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A New Approach on the Correction for Compton Escape Component in X-Ray Unfolding Algorithm

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ABSTRACT

A new approach on the correction for Compton escape component in X-ray unfolding algorithm was investigated to obtain more accurate X-ray source spectrum. The X-ray detector used in this study was a planar type HPGe detector(EG&G ORTEC, GLP-32340/13-P-LP) whose energy response has been known and ISO narrow beam series were employed as source spectrum. At lower energy part of measured X-ray spectrum including the correction for Compton escape component, more accurate unfolded spectrum was obtained by letting down the starting energy level of the correction in existing spectrum correction procedure to consider multiple scattering effects. It is, from this study, concluded that accurate correction for Compton escape component is needed in X-ray unfolding procedure since Compton scattering becomes more important as incident X-ray energies increase.

1. INTRODUCTION

Since the objective of many radiation measurements is to deduce the energy distribution of the incident radiation, proper and accurate correction of the experimental data for the energy response of the detector is very important to the determination of X-ray spectra. Generally, two ways, response matrix method(1,2) and rectangular approximation method(1,2), are known as spectrum correction method. Response matrix method is slightly more accurate than rectangular approximation method but it is complex and requires large computer memory as compared with rectangular approximation method which approximates the Compton continua as rectangular distribution. The differences in the resuts of these two method are, in fact, small, so the simple rectangular approximation method is prefered to most spectral measurements(1). However, the correction of spectra for the distortion due to the Compton effect which was used by early investigators, e.g., C. S. Chen(2,3), seems to cause some error in X-ray unfolding. Especially, it is shown that the error becomes so large as incident X-ray energy increases.

The purpose of in this study is to obtain more accurate unfolded spectrum through the some changes in correction for Compton escape component in X-ray unfolding algorithm using the ISO narrow beam series.

2. CORRECTION of X-RAY SPECTRA

2.1 Correction method

The simplest way to correct a measured spectrum is to divide the measured photon counts in a given channel by the photopeak efficiency at the same energy. A more advanced correction technique takes into account the K-escape radiation loss and Compton scattering effect as well as the photopeak efficiency correction. The correction for Compton escape component is, however, more difficult because the distribution of escaped Compton scattered photons is complicated and depends on energy. If the distributions of the Compton contivuum are not known, it is common to assume a rectangular-shaped distribution which had been suggested by Svahn for all energies[3]. The photopeak efficiency correction begins at the maximum energy of the measured spectrum and the K-escape fraction for that particular energy is then multiplied by the corresponding number of counts and subtracted from the number of counts in the channel whose energy is equal to that less the K-fluorescence energy. The correction for Compton escape component is similar to that used for the K-escape correction except that the Compton fraction of photons is subtracted from the low-energy channels as a rectangular distribution.

The details of the correction method are as follows. In the high energy range, the corrected spectrum, $S(E)$, is calculated from the measured spectrum, $M(E)$, by

$$S(E)=\frac{M(E)}{P(E)} \qquad \text{for } E_{\max}-E_K < E \leq E_{\max} \tag{1}$$

where $P(E)$ is the photopeak efficiency, and $E_{\max}$ and E_K are the maximum energy of the measured spectrum and the K-fluorescence energy, respectively. In the middle energy range, the K-escape correction is included as

$$S(E)=\frac{M(E)-S(E+E_K)\cdot K(E+E_K)}{P(E)} \qquad \text{for } E_{Cmax} < E \leq E_{\max}-E_K \tag{2}$$

where $K(E)$ is the K-escape fraction, and Ecmax is the Compton edge energy for maximum incident X-ray energy, Emax. In the low energy range, the correction for the Compton escape component is given by

$$S(E)=\frac{1}{P(E)}\left\{\left[\ M(E)-S(E+E_K)\cdot K(E+E_K)-\sum_{E_X=E_0(E)}^{E_{\max}} S(E_X)\cdot C(E_X)\cdot\frac{\Delta E}{E_{CX}}\right]\right\}$$

$$\text{for } E\leq E_{Cmax} \tag{3}$$

where $C(E)$ is the Compton fraction. $E_0(E)$ corresponds to the incident X-ray energy yielding a Compton edge at the energy E, and E_{CX} is the Compton edge energy for E_X. The energy interval, ΔE, is equal to the channel width used in the spectral measurements.

2.2 New correction for Compton escape component

Noting the summation term in equation (3), it is noticed that starting energy level of the correction for Compton escape component is $E_0(E)$. However, some monoenergetic X-ray photons which have energies less than $E_0(E)$ will contribute the counts to energy channel E in measured spectrum. To investigate the fact, five monoenergetic photons, 300keV, 298keV, 296keV, 294keV, and 292keV, which have considerable Compton escape fraction were used for determination of the measured spectrum. The five measured spectra were obtained by having the MCNP code[4] simulate the interactions of the five monoenergetic photons with the detector, GLP-32340, and shown in Figure 1 and 2. The measured spectra were shown to have, from the figures, continuous distribution. If 300keV is assumed to be $E_0(E)$, 299keV, 298keV, 297keV, ··· X-ray photons also can contribute the counts to energy channel E as well as 300keV X-ray photons. That is to say, it seems to reasonable to let down the starting energy level of the correction in existing spectrum correction procedure to consider multiple Compton scattering effects. In this study, $E_0(E)$ in equation (3) was, therefore, replaced with $E_0(E)$-25 to lower the starting energy level of the correction. The value of 25 was found to be the optimized one which was obtained from the several unfolding calculation to minimize the differences between true spectra and unfolded spectra. Since the energy response data of GLP-32340[5] had been tabulated in 1keV increments, $E_0(E)$-25 means the energy level below $E_0(E)$ by 25keV. Also, K-escape correction in equation (2) was divided into K_α-escape correction and K_β-escape correction that is given by

$$S(E)=\frac{M(E)-S(E+E_{K_\alpha})\cdot K_\alpha(E+E_{K_\alpha})}{P(E)} \quad \text{for } E_{\max}-E_{K_\beta} < E \le E_{\max}-E_{K_\alpha} \quad (4)$$

and

$$S(E)=\frac{M(E)-S(E+E_{K_\alpha})\cdot K_\alpha(E+E_{K_\alpha})-S(E+E_{K_\beta})\cdot K_\beta(E+E_{K_\beta})}{P(E)}$$

$$\text{for } E_{Cmax} < E \le E_{\max}-E_{K_\beta} \quad (5)$$

where E_{K_α} and E_{K_β} are the K_α and K_β-fluorescence energy, respectively, and $K_\alpha(E)$ and $K_\beta(E)$ are the K_α and K_β-escape fraction, respectively.

ISO narrow series of filtered X-rays were, as mentioned earlier, employed to demonstrate the suitability of the new correction for Compton escape component in X-ray unfolding algorithm. As an indicator to evaluate how well the corrections performed, the root mean square(RMS) value of the average difference between the true incident spectra and corrected measured spectra was calculated according to

$$RMS = \left[\frac{1}{N} \sum_{i=1}^{N} (Ti - Si)^2 \right]^{\frac{1}{2}} \qquad (6)$$

where T_i and S_i represent the number of counts in the ith energy interval of the true and corrected spectra, respectively.

3. RESULTS

The average energy of unfolded spectrum calculated by using the new concept of correction were tabulated in Table 1 together with that from existing correction method and compared with the source spectrum, ISO narrow series. Also, the RMS values were given in Table 2 between unfolded and source spectrum together with those between measured and source spectrum to evaluate the accoplishments of this work. From the Table1, it is seen that average energy from existing correction method is low as compared with that from the new correction method when the X-ray tube voltage is high and, for 300kV tube voltage, the difference of average energy between unfolded spectrum calculated by existing method and source spectrum is about 5keV. Comparison of two unfolded spectra which were obtained from new correction method and existing method was presented in Figure 2 for 300kV tube voltage. The correction of unfolded spectrum was not properly carried out in the range from 110keV to 165keV when the existing correction method was used. That means what the correction for Compton escape component in existing correction method is not suitable in case the Compton scattering is dominant.

4. CONCLUSIONS

A new approach on the correction for Compton escape component in X-ray unfolding algorithm was done in this study to obtain more accurate X-ray source spectrum by using the ISO narrow series filtered X-rays to verify the suitability of new correction method. As expected earlier, it is found that the existing correction method does not well correct the measured spectrum and the new correction method makes an improvement in X-ray unfolding method.

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Table 1. Comparison of Mean Energy between Source Spectrum and Unfolded Spectrum

Tube Voltage (kV)	Mean Energy (keV)		
	ISO spectrum	Using existing correction method	Using new correction method
40	32.50	32.49	32.49
60	47.11	47.09	47.09
80	63.97	63.72	63.90
100	82.34	81.79	82.10
120	99.33	98.53	99.00
150	116.72	115.92	116.56
200	163.86	162.08	163.17
250	207.95	204.25	206.30
300	250.52	244.93	248.47

Table 2. RMS Values

Tube Voltage (kV)	Root Mean Square	
	Measured spectrum	Unfolded spectrum
40	0.0123877	0.0046604
60	0.0074518	0.0038475
80	0.0052029	0.0021962
100	0.0122327	0.0045579
120	0.0225097	0.0055595
150	0.0483988	0.0103620
200	0.1081192	0.0114062
250	0.1821944	0.0179200
300	0.2532284	0.0126516

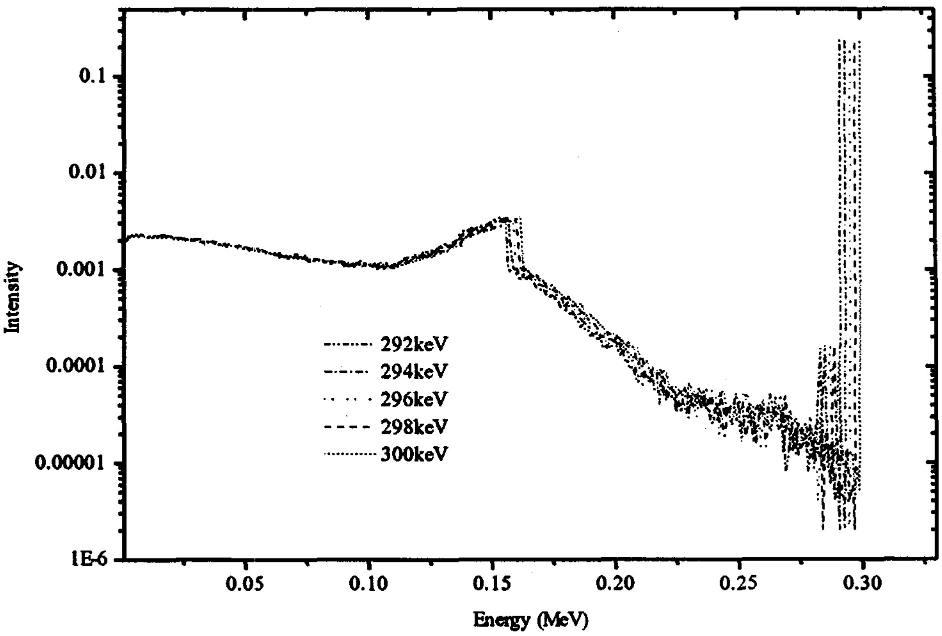

Figure 1. Measured Spectra from Five Incident Monoenergetic Photons

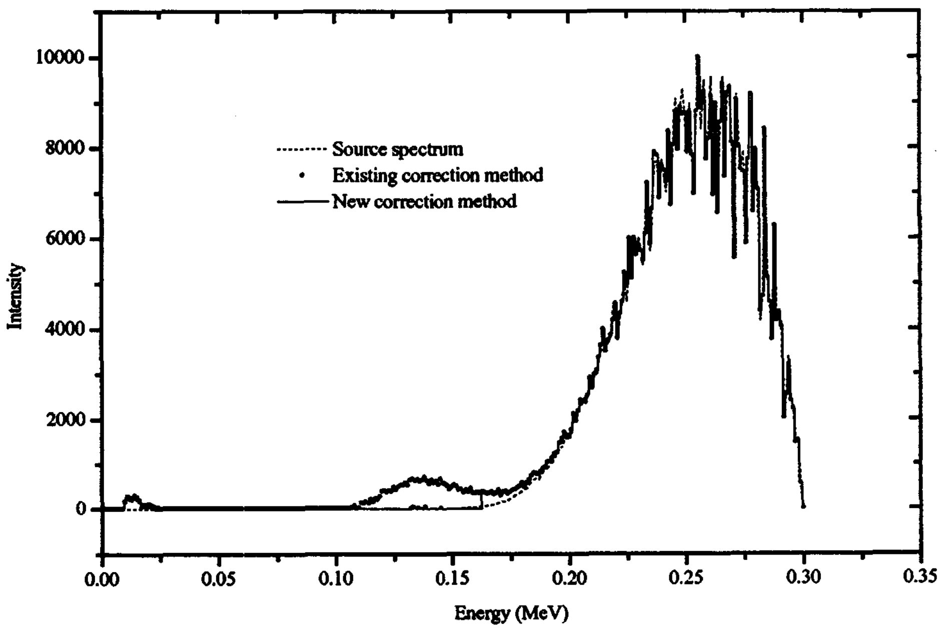

Figure 2. Comparison of Two Unfolded Spectrum for 300kV Tube Voltage