RADIOLOGY

Y-90 SPECT maximum likelihood image reconstruction with a new model for tissue-dependent bremsstrahlung production

- 2017 SNM Annual Meeting -

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Disclosure

- Yuni Dewaraja and Jeffrey Fessler are consultants for MIM software Inc., Cleveland, Ohio

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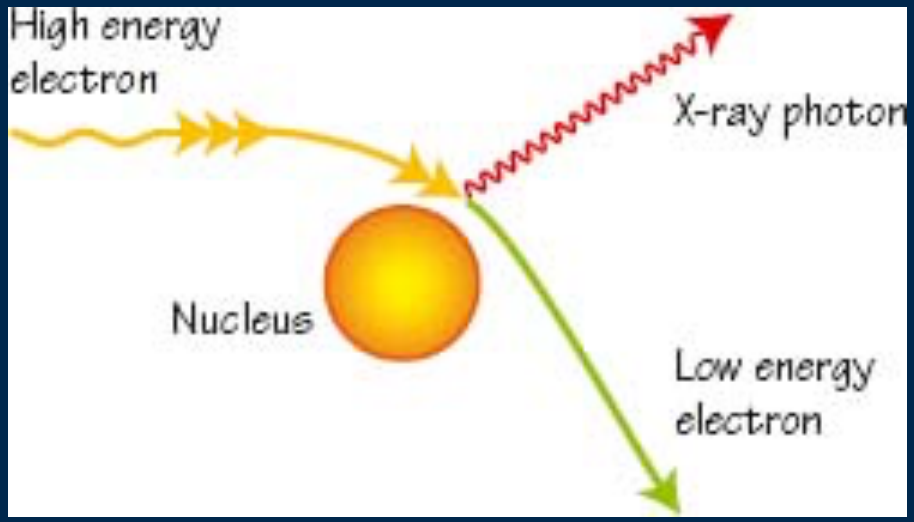
Objectives

- Material dependence of the bremsstrahlung generation
  - Bremsstrahlung production is proportional to Z^2 of absorber



Bremsstrahlung generation illustration

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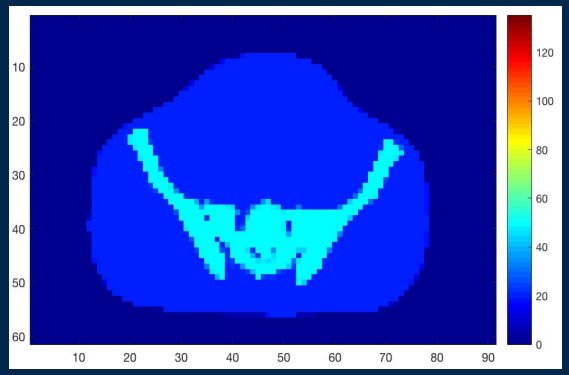
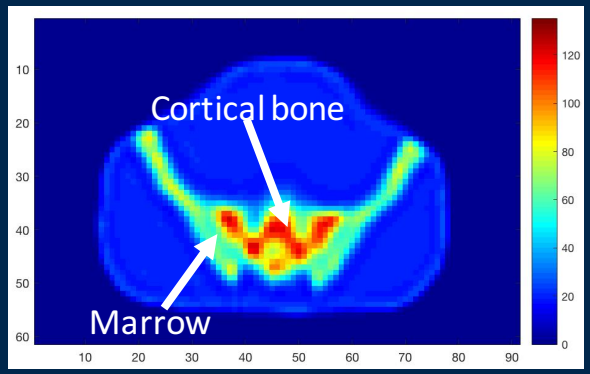
Objectives

- Y-90 SPECT
  - Existing reconstruction methods do not account for tissue-dependency

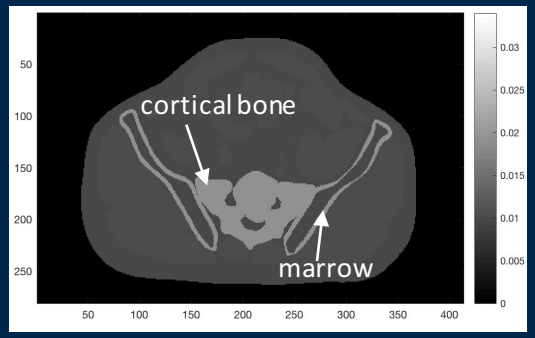


True image with equal activity conc. in bone & marrow

Reconstruction



Reconstructed image



CT

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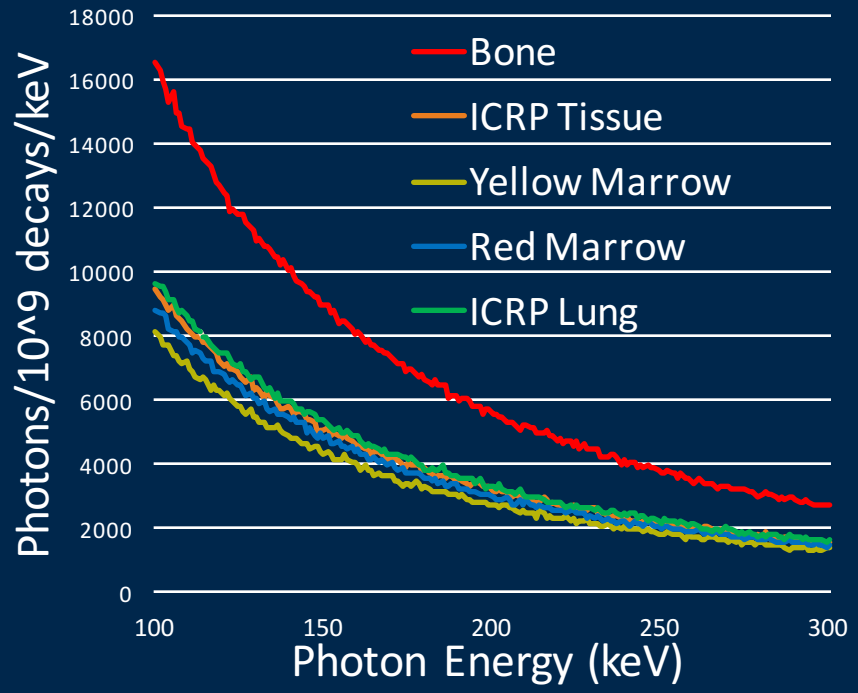
Methods

- Monte Carlo simulation
  - Bremsstrahlung generation in bone is ~2 times higher than in other tissues



- Simulation Software: EGS5 [1]
- Simulated for Bone, Tissue, Marrow, Lung in an infinite media

→ Same amount of activity in different tissue will produce different numbers of bremsstrahlung photons

[1] Hirayama H, Namito Y., Bielajew AF, Wilderman SJ, and Nelson WR, The EGS5 Code System, Stanford Linear Accelerator Center Publication SLAC-R-730, 2005.

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Methods

- New system matrix
  - Incorporated the tissue-dependent bremsstrahlung generation probability (based on CT) into the reconstruction system matrix :

$$
\begin{aligned}
y &\approx \text{Poisson}(Ax + s) \\
\text{Where, } A &= A_{\text{attn+psf}} B_{\text{prob}} \\
B_{\text{prob}} &= \text{diag}(b) \\
b_j &= q_{\text{tissue}} * (1 - \text{BVF}_j) + q_{\text{bone}} * (\text{BVF}_j) \\
q_{\text{bone}} &\simeq 2 * q_{\text{tissue}} \\
&\text{BVF}_j\text{: Bone-Volume Fraction of } j\text{th voxel in SPECT}
\end{aligned}
$$

  - Modification to standard system matrix:

$$
A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \begin{bmatrix} b_1 & 0 & \dots & 0 \\ 0 & b_2 & \dots & 0 \\ \dots & \dots & \dots & 0 \\ 0 & 0 & \dots & b_n \end{bmatrix}
$$

Standard system matrix Our modification

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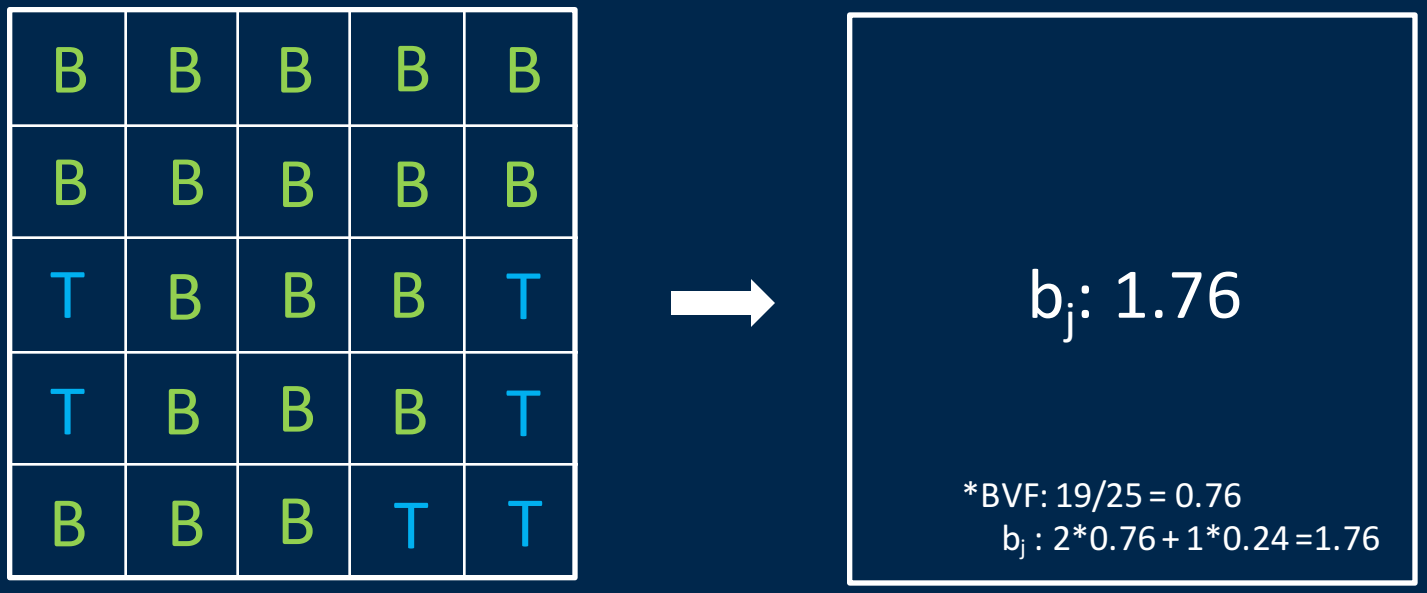
Methods

- BVF example:



25 voxels in CT image

* B: Bone, T: Tissue
→ Determined by thresholding

1 voxel in SPECT image

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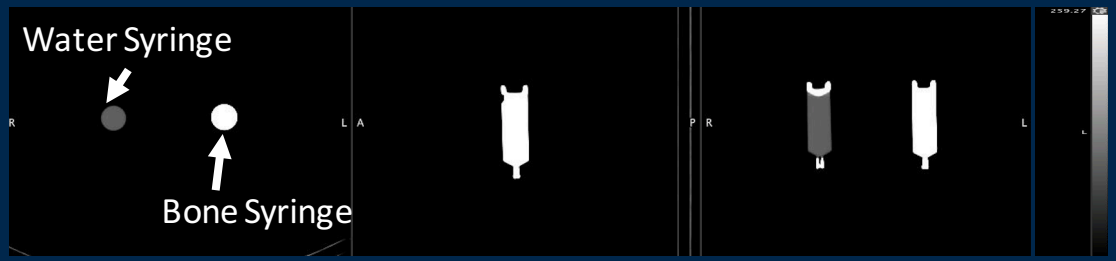
Results

- Measurement setup
  - Same Y-90 concentration in syringes with water and bone equivalent solution

	Water Syringe	Bone Syringe
Injected Y-90 Amount	6.94mCi	6.81mCi
Solution	Water	Bone equivalent solution [2] (K_2HPO_4, Dipotassium Hydrogen Phosphate)
Solution Density	~ 1.0 g/cm^3	~ 1.68 g/cm^3
Solution Amount	40 cc	40 cc

  - CT Image:



Axial Sagittal Coronal

[2] de Dreuille, Olivier, et al. "Bone equivalent liquid solution to assess accuracy of transmission measurements in SPECT and PET." IEEE Transactions on Nuclear Science 44.3 (1997): 1186-1190.

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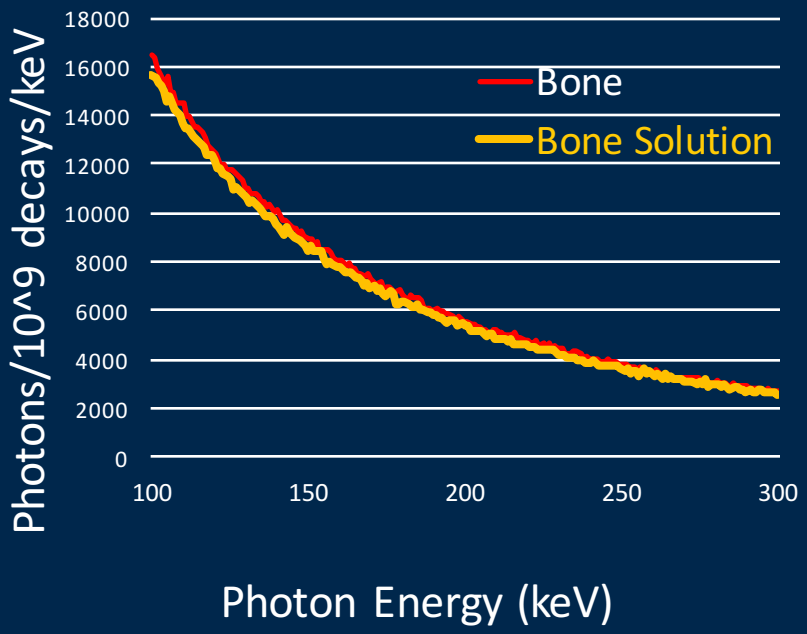
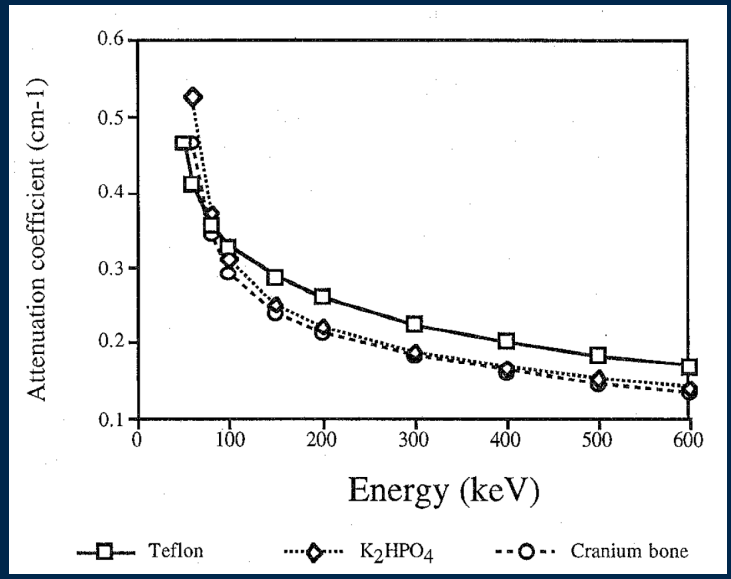
Results

- Bremsstrahlung yields from our EGS5 simulations



Photon generation vs Photon Energy

- Attenuation coefficients from [2]



Attenuation coefficient vs Photon Energy

[2] de Dreuille, Olivier, et al. "Bone equivalent liquid solution to assess accuracy of transmission measurements in SPECT and PET." IEEE Transactions on Nuclear Science 44.3 (1997): 1186-1190.

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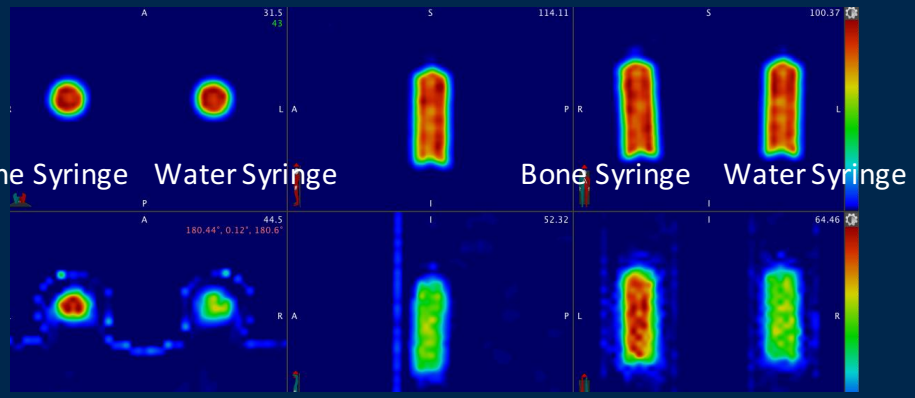
Results

- Commercial PET and SPECT OSEM

PET
(consistent w/ TRUE)

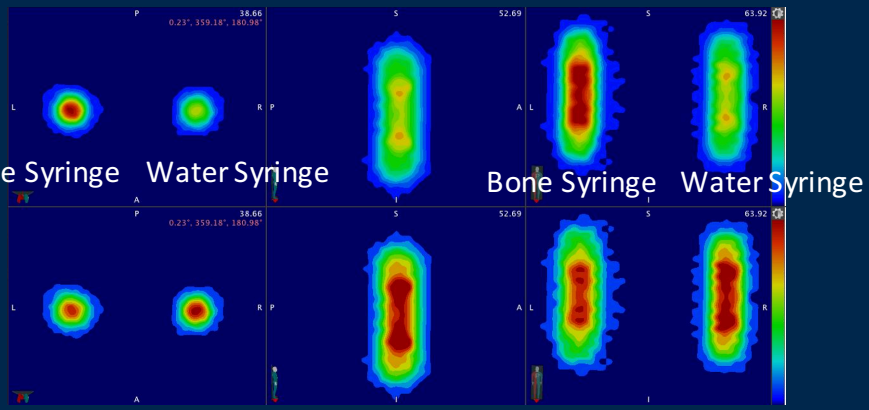
SPECT



- Our in-house SPECT OSEM reconstruction

Standard method

New method
(consistent w/ TRUE)



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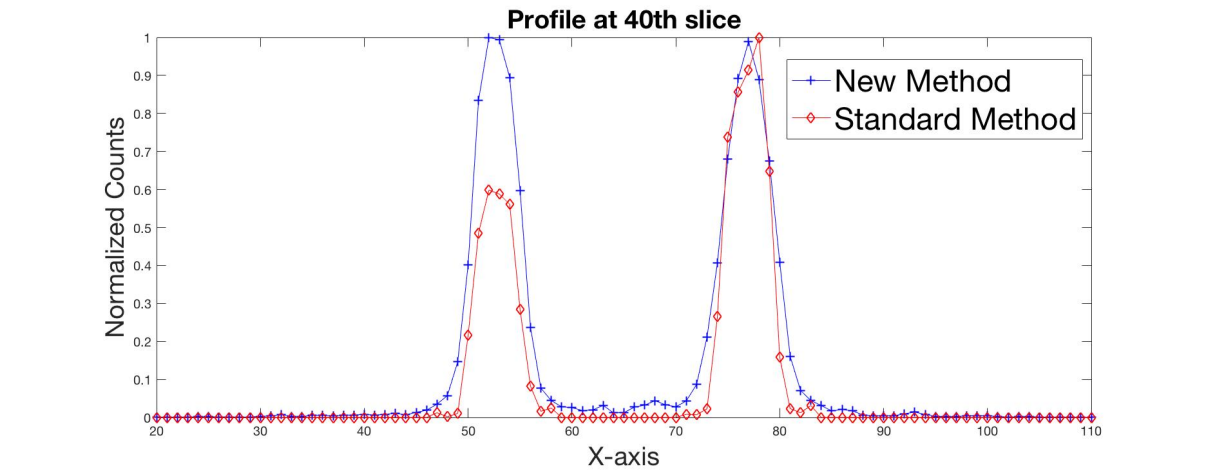
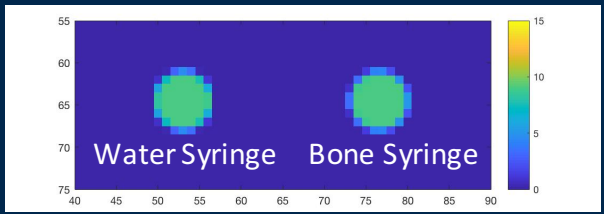
Results

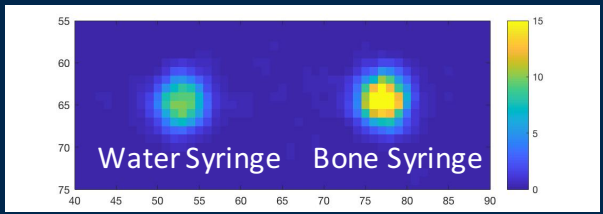
- Profile comparison:



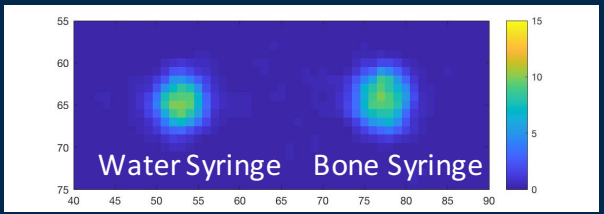
- Slice comparison



True Image



Standard Reconstruction



New Reconstruction

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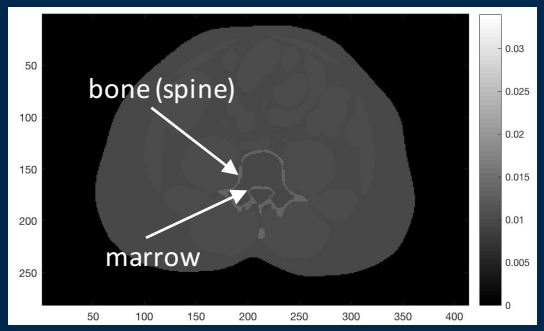
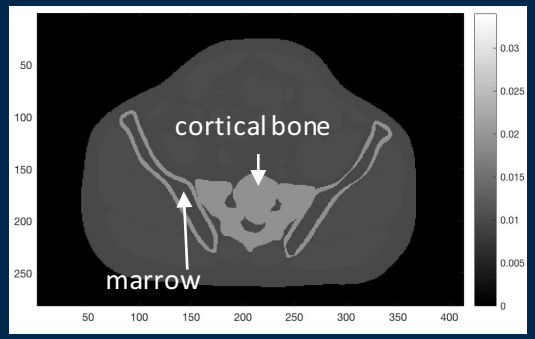
Results

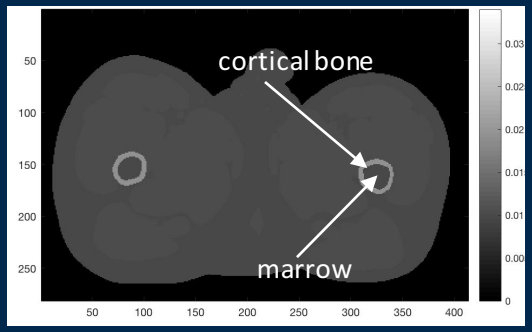
- Simulation setup
  - XCAT phantom slices from spine to upper femur
  - Attenuation map at three slices:



Spine

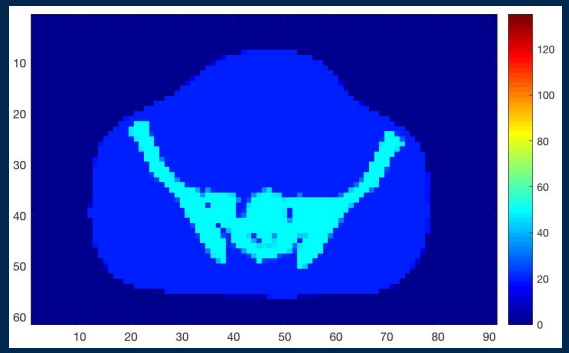


Pelvis



Upper femur

  - Set amount of activity in bone and marrow region as 1:1, 3:1, 1:3



True Activity Map (1:1 case) at Pelvis

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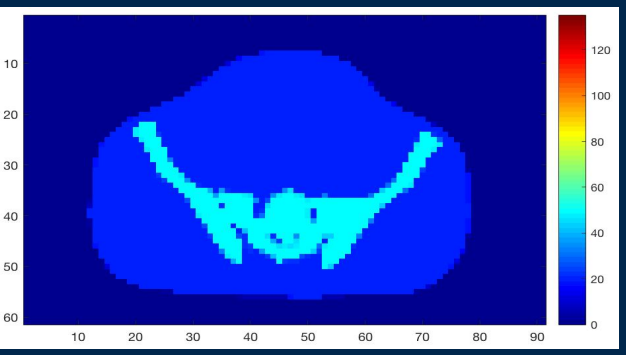
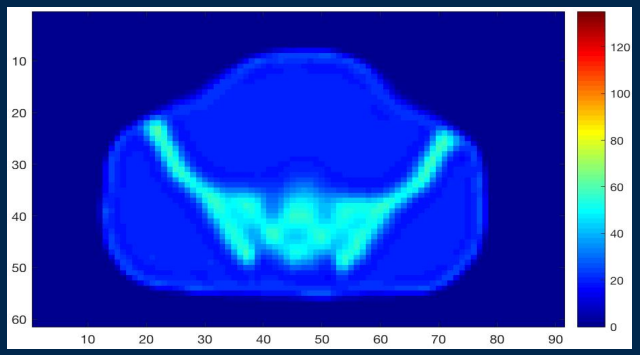
Results

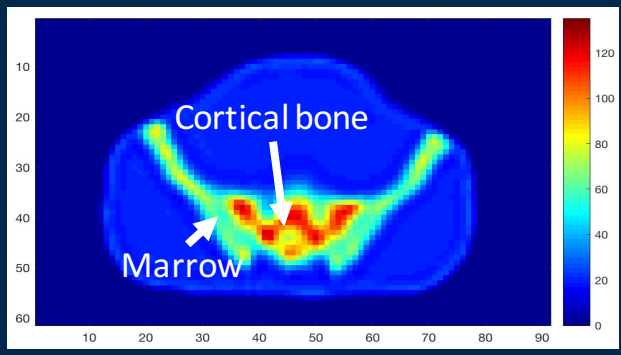
- Simulation result (ratio = 1:1)
  - Qualitative result



True Image



New Reconstruction



Standard Reconstruction

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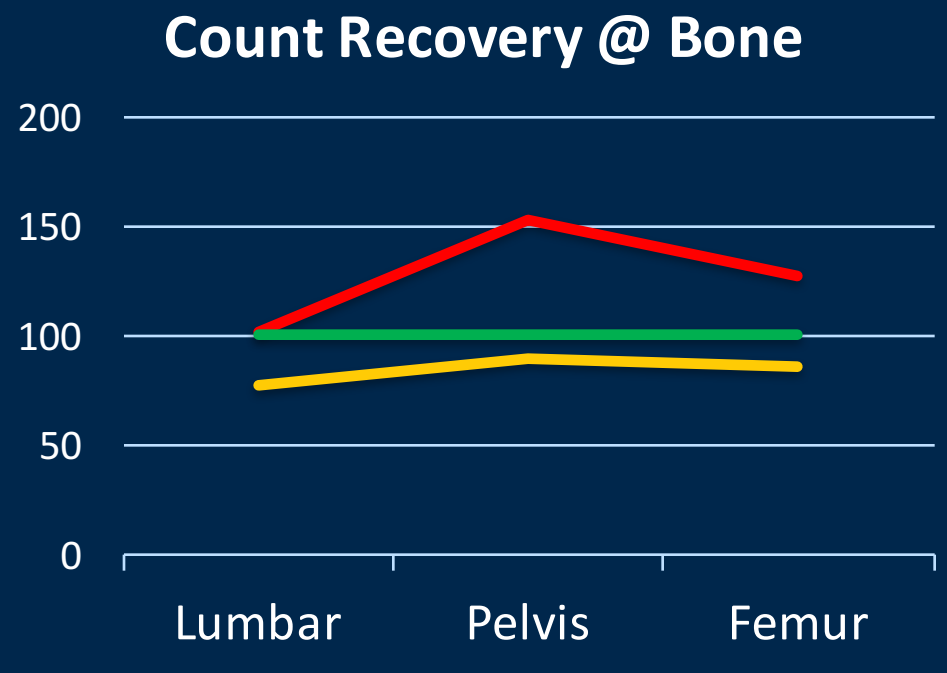
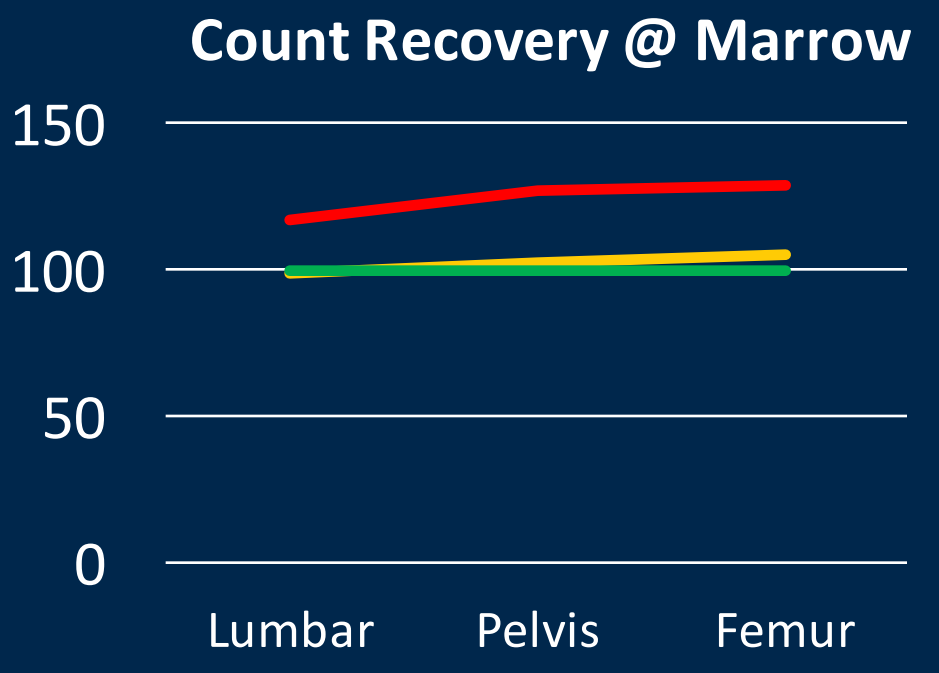
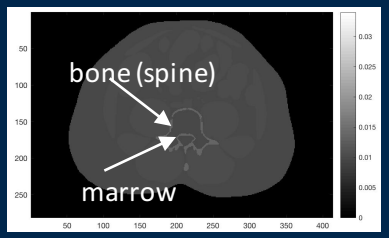
Quantitative Results

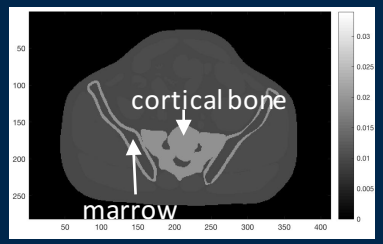
- Simulation result (ratio = 1:1)



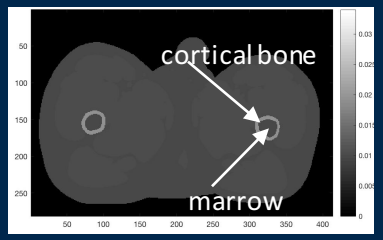




[Lumbar]



[Pelvis]



[Upper femur]

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Quantitative Results

- Simulation result
  - When activity ratio between bone:marrow is 3:1 and 1:3

Uptake ratio (Bone:marrow)	Model	ROI	Count Recovery @ Marrow	Count Recovery @ Bone
3:1	New model	Average	169.4	69.4
	Standard model		217.9	110.6
1:3	New model		81.6	109.6
	Standard model		92.6	160.3

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Summary / Conclusion

- Demonstrated the tissue-effect in simulation and measurement
- Demonstrated proof of concept of reconstruction incorporating tissue-dependent bremsstrahlung generation
- Potentially applicable to Y-90 therapies such as radio immunotherapy and synovectomy

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Thank you.

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