^{90}Y Bremsstrahlung SPECT on NaI and CZT Systems Using Energy Window–Based Background Compensation: Initial Phantom and Clinical Evaluation with Practical Protocol Implications

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ABSTRACT

Purpose

Direct imaging of ^{90}Y bremsstrahlung with SPECT remains challenging because the continuous photon energy spectrum introduces substantial object scatter, septal penetration, and lead x-ray contamination, all of which reduce contrast and complicates quantitative reconstruction. Optimal energy-window placement is therefore critical, with prior studies identifying ~80–180 keV often centered around ~90–125 keV, as a practical range for balancing detection efficiency and contrast, while higher-energy windows support empirical background-estimate techniques. As a result, practical energy-window (EW) based background compensation approaches have gained traction. This study provides an initial comparison of NaI and CZT SPECT/CT systems for 90Y bremsstrahlung imaging using matched energy windows and two reconstruction strategies.

Materials and Methods

Phantom and clinical data were acquired on a GE NM/CT D670 (NaI, MEGP collimator) and NM/CT D870 (CZT, MEHRS collimator). A 25 mCi 90Y vial was imaged with identical primary (108 keV ± 16%) and high-energy (360 keV ± 14%) windows. All reconstructions used OSEM with CT-based attenuation correction (AC) and resolution recovery (RR). Two reconstruction variants were qualitatively and quantitatively evaluated: AC+RR alone and AC+RR+SC, where SC is energy-window–based background compensation followed a 0.53× high-energy-window scaling (Siman et al., 2013). Two radiologists qualitatively reviewed two NaI and two CZT 90Y patient studies.

Results

For both detectors, BC reduced background noise and improved sharpness. CZT FWHM improved from 12.29 mm to 8.61 mm; NaI improved from 10.50 mm to 8.04 mm. Post-SC FWHM values were similar, likely reflecting the low-scatter phantom geometry. Clinical reviews showed improved lesion contrast and reduced halo artifacts with SC, with radiologists preferring AC+RR+SC images.

Conclusion

EW-based background compensation meaningfully enhances 90Y bremsstrahlung SPECT for both CZT and NaI. Future work will expand to larger phantoms and broader patient cohorts to refine harmonized quantitative SPECT/CT protocols.

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INTRODUCTION

- Yttrium-90 (^{90}Y) glass-microsphere radioembolization is an effective treatment for hepatocellular carcinoma (HCC).
- Once treatment is complete, post-treatment imaging is recommended to confirm the distribution of the ^{90}Y spheres and to estimate the absorbed dose.
- An alternative approach is bremsstrahlung SPECT imaging, which offers higher sensitivity and broader accessibility.
- To perform this reliably, current ^{90}Y imaging protocols need to be developed and optimized on Nuclear Medicine (NM) SPECT/CT-capable scanners.

^{90}Y SPECT/CT Imaging

Imaging limitations:

- ^{90}Y bremsstrahlung produces a broad, continuous photon spectrum resulting in high object scatter and significant septal penetration.
- This results in reduced image contrast and complicated quantification.

Acquisition Energy Window (EW) selection:

- Optimal detection / contrast commonly found in the ~80–180 keV range.
- Higher-energy background window useful for background estimation.

Background compensation approaches:

- Practical EW-based methods developed with scaled high-energy window techniques.
- Validated using phantom studies and patient datasets.

Aim of the Study

Building on our initial CZT-only evaluation [2], this study compares NaI and CZT SPECT/CT systems for ^{90}Y bremsstrahlung using matched windows and two reconstructions with phantom and clinical data evaluations.

METHODS & MATERIALS

Phantom	25 mCi ^{90}Y-filled vial
Clinical	Patient scans
Scanners	CZT — Discovery NM/CT 870 (MEHRS) NaI — Discovery NM/CT 670 (MEGP)
Energy windows	Primary 108 keV ± 16% High-energy 360 keV ± 14%
Acquisition	120 projections / 360° Matrix: 128 × 128 Acqusition Time: 25 min
Reconstruction	Xeleris / MIM OSEM: 4i x 8s / 16i x 8s Corrections: AC + RR / AC + RR + SC (SC = EW background compensation, 0.53× high-energy window)
Analysis	
Line Profiles	FWHM from line profiles
Dosimetry	MIM, Local Deposition Method (LDM — all emitted β-energy deposited in-voxel); Absorbed dose = time-integrated activity × dose-conversion factor
Qualitative Evaluation	Radiologist review: image quality, signal-to-noise, lesion-edge delineation, artifact presence, clinical findings (desirable/undesirable)

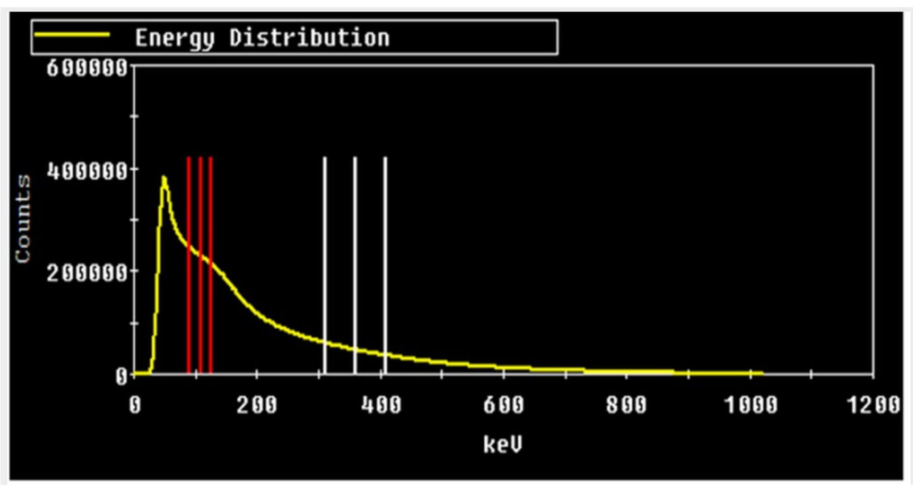

Figure 1. Y-90 bremsstrahlung energy spectrum with the primary acquisition window (108 keV ± 16%, red) and background window (360 keV ± 14%, white) used for background compensation.

RESULTS & DISCUSSION

Vial imaging demonstrated clear benefits of EW–based background compensation (SC) on both CZT and NaI systems.

- CZT: Reduced background streaking, improved point spread function (PSF); FWHM improved from 12.29 mm (no BC) to 8.61 mm (with SC).
- NaI: Similar improvement in image quality; FWHM decreased from 10.50 mm (no SC) to 8.04 mm (with SC).
- Post-SC FWHM values were similar for both CZT and NaI despite different detector technologies.

Count & Rate Comparison

- CZT: 8.6 Mcounts at 5,700 cps
- NaI: 2.0 Mcounts at 1,450 cps

CZT: ~4X more counts and ~3.7× higher count rate, demonstrating >50% shorter CZT scans for equivalent image statistics.

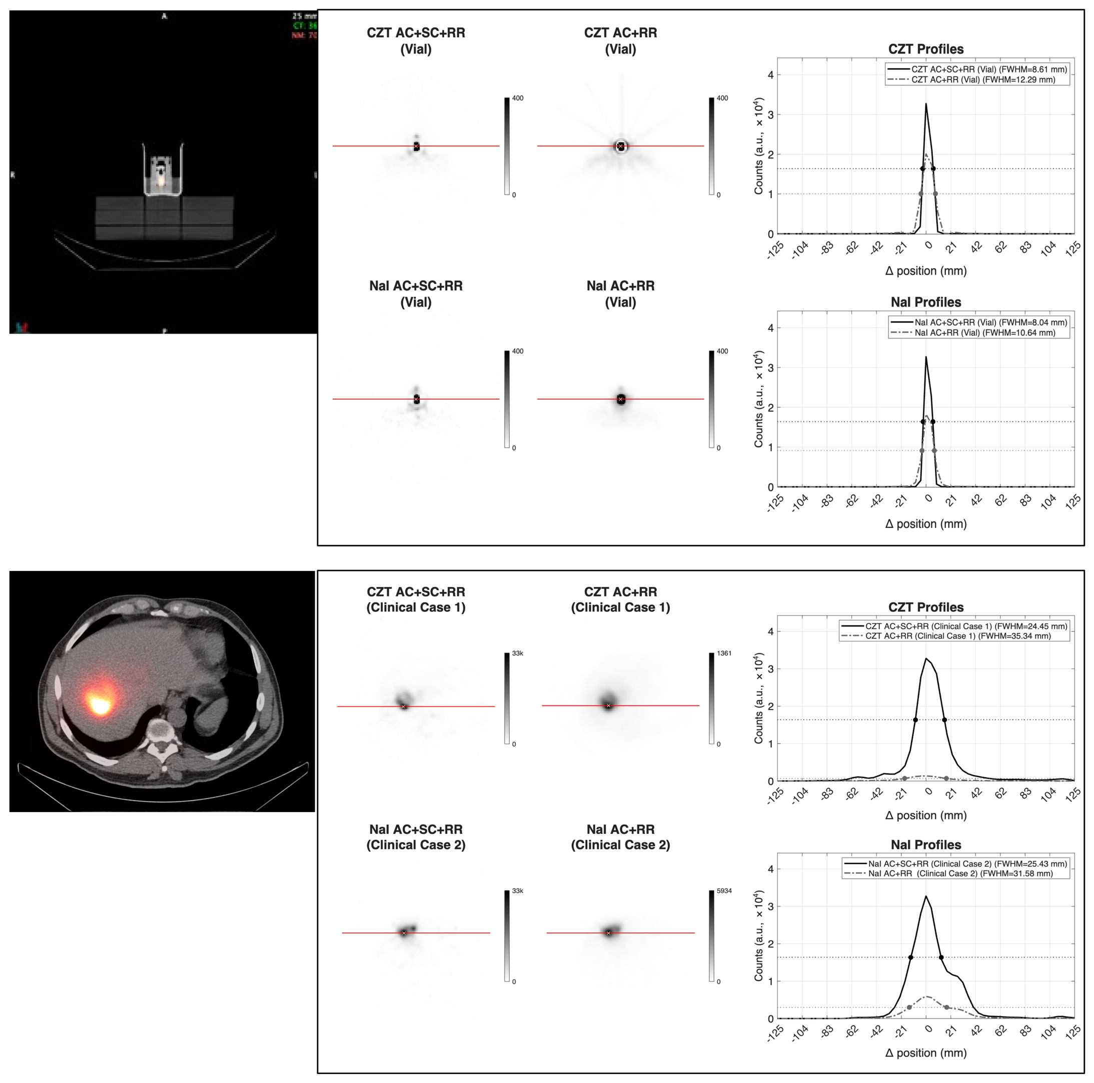

*Figure 2. ^{90}Y vial-phantom (top) and clinical (bottom) reconstructions for CZT and NaI, comparing AC + RR with AC + RR + **SC** and the corresponding line-profile / FWHM plots; background compensation improves lesion contrast and reduces halo artifacts.*

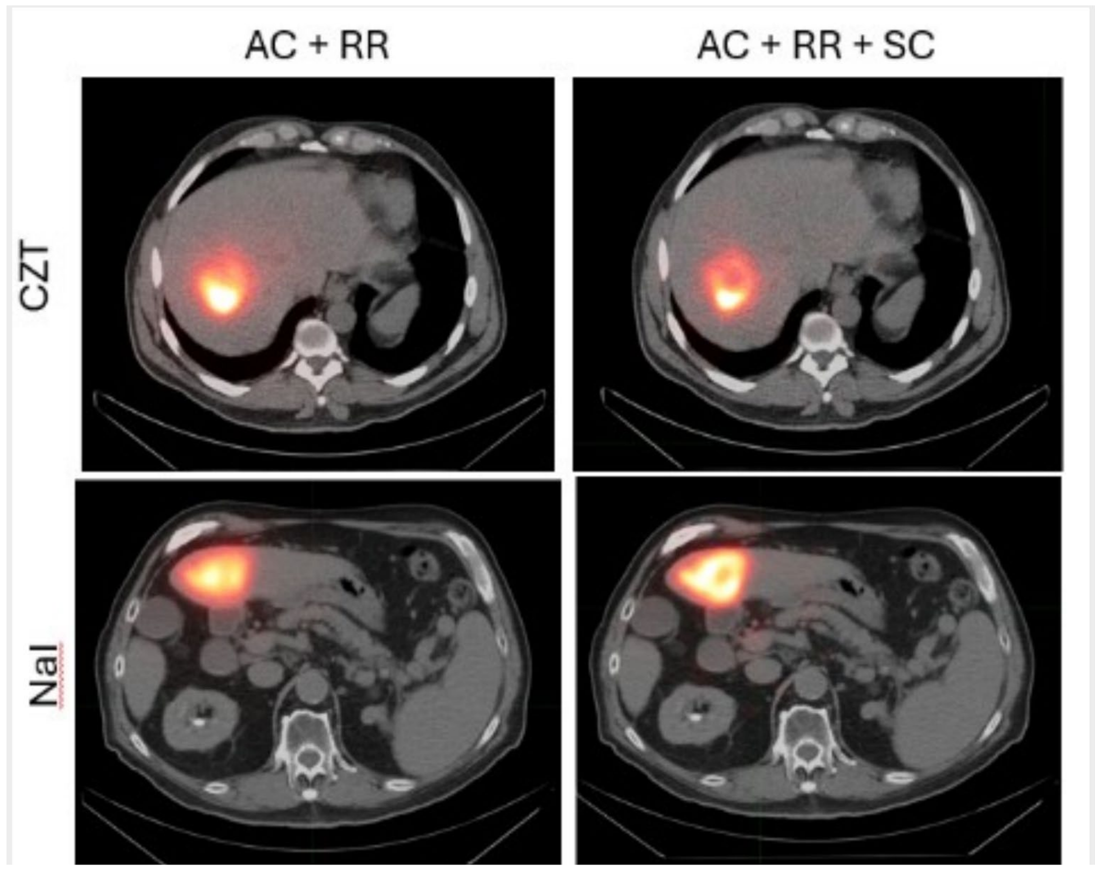

*Figure 3. Clinical datasets (CZT and NaI) showing increased lesion contrast, improved image quality, and reduced scatter-halo artifacts for both detectors when background compensation (**SC**) is added to AC and RR.*

Clinical findings:

- SC increased lesion contrast across clinical datasets.
- Overall image quality improved with the application of SC.
- SC reduced scatter-halo artifacts for both detector types (NaI and CZT).
- The greatest improvements were seen with AC + RR + SC.
- Radiologists showed a clear preference for AC + RR + SC images over AC + RR.

Dosimetry findings (Qualitative and Quantitative):

Adding SC (right column) for both scanners resulted in:

- A more compact and concentrated high-dose region (red/orange core) with reduced spread of lower-dose regions (green/blue outer areas)
- This indicates improved localization of dose that becomes tighter and more confined to the tumor and less peripheral dose spill with clearer boundary between high-dose core and surrounding tissue.
- Adding scatter correction (SC) to the AC + RR reconstruction produced a more accurate, compact, and localized tumor dose distribution with CZT detectors, showing more uniform and reliable results compared to NaI systems.
- Both scanners show increased tumor absorbed dose (max and mean) with the addition of SC.

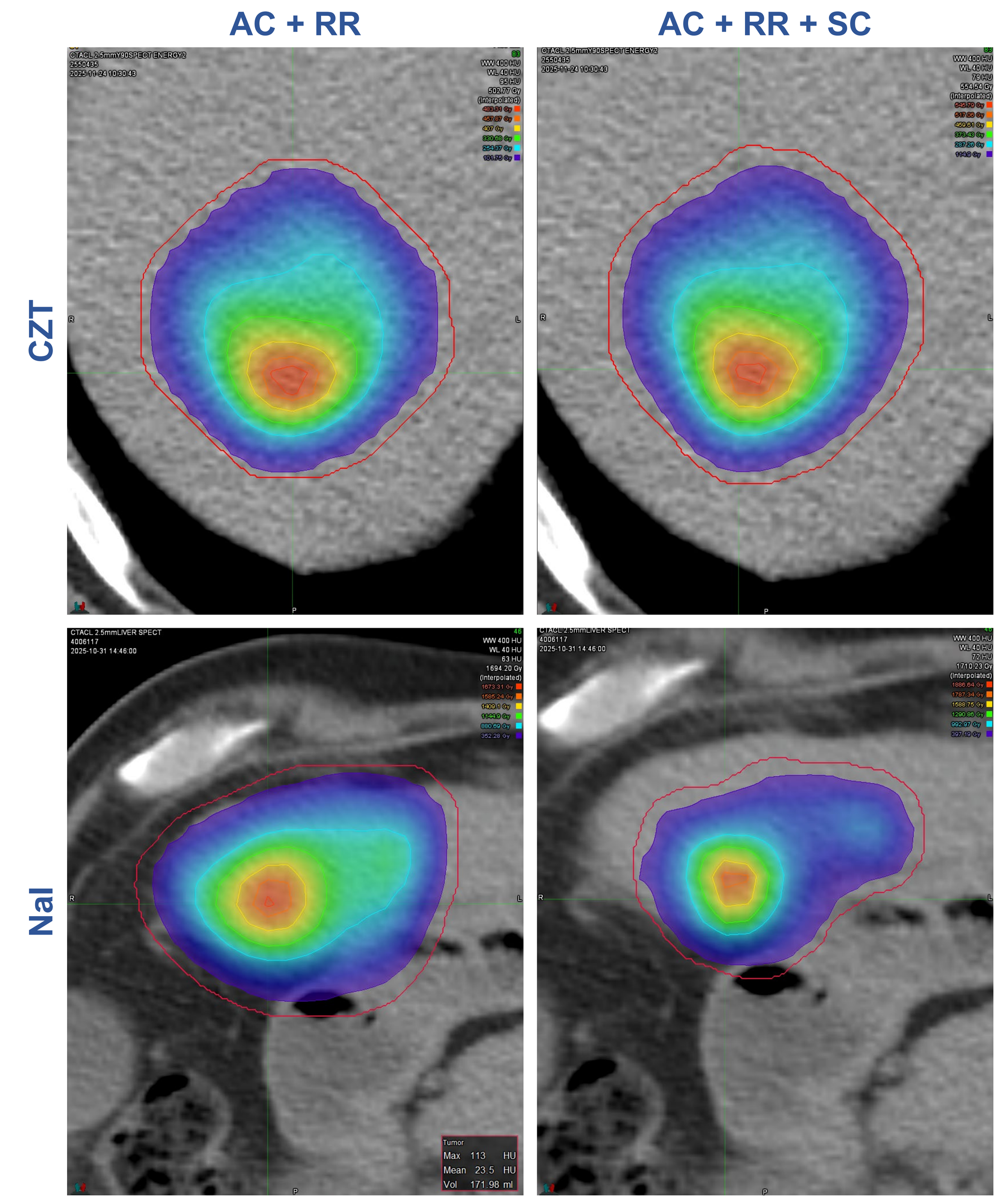

Figure 4. Color-rendered clinical SPECT/CT for CZT (top) and NaI (bottom): AC + RR versus AC + RR + SC. Tables summarize tumor maximum and mean absorbed dose (Gy).

Tumor Maximum Absorbed Dose (Gy)

	AC+RR	AC+RR+SC	%Change
CZT	508.75	574.51	+12.93
NaI	1761.38	1985.93	+12.75

Tumor Mean Absorbed Dose (Gy)

	AC+RR	AC+RR+SC	%Change
CZT	168.78	182.55	+8.16
NaI	593.44	662.37	+11.62

Tumor Volume (ml)

	AC+RR	AC+RR+SC	DOSE Injected
CZT	165.68	153.8	16.2 mCi
NaI	171.3	153.35	58.6 mCi

CONCLUSIONS

- EW-based background compensation (SC) improves 90Y bremsstrahlung SPECT image quality on both CZT and NaI systems.
- This study is an initial step, with future work including phantoms and a larger patient cohort.
- Ongoing efforts aim to optimize quantitative SPECT/CT through harmonized protocols, calibration, and proper use of SC, AC, and RR.

REFERENCES

[1] Siman, W., Mikell, J.K. and Kappadath, S.C. (2016). Practical reconstruction protocol for quantitative ^{90}Y bremsstrahlung SPECT/CT. Med. Phys., 43: 5093–5103.

[2] James, J.R., Halama, J., Wagner, R. and Dasari, P. (2025). An Initial Evaluation of ^{90}Y Bremsstrahlung SPECT Imaging Using CZT Detectors. J. Nucl. Med., 66 (Supplement 1): 251395.