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Determination of an Unknown Volume in the Material based on Gamma Ray Scattering Using GEANT4 Simulation

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The energy spectrum characteristic detected as the result of gamma ray photon interaction with a material has an information that can be used to identify the material characteristics. Using a Monte Carlo code of GEANT4, the simulation study has been conducted for 0.662 MeV scattered energy from the acrylic block to investigate the existence of pores in the acrylic block. In order to verify the validity, the simulation result was compared to the measurement data. Both of the simulation prediction and measurement show the similarities of the detected spectrum.

KEYWORDS: Non-destructive test, Compton scattering, energy spectra, GEANT4, acrylic

1. Introduction

Non-destructive testing (NDT) is one of the most techniques that has been developed for variety of material testing purposes in recent years, especially in industrial applications. The ability of gamma rays to penetrate more deeper into the object and energy spectrum modified as the result of gamma ray photon interaction with a material are potential characteristic applicable to perform the material structure investigation. This developing technique is more useful to apply for the NDT. Sharma (2010) reported the potential usage of incoherent (Compton) scattering by giving the information about density and thickness of an inspected object [1]. Singh et al. (2007) have utilized an intensity ratio method for assigning an effective atomic number of composite material [2]. Considering to the gamma ray backscattering, it's an important review for radiation shielding, radiation absorption and NDT. The advantages of the gamma ray backscattering technique are the sample can be accessed from the same side, simple to construct an image, and provide a physical three-dimensional[3]. It's applied to security examine for hidden object detection, erosion control, deposition and structure defect, and mine detection [4, 5, 6].

Monte Carlo method is an appropriate method for modeling a large variety of physical situations and predicting the experimental results. GEANT4 is a one of the simulation computational tool which based on Monte Carlo method [7]. GEANT4 simulation was successfully applied to analyze the responce function and charge collection from CdTe detector [8], and light collection efficiency of NaI(Tl) detector [9].

Herein, we extend our study to detect pore inside of the material by the inspection of gamma rays energy scattering spectrum using a small activity source of Cs137 gamma energy. This work is important for the development of NDT. Initially, we construct the air rods volume in the inside of the acrylic (PMMA) block to compare with the GEANT4 simulation. The simulation result is compared with the measurement.

2. Theoretical background

Incoherent scattering or Compton scattering, is one of photon (x-rays or gamma rays) interaction process of penetrating radiation through the material. The photon beam will be deflected with θ scattering angles to the initial direction after collision with an atomic electron. The scattered photon energy is expressed by the formula,

$$E_{Scatt} = \frac{E_\gamma}{1 + \frac{E_\gamma}{0.511}(1-\cos\theta)} \quad (MeV) \tag{1}$$

where the scattering energy, E_{Scatt} is depend on the different scattering angle (θ) and incident photon energy (E_γ) [10]. In the scattering event, the intensity response (dI) which generated to measured signal is,

$$dI = \frac{S}{4\pi r_1^2} ndV \left(\frac{d\sigma}{d\Omega}\right) \exp\left(-\left(\frac{\mu(E_1)}{\rho}\right)\rho r_1\right) \exp\left(-\left(\frac{\mu(E_2)}{\rho}\right)\rho r_2\right) \frac{A\,x\,k}{r_2^2} \tag{2}$$

where S is the source strength (disintegration s^{-1}), r_1 and r_2 are the distance of radiation source-element volume and element volume to detector, n is the electron density of material, ρ is material density (gr cm^{-3}), ($d\sigma/d\Omega$) is Compton scattering differential cross-section (cm^2 $electron^{-1}$) (*Klein-Nishina* formula), ($\mu(E_1)/\rho$) and ($\mu(E_2)/\rho$) are the mass absorption coefficient of incoming photon and scattering photon (cm^2 g^{-1}), and k is slope factor for detector surface contact area A [11]. According to the equation (2), the presence of an unknown volume inside the material like holes or cracks can influence the intensity response.

3. Method

Initially, we construct the experiment setup by the GEANT4 simulation toolkit as shown in Fig. 1. Dimension of acrylic block (PMMA) is 10 cm x 7 cm x 3 cm, with five air rods with 2.5 mm radius and 7 cm height inside. An air rod's position is 2.5 cm from the edge of a block and the distance between axes of adjacent rods axis is 1 cm. For the measurement of scattered radiation, Hamamatsu PMT E 1198-05 with a 76.2 mm x 76.2 mm NaI(Tl) detector is placed inside of the Pb chamber shielded with the 4 cm thickness and 2 cm collimator hole diameter (Fig. 2). A 15μCi of Cs-137gamma source was positioned behind of the colimated Pb hole with 1 cm diameter. The source angle position (θ) was setup for 40^0 and 50^0 to the main axis of detector. The measuring time is about 30 minutes with -1.1 kV of the PMT high voltage setup. Data acquisition was performed using Multi Channel Analyzer (MCA) ORTEC 927 with a Maestro Program 16384 channel. ROOT program is used for the spectrum analysis.

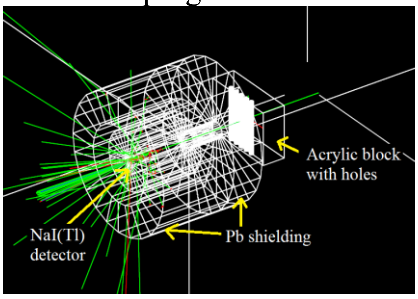

Fig. 1. Geometry simulation visualization.

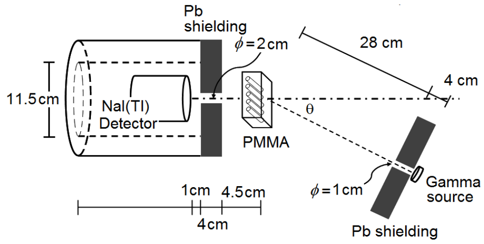

Fig. 2. Experimental setup of measurement.

4. Result and discussion

Calibration of the Cs-137 gamma energy source is performed. In the inset picture as shown in Fig.3, according to the peak position channel of the Cs-137 source in spectrum (recorded in 10 minutes), a conversion constant of Cs-137 source is about 3995 Chn/0.662 MeV (5431 Chn/MeV).

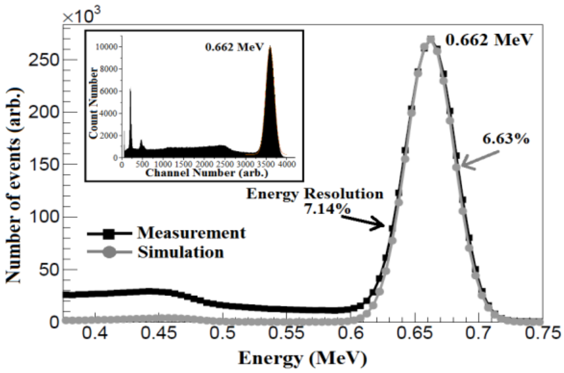

Fig. 3. Pulse height spectrum calibration both of experiment and simulation.

The simulation curve peak's has shown excellent agreement with the measurement results as shown in Fig. 3. Energy resolution for the simulation is about 6.63% and 7.14% for measurement which is determined from gaussian fitting curve.

In order to study the existence of holes in material based on gamma scattering. Fig.4 and Fig.5 shows the energy scattering distribution of the influence of the air rods existence in acrylic (PMMA). The gamma scattering energy spectra both from the simulation and measurement result was converted into 300 bins and using histogram smoothing setup (ntimes = 25) in the ROOT. Subtractions of some element volume in material gives an effect on the intensity response. There are different intensity responses as depicted in the Fig. 4 and Fig. 5 between acrylic block with and without pores. This result same as theoretical explanation in the equation (2). Both scattered gamma ray for simulation and measurement shows the similar spectrum response. Meanwhile, there are still detected the existence of the 0.662 MeV photopeak in the energy spectrum. The height of scattered gamma ray for 50^0 scattered angles (source position) is lower than 40^0.

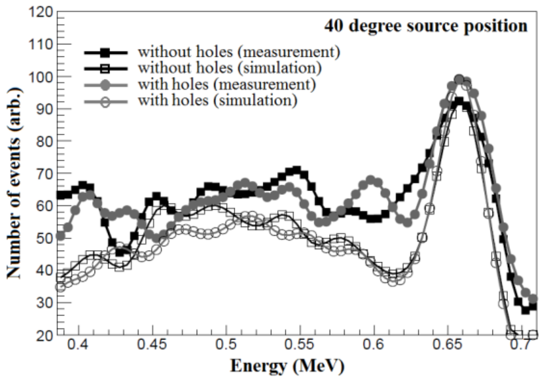

Fig. 4. Energy scattering spectrum of 40^0 source position.

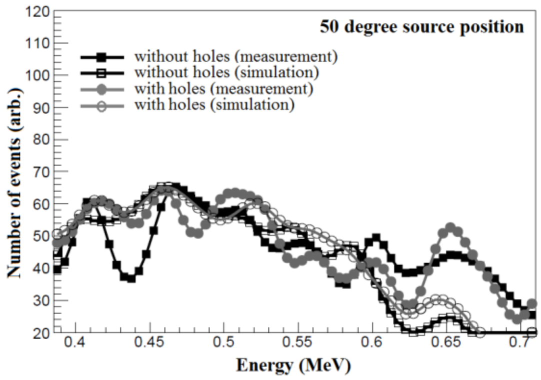

Fig. 5. Energy scattering spectrum of 50^0 source position.

According to the relation between the scattered angle and the interaction probability (*Klein-Nishina* formula), the interaction probability will decrease when the scattering angles increase. So these affect the intensity of response or the peak height energy spectrum.

5. Conclusions

The existence pores inside of the acrylic (PMMA) block influence the scattering energy spectrum of gamma source. According to the simulation approach and measurement, this method can be devolped for NDT with a small source activity.

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