Transactions of the Korean Nuclear Society Autumn Meeting
Busan, Korea, October 27-28, 2005

Study on Material Discrimination by Atomic Number Using Dual Energy γ-Rays

Y. M. Gil, Y. S. Lee, H. S. Lee, M. H. Cho, and W. Namkung
School of Environmental Engineering, Pohang Univ. of Science &Technology, Pohang, Korea
ohmailyo@postech.ac.kr

Abstract

This study aims to demonstrate the practical value of radioscopic differentiation of materials. The dual energy method is proposed for identifying materials according to atomic numbers. The differentiation of materials is achieved by comparing the attenuation ratio of low and high energy photons. We used gamma-rays of 0.662 MeV and 1.25 MeV and NaI(Tl) scintillation detector with a Multi-channel Analyzer (MCA). We also carried out the Monte Carlo simulation for the case of bremsstrahlung radiation from dual electron beams of 4 MeV and 9 MeV.

1. Introduction

In the dual energy method, the differentiation of materials is achieved by comparing the attenuation ratio of low to high energy photons. The discrimination is possible due to the fact that the different materials have different degrees of attenuation profiles for low and high energy photons, and that one may identify "organic" (low Z) and "inorganic" (high Z) materials for the controlled objects. Using this method, materials can be distinguished into different categories, according to their atomic numbers. In experiments, we used gamma-rays of 0.662 MeV and 1.25 MeV as low and high energies to classify materials into four different categories: polyethylene, Aluminum, steel, and lead.

In order to discriminate materials according to Z, it is useful to introduce a ratio of logarithmic transparencies (inverse value of absorption) at two different energies of E_1 and E_2 as the boundary energy of bremsstrahlung radiation:

$$R(E_1,E_2,t,Z)=\frac{\ln T(E_1,t,Z)}{\ln T(E_2,t,Z)}=\frac{\overline{\mu}(E_2,t,Z)}{\overline{\mu}(E_1,t,Z)}, \quad (1)$$

Where, T is the transparency of material with a mass thickness t and an atomic number Z for a bremsstrahlung radiation from a beam with boundary energy E, and μ is the absorption coefficient.

Equation (1) is simply the ratio of the total absorption coefficients for two monochromatic gamma rays of energy E_1 and E_2, which is a constant and uniquely characterizes the irradiated materials [1-4].

2. Experiment and Simulation

2.1. Experimental Setup

The experimental setup consisted of the gamma-ray sources, objects for inspection, and the detector system shown in Fig. 1. The radioisotopes of ^{137}Cs and ^{60}Co were used as dual energy gamma-ray sources. The selected objects undergoing inspection were the polyethylene, aluminum, steel, and lead as distinctive four groups in the periodic table. Model 802 NaI(Tl) scintillation detector was used for the gamma-ray spectrometry with a MCA.

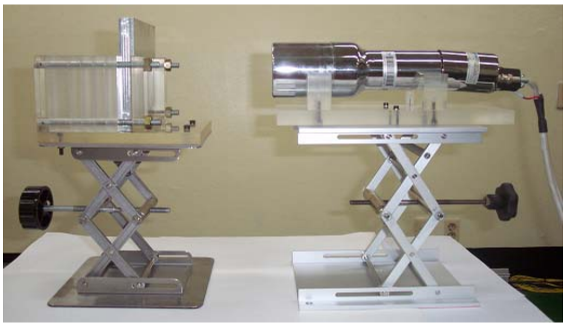

Fig. 1. Experimental setup for dual energy gamma-ray system.

2.2. Results of Experiment

Figure 2 shows the results of the spectral measurements of gamma-rays transmitted through steel, where the upper, medium, and lower lines are the spectra for without steel, 0.44 cm thick, and 1.32 cm thick steel plates.

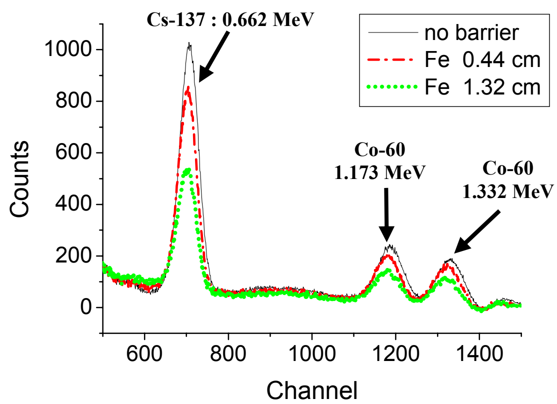

Fig. 2. Spectra of gamma-rays transmitted through the steel plates.

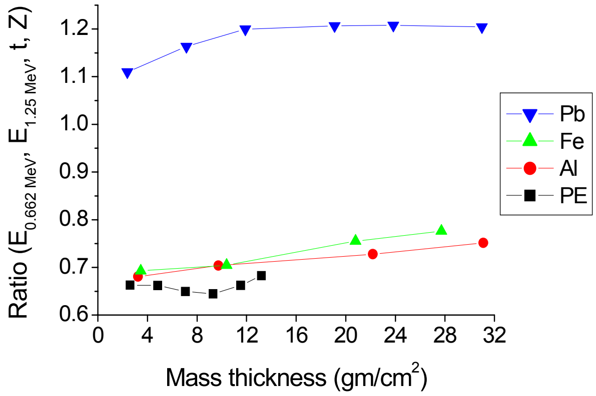

Fig. 3. Ratio R ($E_{0.662\ MeV}$, $E_{1.25\ MeV}$, t, Z) vs. mass thickness for the following materials: lead, steel, aluminum, and polyethylene.

Figure 3 shows the result of dual energy measurement. In this case, each line is nearly parallel to x-axis. According to Fig. 3 result one can identify Pb clearly by setting R value approximately from 1.1 to 1.2. Rest of materials is very difficult to discriminate.

With this result, one should find the suitable e-beam energy choices for better discrimination of materials using MCNP simulation.

2.3. MCNP Simulation

The MCNP simulation was performed under the same conditions, as shown in Fig. 4, which is very close to those in Fig. 3. We considered this result as a good bench mark for the different gamma-ray energy case.

The MCNP simulation study for bremsstrahlung radiation from 4 MeV and 9 MeV dual electron beams are performed. Fig. 5 demonstrates that radioscopic discrimination is possible irrespective of the thickness of material. One can observe much improved results compared to Fig. 4. If the low and high energy pairs are chosen properly, it would be more effective for the discrimination of materials [5-6].

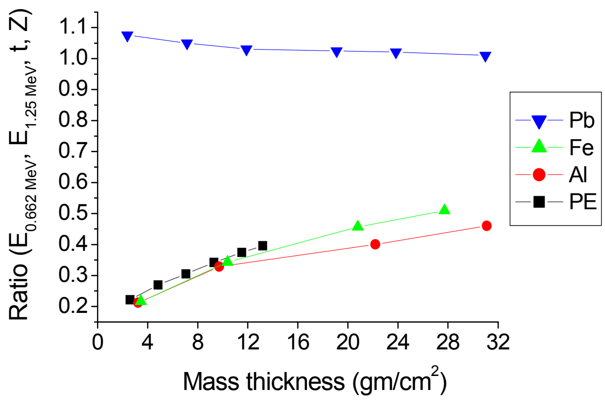

Fig. 4. Results of MCNP simulation of discrimination effect at 0.662/1.25 MeV for lead, steel, aluminum, and polyethylene.

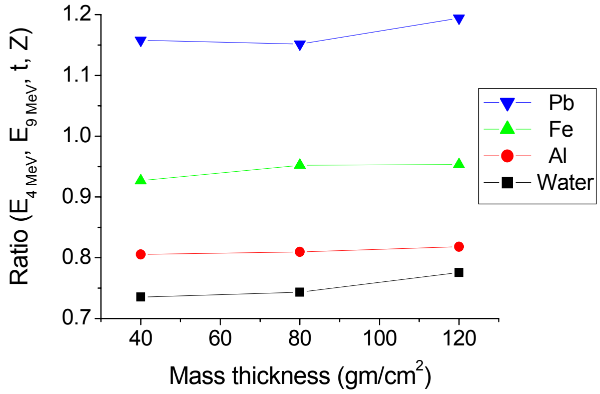

Fig. 5. Results of MCNP simulation of discrimination effect at 4/9 MeV for lead, steel, aluminum, and water.

3. Conclusion

Material discrimination experiments using two gamma-rays from ^{137}Cs and ^{60}Co were performed. The result shows that only Pb can be identified. The MCNP simulation successfully reproduced the experimental test results. We extended the preliminary results of MCNP simulation study to bremsstrahlung radiation produced by 4 MeV and 9 MeV e-beams. It shows much improved result. However, we need further study for the better discrimination.

References

[1] S. Ogorodnikov and V. Petrunin, Phys. Rev. ST Accel. Beams **5**, 104701 (2002).

[2] S. A. Ogorodnikov, V. I. Petrunin, and M. F. Vorogushin, in *Proc. of 7th European Particle Accelerator Conf. (Vienna, 2000).*

[3] S. A. Ogorodnikov, V. I. Petrunin, and M. F. Vorogushin, in *Proc. of XXth Int.. Linac Conf.* (SLAC, Stanford, 2000).

[4] V.L. Novikov, S. A. Ogorodnikov, and V.I. Petrunin, Problems of Atomic Science and Technology **4**, 93 (1999).

[5] J. F. Briesmeister (Ed.), MCNP – a General Monte Carlo N-Particle Transport Code, Version 4C, Report LA-13709-M (LANL, New Mexico, December 2000).

[6] E. Storm and H. Israel, "Photon Cross Section from 0.001 to 100 MeV for Elements 1 through 100", Los Alamos National Laboratory (New Mexico, 1967).