Monte Carlo Modeling of Cascade Gamma Rays in ^{86}Y PET imaging: Preliminary results

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Abstract: ^{86}Y is a PET agent that could be used as an ideal surrogate to allow personalized dosimetry in ^{90}Y radionuclide therapy. However, ^{86}Y also emits cascade gamma rays. We have developed a Monte Carlo program based on SimSET to model cascade gamma rays in PET imaging. The new simulation was validated with the GATE simulation package. Agreements within 15% were found in spatial resolution, apparent scatter fraction (ratio of coincidences outside peak regions in line source sinograms), singles and coincidences statistics and detected photons energy distribution within the PET energy window. A 20% discrepancy was observed in the absolute scatter fraction, likely caused by differences in the tracking of higher-energy cascade gamma photons. On average the new simulation is 6 times faster than GATE, and the computing time can be further improved by using variance reduction techniques currently available in SimSET. Comparison with phantom acquisitions showed agreements in spatial resolutions and the general shape of projection profiles; however, the standard scatter correction method on the scanner is not directly applicable for ^{86}Y PET as it leads to incorrect scatter fractions. The new simulation was used to characterize ^{86}Y PET. Compared with conventional ^{18}F PET, in which major contamination at low count rates comes from scattered events, cascade gamma-involved events are more important in ^{86}Y PET. The two types of contaminations have completely different distribution patterns, which should be considered for the corrections of their effects. Our approach will be further improved in the future in the modeling of random coincidences and tracking of high energy photons, and simulation results will be used for the development of correction methods in ^{86}Y PET.

1. Introduction

Targeted radionuclide therapy (TRT) and radioimmunotherapy (RIT) are at the forefront of molecular cancer treatment modalities that involve the use of cancer cell targeting radiopharmaceuticals, such as radiolabeled antibodies, which selectively target certain tumor cells (Ghobrial et al 2004). ^{90}Y is a very promising isotope for internal radionuclide therapy, especially TRT where the linking of therapeutic radioligands with cell-specific carriers allows targeting of tumor cells without reaching the toxicity levels of traditional chemotherapy (Podoloff et al 2002). Patient-specific dosimetry based on personalized biodistribution information is essential in ^{90}Y radionuclide therapy for pre-therapeutic treatment planning and accurate absorbed dose estimation in individual patients. However, since ^{90}Y is a pure beta emitter, its biodistribution cannot be readily imaged. A chemically identical surrogate, such as ^{86}Y, would be very desirable as a molecular imaging surrogate for ^{90}Y therapy.

PET imaging is usually performed with short-lived pure positron emitters, such as ^{18}F, ^{11}C or ^{15}O. Certain other radionuclides, such as ^{86}Y, ^{76}Br, ^{124}I and ^{66}Ga, are being explored for use in PET imaging because of their chemical properties and longer half-lives (Beattie et al 2003). However, in addition to positron emission and electron capture (EC), these radionuclides also emit prompt gamma rays that are in cascades with a positron or other gamma rays, which causes spurious activity in the images. Correction methods of spurious activity have

Representative Results:

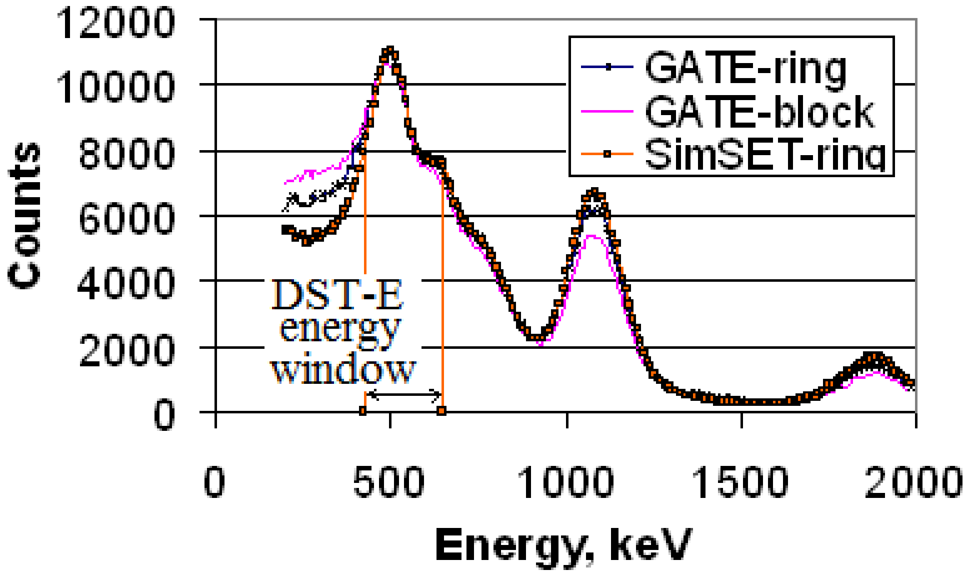

Figure 1 Energy spectra of detected photons from ^{86}Y flood phantom simulations

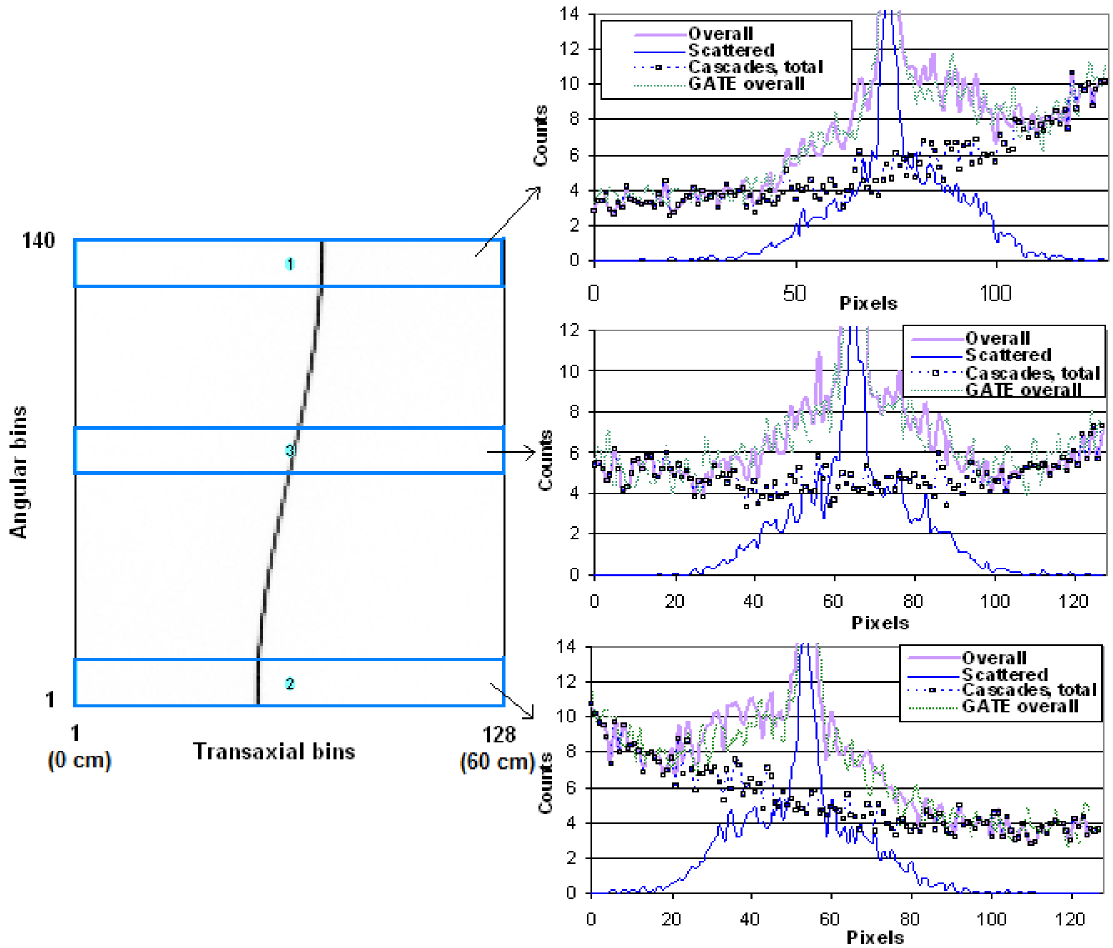

Figure 2 Sinogram projection profiles of a ^{86}Y line source in a water phantom. The scattered events include coincidences between two annihilation photons, at least one of which has been scattered before reaching the detector. These are equivalent to scattered events distributions in conventional ^{18}F PET. The cascade events include coincidences involving at least one cascade photon, regardless of the scattering history of both photons.

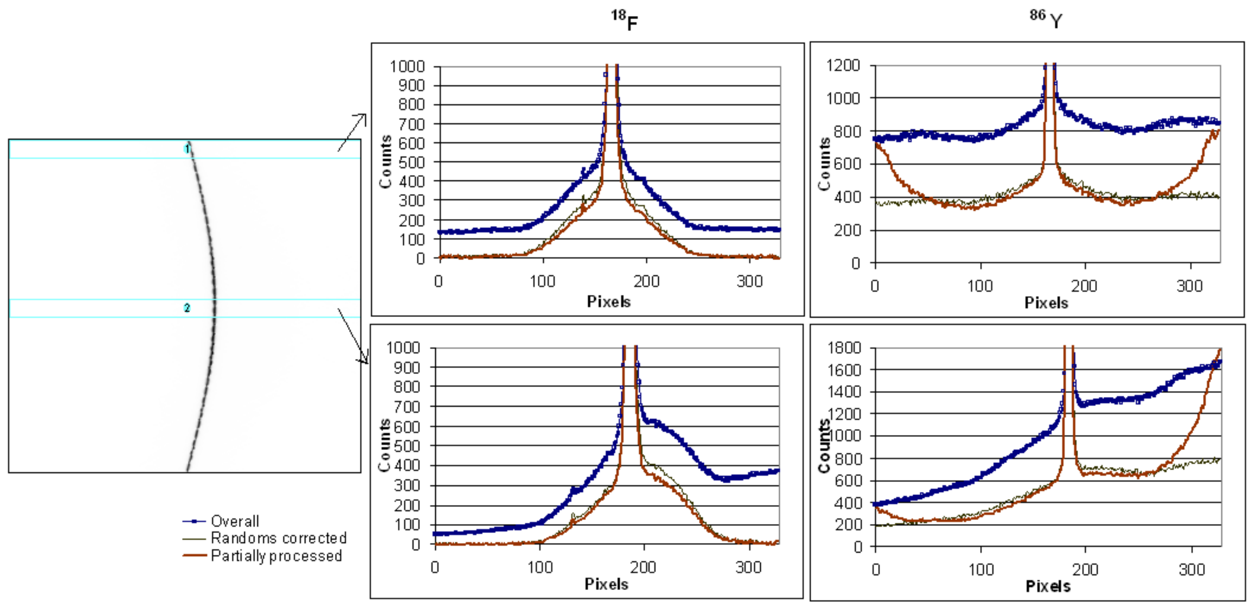

Figure 3 Sinogram projection profiles from line source phantom acquisitions. In the “randoms corrected” profiles, random coincidences were corrected with the delayed events subtraction method. In the “partially processed” profiles, standard methods for randoms/deadtime/normalization/geometry corrections available on the scanner were applied to the sinograms.