July 13, 2021

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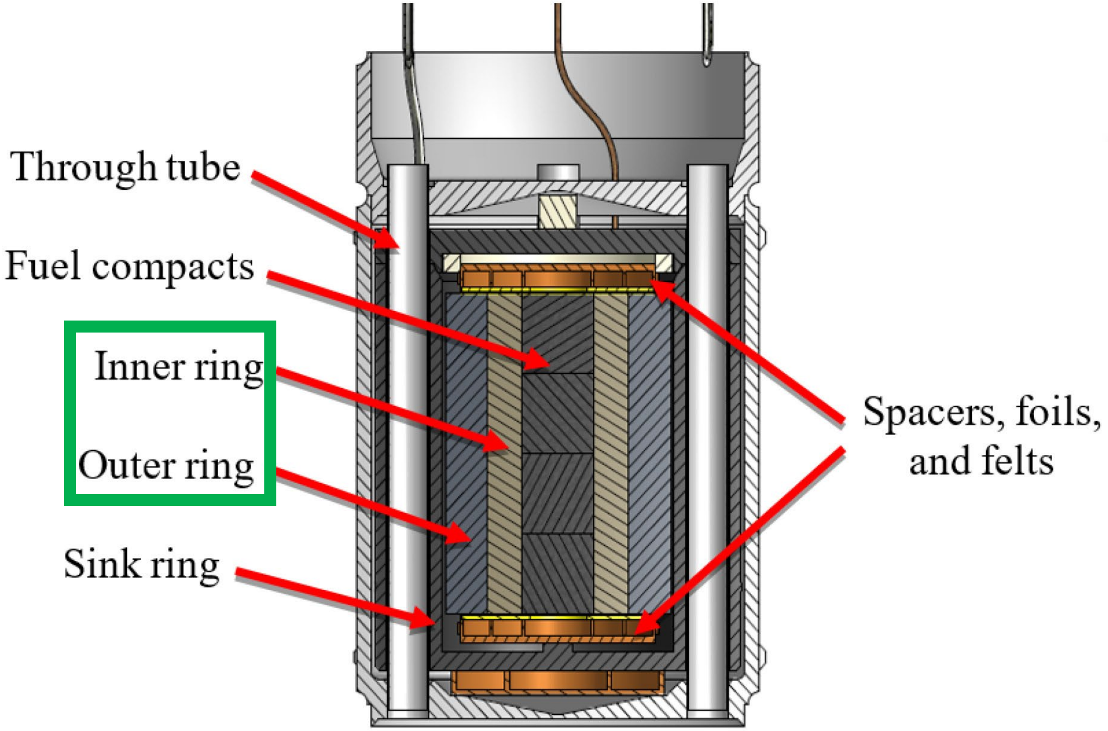
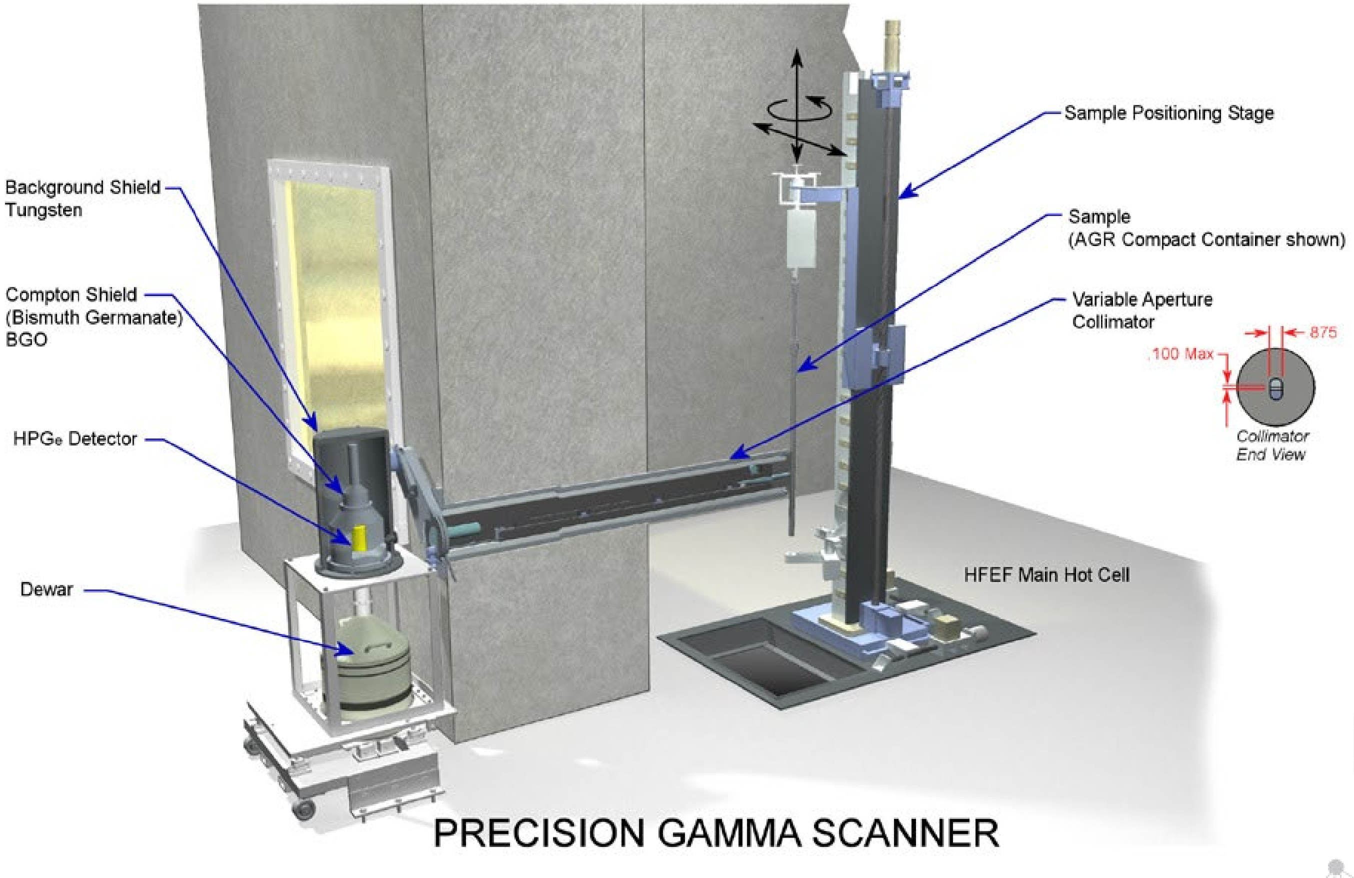
Modeling of AGR-3/4 PIE

Gamma tomographic reconstructions and finite element transport simulations

ART
Advanced Reactor Technologies

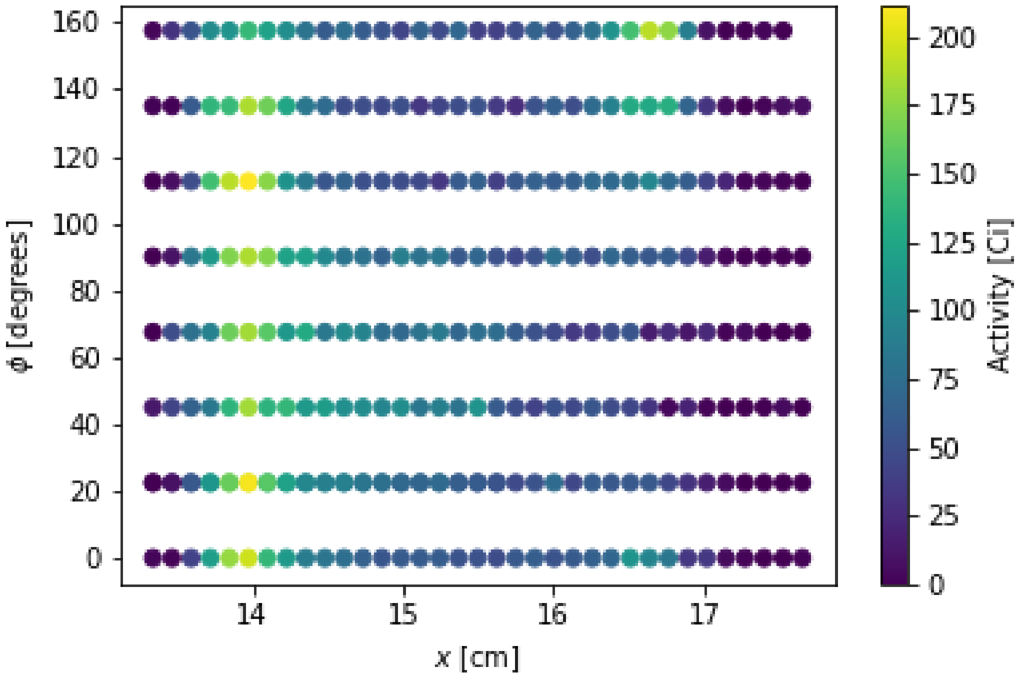
Precision Gamma Scanner (PGS) Overview

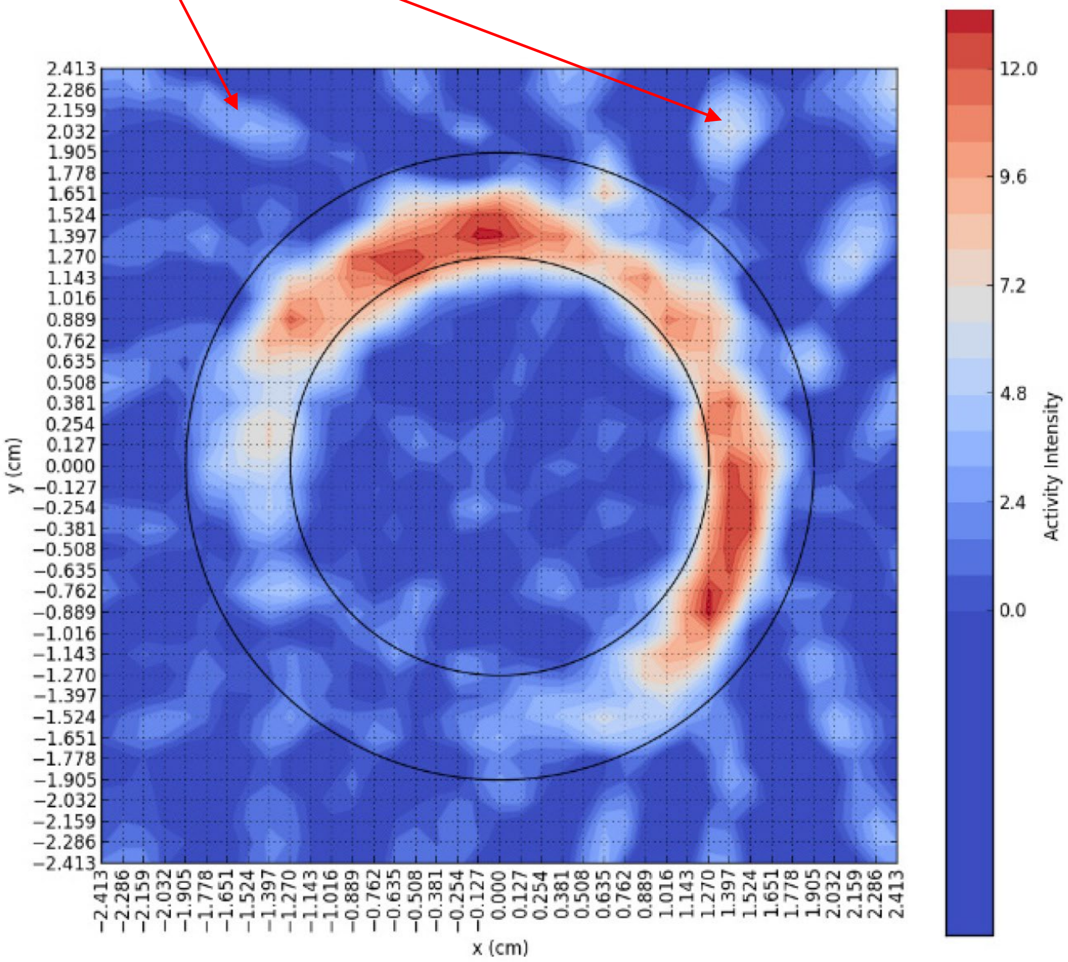




Prior Work – Nonphysical activity outside of ring

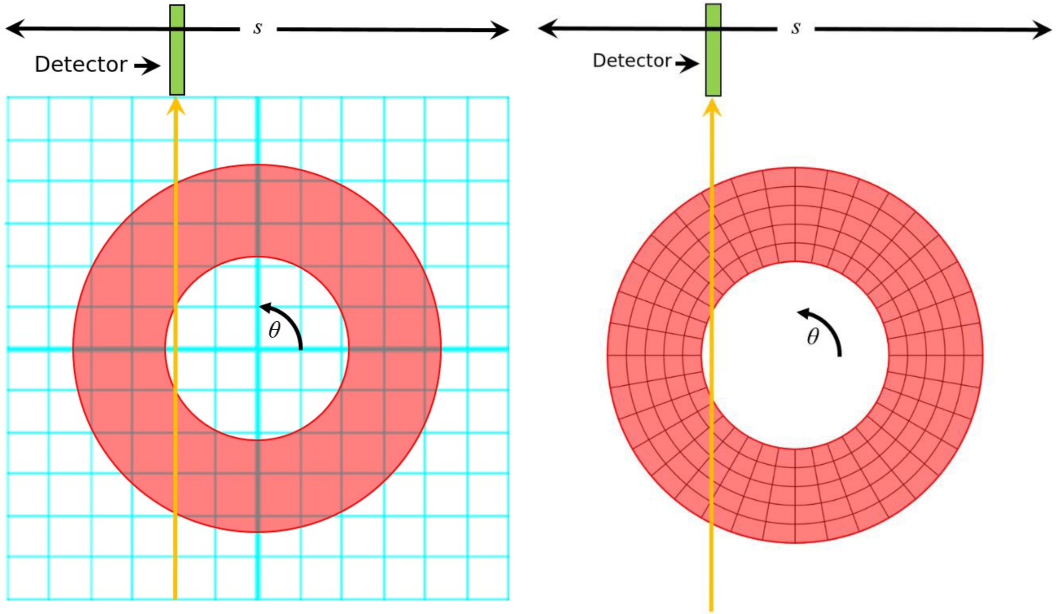
OR-08 Ag-110m





Problems/Changes

- Reconstructed activity observed outside of physical sample
  - Confined activity to within the geometry of the cylinders as measured in PIE metrology
  - PGS fixture may not have perfectly centered ring, centering adjustments necessary
- As the cylinder is not convex, the windowing function used in typical tomographic reconstructions is inappropriate and skews results
  - We use a nonlinear optimization function to find the activity within the cylinder from the scans $\|Mf - g\|_2^2 + \lambda^2 |Lf|_2^2$

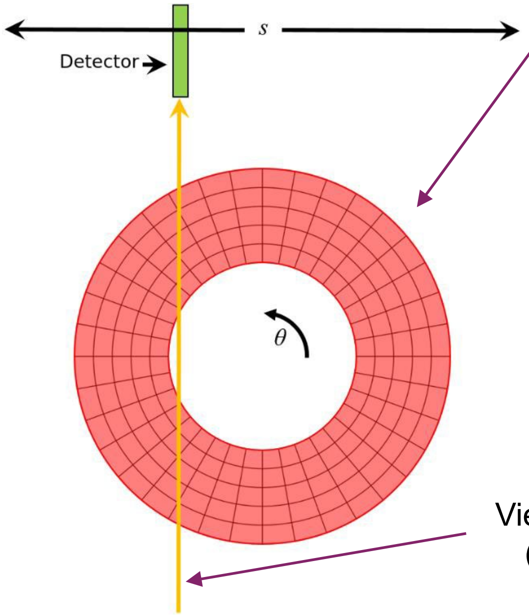


Optimization

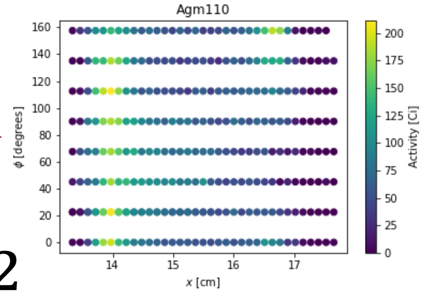
The solution is not unique. A Tikhonov regularization parameter is used to reduce nonphysical ‘salt and pepper’ noise in the final reconstruction

Image (pixel vector)

Scanned activities



$$\|Mf - g\|_2^2 + \lambda^2 \left\|\frac{\partial^2 f}{\partial r \partial \theta}\right\|^2$$

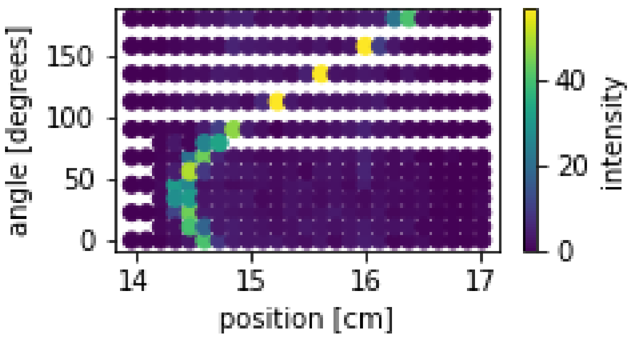


Tikhonov regularization parameter

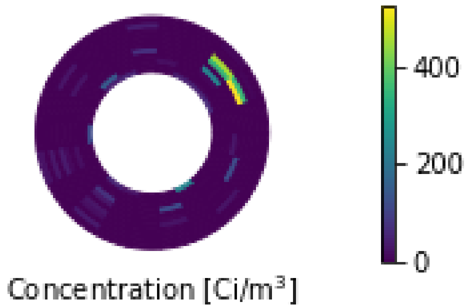
Viewing matrix (basis set)

Tikhonov Regularization

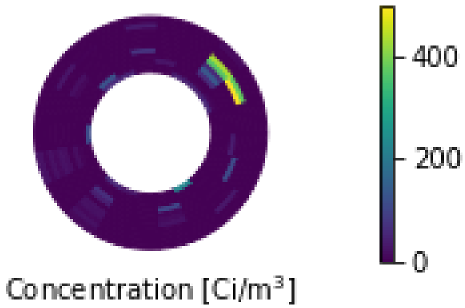
- Co-60 scans were used to determine λ
  - clearly showed localized phenomena (flux wire)
- $\lambda = 0.03$ was chosen
  - preserved local information while reducing noise



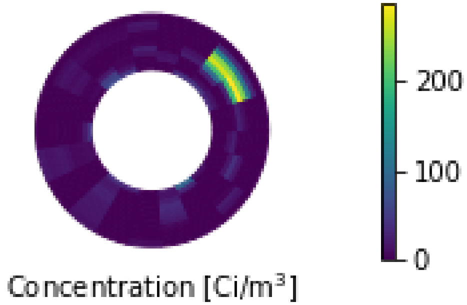
$\lambda = 0.0005$



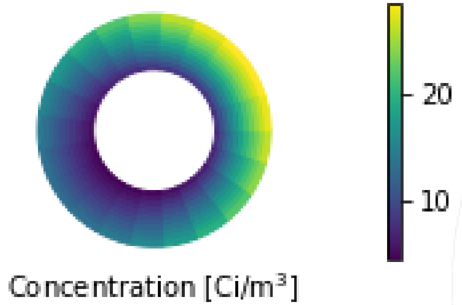
$\lambda = 0.005$



$\lambda = 0.03$



$\lambda = 0.5$



Finding the Center

$$\frac{\sum_x x \cdot g(x,\phi)}{\sum_x g(x,\phi)} = A(\phi)$$

$$A(\phi) = \left(x_{0,init} + \left(x_{cor,init} - x_{0,init}\right)\cos(\phi) + y_{cor,init}\sin(\phi)\right)$$

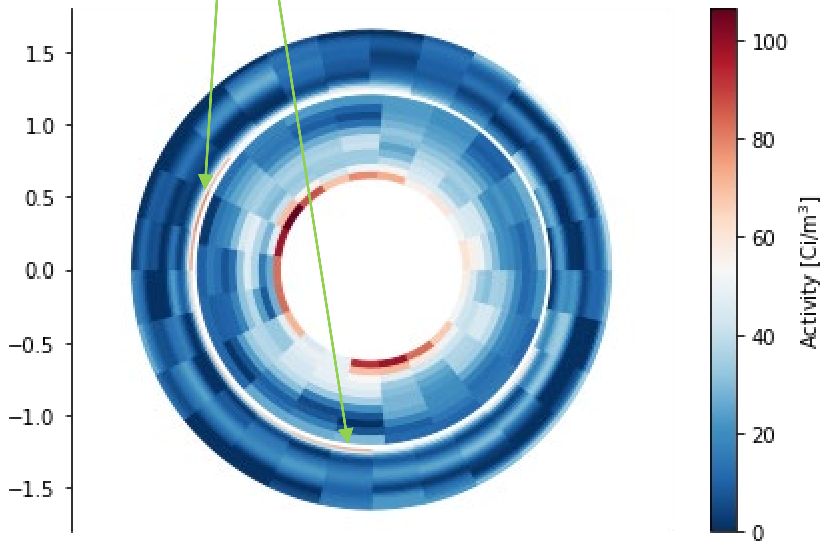
- A separate algorithm was used to determine the center of location and center of rotation of the cylinders
  - First, the initial center of rotation was estimated by defining the activity-weighted location vector $A(\phi)$ (top right)
  - $A(\phi)$ was then curve-fitted to a rotational transform, obtaining initial parameters $(x_{0,init}, x_{cor,init}, y_{cor,init})$
  - Then, used nonlinear optimization with (x_0, x_{cor}, y_{cor}) as parameters to minimize the function $\|Mf - g\|^2$
    - f found iteratively according to rules listed on the right
  - Faster method and resulted in a smoother objective function but tended to underestimate concentrations at cylinder edges.

$$f^{k+1} = f^k + b^k \frac{\sum_j \left(\frac{M_{ij}\left(g_j - M_j^T f^k\right)}{\sum_{i=1}^N M_{ij}}\right)}{\sum_j M_{ij}}$$

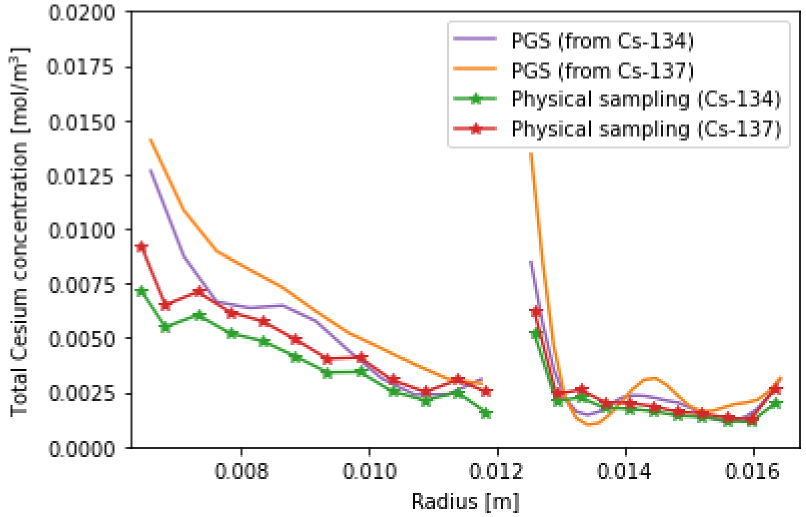
$$b^{k+1} = \begin{cases} 0.5b^k, & \left\|Mf^{k+1} - g\right\|^2 > \left\|Mf^k - g\right\|^2 \\ \min\left(1.1\,b^k, 1.5\right), & \left\|Mf^{k+1} - g\right\|^2 < \left\|Mf^k - g\right\|^2 \end{cases}$$

Results

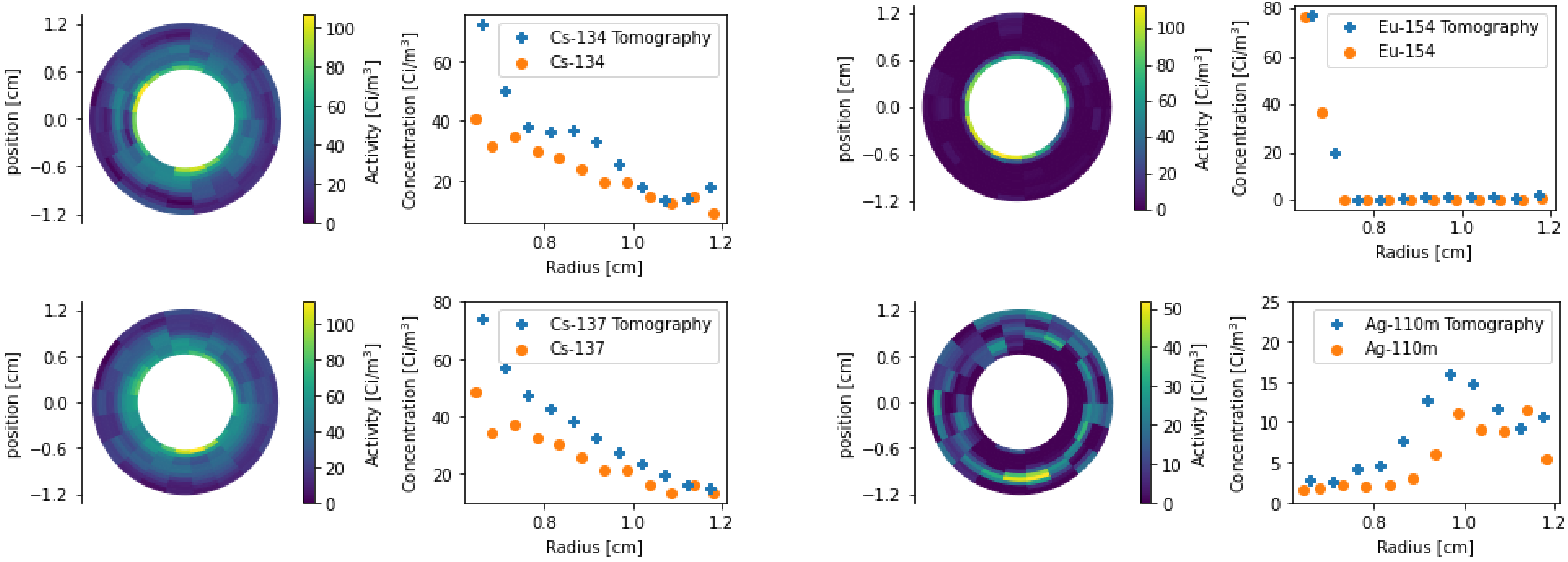
High concentrations on surfaces suggest the possibility of faster transport between the rings than within the rings



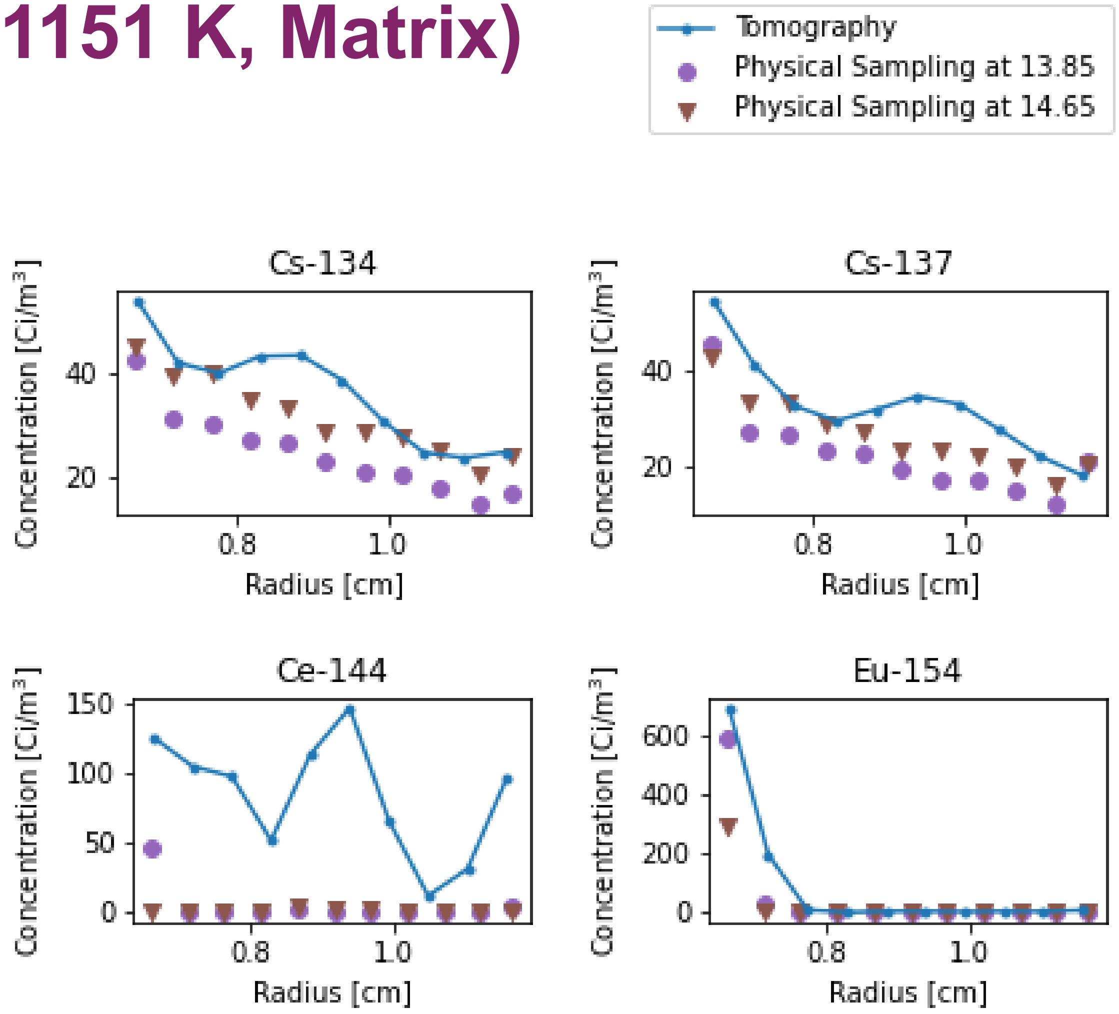
Capsule 3 inner and outer rings Cs-134 concentrations



Inner Ring 3 – Upper (TAVA 1026 K, PCEA)



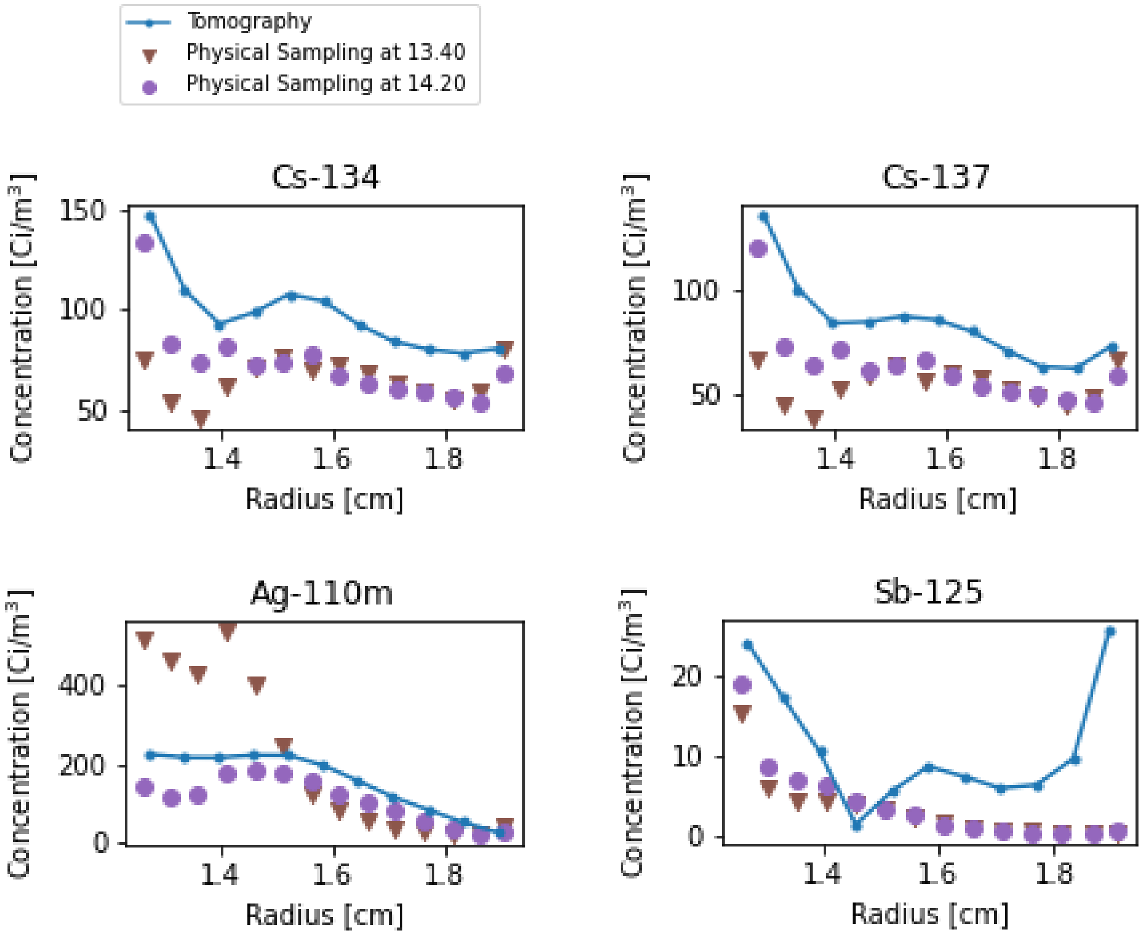
Inner Ring 7 – Middle (TAVA 1151 K, Matrix)



- Agreement with physical sampling for Ag, Cs, Eu
- Overestimates activity when measured concentrations are near the MDL, as in Ce144

Outer Ring 8 – Middle (TAVA 917 K)

- Good agreement with physical sampling for Ag, Cs
- Overestimates activity when measured concentrations are near the MDL, as in Sb125 and Eu154



Summary

- PGS tomographic scan reconstructions have been completed using the developed methodologies
- Report forthcoming prior to end of fiscal year
- Tomographic scans in agreement with physical sampling
- Noise floor is higher for PGS than for physical sampling
- Local phenomena is directly observable, highlighting areas not amenable to 1D treatment

FEM (MOOSE) model

- Using MOOSE (Multiphysics Object-Oriented Simulation Environment) to address the possibility of gas-phase transport and short-circuit diffusion to explain anomalous results
  - Explicitly modeling the vapor phase using sorption isotherms (Cs, Sr) where available
  - Investigating possibility of surface transport and GB diffusion, leakage of vapor around the rings
- Thermal modeling is done based on outputs from ABAQUS analysis (INL/EXT-15-35550)
- Model will be used for transport parameter estimation

Next Steps

- Estimate diffusivity using MOOSE Model / 1D Analytical model
- Determine possible magnitude of 1.5 D effects
  - Possible leakage of gas around rings
  - Possibility of surface transport / GB diffusion