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Development of Compton camera imaging and dosimetry techniques for radionuclide therapies

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Targeted radionuclide therapy (TRT) with alpha-emitters is rapidly gaining importance in oncology due to the high linear energy transfer and short range of alpha particles, enabling effective tumour control while sparing healthy tissue. However, accurate dosimetry remains a major challenge, as conventional nuclear medicine imaging is not optimized to determine radionuclide distributions from high-energy photons commonly associated with alpha decay. In theranostics, ^{212}Pb has seen increasing therapeutic use due to its favourable chemistry, half-life, and decay properties, but dosimetry relies on ^{203}Pb as an imaging surrogate, providing an indirect and limited estimate of the true ^{212}Pb biodistribution. This work investigates the feasibility of Compton camera imaging for TRT verification with improved accuracy.

The IRIS group has developed imaging and dosimetry methods for radiotherapy applications using the MACACO III+ Compton camera, which is well-suited for high-energy photons. A model of the camera has been implemented in GATE 10, enabling efficient simulations with recent GATE features. To support correlation of detected photons and absorbed dose, dose point kernels for the ^{212}Pb decay chain were calculated with 1E6 primaries in a 13.38 mm water sphere, equal to 1.2× the CSDA range of the maximum-energy β^- emission. The therapeutic range X_{90} was defined as the radius containing 90% of energy deposited, and emission profiles were benchmarked with NuDat 3.0.

Following ^{212}Pb disintegration, decays of ^{212}Bi and ^{212}Po contributed ~95% of the total energy deposited. The full decay chain deposited 8.9 MeV/decay on average with a therapeutic range of X_{90} = 0.091 mm. Individual contributions from ^{212}Pb, ^{212}Bi, ^{212}Po, and ^{208}Tl yielded X_{90} values of 0.41 mm, 1.8 mm, 0.086 mm, and 5.8 mm, respectively, highlighting that dose is dominated by ^{212}Po decay and accurate reconstruction of radionuclide distributions requires high-resolution imaging. Furthermore, discriminating the 727 keV photons (6.7% intensity) in the ^{212}Bi to ^{212}Po branch from abundant ^{208}Tl photons can help distinguish α and β^- decay pathways, supporting precision dosimetry. Photon intensity histograms (photons/decay) showed excellent agreement with NuDat 3.0 and single-source GATE simulations. However, initializing multiple sources to establish transient equilibrium uncovered a GATE timing issue that condensed emissions into the acquisition window, inflating apparent count rates and potentially biasing activity and dose estimates.

Future work will address the GATE timing issue and establish correlations between Compton camera images and absorbed dose. Once validated, the recent Photon from Ion Decay (PHID) source will be used to efficiently simulate photon emission without tracking charged particles. This approach is expected to accelerate Compton camera studies and support robust dosimetry in TRT with alpha-emitters, ultimately contributing to more precise and clinically viable treatment verification.

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