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Development and evaluation of linear array type ring detector for patient dose delivery monitoring system in high dose-rate brachytherapy

High dose-rate brachytherapy (HDR-BT) is a treatment technique in which a radioisotope (RI) is directly inserted into the human body. This allows for minimizing the dose to surrounding critical organs while concentrating the radiation dose on the tumor tissue, resulting in high therapeutic efficacy. Treatment planning for HDR-BT is performed based on anatomical images including the clinical applicator, and the prescribed dose is delivered to the clinical target volume. The dose distribution is determined by adjusting the dwell positions and dwell times of the source within the applicator, necessitating verification of dose accuracy under specific dwell conditions. In external beam radiotherapy, patient-specific quality assurance (PSQA) is routinely performed prior to treatment to verify the patient dose, typically using a flat panel detector mounted on the treatment machine. Similarly, research has been conducted to implement a PSQA system for HDR-BT using flat panel detectors. However, such systems are subject to limitations due to the dependency on irradiation distance and angle of the RI. Therefore, a new approach is required that allows for consistent control of source distance and angle while accommodating the curved geometry of clinical applicators.

In this study, a ring detector with a fixed radius was developed to evaluate the feasibility of measuring dose distributions under specific RI dwell conditions. Monte Carlo (MC) simulation results using GATE v9.1 were also compared to validate the experimental results. A flexible material based on polydimethylsiloxane (PDMS) polymer was fabricated to allow bending to the irradiation radius of the Iridium-192 (Ir-192) source. Polycrystalline mercury (II) iodide, a material with high radiation conversion efficiency, was used as the sensing material, and mixed with PDMS to create a flexible detector. A flexible printed circuit board (fPCB) with 25 pixel electrodes was configured as a linear array, with each electrode measuring 2 cm × 0.1 cm and spaced at 0.3 cm intervals. The ring detector was constructed by fixing the fPCB into a semicircular shape, resulting in a radius of 3.85 cm.

The repeatability of the detector was evaluated using the median value of the 25 pixels (57.0 nC), with a relative standard deviation of 0.87% over 10 repeated measurements. The linearity of dose with respect to dwell time showed a coefficient of determination of 0.9997. Dose measurements were conducted at positions spaced 0.5 cm apart from the pixel center point up to a distance of 2.5 cm. The experimental results were compared with MC simulations. The dose distribution decreased linearly as the Ir-192 source moved further from the detector. The slope of the linear function was 0.0051 for the measurement and 0.0137 for the simulation, indicating a difference of 0.0086 and a more gradual decrease in the measured data. Ir-192 follows the inverse square law, resulting in a power function for dose fall-off with distance.

This study fixed the detector radius at 3.85 cm based on the detector size, resulting in a source-to-surface distance (SSD) of over 1 cm. In the future, by configuring an SSD of less than 1 cm to monitor the rapid intensity changes near the source, a PSQA system capable of verifying the calculated dose of HDR-BT applicators could be established.

Workshop topics

Sensor materials, device processing & technologies

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