Simulation study of NEMA characteristics of double-isotope imaging with J-PET

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The modular prototype J-PET scanner has extended its applications by enabling detection of various photon topologies [1, 2], opening an emerging field in nuclear medicine: simultaneous double-tracer imaging. This work is a simulation-based study of double-isotope imaging using the NEMA phantom with the GATE toolkit [2, 3], computed at the Cyfronet academic supercomputing center in Krakow, Poland. The three largest spheres of the phantom were filled with positron-prompt gamma-emitting isotopes (^{44}Sc, ^{55}Co, or ^{52}Mn), while the three smallest spheres were filled with ^{18}F (back-to-back), enabling the simulation and tracking of 2γ and 2γ + γp events. The simulated events were further processed for reconstruction to estimate the emission point in both cases. Additionally, subtraction was applied to enable us to obtain the separated images of ^{18}F.

Table of isotopes, Nema phantom and simulating $\beta^+\gamma$ emitters with Gate

The utilized isotopes are ^{18}F as a pure β^+ emitter and ^{44}Sc, ^{55}Co, and ^{52}Mn as $\beta^+\gamma$ emitters, summarized in Table 1. The three smallest spheres of diameters 17 mm, 13 mm, and 10 mm were filled with ^{18}F, with activities of 54.5 kBq, 24.4 kBq, and 11.1 kBq, respectively. The three largest spheres of diameters 37, 28, and 22 mm are filled with a $\beta^+\gamma$ emitter. However, due to the complicated decay channels and deexcitation gammas of ^{55}Co (0.477, 0.931, 1.316, and 1.409 MeV) and ^{52}Mn (0.744, 0.936, and 1.434 MeV), the source information was computed to mimic the ^{55}Co and ^{52}Mn isotopes; they are summarized in Table 2.

Table 1: The table contains the basic physical properties for the isotope.

Isot.	HL	β^+ (%)	γ_P (MeV & %)	$\beta^+\gamma_P$	$\frac{Y_{(\beta^+\gamma)}}{\beta^+}$	$\frac{\varepsilon_{\gamma_P}}{\varepsilon_{511}}$
^{18}F	110 min	97	---	---	---	---
^{44}Sc	3.97 hr.	94	1.157 (100.0)	100.0	100	0.56
^{55}Co	17.53 hr.	57	0.477 (20) 0.931 (75) 1.316 (7.1) 1.409 (17)	13 59 3.5 11	17.8 77.7 3.8 10.7	1.02 0.63 0.57 0.51
^{52}Mn	5.6 da.	29	0.744 (90) 0.936 (94) 1.434 (100)	100	100	0.72 0.62 0.50

Table 2: The three largest NEMA phantom spheres filled with ^{44}Sc, ^{55}Co, or ^{52}Mn.

Isotopes		$\beta^+ + E_{\gamma_P}$ (MeV)	NEMA spheres and filed activity		
			D=37 cm	D=28 cm	D=22 cm
^{44}Sc + ^{18}F	^{44}Sc	β^+ + 1.157	562 kBq	242 kBq	118 kBq
^{55}Co + ^{18}F	^{55}Co	β^+ + 0.477	71.47 kBq	30.97 kBq	15.07 kBq
		β^+ + 0.931	268.53 kBq	116.37 kBq	56.45 kBq
		β^+ + 1.316	25.27 kBq	10.95 kBq	5.31 kBq
		β^+ + 1.409	60.40 kBq	26.18 kBq	26.18 kBq
^{52}Mn + ^{18}F	^{52}Mn	β^+ + 0.744	178 kBq	77 kBq	3.7 kBq
		β^+ + 0.936	187 kBq	81 kBq	3.9 kBq
		β^+ + 1.434	198 kBq	86 kBq	4.1 kBq

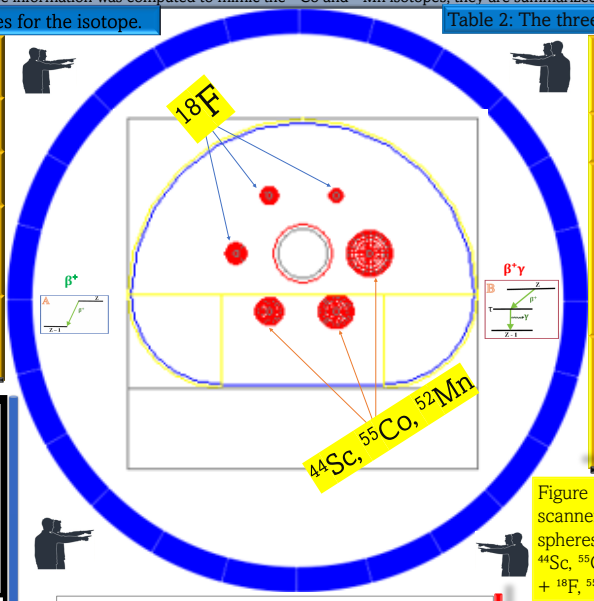


Figure 1: The panel shows the NEMA phantom in the modular J-PET scanner for double-isotope studies with Gate, where the smallest three spheres were filled with ^{18}F. The largest three spheres were filled with ^{44}Sc, ^{55}Co, or ^{52}Mn. The simulation was conducted with each pair of ^{44}Sc + ^{18}F, ^{55}Co + ^{18}F, and ^{52}Mn + ^{18}F isotopes.

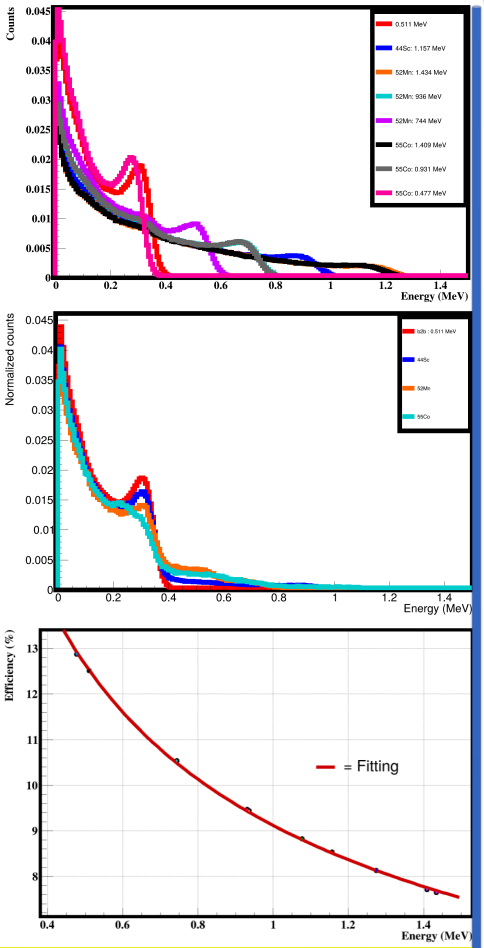
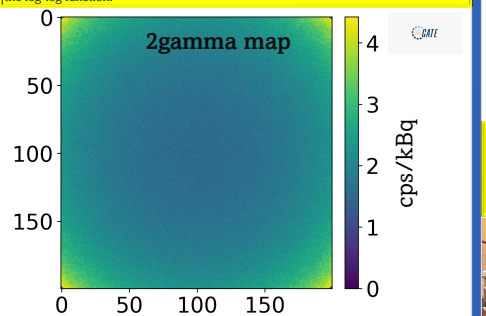


Figure 2. Top: The energy deposition spectra of various gamma energies plotted using the single-photon mode incorporated in the gate documentation. Middle: energy deposition spectra for 0.511 MeV, ^{44}Sc, ^{55}Co, and ^{52}Mn isotopes. Bottom: the efficiency as a function of energy deposition, and a fitting curve was adopted using the log-log function.



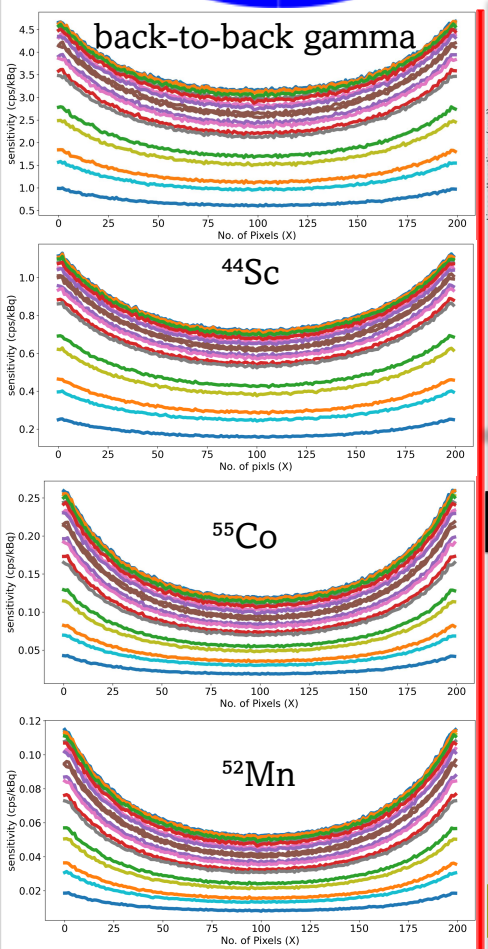


Figure 3 shows the sensitivity map for 2γ and the profiles for back-to-back gamma, ^{44}Sc, ^{55}Co, and ^{52}Mn isotopes in triple events. The simulation is done with a volume sources of radius 35 cm length 23 cm.

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Attenuation of gamma in the Phantom

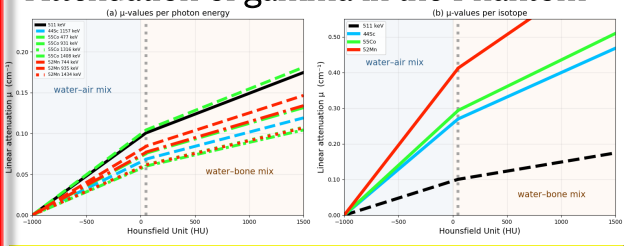


Figure 4: The linear attenuation coefficients (μ) graphs per energy (left) and per isotope (right). It is estimated based on the gamma energies for 511 keV photons, ^{44}Sc (1.157 MeV), ^{55}Co (0.477 MeV, 931 MeV, 1.316, and 1.409 MeV), and ^{52}Mn (0.744 MeV, 1435 MeV) based on the Carney bilinear model for 120 kVp with a 1047 breakpoint; the relative scales in water and bone are calculated and plotted based on NIST data [6, 7].

Reconstructed images

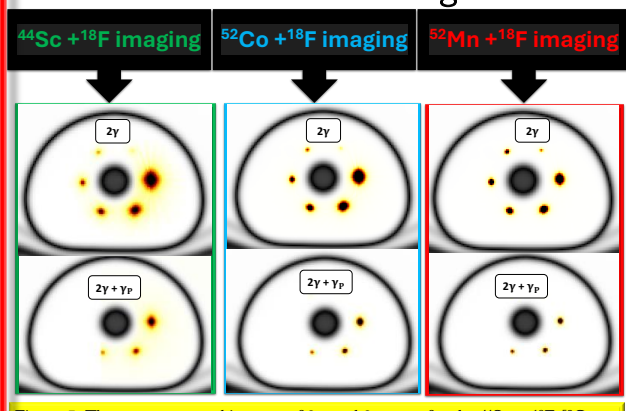


Figure 5: The reconstructed images of 2γ and 2γ + γ_p for the ^{44}Sc + ^{18}F, ^{52}Co + ^{18}F, and ^{52}Mn + ^{18}F pairs of isotopes.

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