Detection of explosive substances by tomographic inspection using neutron and gamma-ray spectroscopy

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Introduction: This work discusses research and development of a technique capable of detecting and imaging hidden explosives applying Pulsed Fast Neutron Analysis (PFNA) and Compton camera techniques. We present our approach to the design and implementation of this detection system. The simulation in a Monte Carlo framework using GEANT4 has been carried out for the spectroscopy and for the imaging of gamma-ray events using the Compton camera design which is discussed. The results of Compton camera measurements using Germanium (Ge) detectors and the subsequent reconstructed images are also presented.

Detection system principle

A fast (pulsed) neutron source will be used to activate the object under investigation (Fig. 1). The prompt gamma emission from inelastic scattering will be detected, which provides a fingerprint of the explosive and thus aids of its identification. Direct imaging of the elemental contents of the material can be accomplished using the Compton camera principle. In addition, detection of scattered-neutron recoils will provide a tomographic image.

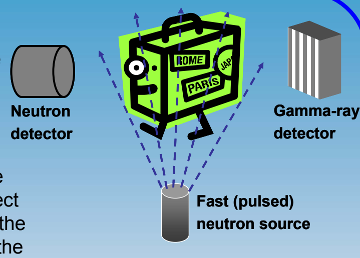

Fig. 1: *A schematic view of the detection system.*

Gamma-ray detector

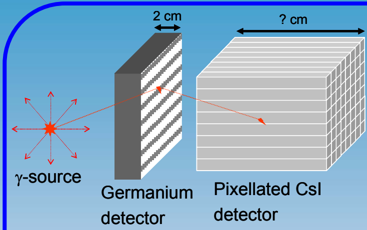

Fig. 2: *A schematic view of gamma-ray detector setup. A segmented Ge detector will be used as scatter and a pixellated CsI detector will be applied as absorber.*

The gamma-ray detector has to be efficient to detect the characteristic gamma radiation for the identification. It also has to be capable of working in Compton camera mode for the direct imaging. Therefore, this project aims to utilise a gamma-ray detector consisting of a segmented Ge detector as a scatter and a pixellated CsI as an absorber (Fig. 2).

GEANT4 simulation results

The GEANT4 toolkit was used for the simulation of the gamma spectroscopy and for the imaging of gamma-ray events using the Compton camera design. The basic setup for the simulations consists of a segmented planar Ge crystal and a pixellated CsI crystal. The former has an active volume of 60×60×20 mm^3 which is segmented into 12 by 12 voxels of 5×5×20 mm^3. The dimensions of the latter have been varied to study the performance of the detector. Fig. 3 displays a snapshot of the tracks of 2 MeV gamma-rays passing through Ge and CsI detectors respectively, as simulated with GEANT4.

The distribution of the number of interactions per event in Ge and CsI for full energy peak events for 1 MeV and 6 MeV gamma-rays are shown in Fig. 4. To consider the effect of detector thickness, simulations have been carried out utilising a CsI crystal which is segmented into 8 by 8 pixels of 5.6×5.6 mm^2 with thicknesses of 100 and 50 mm. The results for these two configurations are displayed in Fig. 5. Another configuration has been simulated applying CsI crystal which is segmented into 16 by 16 pixels of 5.6×5.6×50 mm^3. A comparison of the results is shown in Fig. 6.

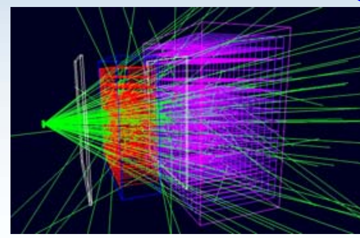

Fig. 3: *A snapshot of the tracks from a gamma source of 2 MeV. The segmented planar Ge crystal (12 by 12) and the pixelated CsI crystal (16 by 16) are shown.*

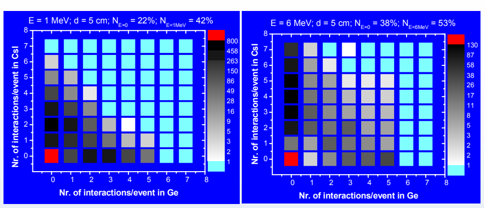

Fig. 4: *Distribution of the number of interactions per event in Ge and CsI for full absorption events of 1 MeV and 6 MeV photons.*

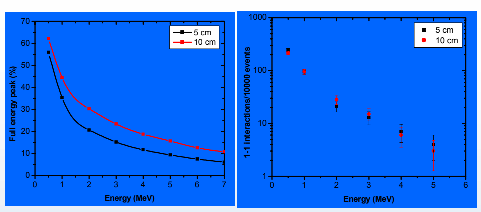

Fig. 5: *The calculated full energy peak and 1-1 interaction events as a function of photon energy for pixellated CsI detector of 8 by 8 for thicknesses of 10 cm and 5 cm.*

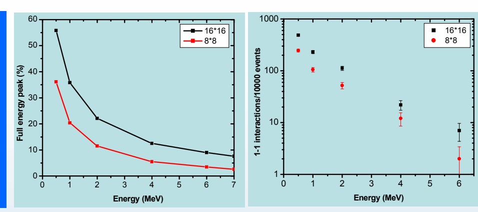

Fig. 6: *Comparison of the calculated full energy peak and 1-1 interaction events as a function of photon energy for pixellated CsI detectors of 8 by 8 and 16 by16 each having a thickness of 5 cm.*

Measurement

Compton camera measurements have been performed using two planar Ge detectors each with an active volume of 60×60×20 mm^3, with 12 by 12 pixel segmentation of 5×5×20 mm^3. A ^{152}Eu source (0.13 MBq) was placed 60 mm from the front face of the scattering detector. The scattering and absorbing detectors were separated by a distance of 5 cm. The source was rotated from the normal (0º) up to 60º relative to the face of the crystal in 15º steps. For the 1408 keV decay line in ^{152}Eu, reconstruction images have been generated which are shown in Fig. 7. For the image reconstruction an algorithm has been used based on an analytical technique using a back-projection method.

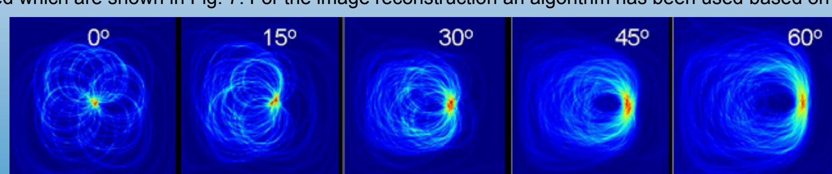

Fig. 7: *Reconstructed images (J. Gillam, Monash University) from ^{152}Eu point source rotating from the normal (0º) up to 60º relative to the face of the detector applying two planar Ge detectors with a separation of 5 cm.*

Conclusion: A technique capable of detecting and imaging hidden explosives applying PFNA and Compton camera principle has been described. The gamma-ray detector design considerations of this system which consists of a segmented Ge detector and a pixallated CsI have been discussed. The GEANT4 simulations have been carried out for various CsI detector configurations. It has been shown that reducing the depth of CsI detector from 10 cm to 5 cm decreases the detector efficiency. Utilising a physically larger CsI crystal will cause an increase in the efficiency as well as in the number of 1-1 interaction events. The Images of cone beam reconstruction applying two planar Ge detectors working in Compton camera mode have been presented.

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