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Nuclear fuel imaging using position-sensitive detectors

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We are evaluating the performance of a Passive Gamma Emission Tomography (PGET) device [1] equipped with 3D position-sensitive cadmium zinc telluride (CZT) gamma-ray detectors when used for inspecting spent nuclear fuel assemblies (SFAs). Before their disposal in a geological repository, SFAs undergo verification using the PGET device, developed under the guidance of the IAEA and approved by the IAEA for safeguards inspections. Recent advancements in imaging detector technology may offer a method to extend the capabilities of such devices beyond standard safeguard applications, allowing an efficient non-invasive way to characterise the properties of nuclear fuel assemblies accurately.

The efficiency of the currently used small CZT detectors is restricted by the limited likelihood of full gamma-ray absorption, which is needed for optimal imaging information. Employing larger CZT detectors would increase the probability of capturing the full energy of gamma rays, thereby enhancing the sensitivity of the PGET device and the quality of the reconstructed images. Large CZT detectors need to be position sensitive to determine through which collimator slit a gamma ray travelled. Position sensitivity results from the pixelated readout of the CZT crystals. Pixelation potentially increases the spatial resolution of the system, which is currently determined by the collimator used. Pixelation allows resolving the position of arrival up to (readout pitch)/$\sqrt{12}$. We are additionally exploring the potential of utilising Compton imaging to provide information on the origin of gamma rays along the SFA.

Simulations are used to estimate the increase in full photon absorption efficiency when comparing large and current, small, crystals. A dedicated simulation is created using Geant4, where gamma rays of energy 661.7 keV are targeted to the model describing the approved apparatus now equipped with 22 mm x 22 mm x 15 mm crystals of CZT. It is observed that the efficiency for photon absorption in this case is greatly increased when compared to the existing detectors.

[1] M. Mayorov et al., "Gamma Emission Tomography for the Inspection of Spent Nuclear Fuel," 2017 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), Atlanta, GA, USA, 2017, pp. 1-2, doi: 10.1109/NSSMIC.2017.8533017.

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