Design of a linear array of scintillator detectors considering absorbed energy distributions for high-energy x-ray container inspection

Jiwoong Park, Jinwoo Kim, and Ho Kyung Kim

School of Mechanical Engineering, Pusan National University, Busan, South Korea
Center for Advanced Medical Engineering Research, Pusan National University, Busan, South Korea
* Corresponding author: hokyun@gpusan.ac.kr

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Background
- Related to homeland security and contraband control, the megavoltage (MV) x-ray screening system is widely used.
- Secondary quanta produced by x-ray interactions can be absorbed far away from the primary interaction sites, and which results in spreading of signal
- Analysis of spatial energy distributions is important for analyzing the signal characteristics of the linear detector

Energy moment analysis
- For an incident x-ray spectrum \( S(E) \) with \( \int_{0}^{\infty} S(E) dE = 1 \), the absorbed energy distribution (AED) recorded in a detector can be given by
  \[
  A(E) = \int_{0}^{\infty} E^a \cdot A(E, E') dE' 
  \]
  where \( A(E, E') \) = the detector response function describing the probability of depositing energy \( E \) given an incident photon with energy \( E' \)
  
  \[ M_0 = \int_{0}^{\infty} E^\alpha A(E) dE \]
- Quantum efficiency, \( \alpha = M_0 \)
- Swank noise factor, \( I = M_0^2 / M_0 + M_2 \)
- Detector quantum efficiency, \( DQE = \alpha \cdot I = M_0^2 / M_2 \)

Monte Carlo simulations
- Simulation code: the MCNP version 5 (RSICC, Oak Ridge, TN)
- Monte Carlo geometries:
  - A single block of CdWO\(_4\) with dimensions of \( x \times y \times z = 4 \times 4 \times 3 \) mm\(^3\)
  - A 15-channel linear array detector having a pitch of 4.6 mm, including the corresponding anti-scatter grid
- Spatial energy distribution
  - The spatial energy distribution can be obtained by using a list-mode analysis, which analyzes the position and deposited energy of each interactions of particle
  - Interaction mechanisms are categorized to 7 types (PE, PP, FX, PSS, RSS, PMS, RMS)
  - Absorbed energy profiles representing the energy spreading are also calculated along the y-direction

Results
- Energy moment analysis
  - At 0-th channel, the absorbed energy due to the scattering process is larger than the photoelectric absorption
  - The most of the signal at the adjacent channels is due to the scattering process including partial energy deposition and secondary quanta reabsorption. As shown in profiles, the process of RSS, RMS causes the spreading of signal in the space

Spatial energy distribution
- The increasing trend of DQE with increasing detector thickness is mainly governed by the QE
- The detector Swank noise factor is nearly independent of detector thickness
- Monoenergetic analysis largely overestimate the DQE performance because it ignores the spectral uncertainty in incident x-ray beam and this discrepancy can be reduced by considering the incident spectrum Swank factor

Discussion & Conclusion
- The improvement of DQE from a detector with a thickness of 10 mm to 30 mm is 46% whereas the improvement from 30 mm to 50 mm is only 11%, and the detector thickness of 30 mm would be the best for x-ray interaction-induced signal and noise performance as well as cost
- In the linear detector, the scattering process is the main cause of the signal spreading
- It is expected that the optical signal conversion and its transportation will widen further the signal spreading

Radiation Imaging Laboratory
(http://bml.pusan.ac.kr)

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