Abstract

Targeted radionuclide therapy (TRT) and brachytherapy with alpha particles has gained significant clinical relevance recently. Absorbed dose traceability to a standard is currently lacking in the dosimetry chain. The short range of alpha particles in water of <100 μm complicates the absorbed dose measurements in the form of significant attenuation and perturbation effects. The purpose of this work was to develop and validate absorbed dose to water standards for alpha-emitting radionuclides. Dosimetric formalisms to measure surface absorbed dose to water per radioactivity using windowless cylindrical parallel-plate extrapolation chambers (ECs) were introduced.

Monte Carlo (MC) investigations were launched to probe the alpha transport mechanism using a Fano cavity test. Optimal electromagnetic transport parameters were extracted from this study. The assumptions of the cavity theories were evaluated and the impact of source parameters on absorbed dose was studied. Following the construction of the apparatus, a thin film ^{210}Po source was employed with a radioactivity of 1.253 μCi for evaluation. A parallel-plate EC with a 4.00 mm collector diameter composed of D400 polystyrene-equivalent material was utilized as a standard. Addtionally, a printed circuit board (PCB) with a segmented guard was constructed to align the detector and the source plates using a differential capacitance technique. The PCB EC aimed to enhance the repeatability of the ionization current measurements. EC-based and MC-based correction factors were calculated for a planar circular ^{210}Po alpha emitter. Lateral and rotational alignment between the EC and the source was performed using translational and rotational shifts applied to the source using a hexapod motion stage. The initial air gap was determined using a contactless capacitance method. Ionization charge was collected as a function of applied voltage, varied between 1-200 V for a 0.3 mm air gap, to calculate the recombination correction. The polarity correction was measured by reversing the polarity

of the applied bias. Multiple measurement trials were performed to measure ionization current at air gaps in the 0.3-0.525 mm range. The proposed dosimetric formalisms were employed to calculate the surface absorbed dose to water from a point-like ^{210}Po source.

Negligible self-attenuation was found for the ^{210}Po source and the radius of the source was measured to be 1.60 mm. Lateral and rotational offsets of up to 0.20 mm and 1.50 deg were measured, respectively, when aligning the EC parallel to the source with their centers coincident with each other. The recombination and polarity correction factors were measured to be $<$0.50% when a 150 V/mm electric field strength was applied. The MC-calculated and measured absorbed dose to air agreed within 2.05% and 4.50% for the D400 and the PCB IC, respectively. Using the extrapolation method, the surface absorbed dose to water for the ^{210}Po was measured to be 2.8913×10^{-6} Gy/s/Bq and 2.304×10^{-6} Gy/s/Bq with a combined uncertainty of 3.74% and 3.55% for the D400 and the PCB IC, respectively. Large uncertainties, above 7% at k=1, were reported for the absorbed dose calculated using the cylindrical shell dosimetric formalism. Therefore, the extrapolation method was preferred to measure the surface absorbed dose to water.

This work demonstrated the ability of two windowless parallel-plate ECs as absorbed dose standards for alpha-emitting radionuclides.