The feasibility of neutron interrogation as dry cask inspection

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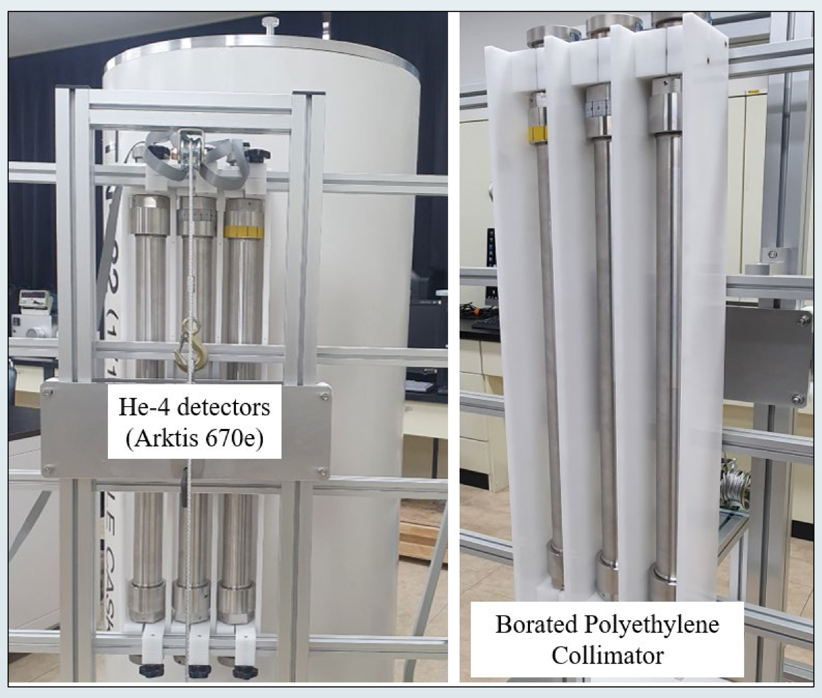
Abstract

In this work, we demonstrate the feasibility of using neutron interrogation in safeguards and verification of spent nuclear fuel (SNF) in a dry canister. In particular, we adopted a tomographic approach to explore the unique signatures of emitted neutrons for dry cask inspection through a lab-scale demonstration. The Arktis S670e He-4 scintillation detectors with borated polyethylene collimators were utilized to measure neutrons. A 1/10th model cask was also built to mock-up the dry cask and a ^{252}Cf source was placed inside the model cask as a test bench. While having ^{252}Cf source inside the cask, the projection data were collected from 0° to 360° at 10° interval. Then, a MATLAB script was used to perform image reconstruction through the filtered back projection. Finally, MCNP simulation was performed to intercompare the experimental results with computational ones.

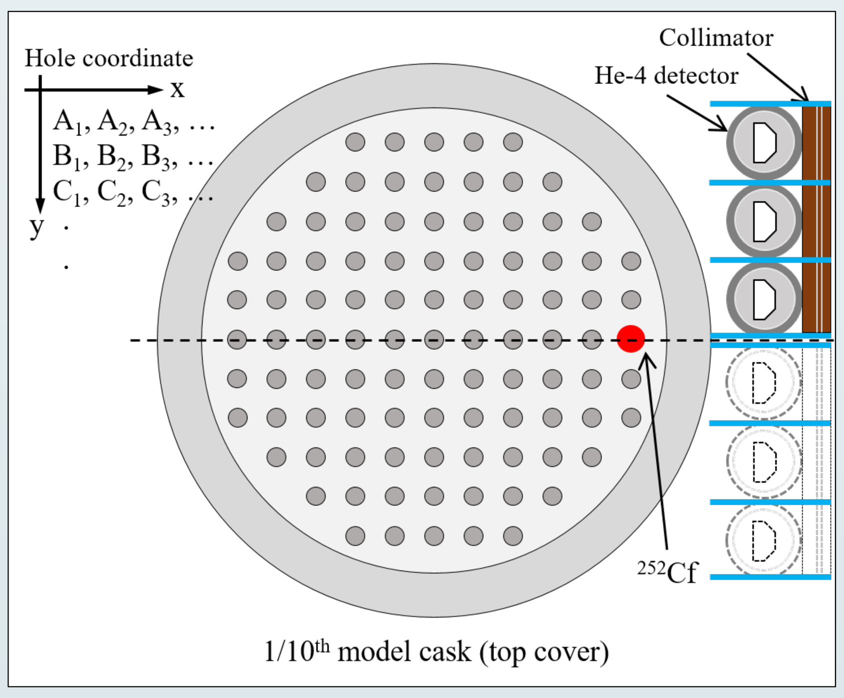
Introduction

- The IAEA safeguards manual and criteria addresses that SNF have to be verified by item counting if dual containment and surveillance (C/S) cannot be adequately evaluated.
- A new safeguards approach for dry cask inspection has been developed at KINAC.
- In particular, a lab-scale measurement was carried out using a 1/10th scale model cask, a ^{252}Cf source, and a He-4 detector array manufactured by Arktis Radiation Detection Ltd.
- Also, a tomographic approach was adopted to image fast and thermal neutrons emitted on the model cask boundary.
- This research aims to assess the use of unique signatures of neutrons emitted outside the cask peripheral for dry cask inspection through neutron imaging.

Methodology



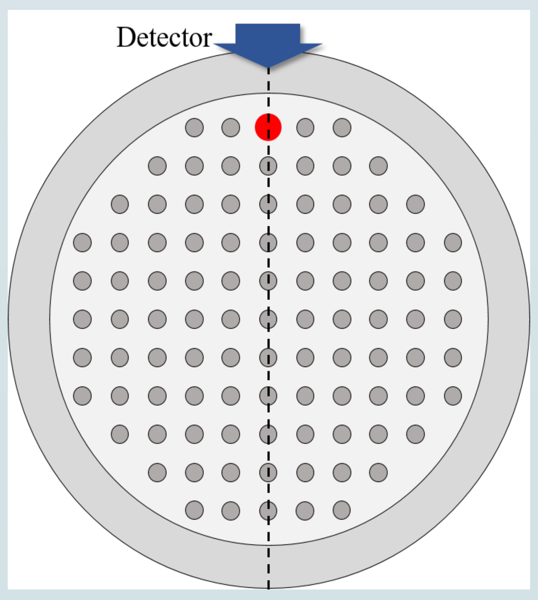
Picture of a lab-scale setup for neutron tomography



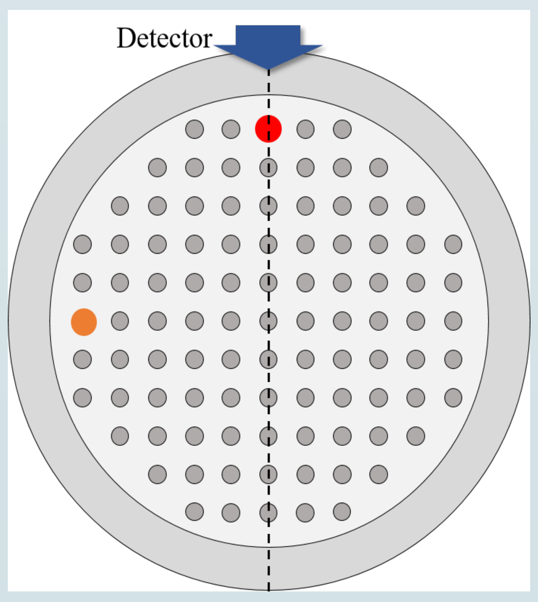
Top view of the experimental setup with coordinates

Measurement setup:

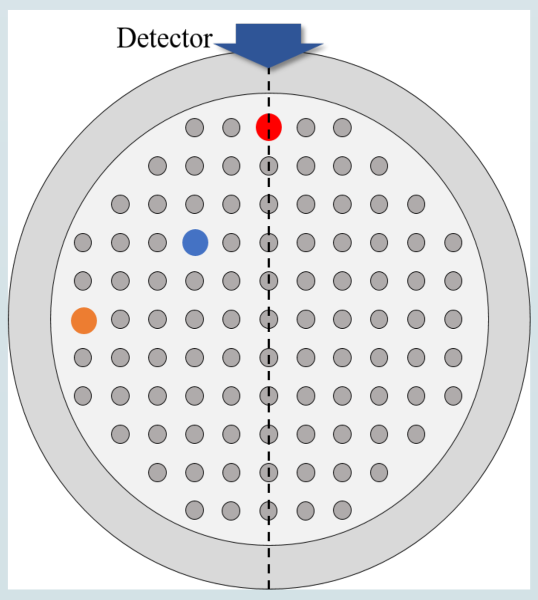
- 1/10 th scale model cask based on TN-32 with a rotatable top cover
- Three ^{252}Cf source layouts: 70.5 µCi (red), 58.6 µCi (orange), 46.1 µCi (blue)
- Three Arktis 670e He-4 detectors with borated polyethylene collimator
- Projection angle : 0 ~ 360°, 10° step
- Measurement time: 10 minutes



Source layout #1 (Single)



Source layout #2 (Double)

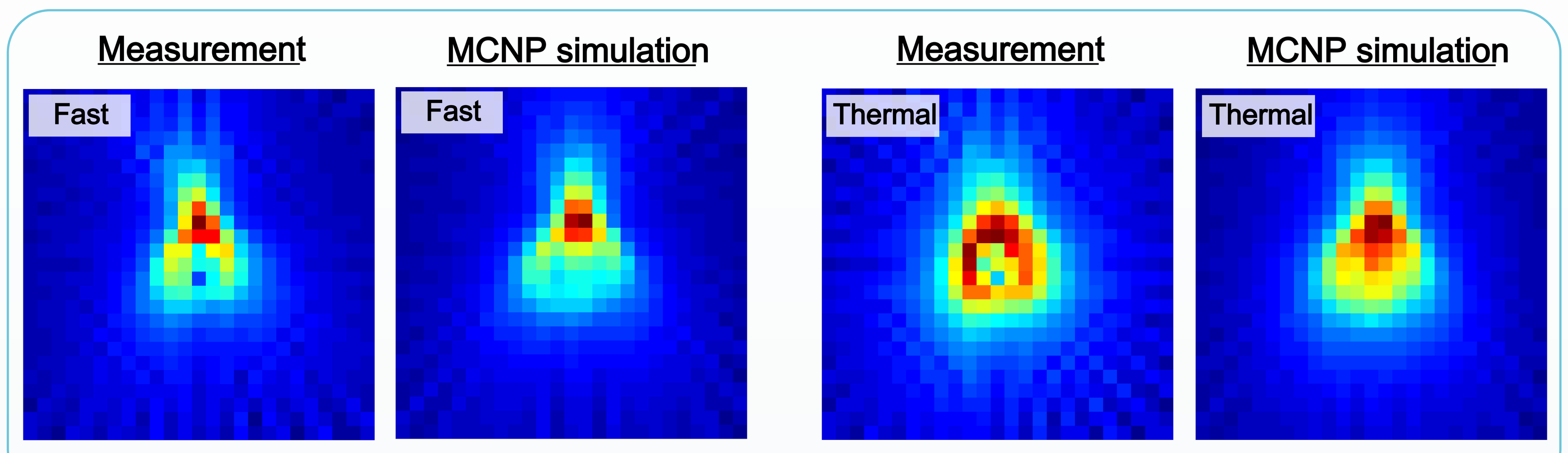


Source layout #3 (Triple)

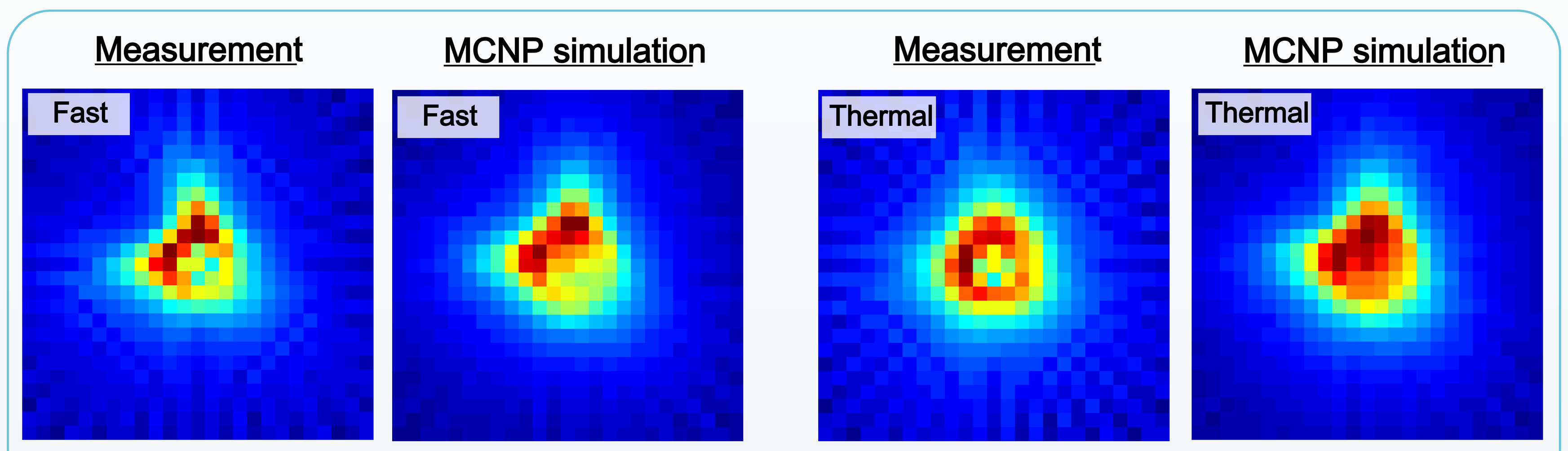
Data Acquisition and image reconstruction :

1. The detector array is fixed closed to the cask for the rest of the measurement.
2. Starting at 10°, the fast and thermal neutrons are measured simultaneously.
3. The same measurement is repeated for one full rotation at 10° interval.
4. A MATLAB script is used to perform filtered back projection of acquired data.

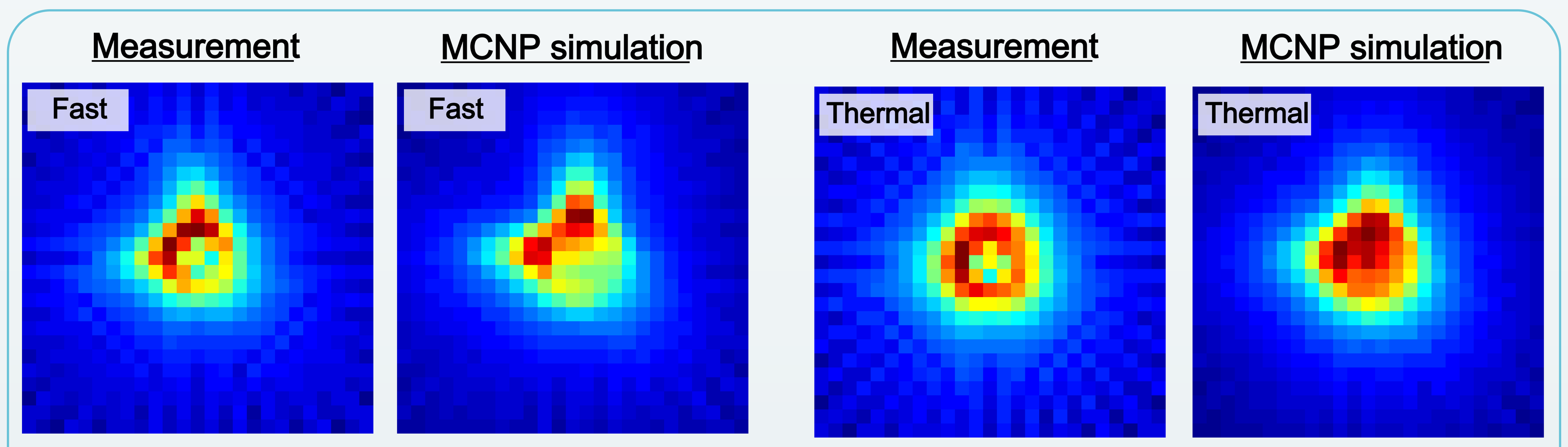
Results



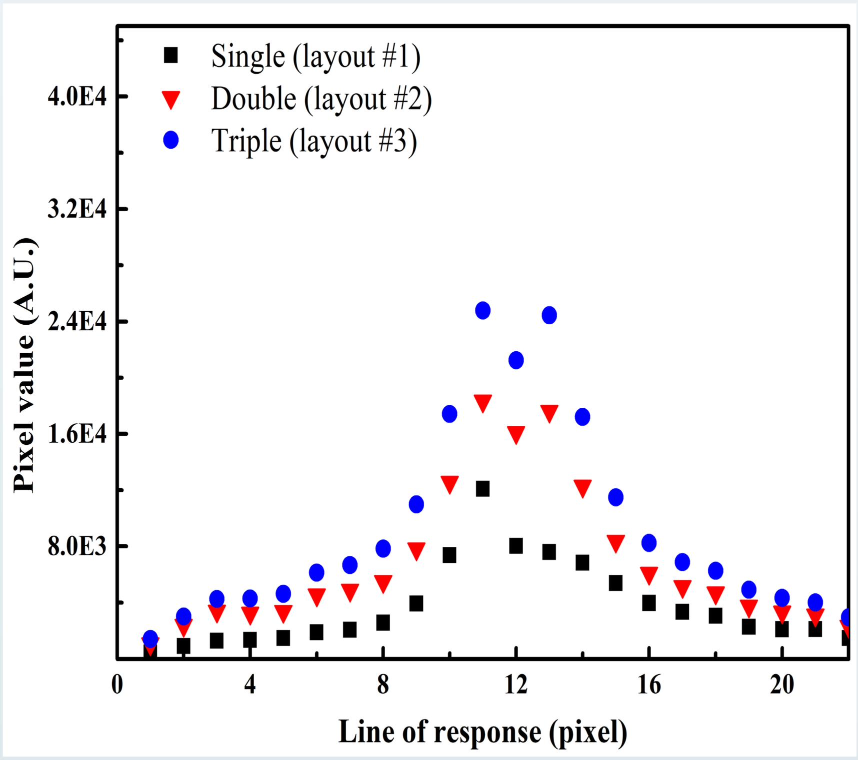
Source layout #1 (single case)



Source layout #2 (double case)



Source layout #3 (triple case)



Line profiles for three source layouts. The values are based on the measured fast neutron images and the lines are drawn from (1,3) to (22, 25).

- The location of neutron sources are traceable in fast neutron images.
- The cask boundaries are more vivid in thermal neutron images.
- The two neutron sources are well defined in the layout #2.
- In contrast, it is difficult to distinguish between the layout #2 and #3.
- Discrepancies in between the measured and simulation results for the thermal cases are due to the mismatched thermal neutron energy-range.

- The line profiles for three fast neutron images confirm that the it can distinguish two neutron sources that are reasonably separated. However, it is challenging to identify source positions for more than two sources.

Conclusion

- The feasibility of neutron interrogation for dry cask inspection has been assessed by utilizing a lab-scale experimental setup based on a 1/10th scale model cask, a ^{252}Cf source, and a He-4 detector array.
- Through the test bench, we successfully demonstrated that verifying the content in dry cask is plausible through measuring fast neutrons at the cask peripheral via tomography.
- Comparison between experimental and simulation data suggests some challenges need to be addressed in the present work, such as fast/thermal neutron separation and design optimization.

References

(1) Arktis Radiation Detectors Ltd., "Arktis-670(e) Detector Series Operating Manual," 2016.
(2) C.Greulich et al., High energy neutron transmission analysis of dry cask storage, NIM A 874 (2017).5

Acknowledgements

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