Reconstruction of Mock Fuel Pins in a Fast Neutron Emission Tomography Imager for Spent Nuclear Fuel Verification

Dr. Mairead E. Montague
Postdoctoral Researcher, University of Michigan, University of Tennessee
Paul A. Hausladen, Jason P. Hayward
Oak Ridge National Laboratory, University of Tennessee

Introduction and Motivation

- IAEA has a vested interest in developing technologies to help support the Continuity of Knowledge over special nuclear materials and prevent the diversion of materials.
- Technologies are under development which will be able to verify spent nuclear fuel, including a fast neutron emission tomography (NET) imager.
- NET proposes using the spontaneous fission rates of ^{244}Cm to monitor and image spent nuclear fuel by detecting the fast neutron emissions and reconstructing the fuel assembly from which the neutrons originated.

Imager Design

Neutron Detector Modules:

- 1 detector module consists of 24 rows of 8 boron coated straws embedded in high density polyethylene
- Each row of 8 straws has single readout channel
- Located 0.5 cm behind collimator to allow for collimator rotation

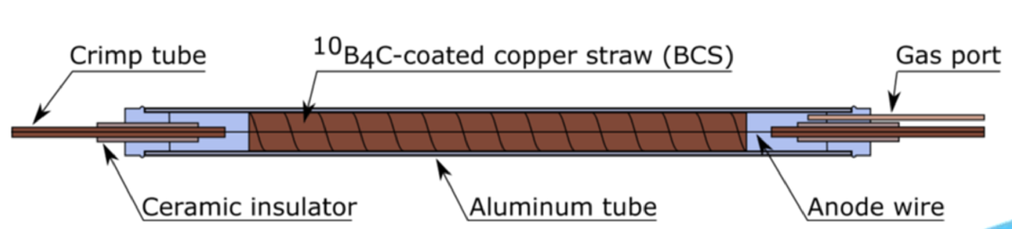

Fig 1. Diagram of a Boron Coated Straw detector

Full Detector:

a) 10 cm stainless-steel for gamma dose reduction
b) 30 cm of borated polyethylene to collimate neutrons
c) 72 collimator slits for direct neutron transmission
d) Neutron detector modules using 24 rows of 8 boron coated straw detectors embedded in HDPE
e) 5 cm of borated polyethylene

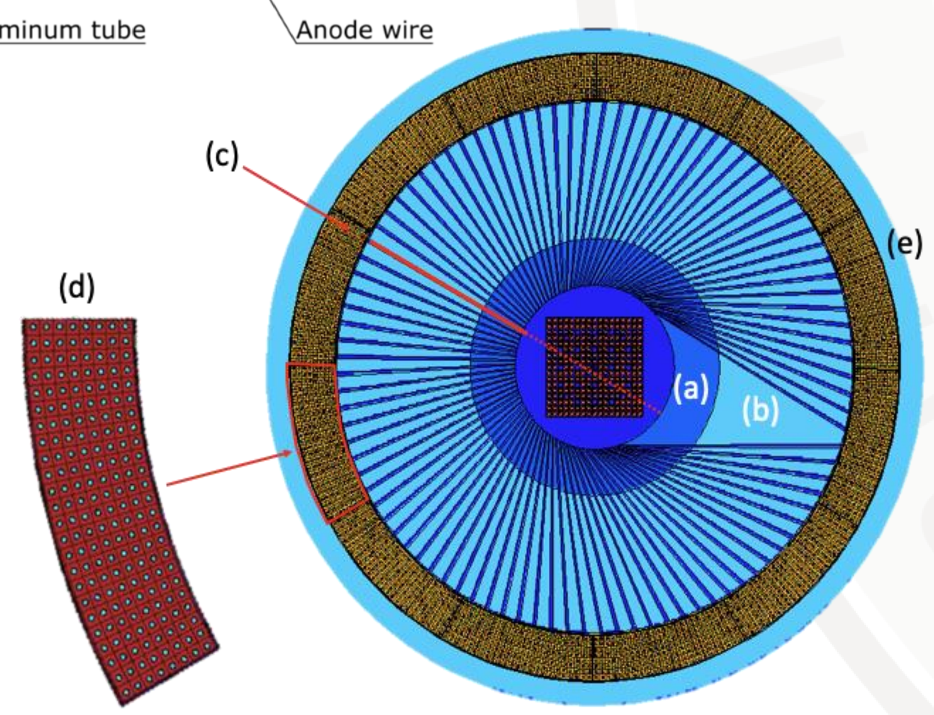

Fig 2. Top-down diagram of the collimator and detector modules with labelled parts

- Collimator rotates at 1 rev/min for the duration of the measurement to create different reconstruction projections

Experiment

The Fast Neutron Emission Tomography Imager was built and tested at Oak Ridge National Laboratory.

Mock PWR Grid:

- 17 x 17 PWR fuel assembly grid created to hold mock source rods
- Center fuel pin is (0,0)
- Fuel pin diameter: 0.96 cm
- Fuel pin pitch: 1.27 cm

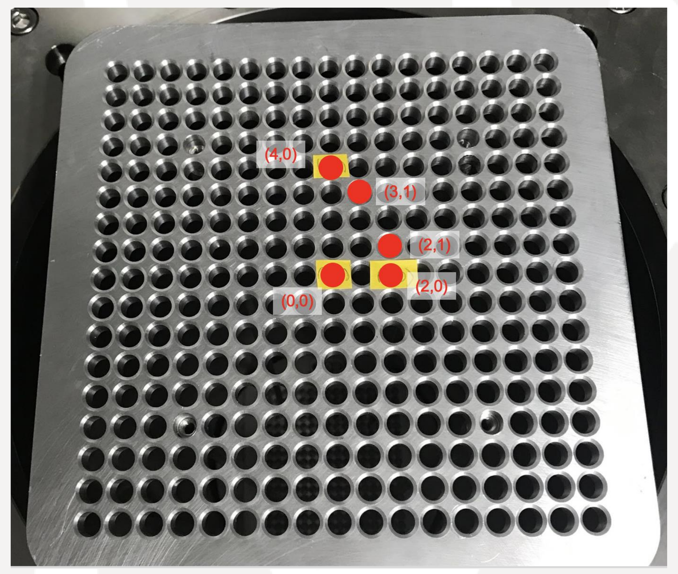

Fig 3. Mock fuel assembly grid with fuel rod placements marked by red dots

Fig 4. Fully constructed imager located at ORNL

Measured Fuel Pins:

- Need to determine if individual pins can be differentiated at various distances
- 5 source rod positions measured at (0,0), (4,0), (0,2), (3,1), and (1,2)
- Pin pitch distances: 1, √2, 2, and 4

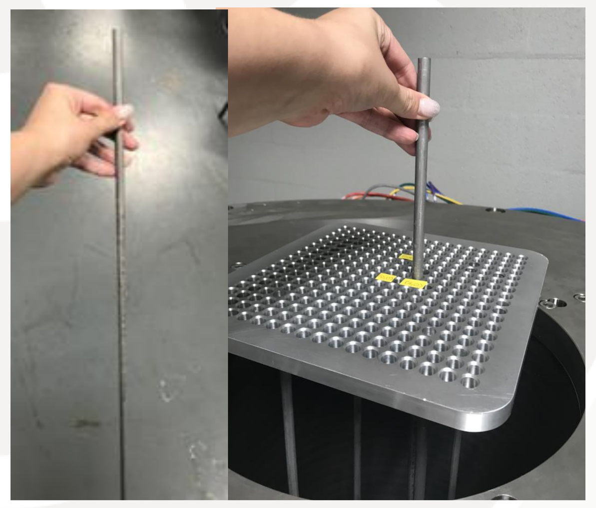

Fig 4. Mock fuel rod used to hold Cf-252 source (left) and rod in position within the assembly grid (right)

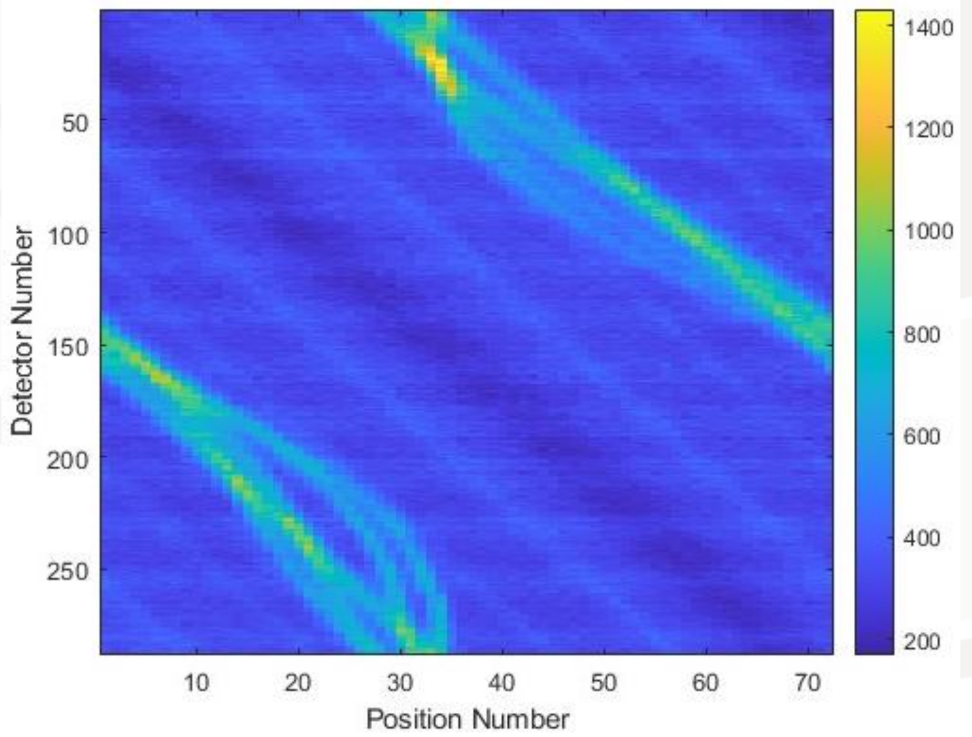

Fig 5. Sinogram created by plotting the neutron counts in terms of the detector and the collimator position at the time of detection

5 Sources Sinogram:

- Plot counts by detector # and projection #
- Individual source rods summed to represent a single measurement with 5 identical sources in various locations
- Subtract background and room return

Results

Iterative Reconstructions:

- Experimental data is then reconstructed using a Maximum Likelihood Expectation Minimization reconstruction algorithm
- Imager demonstrates sufficient spatial resolution to resolve individual fuel pins at 1 fuel pin pitch apart (1.27 cm).
  - Sources at (1,2) and (0,2) are visibly separate sources.

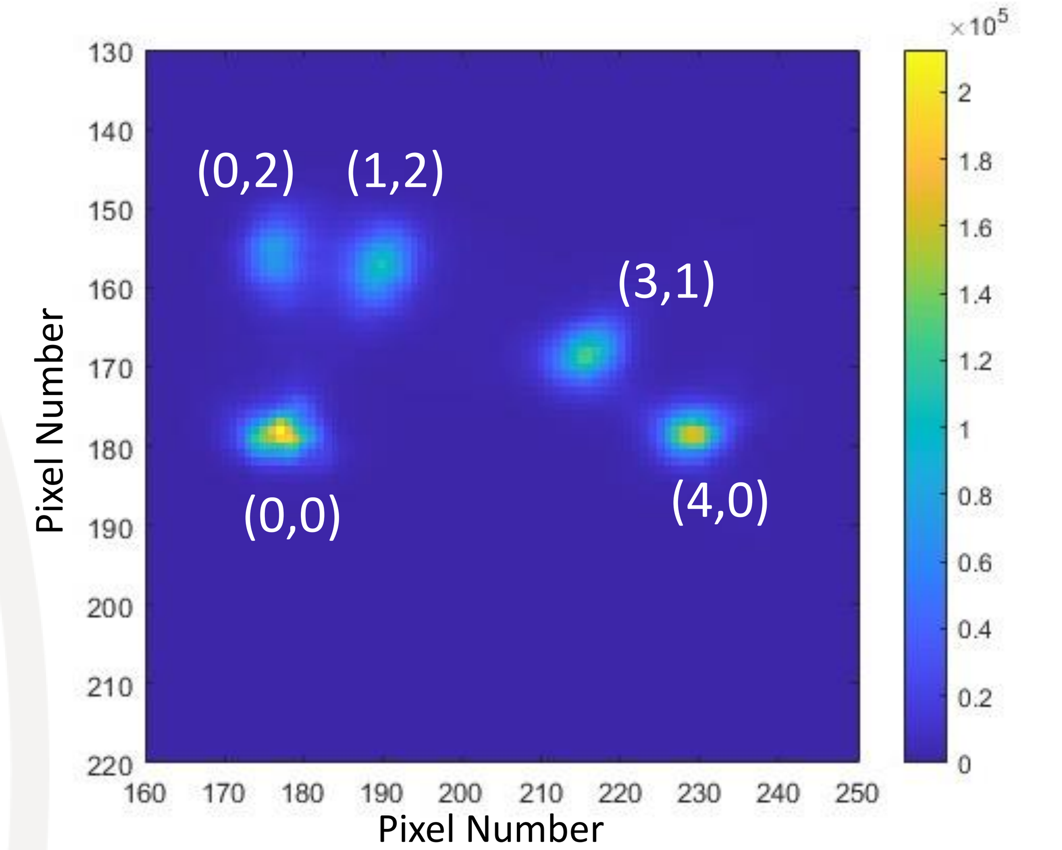

Fig 6. Image reconstruction of 5 source points within the imager field of view.

- Issues with spatial reconstruction
  - Sources, except the one at the origin, are oblong-shaped, rather than circular
  - Intensities of each source should be similar, but the image shows a much greater intensity for the source at the center
  - Total integrated source intensity in the image is accurate but overly weighted toward the center

Conclusion

- The initial testing of the imager demonstrates its potential as a nondestructive verification tool for SNF exceeding the IAEA's guidelines for partial defect detection in spent fuel assemblies.
- More work must be performed to characterize the as-built imager to improve the source intensity distribution and source localization.
- As-built imager characterization results must be implemented into the MLEM image reconstruction algorithm.

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