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

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Motivation

The **NRC primary standard water calorimeter** is well-established for measuring dose to water in high-energy (**18 MeV** and **22 MeV**) linac electron beams.
The calorimeter cannot be used for lower-energy electron beams due to practical constraints.
This work aims to develop a hybrid absorbed-dose standard.

Why Alanine?

Alanine is an amino-acid which can be used for medical and industrial radiation dosimetry applications due to the high stability of the radiation induced free radical concentration.

Procedure

- Alanine dosimeters are 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 is 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 is validated using Monte Carlo calculations of the absorbed dose to water and the absorbed dose to alanine for the beam energies used.

- 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. **Figure 1** shows the irradiation set-up.

Depth-ionization measurements were obtained prior to irradiations to determine the beam quality specifier, R_{50}, the depth at which the absorbed dose falls to 50% of its maximum, and to obtain the reference depth,

$$d_{ref} = 0.6R_{50} - 0.1\ \text{cm},$$

the depth in water where measurements are made.

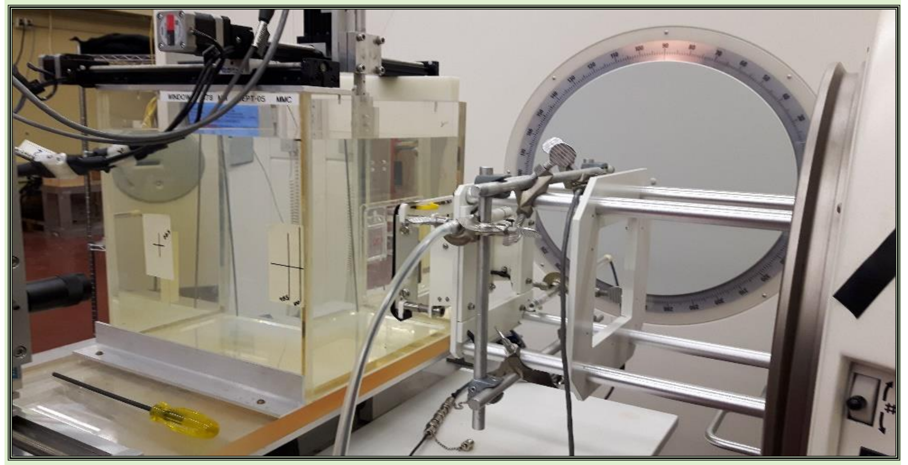

Figure 1. The set-up of an ionization chamber in a water tank in front of the linac.

In **Figure 2** and **Figure 3**, the holders fabricated at NRC used to hold the alanine pellets for 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.

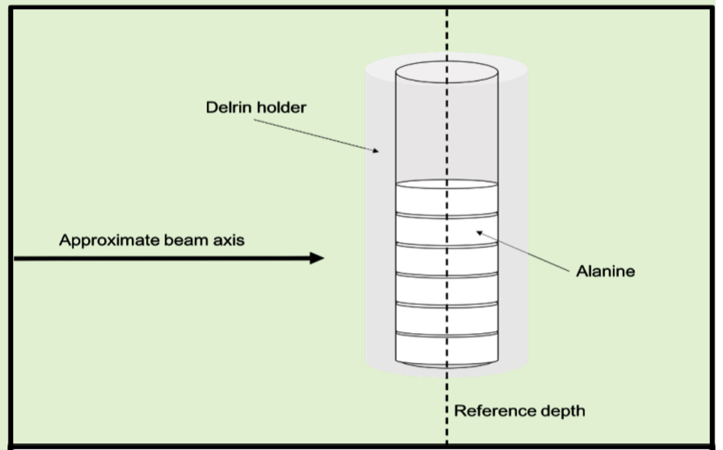

Figure 2. The cylindrical Delrin holder.

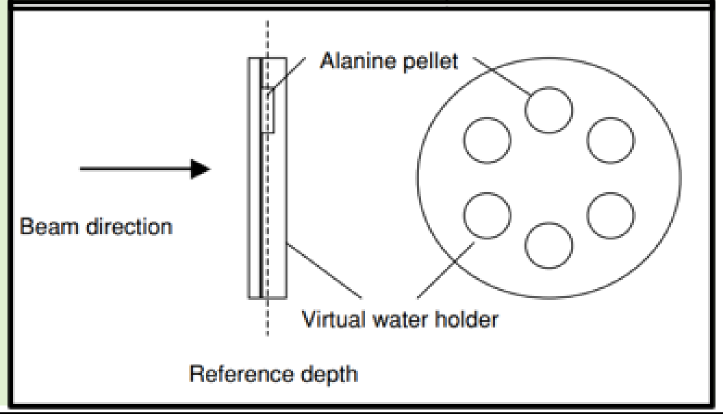

Figure 3. The parallel-plate Virtual Water holder.

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,

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

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

Results

- The Monte Carlo results shown in **Figure 4** demonstrate that absorbed dose energy-dependence is **±0.2 %.**
- Measured k_Q factors were obtained for five cylindrical and parallel-plate ionization chambers that are commonly used in clinical practice. The results are corrected for energy dependence and alanine holder (wall) effects.
- **Figure 5** shows the results for one of the cylindrical ionization chambers investigated.

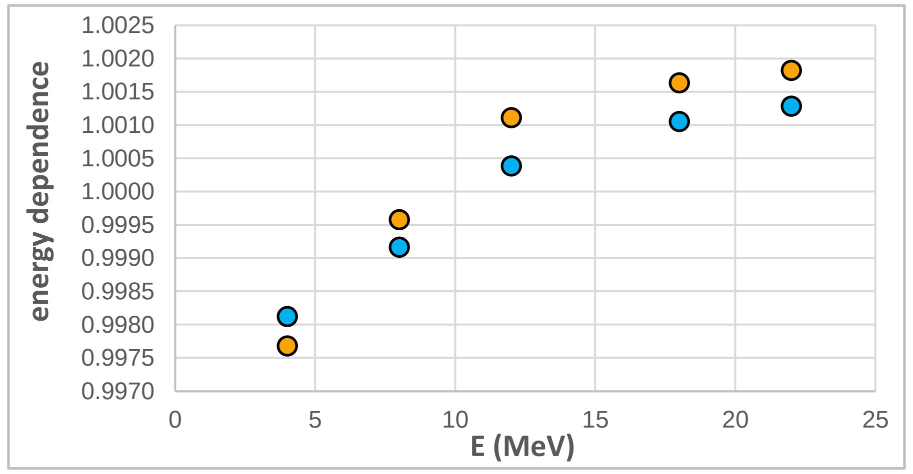

Figure 4. The EGSnrc Monte Carlo calculations of the ratio of dose to alanine to dose to water normalized to the mean of all values for a single alanine pellet in phantom (blue points) and for an independent calculation with the alanine holder modelled (orange points). Statistical uncertainties are less than 0.1 %.

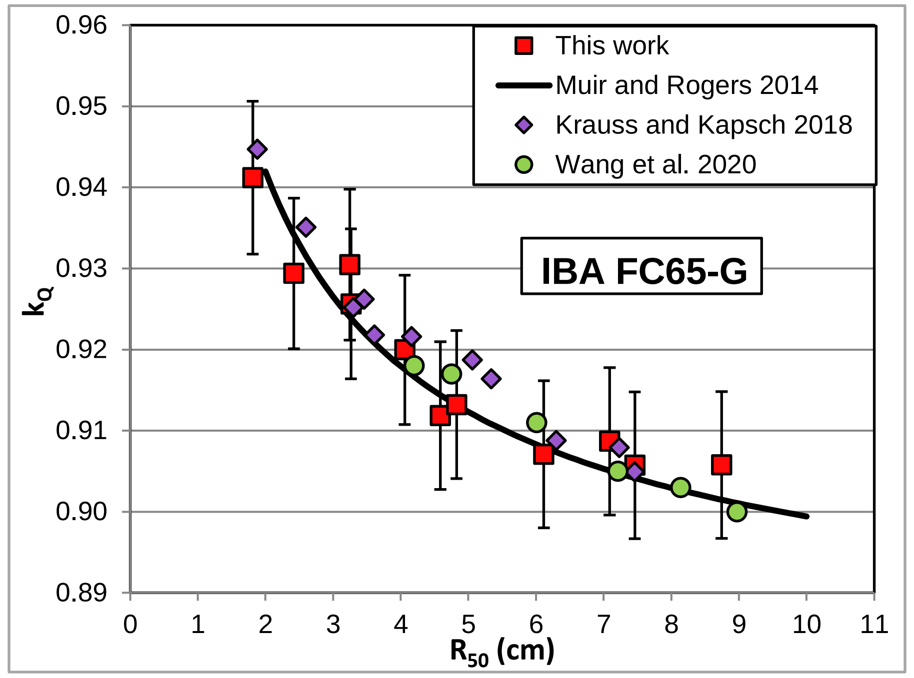

Figure 5. The results for beam quality conversion factors for a cylindrical ionization chamber (an IBA FC65-G) determined in this work compared to those from other publications.[4,5,6]

What you need to know

- Alanine is calibrated traceable to calorimetry primary standards in high-energy electron beams and subsequently used to establish absorbed dose in lower-energy beams.
- The small **(±0.2 %)** absorbed-dose energy-dependence of alanine allows the use of alanine as an absorbed-dose standard in **low-energy electron beams**.
- Results for the ionization chambers investigated are in good agreement within **~1 %** with literature data.
- The good agreement of the k_Q factors measured here with literature data demonstrates the accuracy of **the hybrid alanine-calorimetry standard** established in this work.

References

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3. Almond et al., "AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams," Med. Phys. 26, 1847-1870 (1999).
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5. A. Krauss, R-P. Kapsch, “Direct determination of k_Q factors for cylindrical and plane-parallel ionization chambers in high-energy electron beams from 6 MeV to 20 MeV,” Phys. Med. Biol. 63, 035041 (2018).
6. Wang et al., “Direct measurement of ionization chamber absorbed dose k_Q factors in clinical electron beams,” Rad. Meas. 139, 106481 (2020).