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# An Evaluation of Characteristic X-ray Beam Source for X-ray Inspection System Using Monte Carlo Method

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## 1. Introduction

Recently, new advanced inspection systems have been studied for the detection of explosive and illicit materials, and most of these inspection systems use X-ray tubes for their source modules. However, the wide photon-emission spectrum of X-ray tube causes an increase of uncertainty. For that reason, the beam hardening technique has been performed to modify the X-ray spectrum, but it has made the intensity of the X-ray source become lower. Also, the capability of reducing photons at unexpected energies is limited.

Therefore, the goal of this study is to develop the characteristic X-ray beam source as a quasi mono-energy source. It was mono-energetically generated from an X-ray tube in combination with the target filter assembly and simulated by MCNPX code [1]. And the developed characteristic X-ray beam source was applied to the 90$^o$ Compton scattering X-ray inspection system for validating its practical use.

## 2. Materials and Methods

### *2.1 Modeling the Target Filter Assembly*

Characteristic X-rays are generated at a unique set of energies according to property of each element. To analyze the characteristic X-rays having energies within the range of 60keV to 130keV for inspection systems, the photon cross-sections were calculated by XCOM (photon cross-section database, NIST) [2]. Au (Gold), Bi (Bismuth) and U (Uranium) which have the K-edge energies of 80.72keV, 90.53keV and 115.6keV, respectively, were selected as main target filter materials.

The mechanism for creating the characteristic X-ray beam source was shown in Fig. 1. The designed target filter assembly was located at the distance of 1cm from the industrial X-ray tube (MG452 Bipolar X-ray System, Xylon) which was operated at the voltage of 150kV. Then, the MCNPX code was used for analyzing the above system in order to determine the optimal target filter assembly.

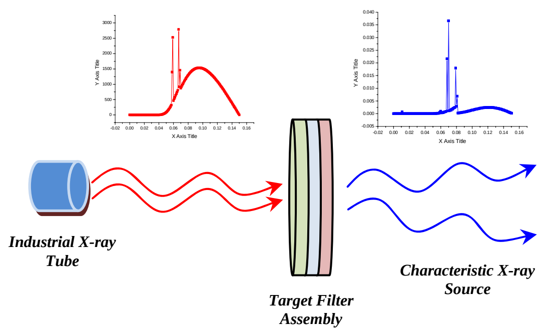


Fig. 1 Mechanism for Creating Characteristic X-ray Beam Source

### *2.2 Application to 90$^o$ Compton Scattering Inspection System*

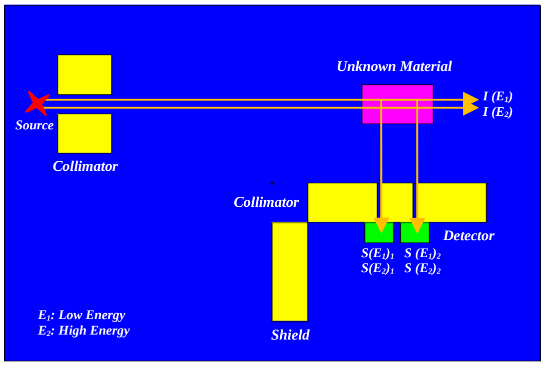


Fig. 2 MCNPX Simulation of X-ray Inspection System Using Dual Energy 90$^o$ Compton Scattering

The X-ray inspection system for substance identification has been studied at Hanyang University [3]. In X-ray inspection system using dual energy [4] as shown in Fig. 2, the relation between the ratio of mass attenuation coefficients for two energies ($R_{E1/E2}$) and effective atomic number ($Z_{eff}$) has been developed as the polynomial fitting equation as shown in equation (1).

$$R_{E1/E2} = \frac{\mu(Z_{eff}, E_1)/\rho}{\mu(Z_{eff}, E_2)/\rho} = \sum_{n=0}^{i} a_n (Z_{eff})^n \qquad (1)$$

Where, $\mu(Z_{eff}, E_1)/\rho$ is the mass attenuation coefficient at energy of $E_1$, and $a_n$ is the coefficient of polynomial fitting equation. The $Z_{eff}$ is conceptualized that chemical compound is consisting of an equivalent monatomic substance [5].

To verify the developed characteristic X-ray beam sources, this inspection system were utilized.

## 3. Results and Discussions

The characteristic X-ray beam source was developed by testing various target arrays. The target filter assembly named Bema70 was composed of 0.2mm-thick Au and 2mm-thick Fe. And it gave a mono-energy peak at 70keV, which came from the characteristic X-rays of Au. The intensity obtained was about thirty times more than that of IN150 as shown in Fig. 3. IN90 and IN150 are the beam hardening sources which have been used for experiments of the inspection system at Hanyang University [3]. These two beam hardening sources were simulated by MCNPX code under the same experiment conditions.

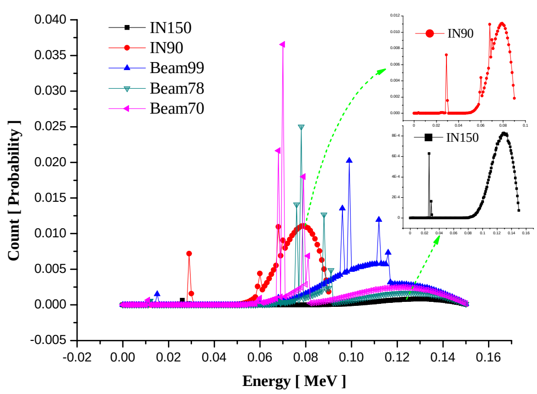


Fig. 3 Spectra of Characteristic X-ray Sources and Beam Hardening Sources

The characteristic X-rays of Beam78 (0.8mm Sn, 0.4mm Bi) and Beam99 (1.2mm Fe, 0.5mm Sn, 0.1mm U) appeared clearly at 78keV and 99keV, respectively. In comparison with beam hardening sources, the characteristic X-rays offered much higher intensity at the energy peak.

To implement the dual energy inspection system, a pair of Beam70 and Beam99 was selected. And mono-energy photons of 70keV and 99keV were also employed to the system as a reference for evaluation. Then, they were simulated by using the point detector tally in MCNPX code.

Fig. 4 shows the spectra of 90$^o$ Compton scattered photons from four different sources in acetal. In cases of 70keV photon and Beam70 sources, the maximum flux of 90$^o$ Compton scattered photons was shown at 62keV. And for cases of 99keV photon and Beam99, the peak flux energy was 83keV. The results were agreed with those calculated by Compton scattering equation [6] at 90$^o$ scattering, 61.57keV and 82.93keV, respectively.

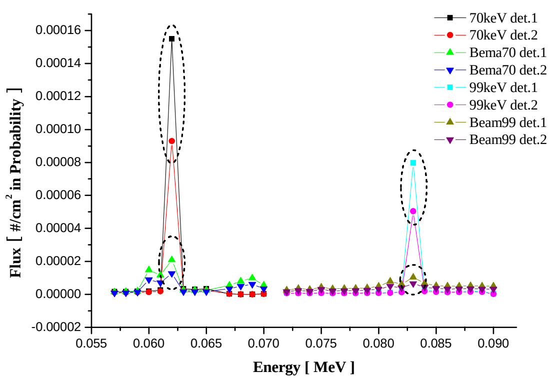


Fig. 4 Flux of 90$^o$ Compton Scattered Photon Spectrum by Mono-energy Sources and Characteristic X-ray Beam Sources

## 4. Conclusions

In this study, a characteristic X-ray beam source was mono-energetically generated by the target filter assembly in combination with X-ray tube in order to improve the source module of X-ray inspection system. Then the beam source was applied to the inspection system for validating its practical use via Monte Carlo simulation. As a result, it is shown that the characteristic X-ray beam sources can be utilized to efficiently as mono-energy X-ray sources for inspection systems.

In future study, delicate researches for the source module of the inspection system are needed for better performance.

## Acknowledgement

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