# Use of Fast Neutron Emission Tomography for Spent Fuel Verification

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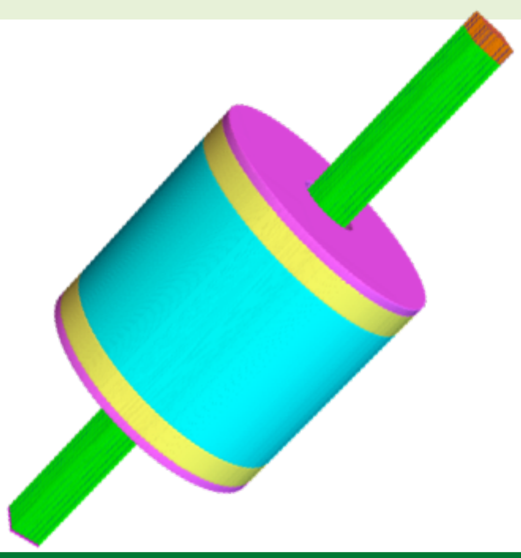
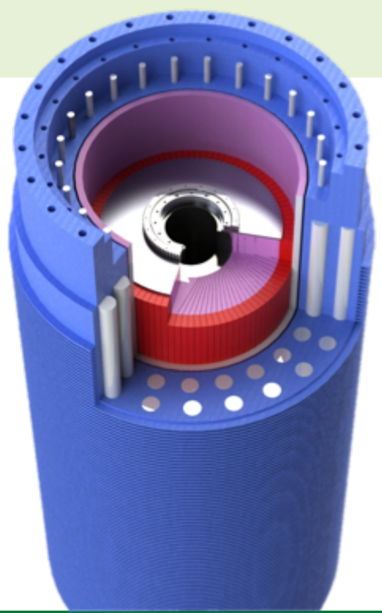
## ABSTRACT


- This project is developing a new capability for fast neutron emission tomography to detect the removal or substitution of individual fuel pins in spent fuel assemblies for safeguards verification applications.
- The capability is intended to address the buildup of spent fuel inventories around the world from decommissioning activities by creating an efficient and effective tool for verification of a variety of fuel types for long-term disposition.
- A laboratory prototype imager is currently under construction.


## BACKGROUND

- Safeguarding spent fuel in spent fuel pools, during transportation, and at dry cask storage sites has been a continuing priority for the IAEA.
- The IAEA implements partial defect testing on all easily dismountable fuel before transfer to difficult-to-access storage.
- Neutron measurements may have better sensitivity for resolving individual pins toward the center of larger fuel assemblies where the sensitivity of gamma emission tomography is limited by self-attenuation.
- Because the neutron signal originates primarily from $^{244}$Cm, which is sensitive to exposure, this method could also be sensitive to assemblies containing fuel pins replaced after a single cycle in the reactor and subsequently irradiated in the core.





## CHALLENGES AND DESIGN CONCEPT

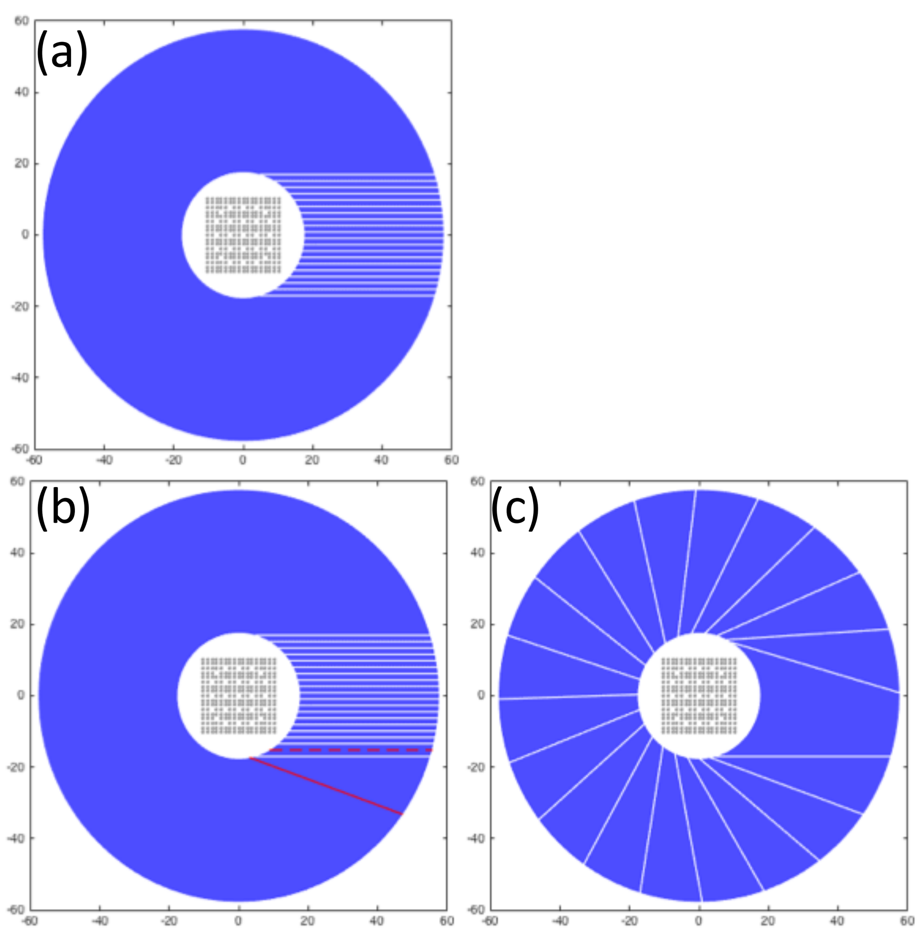
**CHALLENGES**

- Need to reconcile largely incompatible demands: maintaining high efficiency to use the modest neutron source strength, practical size, gamma tolerance, high resolution to isolate pins, and effective modulation of fast neutrons.

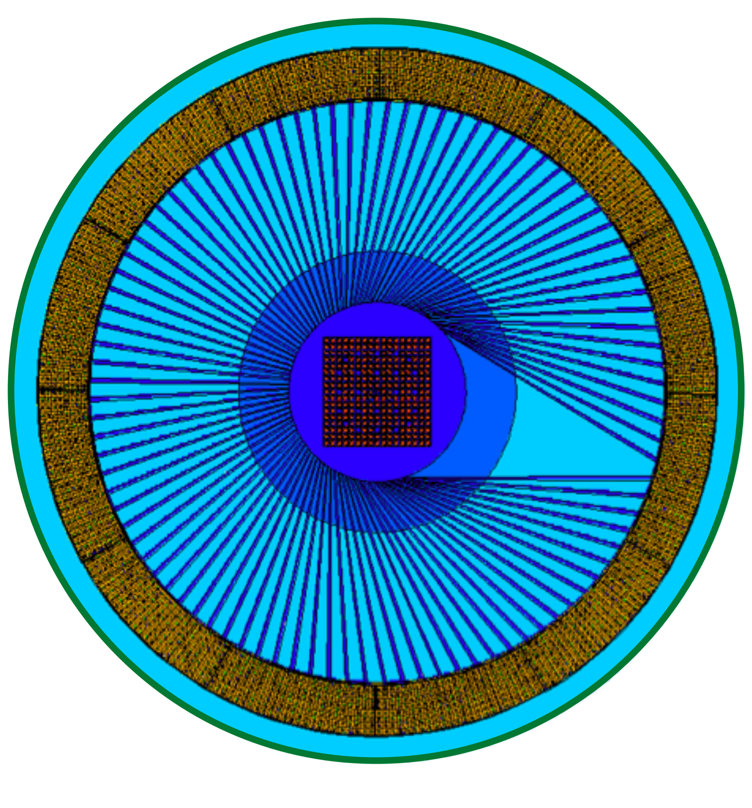
**PARALLEL SLIT RING COLLIMATOR DESIGN CONCEPT**

- A functional equivalent to a parallel slit collimator has been developed, called a "parallel-slit ring collimator," that can be used with large detectors in close proximity to the fuel.
  - ➢ Can construct an imager with enough resolution to identify individual fuel pins but that is also compact, efficient, and radiation resistant.
- Design is based on parallel slits but satisfies spacing requirements by rotating each slit by a known angle to achieve equal detector spacing around the outside of the collimator annulus.

*Parallel-slit ring collimator design concept*




*Final imager concept*



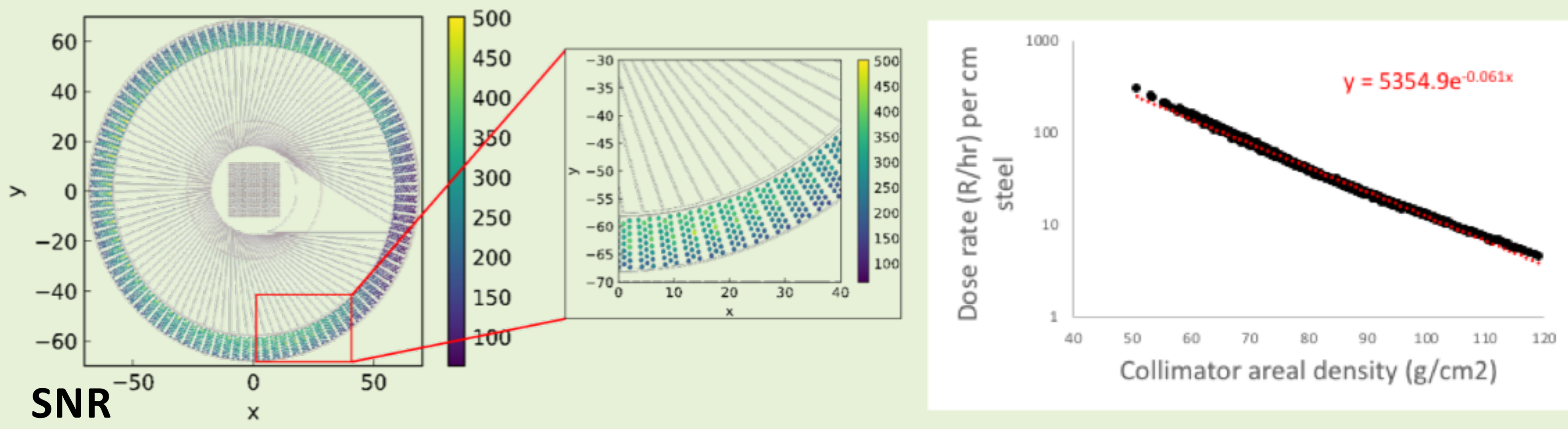
## PARAMETRIC DESIGN STUDY

The optimal imager has the highest signal-to-noise ratio (SNR) to measure fuel assemblies while maintaining gamma dose rates that are tolerable to the detectors. Over 500 collimator configurations were simulated consisting of 16 different combinations of stainless steel and borated polyethylene thickness and 32 different slit widths, both parallel and tapered.

**Gamma Dose Rates**

Expected gamma dose rates at the neutron detectors were calculated for a fuel assembly having a burnup of 40 GWd/MTU and a cooling time of 1 year.

- ➢ Use exponential relationship to find set of acceptable configurations for maximum dose rate of 500 R/hr at detectors.




**SNR**

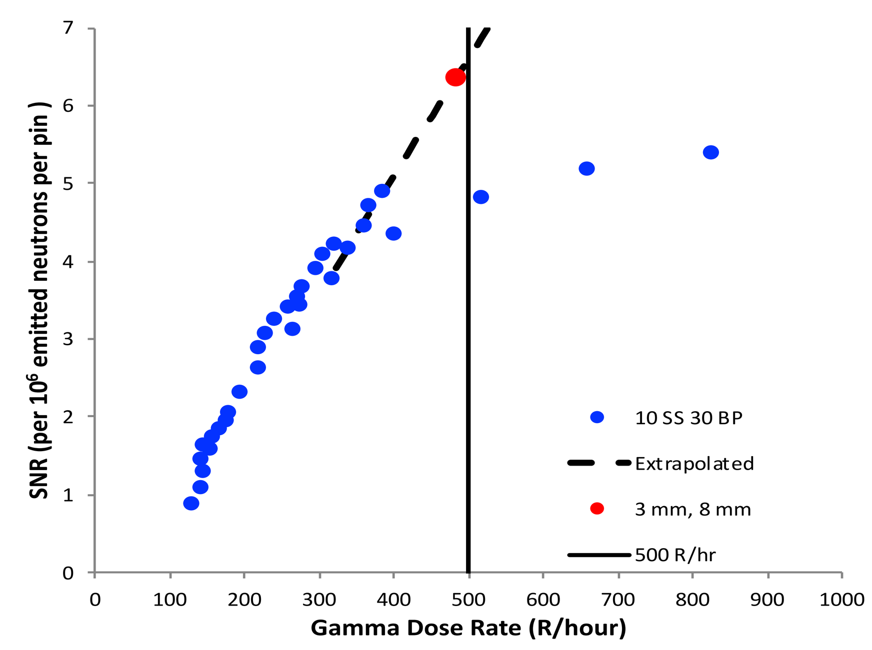
Neutron response of each configuration was estimated by an SNR that quantified the ability of the imager to attribute the neutron activity to fuel pins rather than the inter-pin gaps.

$$SNR = \sum \frac{|\,Response\ to\ pin - Response\ to\ pin\ gap\,|}{\sqrt{Response\ to\ full\ assembly}}$$

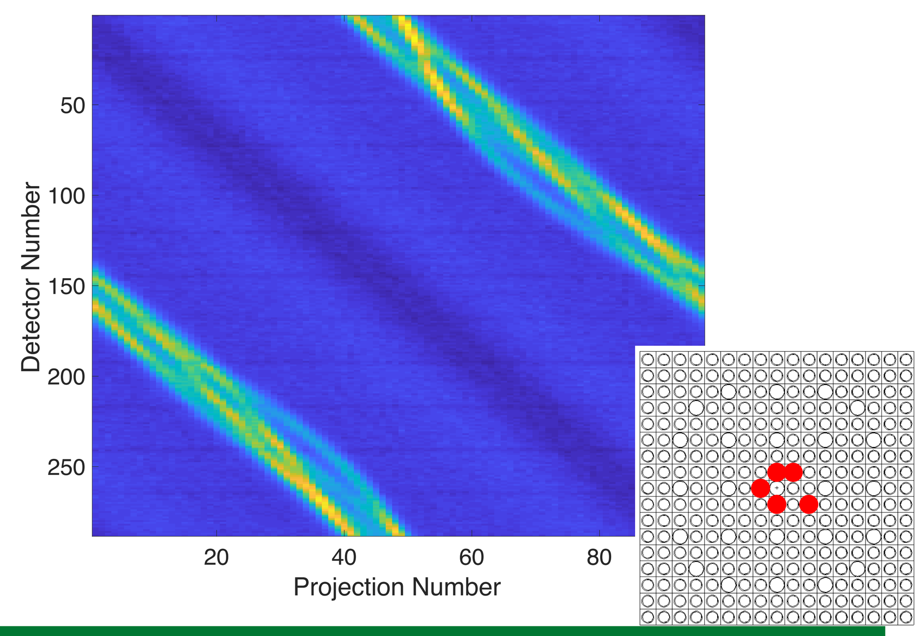
The SNR is calculated by predicting an approximate imager response over the entire field of view on a millimeter scale for each projection angle. The predicted response was obtained from simulating the direct component of the response, collimator penetration, and inter-detector scattering.

- ➢ SNR of collimator configurations using the same slit width are similar, so it is desirable to choose the most compact geometry that can accomplish sufficient dose control.

*Calculated SNR vs. maximum dose*



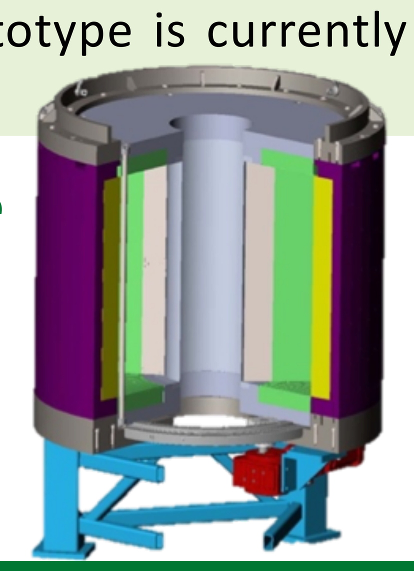

*Sinogram of five Cm-244 line sources*




## STATUS

- A lab scale prototype is currently under construction to be completed by end of 2019

*Imager prototype design*



*Neutron detectors*

## CONCLUSIONS

- Tomography using fast neutrons is feasible.
- Tapered slits enable a desirable combination of dose control and efficiency.
- The final design was chosen to be a collimator consisting of 10 cm of stainless steel and 30 cm of borated polyethylene with 96 tapered slits that taper from 3 mm on the inside to 8 mm on the outside.

## ACKNOWLEDGEMENTS

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