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■ 논 문 ■

A Study on the Comparison of HPGe Detector Response Data for Low Energy Photons Using MCNP, EGS, and ITS Codes

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MCNP, EGS, ITS 코드를 이용한 고순도 게르마늄 검출기의 저에너지 광자에 대한 반응 비교연구

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Abstract — The energy response of HPGe detector for low energy photons was determined by using three Monte Carlo codes, MCNP4A, EGS4, and CYLTRAN in ITS3. In this study, bare HPGe detector(100 mm^2 × 10 mm) was used and a pencil beam was incident perpendicularly on the center of the detector surface. The photopeak efficiency, K_α and K_β escape fractions were calculated as a function of incident X-ray energies ranging from 12 to 60 keV in 2-keV increments. Since the Compton, elastic, and penetration fraction were negligible in this energy range, they were ignored in the calculation. Although MCNP, EGS, and CYLTRAN codes calculated slightly different energy response of HPGe detector for low energy photons, it appears that the three Monte Carlo codes can predict the low energy photon scattering processes accurately. The MCNP results, which are generally known as to be less accurate at low energy ranges than the EGS and ITS results, are comparable to the results of EGS and ITS and are applicable to the calculation of the low energy response data of a detector.

Key words : HPGe detector, low energy photons, MCNP4A, EGS4, CYLTRAN, photopeak efficiency, Kα escape fraction, Kβ escape fraction

요약 — 저에너지 광자에 대한 고순도 게르마늄 검출기의 에너지 반응데이타를, 3개의 몬테칼로 코드(MCNP4A, EGS4, ITS3의 CYLTRAN)를 사용하여 계산하였다. 본 연구에서는, bare 고순도 게르마늄 검출기(100 mm^2 ×10 mm)가 사용되었고, 측정기표면의 중앙에 pencil beam을 수직으로 입사시켰다. 광전효과 효율, K_α 및 K_β 이탈률을, 12keV부터 60 keV 범위까지 2 keV 간격으로 입사된 X-선 에너지의 함수로 나타내었다. 이 에너지범위에서 컴프턴산란률, 탄성산란률 및 투과율은 매우 작기 때문에 본 계산에서는 제외되었다. 비록 MCNP, EGS 및 CYLTRAN 코드의 저에너지 광자에 대한 고순도 게르마늄 검출기 에너지 반응데이터값은 약간의 차이를 나타내지만, 세가지 몬테칼로 코드는 검출기내의 저에너지 광자산란을 정확히 예측하고 있음을 알 수 있다. 또한, EGS나 ITS의 결과에 비해 저에너지 영역에서 정확성이 떨어진다고 여겨지는 MCNP의 결과도 EGS나 ITS의 결과에 상당하는 정확성을 보여주

고 있으며, 저에너지 광자에 대한 검출기 반응데이타 계산에 응용될 수 있다.

중심단어 : 고순도 게르마늄 검출기, 저에너지 광자, MCNP4A, EGS4, CYLTRAN, 광전효과 효율, K_α이탈률, K_β 이탈률

INTRODUCTION

In X-ray dosimetry and diagnostic radiology, an accurate knowledge of X-ray spectra is essential especially for studies involving patient dosage and image quality. When X-ray spectra are measured with a detection system, some distortions due to the incomplete absorption of primary photon or escape before interacting with the detector which have finite dimension may take place. Although HPGe detector has the advantage of high resolution with reasonably high detection efficiency, it is still necessary to correct the measured pulse-height distributions(PHD) for the distorting effects of the detector response. An accurate calculation of energy response of detector is, therefore, very important task.

However, the interactions between X-ray photons and detector crystals are very complex and an accurate determination of the detector response function is not easily calculated analytically. Monte Carlo calculations have been used for detectors in the diagnostic X-ray energy range as well as in the high energy range[1~3]. It was proven to be the most practical means of determining the detector response to monoenergetic photons.

In this study, representative three Monte Carlo codes, MCNP4A[4], EGS4[5], and CYLTRAN in ITS3[6], were employed to determine the energy response of bare HPGe detector for incident X-ray energies up to 60keV and comparison of each result was made to provide a reference data in those low X-ray energy range.

CROSS SECTION DATA OF MCNP4A, EGS4, AND ITS3

In the diagnostic X-ray energy range, the important X-ray interactions are the photoelectric effect, coherent scattering, and incoherent scattering, which have to be considered in the simulation procedure. The cross section data of each interaction process used in three Monte Carlo codes are described in the following sections.

MCNP4A

The photon interaction tables are based on evaluated data from ENDF[7]. Angular distributions of secondary photons are introduced through the differential Thomson cross section modified by form factors for coherent scattering. The differential Klein-Nishina cross section are modified by scattering functions for incoherent scattering. Fluorescence data are, however, not provided in ENDF, so that the data are extracted from a variety of sources[8].

EGS4

The cross sections for the photoelectric effect are taken directly from Storm and Israel's tables[9]. The Compton cross sections for photon scattering from electrons are obtained from the Klein-Nishina formula which applies to free electrons. For coherent(Rayleigh) scattering, the data from Storm and Israel are also used.

ITS3

The photon interaction cross sections are constructed through the combination of photoelectric absorption cross section from Scofield, coherent scattering cross sections from Hubbel and ϕverbφ, and incoherent scattering cross sections from Hubbel et al. in the diagnostic X-ray energy range.

CALCULATION OF ENERGY RESPONSES OF HPGe DETECTOR

Method of calculation

X-ray photon histories generated by random sampling which is analogous to physical processes were traced until they eventually were absorbed, escaped from the detector, or reached a cut-off energy. The distance to the first interaction and the distance between interactions were sampled from a probability distribution governed by an attenuation coefficient comprising the cross sections for photoelectric absorption, coherent scattering and incoherent scattering. The type of interaction was determined according to the relative magnitude of these three cross sections.

If the photoelectric interactions occur, three Monte Carlo codes determine whether a *K*-fluorescence X-ray is produced. K_α and K_β fluorescence X-rays are chosen randomly according to their relative intensities. The *K* photons have a high probability of escaping the detector entirely. It is assumed that all *L* X-rays and Auger electrons produced in the photoelectric events are absorbed locally.

If coherent scattering events occur, the deflection angle is obtained by random sampling from the coherent scattering cross sections used in each of the Monte Carlo code. The scattered X-ray photon is followed until it escapes or is absorbed.

If incoherent scattering events occur, the scattering angle of the photon is sampled from the incoherent scattering cross section used in each Monte Carlo code. In this work, the energy of recoiled electron is assumed to be deposited completely at the site of the Compton interaction since the range of the recoiled electron is short. The scattered photon is then traced.

Computational procedure

In this calculation, it was assumed that a pencil beam of X-ray photons was perpendiculary incident on the center of the surface of cylindrical bare Ge detector, having dimensions of $100mm^2$ x 10mm. The dead layer which forms the frontal contact of the Ge detector, the crystal housing material, and the backing material which may contribute scattered radiation were ignored. The density of Ge was taken to be $5.38 g/cm^3$[10] in order to compare the calculation results with an earlier Monte Carlo result obtained by Chin-Tu Chen et al.[11~12].

Incident X-ray energy ranging from 12 to 60 keV in 2-keV increments were selected to examine the energy response of HPGe detector that was calculated from each Monte Carlo code for low energy X-ray photons. As a photon cut-off energy, 5keV was chosen since the mean free path of the photon is about 7.5μm in germanium at this energy.

Each incident photon was classified in one of the five categories; photopeak efficiency, K_α escape fraction, K_β escape fraction, Compton fraction, and no energy loss fraction. Elastic escape fraction was incorporated in the no energy loss fraction because elastically escaped photon does not deposit any of its energy in the detector.

RESULTS AND DISCUSSION

The energy response of bare HPGe detector was calculated for incident X-ray energies ranging from 12 to 60 keV in 2-keV increments. Fig. 1. through 3 shows photopeak efficiency, K_α and K_β escape fractions as a function of incident X-ray energies, respectively. The earlier Monte Carlo results which had been calculated by Chin-Tu Chen et al. were also included in the Figures for comparison. Compton fraction and no energy loss fraction were so negligible in this ener-

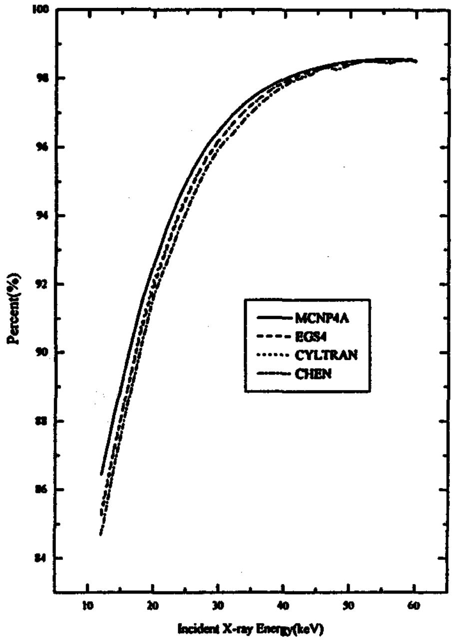

Fig. 1. Results of Photopeak efficiency.

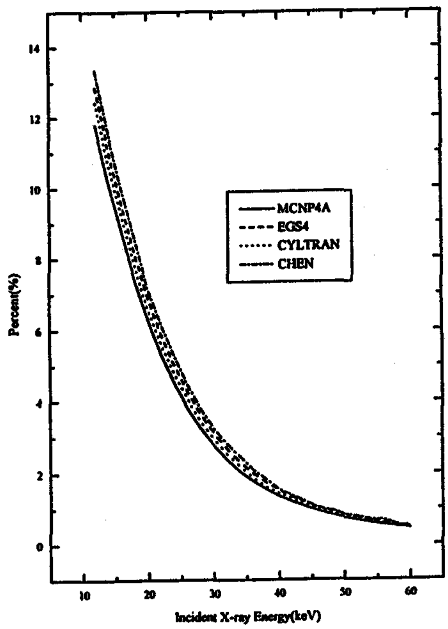

Fig. 2. Results of K-alpha escape fraction.

gy range that the calculation of those fractions were omitted.

From the results, it was found that EGS4 code and CYLTRAN code gave similar results for the photopeak efficiency. The differences between MCNP4A and EGS4 code were large when the incident photon energy approached to 12keV as compared with energy ranges from 50 to 60keV. That may be due to the cross sections used in each code. For K_α and K_β escape fractions, the results calculated from each code also gave rise to the same tendency as the photopeak efficiency by showing the relatively large differences at 12keV whereas, at high energies, the differences are small.

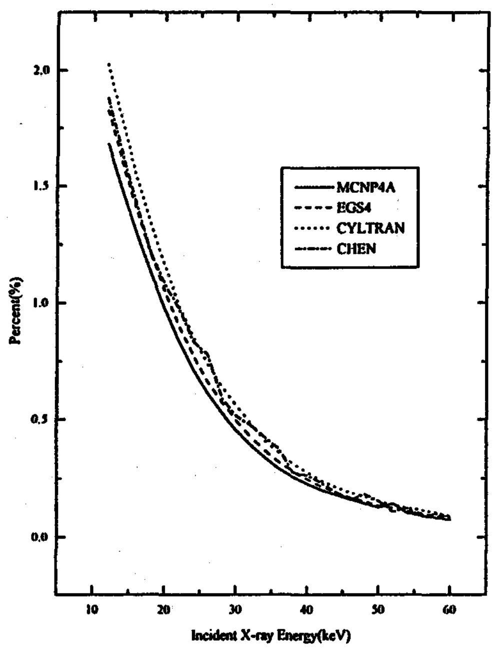

Fig. 3. Results of K-beta escape fraction.

The statistical uncertainties in the results were estimated as the PRE(percentage relative error). All PRE calculated from each code were ranged from 1 to 4% which is generally acceptable for Monte Carlo calculation.

CONCLUSIONS

Three Monte Carlo calculations were carried out by using MCNP4A, EGS4, and CYLTRAN codes to determine the energy response of HPGe detector for low energy photons ranging from 12 to 60keV. In the light of the purpose of this work to verify the confidence of response data in the detector material for low energy photons calculated from three Monte Carlo codes, though MCNP4A, EGS4, and CYLTRAN codes calculated slightly different energy responses of HPGe detector, it appears that the three Monte Carlo codes can predict the low energy photon scattering processes accurately. It is also note that the MCNP results, which are generally known as to be less accurate at low energy ranges than the EGS and ITS results, are comparable to the results of EGS and ITS and are applicable to the calculation of the low energy response data of a detector. Though a bare crystal was used in this work, the energy response of the detector which are covered with surrounding material may also be calculated by three Monte Carlo codes accurately. The results obtained from this work can be used as a reference by code users who are interested in the calculation of energy responses of a such detector.

REFERENCES

1. S. M. Seltzer, "Calculated Response of Intrinsic Germanium Detectors to Narrow Beams of Photons with Energies up to ~300 keV," *Nuclear Instruments and Methods*, **188**, 133-151, March 13, 1981.
2. D. W. O. Rogers, "More Realistic Monte Carlo Caculations of Photon Detector Response Functions," *Nuclear Instruments and Methods*, **199**, 531-548, November 5, 1981.
3. M. J. Berger and S. M. Seltzer, "Response Functions for Sodium Iodide Scintillation Detectors," *Nuclear Instruments and Methods*, **104**, 317-332, April 19, 1972.
4. LANL Group X-6, *MCNP—A General Monte Carlo Code N-Particle Transport Code Version 4A*, LA-12625-M, November, 1993.
5. Walter R. Nelson, Hideo Hirayama and David W. O. Rogers, *The EGS4 Code System*, SLAC-265, December, 1985.
6. J. A. Halbleib, R. P. Kensek, T. A. Mehlhorm, G. D. Valdez, S. M. Seltzer and M. J. Berger, *ITS Version 3.0 : The Integrated TIGER Series of Coupled Electron/Photon Monte Carlo Transport Codes*, SAND91-1634, March, 1992.
7. J. H. Hubbel, W. J. Veigele, E. A. Briggs, R. T. Brown, D. T. Cromer and R. J. Howerton, "Atomic Form Factors, Incoherent Scattering Functions, and Photon Scattering Cross Sections," *J. Phys. Chem.*, Ref. Data 4, 471, 1975.
8. E. Storm and H. I. Israel, *Photon Cross Sections from 0.001 to 100MeV for Elements 1 through 100*, Los Alamos Scientific Laboratory report LA-3753, November, 1967.
9. E. Storm and H. I. Israel, "Photon Cross Section from 1 keV to 100MeV for Elements Z=1 through Z=100," Atomic Data and Nucl. Data Tables A7, 565-681, 1970.
10. D. E. Gray, Ed., "American Institute of Physics Handbook," 3rd ed., pp.2-20. McGraw-Hill, New York, 1972.
11. C. S. Chen, K. Doi, C. J. Vyborny, H.-P. Chan, and G. Holje, "Monte Carlo Simulation Studies of Detectors Used in the Measurement of Diagnostic X-ray Spectra," *Med. Phys.*, **7**, 627-635, November, 1980.
12. H.-P. Chan, C.-T. Chen, K. Doi, T. R. Fewell, R. E. Shuping, "Investigation of Energy Responses of Germanium Detectors and Correction of Measured Spectra by Means of Monte Carlo Simulation," *Radiation Research*, **99**, 443-464, 1984