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Design Verification of a High Energy X-ray Scanner for Cargo Inspections with the Stereo Visualization

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1. Introduction

As the issue of homeland security is being emphasized since the attacks on September 11, the radiation technology is recognized as one of the proper way to strengthen border security. Especially, radiography technique is an effective means to inspect cargo, personal belongings, and vehicles. This is because radiography is not only non-destructive testing, but also a very fast and stable way despite it is an oldest technique.

We had been developed a cargo container inspection system based on high energy X-ray imaging technique. This system will play an important role for the logistics at Gwangyang Port. The inspection system is designed to visualize the inside of a container with stereovision. The schematic structure of the full system is displayed in Fig. 1. It comprises an electron LINAC whose beam energies are 6 MeV/9 MeV, three steel collimators and two set of detector array.

In this study, validity verifications of the design of the system have been carried out with Monte Carlo simulations for the precise technical design. The central goal in this research asks that the designed system is suitable enough for the purpose, which is to inspect cargo container in fast and with good visualization performance.

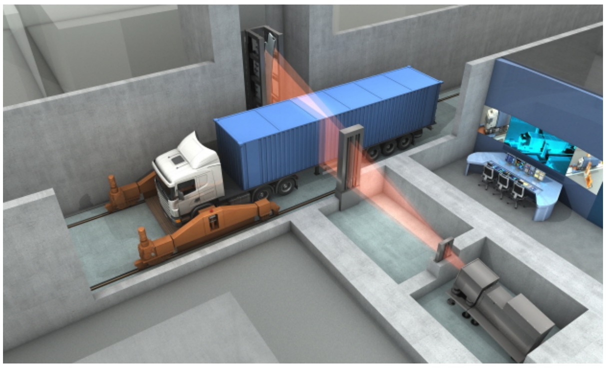

Fig 1. The bird's-eye view of the cargo inspection system with a control facility

This paper is organized as follows: Sec. 1 provides the description of the specific parts of the system. Sec 2 presents the idea for Monte Carlo simulation. Sec. 3 describes simulation results and a suggestion for the best performance in specific purposes. Finally, Sec. 4 gives a summary and future perspectives.

2. System Configuration

The cargo inspection system mainly consists of the beam generator part, the collimator part and the detector part. Each part has key role to allow the full system to work with high performance. In this section, detail descriptions of each part will be given below.

2.1 Accelerator

The electron accelerator will be playing key role to generate gamma ray for cargo imaging. Unlike other vehicles inspection system, the accelerator generates dual-energy beam, energy of 6 MeV and 9 MeV. This dual energy system allows us to discriminate what the items are made from. The generated electrons from the accelerator are collided with a tungsten target, whose thickness is 2.8 mm, and then high energy photons are generated. These photons will be utilized to get transmission images. To get transmission image of the cargo made of thick metal, the accelerator and X-ray conversion target should make high energy photon at least 0.5 MeV.

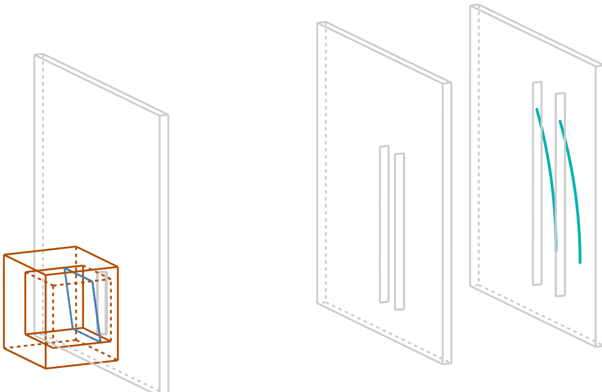

Fig 2. The wire-frame view of the geometry setup for the Geant4 Simulations

2.2 Collimators

For the 3D visualization of stereotype, the X-ray beam has to deliver two directions. Therefore, the collimators should be designed to divide the emitted X-ray into two directions. Unfortunately, the photons generated from the accelerator with the tungsten target have random momentum direction. In addition, these photons can make noise signal in terms of visualization.

For those reasons, three collimators will be constructed. Each collimator has two slit, then one slit tilts owing to make tilting beam. In addition, the collimators prevent that scattered photons pass by detector arrays.

2.3 Detector Array

The detector array is to detect X-ray photons, which have information of the inside of a cargo container. The detector part comprises two detector arrays. The two arrays are identical in shape, structure and size but different in angle. One array, which is projected to the beam window, is inclined by the given angle about *y*-axis. An array is compose of 1024 $CdWO_4$ crystals, which is a commonly used for high energy photon counting.

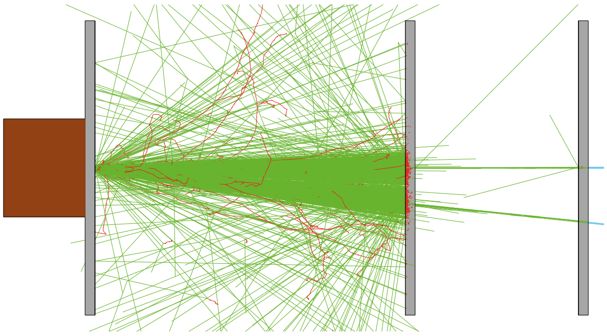

Fig 3. The calculation result of the photon generation and its delivery. This picture shows that three collimators are able to prevent scattered photons

3. Simulations

Geant4 was used to perform this simulation. Geant4 is a widely used Monte Carlo simulation code that has been developed at the European Organization for Nuclear Research (CERN) for calculations of particle transportation.

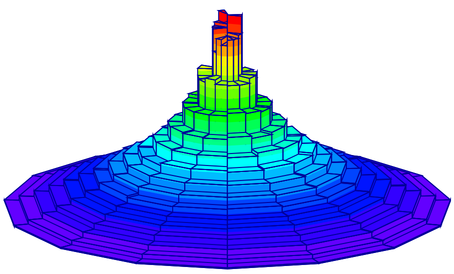

Fig 4. The energy spectrum of photons right after tungsten target with 9 MeV electron beam. Azimuthal angle about *z*-axis is mapped on the angle. Polar angle in on the radius. The beam intensity is weighted by surface element of polar coordinate.

As Geant4 has been updated steadily, Geant4 is being put to use in various fields such as medical applications, nuclear engineering and the field of radiation shielding. Especially, Geant4 has visualization ability; the code makes it possible to understand how to improve the design with ease. Furthermore, since the energy cut of Geant4 is lower than that of the MCNP, Geant4 is able to calculate with wide range of energy. [1]

3.1 Geant4 Setup

The geometrical configuration is presented in Fig. 2 with wireframe view. The particle source in this simulation (particle gun) is placed in front of the X-ray conversion target. And three collimators are placed along the z-axis. The detector arrays, which are 3 cm long, are placed after third collimator. The two built-in physics list, QGSP_BERT_HP, QGSP_BIC_HP, EmLivermore utilized to calculate behaviors of particles due to energy range of interests and accuracy. [2]

3. Results

The simulation code has provided spatial distribution according to angle at significant points such as W target and detector array as shown in Fig. 4 and Fig. 5. It can give an insight about the geometrical coverage of the system according to beam current.

Fig. 4 shows that the directions of photons emitted at the W target; most of photons have large longitudinal momentum. Fig. 5 indicates the intensity of the beam at the detector; the number of photons at a detector array depends on tilting angle of the X-ray beam. [3]

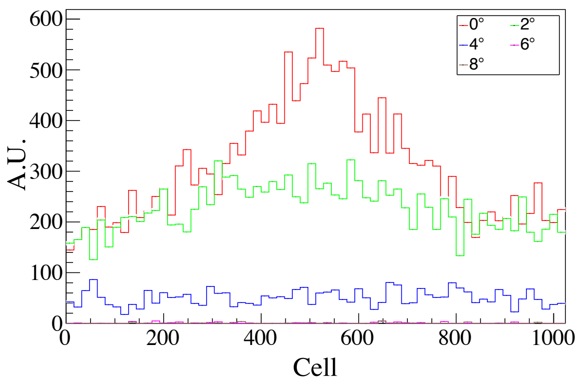

Fig 5. The spatial distribution of photons at detector arrays according to angle of tilting beam. The detectors are regarded as perfect counters.

Fig. 6 and Fig. 7 are shown that energy spectra of emitted photons according to different energy of 6 MeV/9 MeV. To get images with high resolution, high energy photons whose energy is higher than 2 MeV must be generated enough in case of realistic beam current due to the thickness of a cargo container housing, which is made of high density materials. [4] In this result, at least 1 photon with high energy is generated in 10 events despite that most of photons have low energy below 2 MeV.

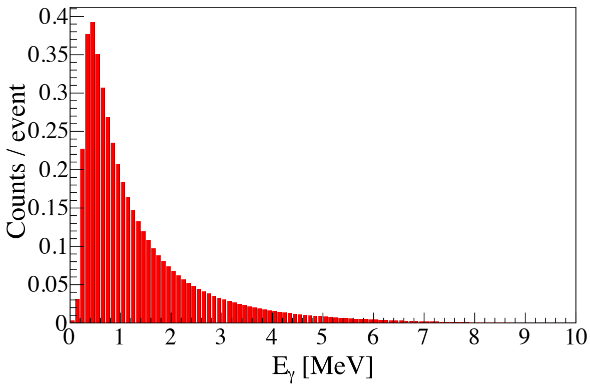

Fig 6. The energy spectrum of photons right after tungsten target with 9 MeV electron beam. This result is calculated with EmLivermore model.

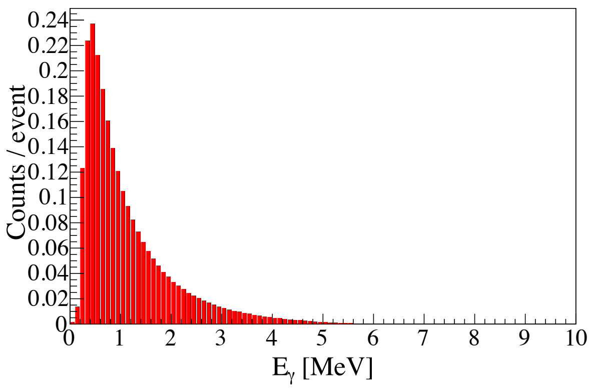

Fig 7. The energy spectrum of photons right after tungsten target with 6 MeV electron beam. This result is calculated with EmLivermore model.

4. Conclusion

The simulation test of the design of the cargo container inspection system has been carried out using Geant4, which is a widely used Monte Carlo code. The calculation is to expect whether the geometrical design is able to visualize the inside of a cargo with reasonable coverage and the results give an insight to achieve the goal.

Acknowledgment

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