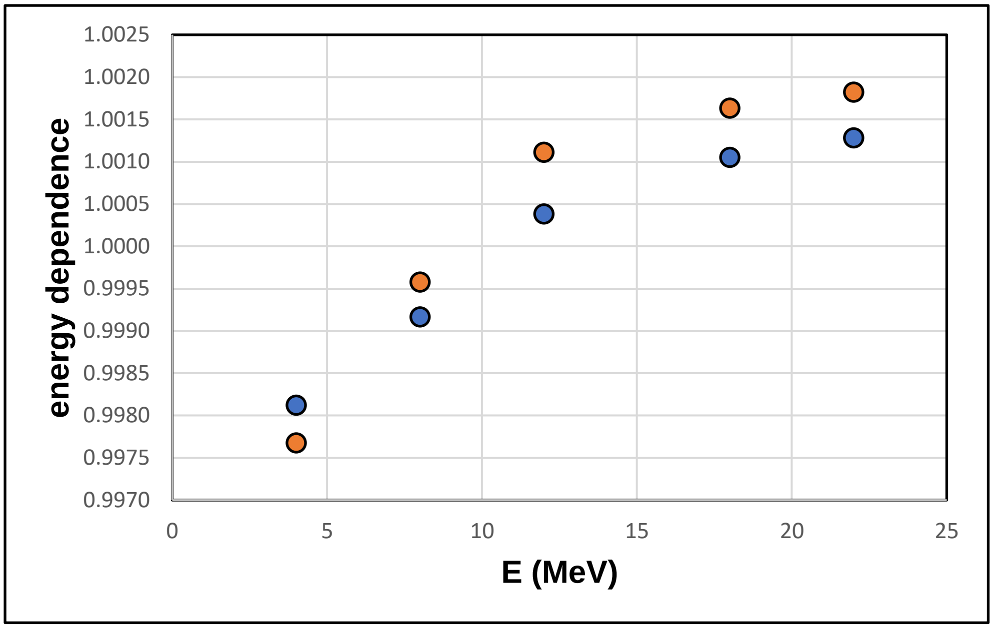


Figure 3. The EGSnrc Monte Carlo calculations of the ratio of dose to alanine to dose to water normalized to the mean of all values for a single alanine pellet in phantom (blue points) and for an independent calculation with the alanine holder modelled (orange points). Statistical uncertainties are less than 0.1 %.

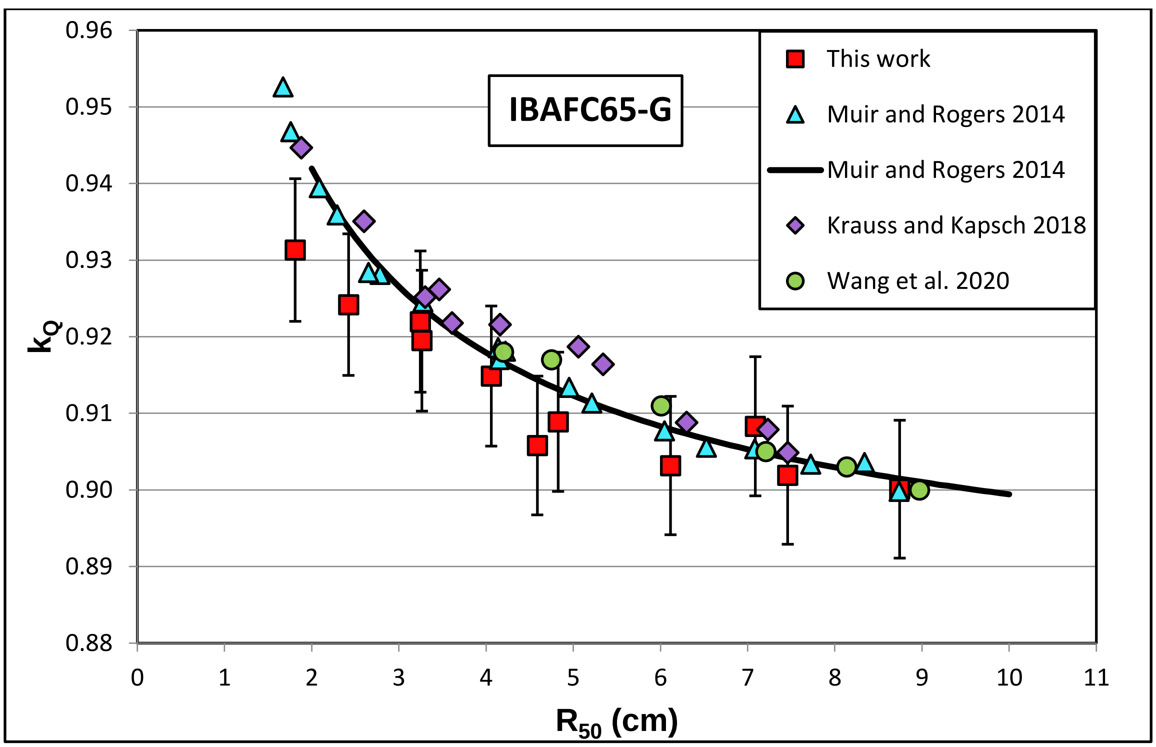


Figure 4. The results for beam quality conversion factors for a cylindrical ionization chamber (an IBA FC65-G) determined in this work compared to those from other publications.[4,5,6]

Conclusions: The low (0.2 %) absorbed dose energy-dependence of alanine demonstrated in this work allows the use of alanine as an absorbed dose standard in low-energy electron beams. The good agreement of the k_Q factors measured here with literature data demonstrates the accuracy of the hybrid alanine-calorimetry standard developed in this work.

Relevance to CIRMS: This work is relevant for the CIRMS Medical Applications subcommittee because it establishes an absorbed dose standard for low-energy electron beams and provides k_Q factors, the central parameters in dosimetry protocols used by all radiotherapy clinics for converting cobalt-60 absorbed dose to water calibration coefficients to obtain absorbed dose in clinical electron beams.

References:

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