Neutron Tomography as a Spent Fuel Cask Verification Technique

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1. Introduction

Dry storage facilities with storage casks necessitate a reliable safeguarding technology that can detect diversions of spent fuel assemblies held in the casks. Recent studies performed by KINAC have shown that fast neutron counting can identify a cask having missing spent fuel assemblies. The demonstrated technique, however, has a limitation that the location of missing fuel assemblies cannot be specified.

As an alternative, we paid attention to neutron tomography, which is a technique that produces internal cross-sectional images by reconstructing multiple image profiles. Dry casks bearing spent fuel inevitably incorporate the emission of neutrons despite heavy neutron shielding. Hence neutron tomography can be a promising method to acquire cross-sectional images of the cask so that locations of missing assemblies can be pinpointed.

In this study, we designed a tomography system comprising detectors that simultaneously measure both fast and thermal neutrons. Two system configurations were taken into account to devise a system that can produce images with a better spatial resolution. Monte Carlo N-Particle transport code (MCNP) 6.2 was utilized to evaluate performances of systems.

2. Methods

We used Arktis S670e, combined fast and thermal neutron detector, that allows simultaneous detections of fast and thermal neutrons. The detector has a cylindrical shape with a diameter of 52 mm and active length of 600 mm. The detector inner wall is lined with Li-6 for thermal neutron detection. The cylindrical body is filled with He-4 gas with an approximate pressure of 180 bar and a gas density of 32.2 mg/cm^3 for fast neutron detection. Either fast or thermal neutrons produces an analog pulse signal as output. The control unit distinguishes whether the signal is produced from fast or thermal neutrons by applying Time Over Threshold (TOT) based on Pulse Shape Discrimination (PSD) method [1]. Using this detector model, tomography systems were constructed.

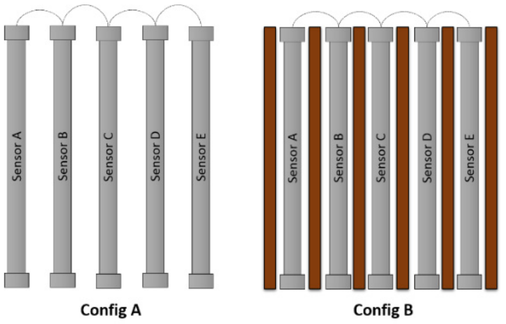

Fig. 1. System configurations; system without collimators (Config A) and system with collimators (Config B).

Figure 1 illustrates system configurations (Configs) evaluated in this study. Both Configs are designed in a 1-by-5 detector array. Config A plainly includes five detectors with 68 mm even spacing. Config B is constructed with plastic wall-shape collimators. The collimators placed between the detectors extend towards the cask as shown in Figure 2. The system intends to be installed vertically on the ground.

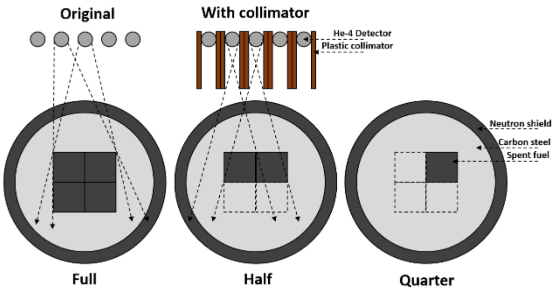

Fig. 2. Schematic diagrams of dry storage casks holding no (full), two (half), and three (quarter) missing assemblies.

Figure 2 demonstrates modelled 1/4-size casks and systems located at zero-degree position. The cask is designed to hold maximum four assemblies with carbon steel and Holtite neutron shielding. System performances were investigated with two diversion scenarios that involve two and three missing fuel assemblies as given in Figure 2. Multiple image profile around the cask was simulated by changing the measurement position along the perimeter in increments of 20 degrees. The simulations were run until simulated fluxes at He-4 gas were calculated to within a 10% error. Inverse radon transform method [2] was used to reconstruct images from the profiles.

3. Results and discussions

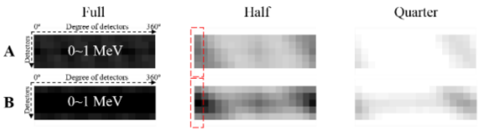

Fig. 3. Sinogram from Configs A (above) and B (below).

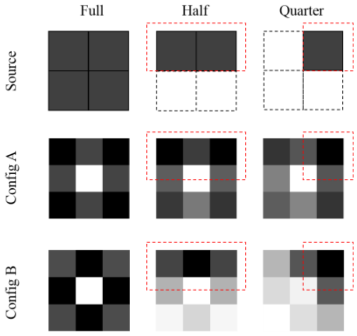

Fig. 4. Reconstruction image from Configs A and B.

Tallied neutron fluxes in the energy of 0~1 MeV were used to generate sinograms shown in Figure 3. Darker pixels represent higher counts recorded, and vice versa. A sinogram contains a 5-by-18 pixel array. Five pixels in a column (highlighted in red-dotted-line) describe tallied flux from five individual detectors. Each column indicates a single measurement position. Figure 4 contains their reconstruction images with fuel assembly positions highlighted in red-dotted-line. The minimum and maximum value of each images were used as white and black of each images, respectively.

Figure 4 proves that empty assembly positions are identified as brighter pixels in the image. Both images from Configs A and B demonstrate that missing assemblies contribute to less neutron counts, which in turn gives rise to brighter pixels. The figure also shows that Config B including the collimators allows the clearer recognition of the positions. Since Config A suffers from the neutron scattering, the system is prone to having the deteriorated spatial resolution.

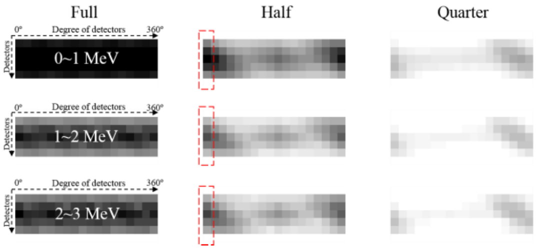

Fig. 5. Sinogram from Config B in different energy ranges.

Results from Config B were further studied. Figure 5 includes additional sinograms generated with two more energy ranges, 1~2 MeV and 2~3 MeV. We then performed the image reconstruction as illustrated in Figure 6. All the images has the same display range.

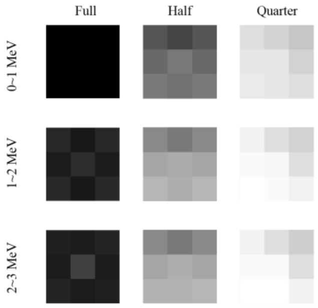

Fig. 6. Reconstruction image from Config B using different energy ranges.

In Figure 6, it is noteworthy that better radiometric resolution can be attained in 0~1 MeV range, whereas better special resolution can be achieved in 2~3 MeV range. It implies that combining images reconstructed using different energy ranges can improve the quality.

4. Conclusions

In this study, we investigated the feasibility of neutron tomography to locate positions of missing spent fuel assemblies accommodated in dry storage cask. Utilizing combined thermal and fast neutron detectors, tomography systems were devised and demonstrated in Monte Carlo space.

The simulation study proved that the modelled tomography system was able to provide location information on the missing fuel assemblies. Taking advantage of the reduced scattering effect, the system with collimators led to the better special resolution. We also found that there is room for improvement in the image quality by consolidating information that can be obtained from different energy ranges. Future works include the development of an optimized algorithm that can allows the effective identification of missing fuel assemblies.

ACKNOWLEDGEMENT

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