Actinium 225: Physical properties, imaging protocol setup, dose calculations and radiation protection principals

25th International Iranian Congress of Nuclear Medicine

April 2025

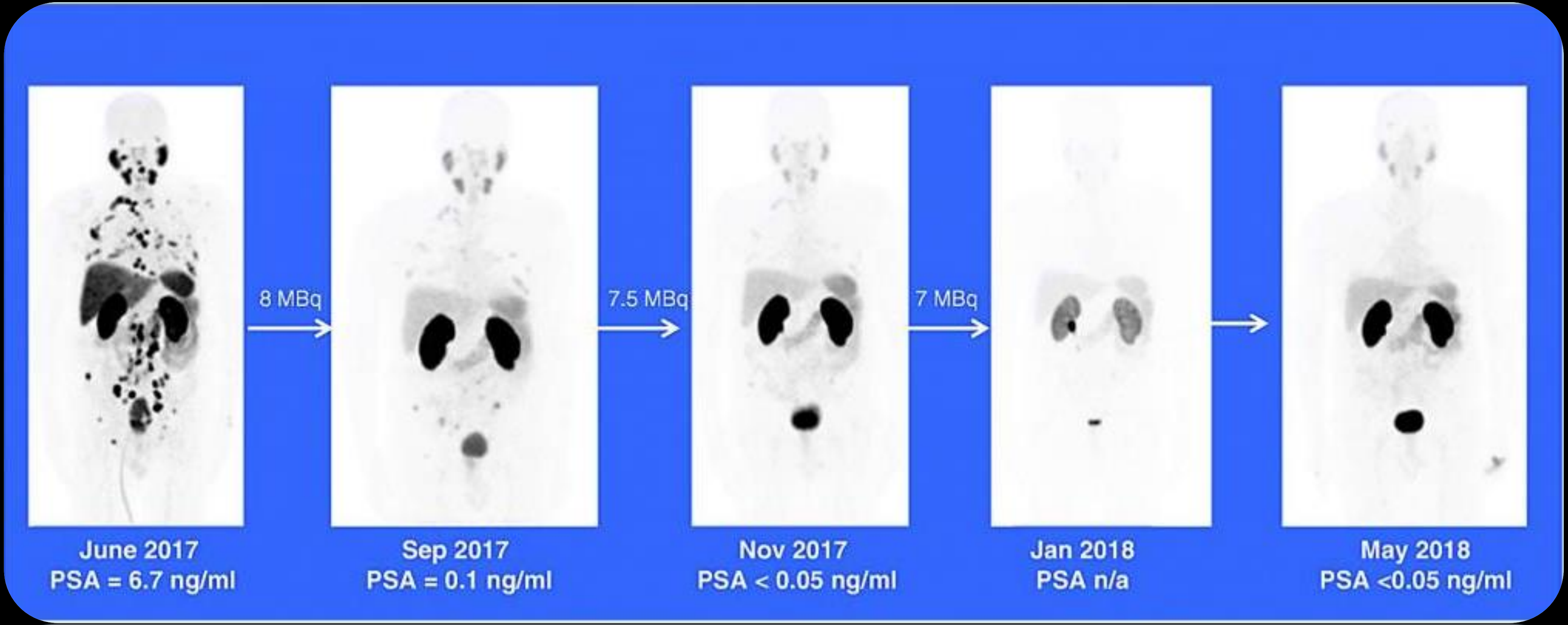
Peyman Sheikhzadeh, PhD

Assistant Professor
Tehran University of Medical Sciences

Medical Physicist, IKHC

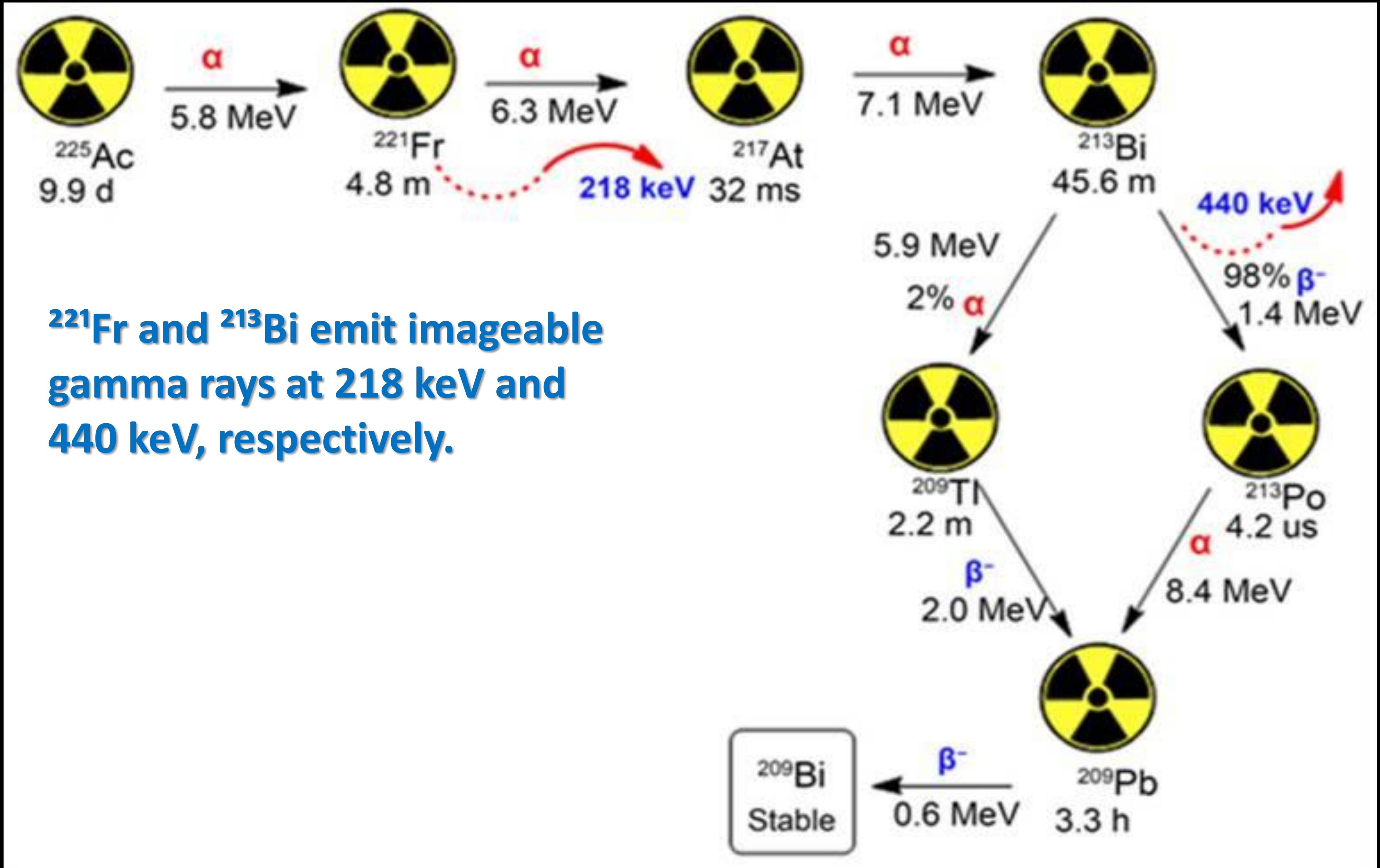
Introduction

- Actinium-225 (Ac-225) is a radioactive isotope of actinium.
- Symbol: Ac-225
- Atomic number: 89
- Mass number: 225
- Half-life: ~9.92 days
- Decay mode: Alpha, Beta, Gamma ➔ Targeted Alpha Therapy (TAT)
- for cancer treatment (e.g., neuroendocrine tumors, prostate cancer).
- The alpha particles are highly energetic but travel only a few cell diameters, making Ac-225 ideal for killing cancer cells precisely while sparing nearby healthy tissue



Mdanda, Sipho, et al. "Recent innovations and nano-delivery of actinium-225: a narrative review." *Pharmaceutics* 15.6 (2023): 1719.

Physical Properties and Decay Scheme



^{221}Fr and ^{213}Bi emit imageable gamma rays at 218 keV and 440 keV, respectively.

Decay Scheme:

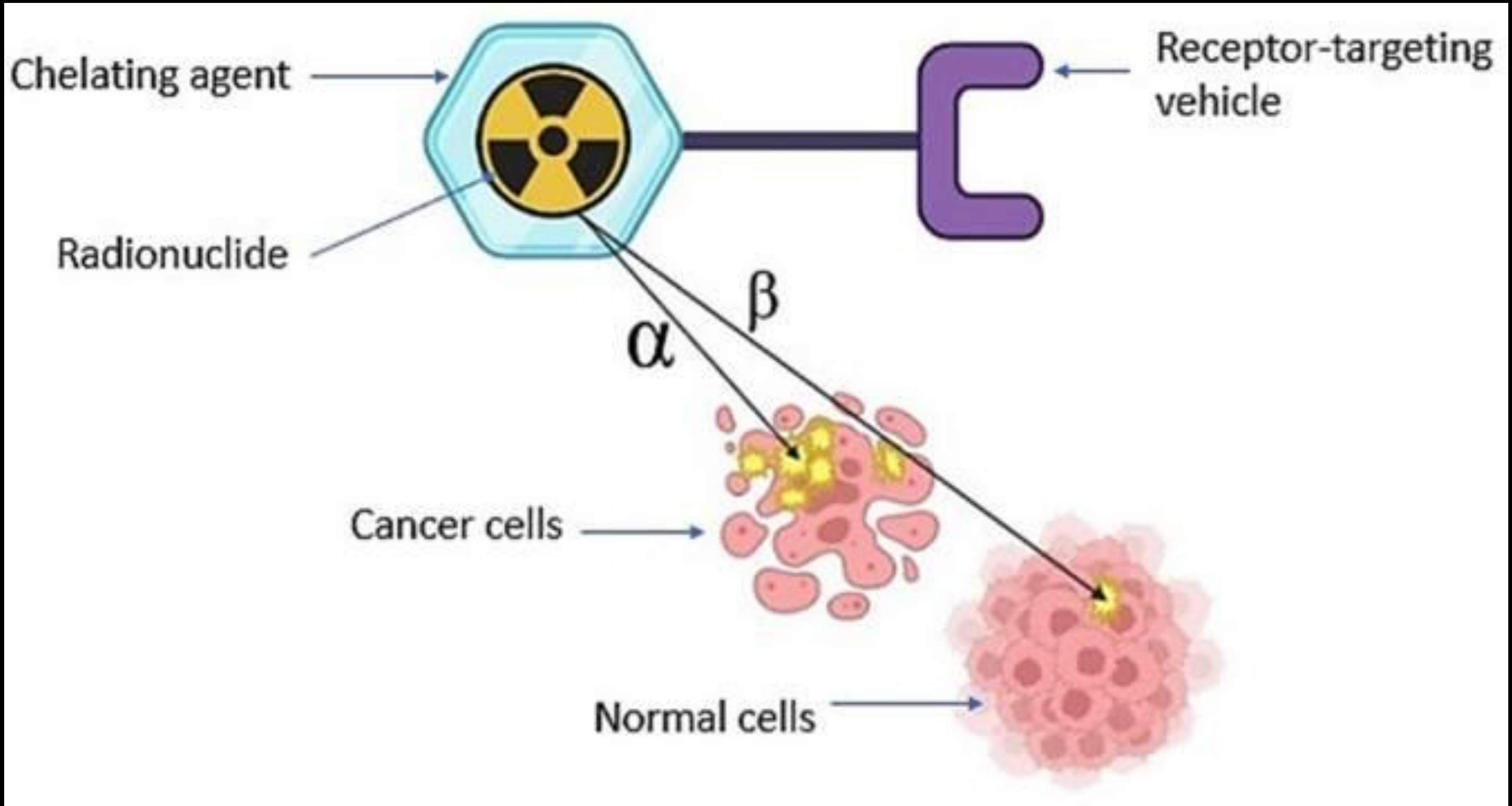
- **225Ac** → Actinium-225
- **221Fr** → Francium-221
- **217At** → Astatine-217
- **213Bi** → Bismuth-213
- **213Po** → Polonium-213
- **209Pb** → Lead-209
- **209Bi** → Bismuth-209 (Stable)

225Ac (9.92 days)
↓ α (5.8 MeV)
221Fr (4.8 min) ★ (218 keV)
↓ α (6.1 MeV)
217At (32 msec)
↓ α (7.1 MeV)
213Bi (46.6 min) ★ (440 keV)
→ β (1.4 MeV)
213Po (4.2 μs)
↓ α (8.4 MeV)
209Pb (3.3 hours)
→ β (0.6 MeV)
209Bi (Stable)

Key Question: As 225Ac has 4 alpha emissions, are we sure the daughter product emissions are localized in the tumor lesions?

• The first two daughters, 221Fr and 217At, are assumed to decay where 225Ac decays, due to short T1/2 (4.8 min and 32 ms).

• The third daughter, 213Bi, has a half-life of 46.6 min, which may be sufficient for redistribution and off-target decay.

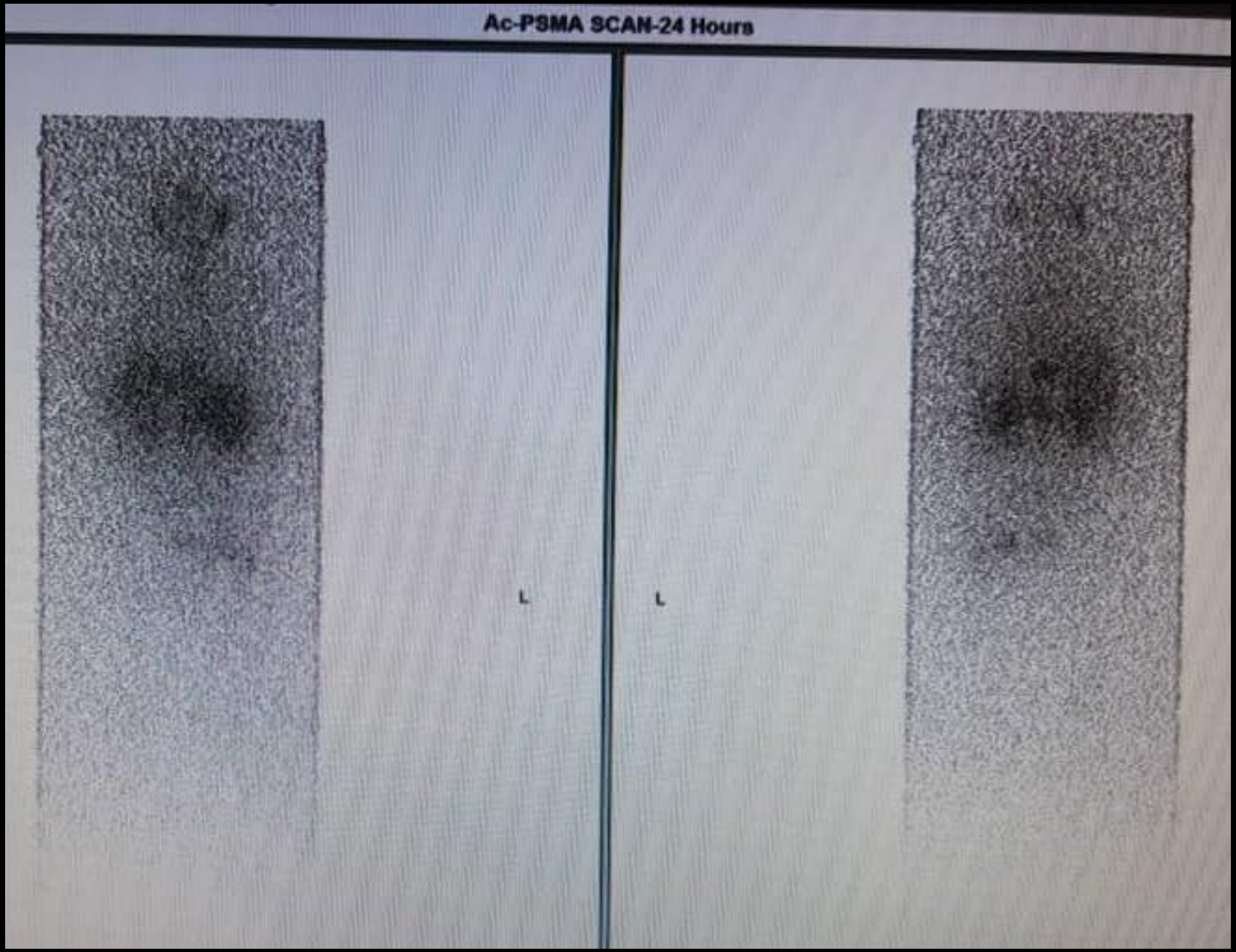

Chelating agent
Receptor-targeting
vehicle
Radionuclide
β
α
Cancer cells
Normal cells

Imaging Protocol Setup

<u>2 different energy windows:</u>

218.2 keV (±20%) to localize ^{221}Fr

440 keV (±20%) to localize ^{213}Bi.



New Protocol Setup for SPECT Imaging

- Monte Carlo Simulation
- PyTomography
- Phantom Study
- Patient Study

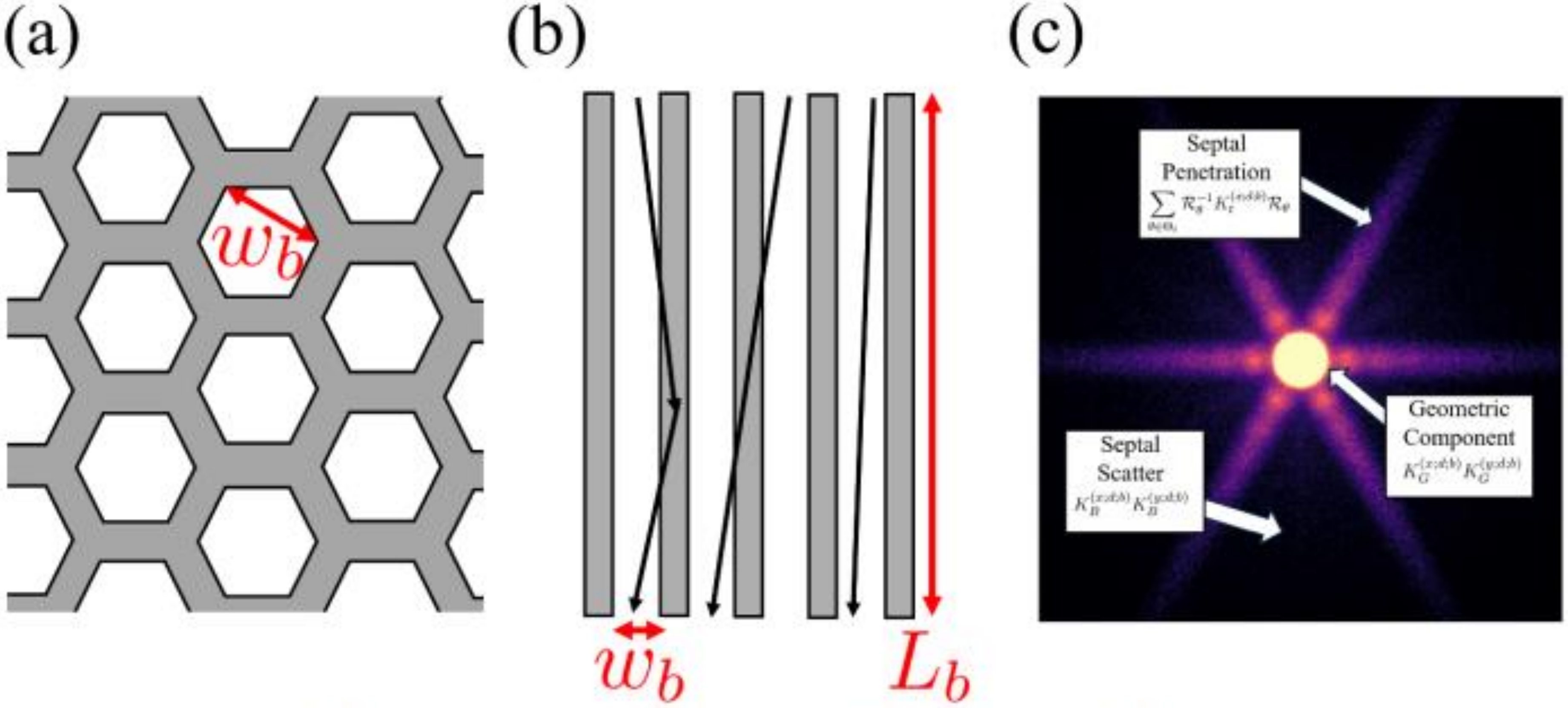


Figure 1. (a) Top view of collimator, where w_b is the collimator hole width. (b) Side view of collimator, where L_b is the length of the collimator. Three different photon detection paths are shown as black arrows; from left to right they correspond to septal scatter, septal penetration, and geometric component respectively. (c) 440 keV PSF obtained by simulating a point source at a source-detector distance of 30 cm using SIMIND. Labeled scatter components that refer to the different terms of equation (8) are shown.

Polson, L. A., Esquinas, P., Kurkowska, S., Li, C., Sheikhzadeh, P., Abbassi, M., ... & Rahmim, A. (2025). Computationally efficient collimator-detector response compensation in high energy SPECT using 1D convolutions and rotations. Physics in Medicine & Biology, 70(2), 025002

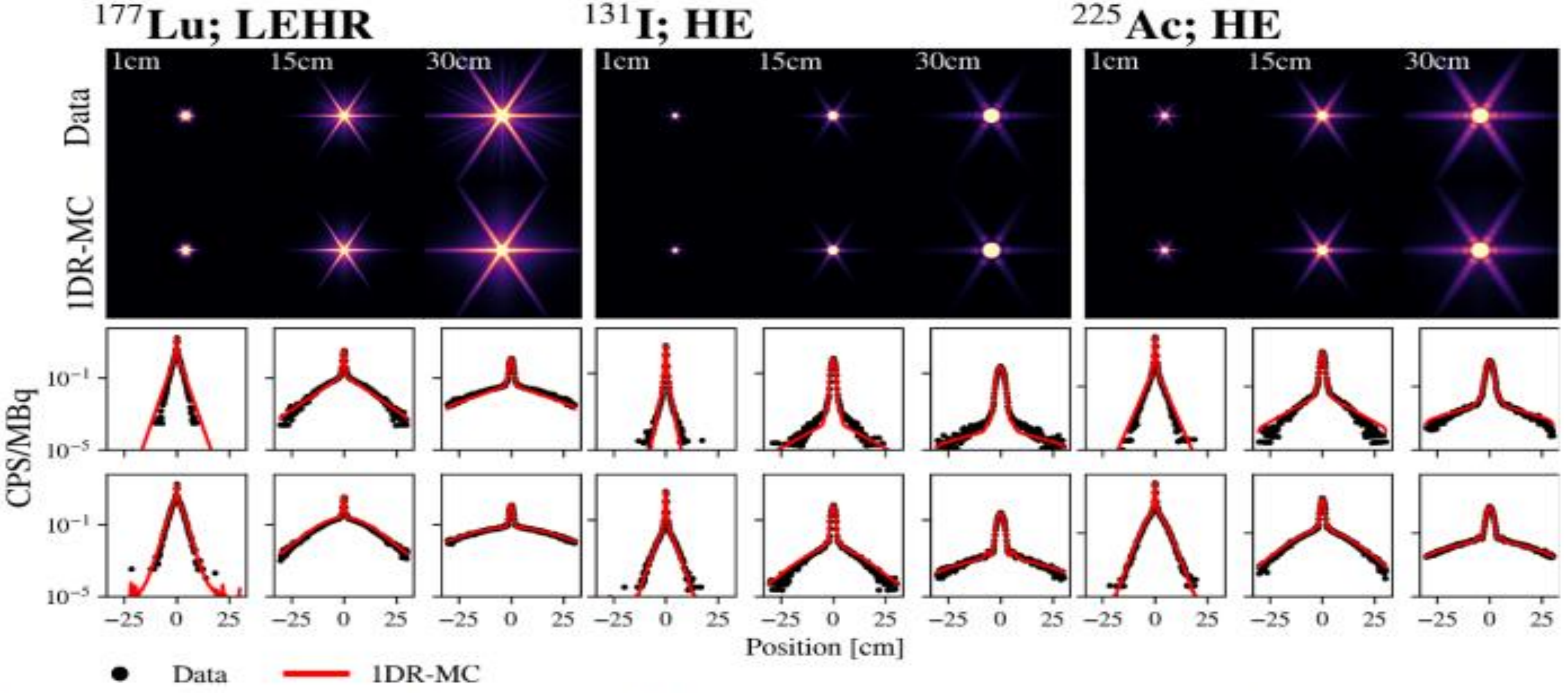


Figure 2. Comparison between Monte Carlo simulated PSF data and the corresponding fit from the 1DR-MC model at different source-detector distances. From top to bottom, (i) 2D profiles of Monte Carlo PSF data, (ii) 2D profiles of 1DR-MC model, (iii) central vertical profile of Monte Carlo and fitted PSFs, (iv) central horizontal profile of Monte Carlo and fitted PSFs; the Monte Carlo data is shown in black scatter points, while the fitted data is shown as a solid red line.

Polson, L. A., Esquinas, P., Kurkowska, S., Li, C., Sheikhzadeh, P., Abbassi, M., ... & Rahmim, A. (2025). Computationally efficient collimator-detector response compensation in high energy SPECT using 1D convolutions and rotations. Physics in Medicine & Biology, 70(2), 025002

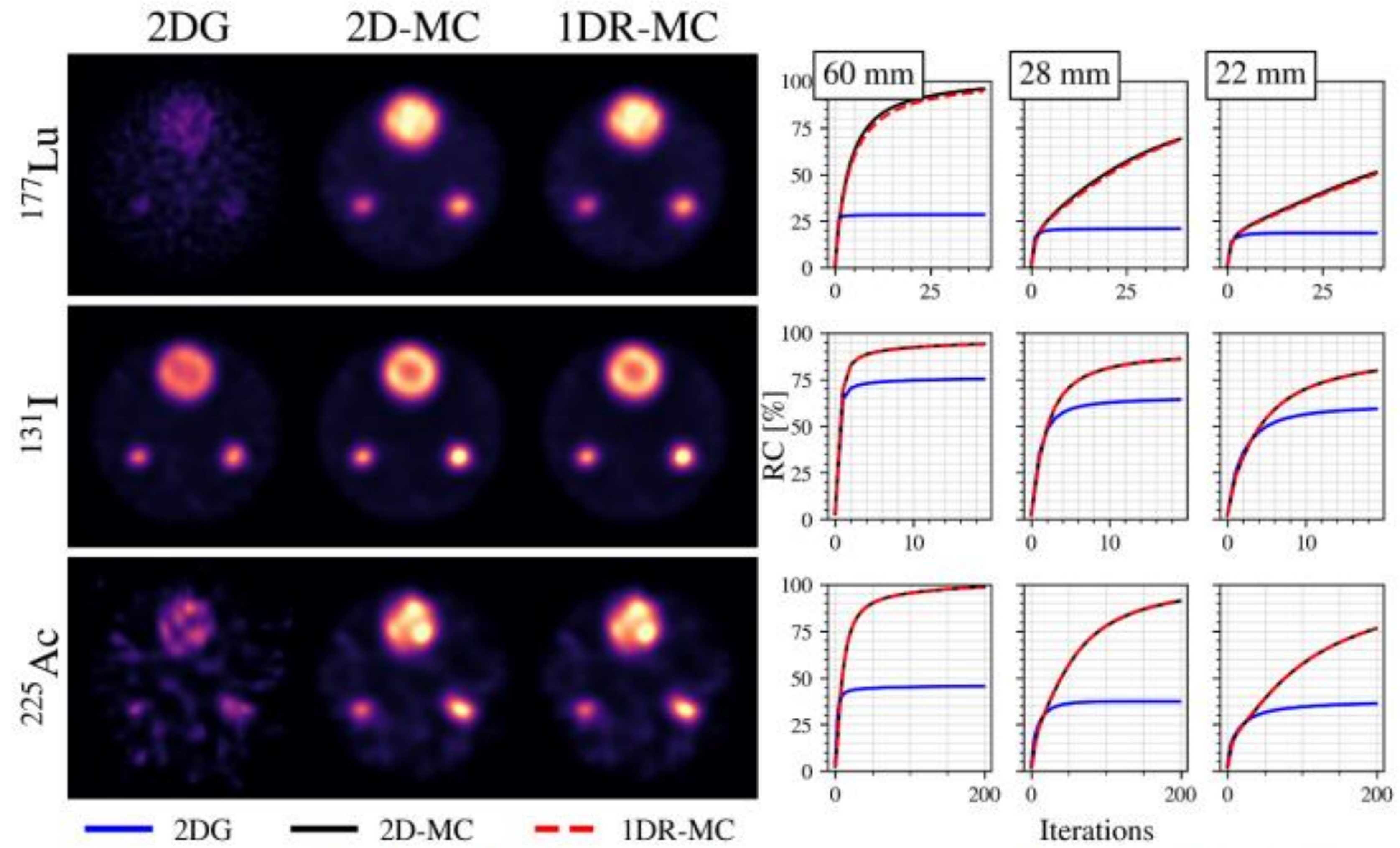
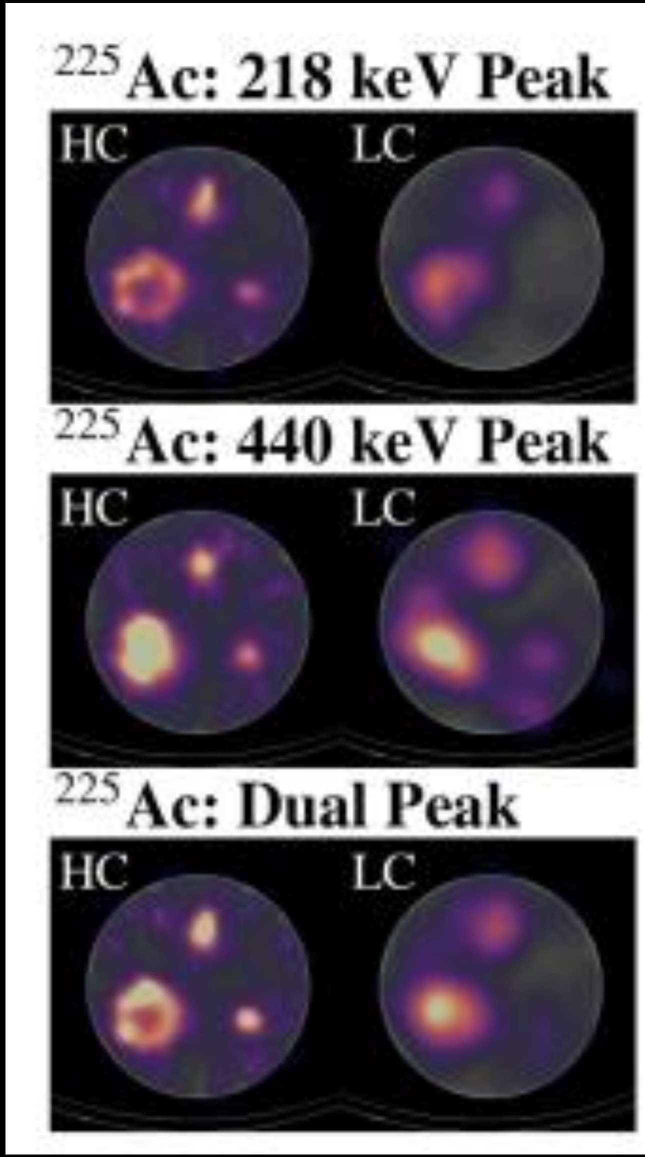


Figure 4. Reconstructions of the MC simulations (left) and corresponding RCs for each of the three spheres at each iteration (right). The displayed images correspond to reconstructions after 40 iterations (^{177}Lu), 10 iterations (^{131}I) and 100 iterations (^{225}Ac).

Polson, L. A., Esquinas, P., Kurkowska, S., Li, C., Sheikhzadeh, P., Abbassi, M., ... & Rahmim, A. (2025). Computationally efficient collimator-detector response compensation in high energy SPECT using 1D convolutions and rotations. Physics in Medicine & Biology, 70(2), 025002



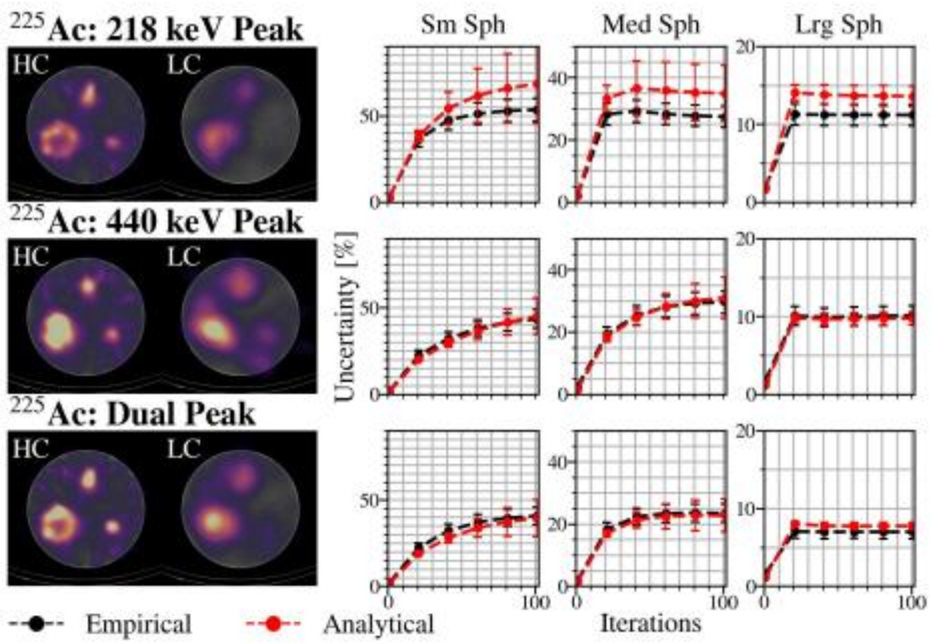


Fig. 2. Reconstruction and uncertainty estimation for the ^{225}Ac NEMA phantom. From top to bottom are reconstructions using 218 keV peak, 440 keV peak, and the dual peaks. High count (HC) was obtained by adding all 33 sets of projection data together and low count (LC) was a reconstruction of a sample acquired image. Images correspond to axial slices of reconstruction (MLEM 100it) with 3 cm Gaussian post filtering used in the LC case. Shown in black is the empirical uncertainty obtained via Eq. 25 with error bars corresponding to the standard error of this statistic. Shown in red is the analytically obtained uncertainty from Eq. 24, with error bars corresponding to the standard deviation across estimates for each acquisition.

Polson, L., Kurkowska, S., Li, C., Esquinas, P., Sheikhzadeh, P., Abbasi, M., ... & Rahmim, A. (2025). Uncertainty propagation from projections to region counts in tomographic imaging: Application to radiopharmaceutical dosimetry. *IEEE Transactions on Medical Imaging*.

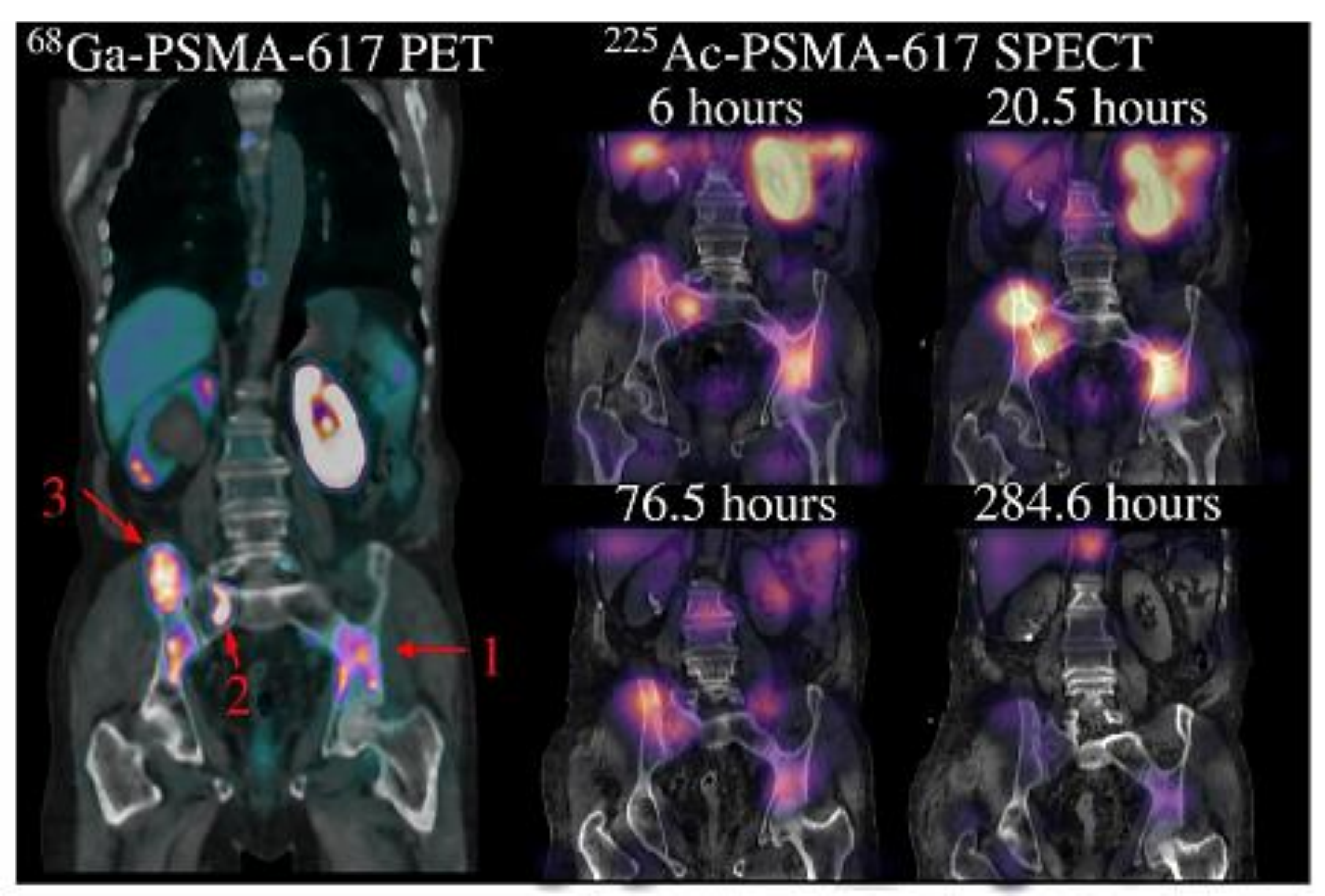
New Protocol Setup for SPECT Imaging

- 32 projections (16 per head) with 2.5min per projection angle

- 128x128 resolution, Zoom=1

- The following energy windows:
- 163.5-196.2keV
- 196.2-239.8keV
- 239.8-272.5keV
- 352.0-396.0keV
- 396.0-484.0keV
- 484.0-572.0keV

- 1hour, 24hour, 48hour, 72hour



Polson, L., Kurkowska, S., Li, C., Esquinas, P., Sheikhzadeh, P., Abbasi, M., ... & Rahmim, A. (2025). Uncertainty propagation from projections to region counts in tomographic imaging: Application to radiopharmaceutical dosimetry. *IEEE Transactions on Medical Imaging*.

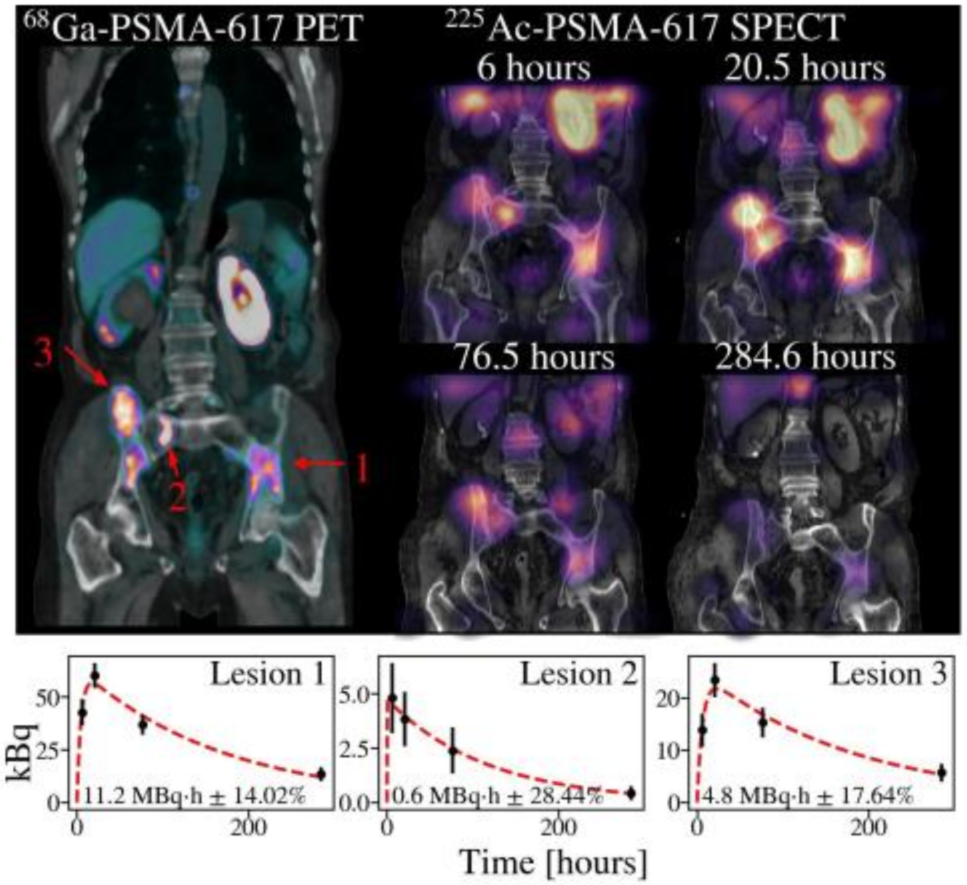
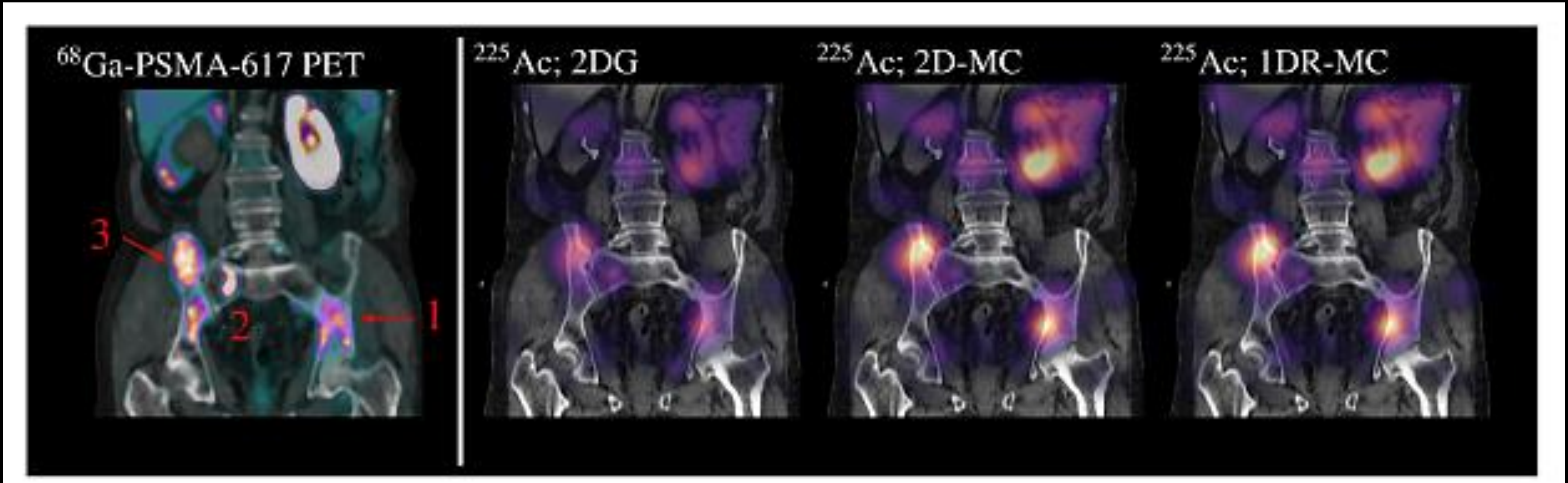


Fig. 7. Reconstruction, TACs, and TIA estimation of multi time point ^{225}Ac-PSMA-617 data using JDP in reconstruction. Top: coronal slices of a pre therapy PET image and reconstructed SPECT images at each time point. Lesions numbers are marked in red. Bottom: TACs for each lesion; TIA and TIA uncertainty is printed on each plot.

Polson, L., Kurkowska, S., Li, C., Esquinas, P., Sheikhzadeh, P., Abbasi, M., ... & Rahmim, A. (2025). Uncertainty propagation from projections to region counts in tomographic imaging: Application to radiopharmaceutical dosimetry. *IEEE Transactions on Medical Imaging*.



2D Gaussian model 2D Monte Carlo model 1D rotation-MC

Polson, L. A., Esquinas, P., Kurkowska, S., Li, C., Sheikhzadeh, P., Abbassi, M., ... & Rahmim, A. (2025). Computationally efficient collimator-detector response compensation in high energy SPECT using 1D convolutions and rotations. Physics in Medicine & Biology, 70(2), 025002.

Dose Calculations and Injected Activity

- Typical dosing: 100 kBq/kg
- Example: 70kg patient ≈ 7 MBq injection
- Importance of activity control (keep <1 mCi in preparation areas)

Radiation Shielding for Ac-225 Therapies

- **Shielding –** do not underestimate

TVL* [mm]	Lu-177	I-131	Ac-225	F-18
Lead	2.5	11.6	21.2	17.2
Concrete	179.1	225.9	237.1	240.0

*TVL: thickness of material required to reduce radiation field to 1/10 of its initial intensity

Caution Needed

- Existing shielding (e.g., for Lu-177) may not be sufficient for Ac-225. Always verify shielding adequacy.
- Ac-225 has a complex decay chain emitting high-energy photons and energetic electrons.
- Similar amount of shielding (lead/concrete) needed as for F-18 to block 90% of emissions.

Waste Storage Considerations:

- Ac-225 has a half-life of 9 days; long-term storage may be required if workload increases.
- Plan space for shielded storage of contaminated waste.

Safety Considerations and Precautions for Preparation and Injection of Actinium-225

- Wear nylon disposable shoe covers.
- Use one layer of nylon gloves plus two layers of latex gloves.
- Wear a lead gown with a disposable full-body cover over it.
- Use goggles with a full plastic face shield.
- Carry a record badge and an electronic digital dosimeter.

- Use an alpha-sensitive radiometer for monitoring.
- Wear a 3-layer mask to prevent accidental ingestion.
- Transfer equipment (e.g., paper documents, batch records) only with contamination control and Health Physics approval.
- Mobile phones are prohibited to prevent contamination transfer.

Patient Radiation Safety Instructions After Treatment

- Flush the toilet twice after each use.

- Use gloves when cleaning blood, urine, feces, or contaminated clothing; dispose of gloves immediately after use.

- If exposed to patient's bodily fluids (blood, feces, semen, vomit), wear disposable gloves, then wash hands thoroughly with soap and water.

- For several days post-treatment, patients and companions must protect eyes and skin from splashes of bodily fluids.

Patient Radiation Safety Instructions After Treatment

- Wash any clothing contaminated with blood, urine, or feces separately and rinse thoroughly.

- If blood, urine, or feces sampling is needed within the first week, inform medical staff about recent radioactive treatment.

- If medical care such as surgery or hospitalization is needed within the first week, inform healthcare personnel about radioactive drug treatment.

- Contact the Nuclear Medicine Department (Imam Khomeini Hospital) for complete guidance when needed.

Conclusion

- Ac-225 therapy is powerful but needs meticulous protection.
- Imaging and dosimetry allow monitoring therapeutic success.
- Importance of radiation safety for staff and patients.