Calibration of a Novel Microdosimetry System for In Vitro Applications of Actinide Radiopharmaceuticals

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Alpha-emitting radionuclides show promise for targeted radiopharmaceutical therapy (TRT). The high linear energy transfer and short range of alphas result in highly localized DNA damage for effective cancer management. However, the distributions of radioactivity and absorbed dose on the cellular scale remain elusive, hindering progress toward understanding α-TRT radiobiologic response, evaluating novel α-TRT drug efficacy, and optimizing administration for personalized treatments. A novel real-time α camera, the ionizing radiation quantum imaging detector (iQID), has successfully mapped the micro-distribution of α-emitting radionuclides in mouse and human tissues. This study characterized the pixel size, spatial resolution, sensitivity, and background rate of the iQID for use in whole-animal α-TRT experiments.

The scintillator-based α detection system maps individual α emissions on a 10 × 10 cm^2 detector area. We measured pixel size using calibrated image templates. Line spread functions (LSF) measured with a 5 µm × 5 mm laser-drilled collimator and a 5 mCi ^{210}Po source (5.4 MeV α) quantified intrinsic spatial resolution. We measured the LSF at 5 locations on the detector surface: center and 4 edges in a × pattern to evaluate uniformity. Decays counted from a 50.2 ± 1.1 Bq source (^{243}Am, ^{242}Pu, and ^{239}Pu; 5.16 – 5.43 MeV α) over 48 hours quantified detection efficiency. Finally, we evaluated the background rate over 60 hours.

Pixels measured 53.7 µm/pixel. The full width at half maximum of LSFs averaged 43.0 ± 5.2 µm. The mean radioactivity over 48 h was 54.34 ± 0.03 Bq, within 10% of the source-certificate value. The mean background rate over 60 hours revealed a lower limit of detection (LLD) of 4.04 mBq/cm^2.

Imaging results with a novel α camera for α-TRT experiments showed that it can image and identify α-emission events with nearly 100% efficiency, low LLD, and spatial resolution approaching the cellular scale. Future work will evaluate energy discrimination and build Artificial Intelligence tools to reconstruct whole-animal volumetric activity concentrations. The iQID is a promising tool for α-TRT experiments, filling a critical need in the field. With advanced microdosimetric understanding, novel applications of α-TRT can offer optimal cancer management to patients with previously intractable disease.

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