Development of Tomographic Image-based Monitoring Technique for Spent Fuel Assembly with Machine Learning and Monte Carlo Methods

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Single-photon emission computed tomography (SPECT) has been considered as one of the most attractive techniques by the International Atomic Energy Agency for verifying of a spent fuel assembly (SFA) because of its intuitive evaluation capability. However, this technique still has limitations in accomplishing the total fuel rod-by-rod verification time of SFA within 1-2 hours for some fuel types. The aim of this study is to develop a fast SPECT-based SFA verification technique using machine learning (ML) and Monte Carlo (MC) methods. The optimal geometry of gamma detection system was designed using GATE (v 8.2) and DETECT2000 MC simulation programs for faster verification of SFA. ML-based tomographic image reconstruction technique using Convolutional AutoEncoder (CAE) model was developed to denoise the low-quality images obtained for a very short time. For training the CAE model, tomographic image data set for 511 patterns of missing fuel rods was constructed with the ground truth (GT) images and the images reconstructed by filtered back-projection (FBP) algorithm for sinograms obtained in GATE simulations. The gamma detection system consists of four 64-channel detectors optimally designed as following geometrical parameters: 4 cm scintillator length (trapezoidal shape), 0.2 cm collimator slit width, 5 cm collimator slit length, and 0.2 cm septum thickness. When comparing the image quality between the GT and FBP images and the GT and CAE images with the proposed denoising algorithm, the mean differences of the pixel values for sample image 1, 2, and 3 were 7.7%, 28.0%, and 44.7% for the FBP images, and 0.5%, 1.4%, and 1.9% for the CAE image, respectively. Furthermore, the CAE model successfully denoise all the FBP images of four different qualities obtained for 0.6, 10, 20, and 60 minutes, which means that the total verification time of SFA was shortened by 10 times at least. With the proposed SFA verification technique with the MC and ML methods, experimental validation of the proposed technique will be performed for an unirradiated test fuel assembly using a SPECT system constructed with four 64-channel detectors in the future.