Proceedings of the Eleventh EGS4 Users' Meeting in Japan, KEK Proceedings 2003-15, p.107-113

ESTIMATION OF 90° SCATTERING COEFFICIENT IN THE SHIELDING CALCULATION OF DIAGNOSTIC X-RAY EQUIPMENT

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Abstract

The calculating method of leakage effective dose in a controlled area boundary is regulated by law No. 188. When calculating the leakage dose by scattered x-rays, the 90° scattering coefficient is required. In this study, the 90° scattering coefficient was calculated using EGS4 as a function of field size and the strength of the incident x-ray spectrum and compared with the value given in law No. 188. It was found that the value given by law No. 188 underestimates the calculated value.

1. Introduction

Diagnostic x-ray equipment may have three sources of x-ray leakage, from the primary x-rays, the scattered x-rays, and the x-ray tube. To calculate the effective dose of the leakage of the equipment it is necessary to determine all three. The notice of the ministry ordinance which revises the part of medical law enforcement regulation (Law No. 188) provides regulations for the various parameters used in the leakage effective dose calculation [1]. This law makes use of data from the National Council on Radiation Protection and Measurements (NCRP) [2]. Because The NCRP data was measured by self-rectified equipment at a target angle of 45°, it isn't fully appropriate for diagnostic x-ray equipment mainly spreads at present. It is therefore necessary to reexamine the numerical values in law No. 188.

In this study, the 90° scattering coefficient, necessary for calculating the leakage dosage by scattered x-rays, was examined. The value of the 90° scattering coefficient in law No. 188 is defined as the ratio of the exposure radiation dose at a distance of 100 cm on a 400-cm^2 organization resemblance phantom at 90° from the useful beam direction to the radiation dose from the primary beam. For different radiation fields, a simple method of calculating the coefficient by taking a ratio of field sizes was used. Monte Carlo simulation code EGS4 was used to obtain the 90° scattering coefficient for different radiation fields and incident x-ray beam strengths. The 90° scattering coefficient generated in this way was then compared to the values given in law No. 188.

2. Method and simulations

2.1 Geometry

The geometry used was that given in the literature [3] and quoted by NCRP. A water phantom was used, 30 cm wide, 20 cm high, and 72 cm long. The detector used was air of volume 15 × 15 × 15 cm^3 and an SID at a distance of 100 cm (Fig.1).

2.2 X-ray spectra

Incidence x-ray spectra were obtained from the equation of Birch and Marshall [4]. 90° scattering coefficient data were measured for a number of tube voltages at a target angle of 45° with filtration of 0.5 mm Al at a tube voltage of 50 kV, 1.5 mm Al at 70 kV, and 2.5 mm Al at 100 kV, 125 kV, and 150 kV. Since a target angle of 12° is currently the most commonly used angle, incidence x-ray spectra at a target angle of 12° and filtration 2.5 mm Al for each tube voltage were also examined.

2.3 Simulations

Firstly, the primary x-ray spectrum in air at 1 m SID without the phantom was calculated using EGS4 (KEK improved) (Fig.1-a). Next, with a phantom in place, scattered x-ray spectra at a distance of 100 cm at 90° to the useful beam direction were calculated (Fig.1-b). The history numbers were 10^7 per keV and the incident photon energy was changed from 10 keV to 150 keV in 1 keV steps. By multiplying each energy-fluence by the mass energy-absorption coefficient, the absorbed dose in air could be calculated. The 90° scattering coefficient was obtained by taking the ratio of the scattered x-ray dose to the primary ray dose. Scattering coefficients were obtained at tube voltages of 50 kV, 70 kV, 100 kV, 125 kV, and 150 kV, target angles of 45° and 12°, and radiation fields of 20 × 20 cm^2, 28 × 28 cm^2, and 34 × 28 cm^2.

3. Results and discussion

The 90° scattering coefficients for different tube voltages at a target angle of 45° are shown in Figure 2. The value of the 90° scattering coefficient calculated using EGS4 for a field size of 20 × 20 cm^2 is less than the value given in law No. 188 by about 20% to 40% for all tube voltage. The reason for this difference is that in the EGS4 calculated coefficient, only the 90° scattered x-ray, which comes from phantom, is detected, while the value given in law No. 188 includes the scattered radiation from the x-ray tube and the mobile restriction.

The 90° scattering coefficients for the different field sizes are shown in Figure 3. The 90° scattering coefficients increase as the field size is increased. For a field size of 20 × 20 cm^2, the EGS4 calculated coefficient is smaller than the value given in law No. 188. However, for larger radiation fields the EGS4 calculated coefficient is greater than the values given in law No. 188. For a field size of 28 × 28 cm^2, the EGS4 calculated coefficient was greater than the value given in law No. 188 by 1.8 to 3.4 times. It therefore appears that law No. 188 underestimates the 90° scattering coefficient when it is calculated as a simple area ratio. The EGS4 calculated coefficient for a field size of 34 × 28 cm^2 is lower than that for a field size of 28 × 28 cm^2 by about 40% at 50 kV, about 10% at 70 kV, and 5% over 100 kV. In spite of the increase in field size, the radiation field doesn’t increase at the detector but by the extended shaft side of the phantom. Therefore, the detected photon number decreases.

The 90° scattering coefficients at a target angle of 12° for different tube voltages are shown in Figure 4. The coefficient at a target angle of 12° is greater than the coefficient at a target angle of 45° by a factor of about 2 at a tube voltage of 50 kV, 1.4 at 70 kV, and 1.2 over 100 kV. Table 1 shows a comparison between the values for the 90° scattering coefficient given in law No. 188 and the values calculated for a target angle of 45°, 12°. The calculated values are larger than those given in law No. 188 when the radiation field is large, for both target angles of 45° and 12°.

X-ray spectra for target angles 45° and 12° were compared in order to examine the difference in the 90° scattering spectrum for the two target angles. Primary x-ray spectra and 90° scattering spectra are shown in Figures 5 and 6. For a target angle of 45° filtration was 0.5 mm Al at a tube voltage of 50 kV, 1.5 mm Al at 70 kV, and 2.5 mm Al at over 100 kV. However, since there is a regulation for filtration to be over 2.5 mm Al for diagnostic x-ray apparatus in medical law enforcement regulations, filtration was set at 2.5 mm Al for the target angle of 12° for all tube voltages. A filter effect is produced by this difference in filtration in the two target angles. For tube voltages of 50 kV and 70 kV the filter effect causes the effective energy of the incident x-rays to rise. The spectral shape for both target angles is almost equal over 100 kV, but the spectra for the target angle of 12° are higher than for a target angle of 45° in effective energy, since the low energy part is small. Spectra for both target angles were almost equal for the peak position of the 90° scattered radiation spectrum. However, the photon number at 50 kV and 70 kV is quite different and the detected photon number for the 12° target angle is greater than that for the 45° target angle, due to an increase in Compton scattering. Hence, it is clear that the 90° scattering coefficient changes with target angle and filtration.

4. Conclusions

It was found that the 90° scattering coefficient calculated by EGS4 was proportional to the size of the radiation field. However, it is not a simple irradiation area ratio. Also, the 90° scattering coefficient is dependent on the target angle and filtration. At present, there are almost no diagnostic x-ray equipment with a target angle of 45° and it is necessary that the filtration be over 2.5 mm Al. Therefore, the numerical values regulated in law No. 188 may become the underestimate the 90° scattering coefficient.

X-rays are scattered not only in the 90° direction, and hence studies are underway on x-rays scattered in other directions.

5. References

[1] Public welfare Ministry of Labor medicine director notice, "On the operation of the ministry ordinance which revises the part of medical law enforcement regulation" (2001).

[2] National Council on Radiation Protection and Measurements: NCRP Report No.49, Structure Shielding Design and Evaluation for Medical Use of X rays and Gamma Rays of Energies Up to 10 MeV, p.59 (1976).

[3] E. Dale Trout, John P. Kelly: Scattered Radiation from a Tissue-Equivalent Phantom for X Rays from 50 to 300 kVp, Radiology 104161-169 (1972).

[4] R. Birch, Marshall: Computation of Bremsstrahlung X-ray Spectra and Comparison with Spectra Measured with a Ge(Li)Detector, PHYS. MED. BIOL. Vol.24, No.3, 505-517 (1978).

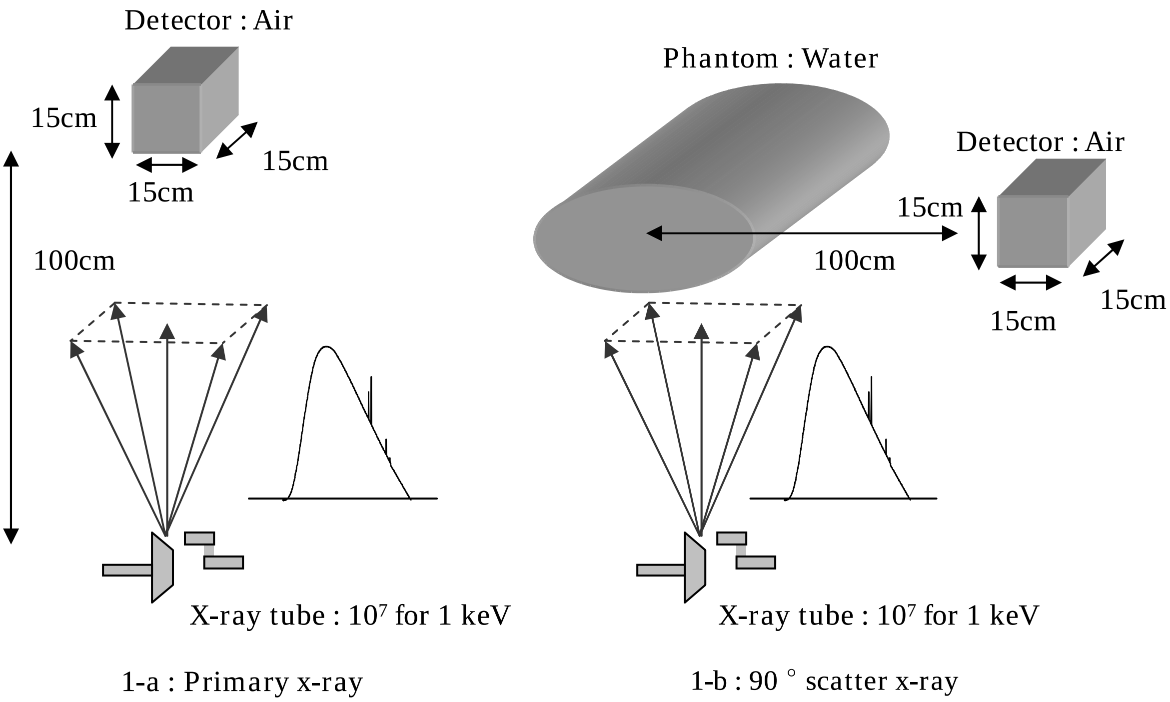

Fig.1 Geometry of EGS4 simulation.

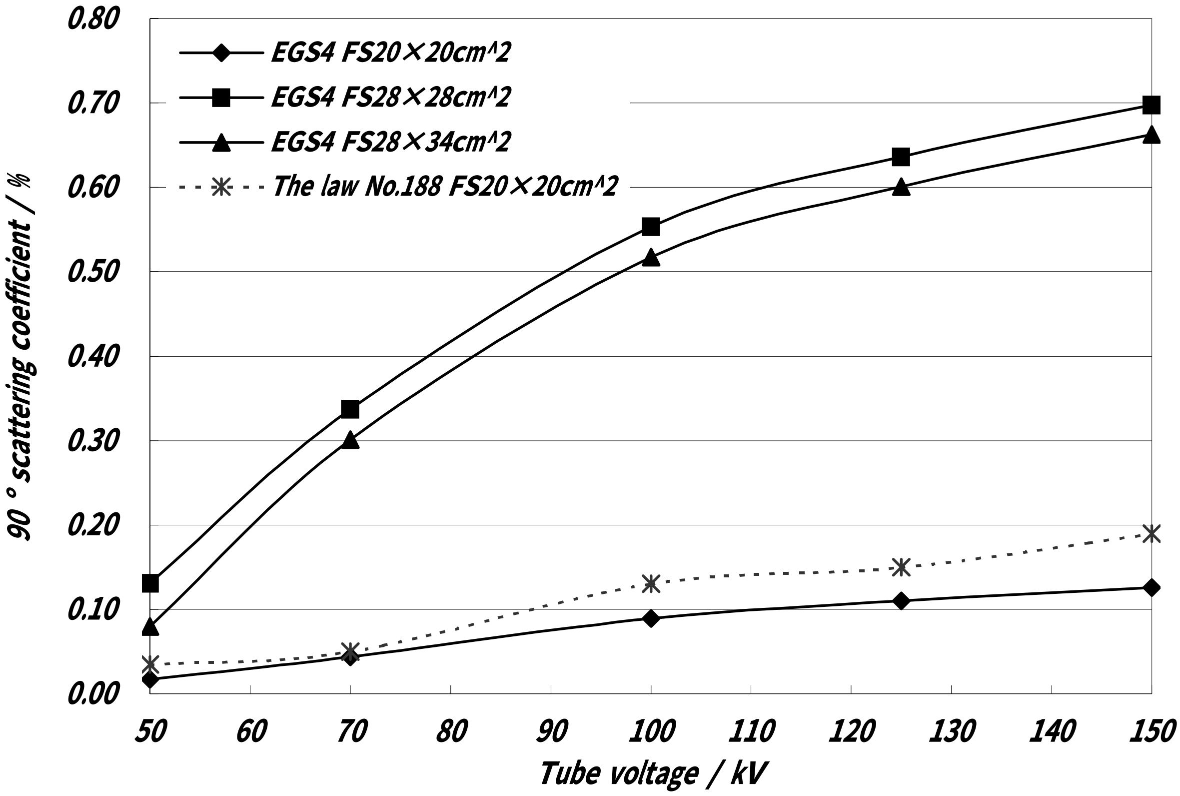

Fig.2 90 ° scattering coefficient as the tube voltage changes at target angle 45 °

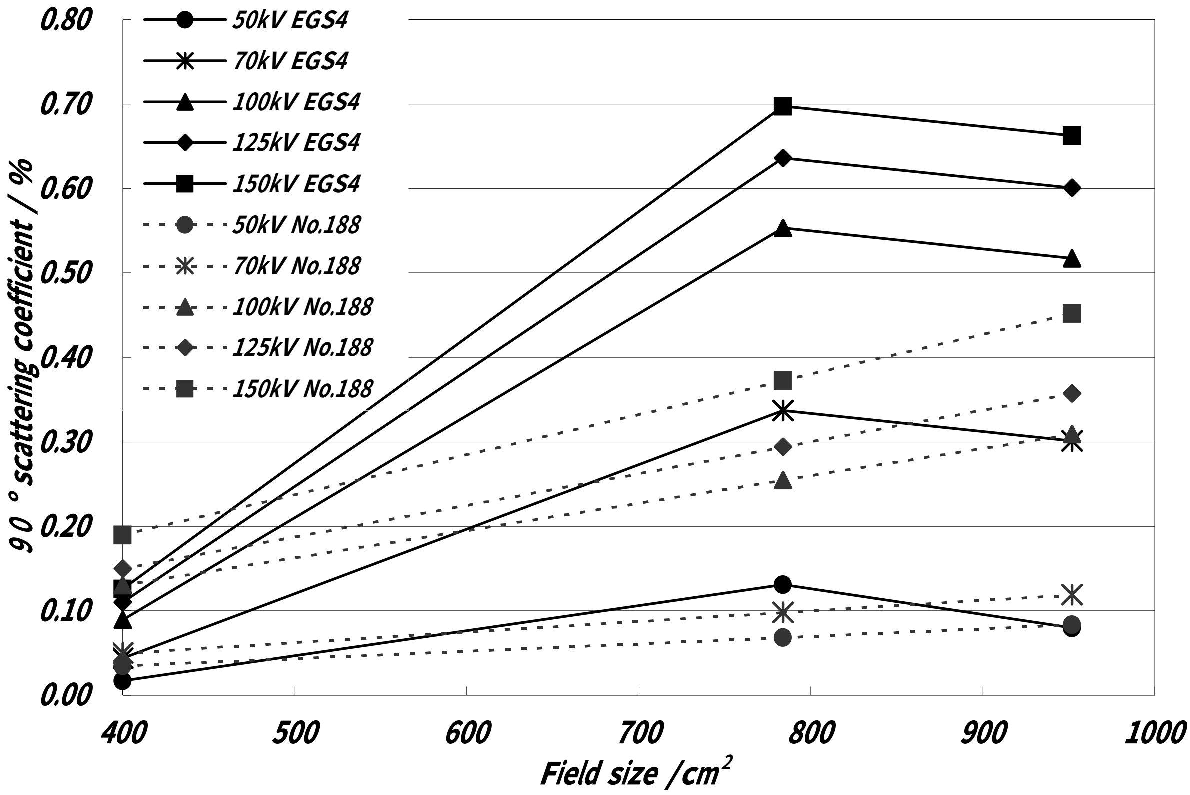

Fig.3 90 ° scattering coefficient as the field size changes at target angle 45 °

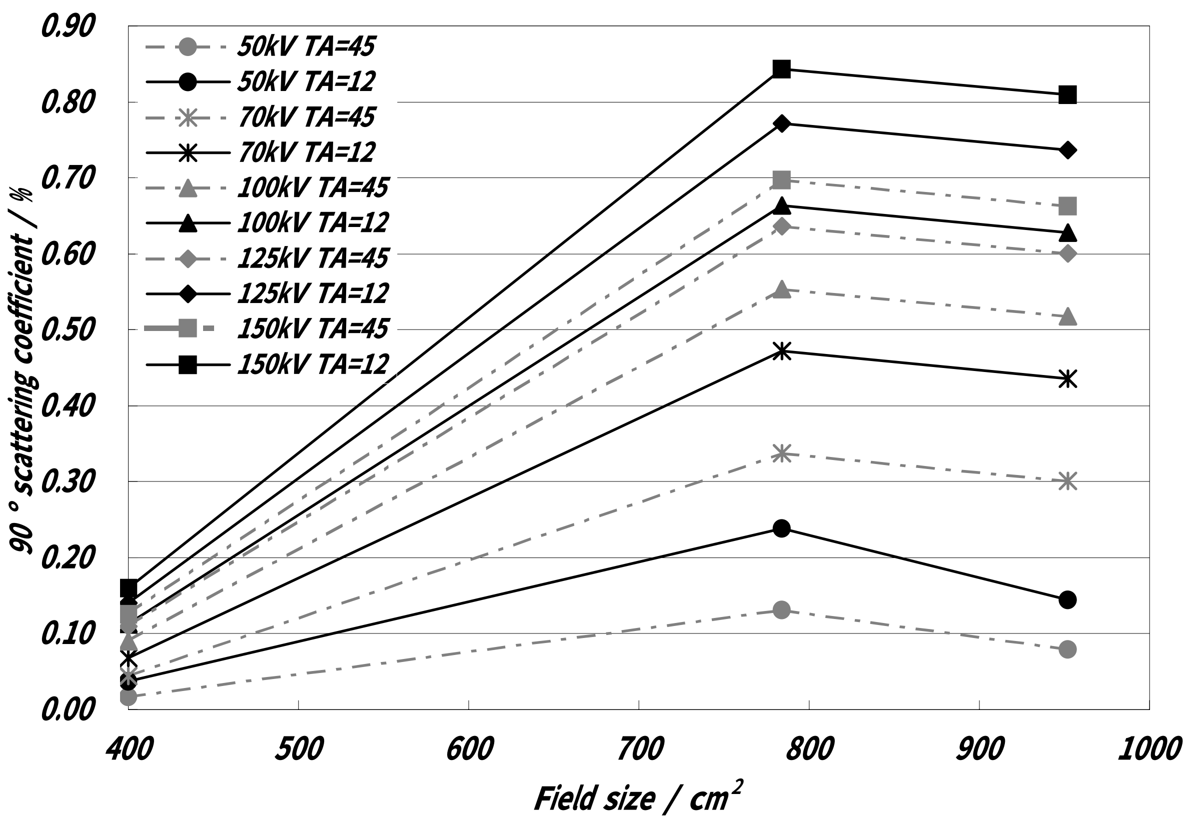

Fig.4 90 ° scattering coefficient as the field size changes at target angle 12 °

Table1. Comparison of EGS4 and The law No.188

Field Size (cm^2)	Target Angle (degree)	50kV	70kV	100kV	125kV	150kV
20×20	45 [188]	1.00	1.00	1.00	1.00	1.00
	45 [EGS4]	0.49	0.88	0.69	0.73	0.66
	12 [EGS4]	1.06	1.36	0.87	0.94	0.84
28×28	45 [188]	1.00	1.00	1.00	1.00	1.00
	45 [EGS4]	1.91	**3.44**	2.17	2.16	1.87
	12 [EGS4]	3.48	**4.81**	2.60	2.62	2.27
28×34	45 [188]	1.00	1.00	1.00	1.00	1.00
	45 [EGS4]	0.95	**2.53**	1.67	1.68	1.47
	12 [EGS4]	1.73	**3.66**	2.03	2.06	1.79

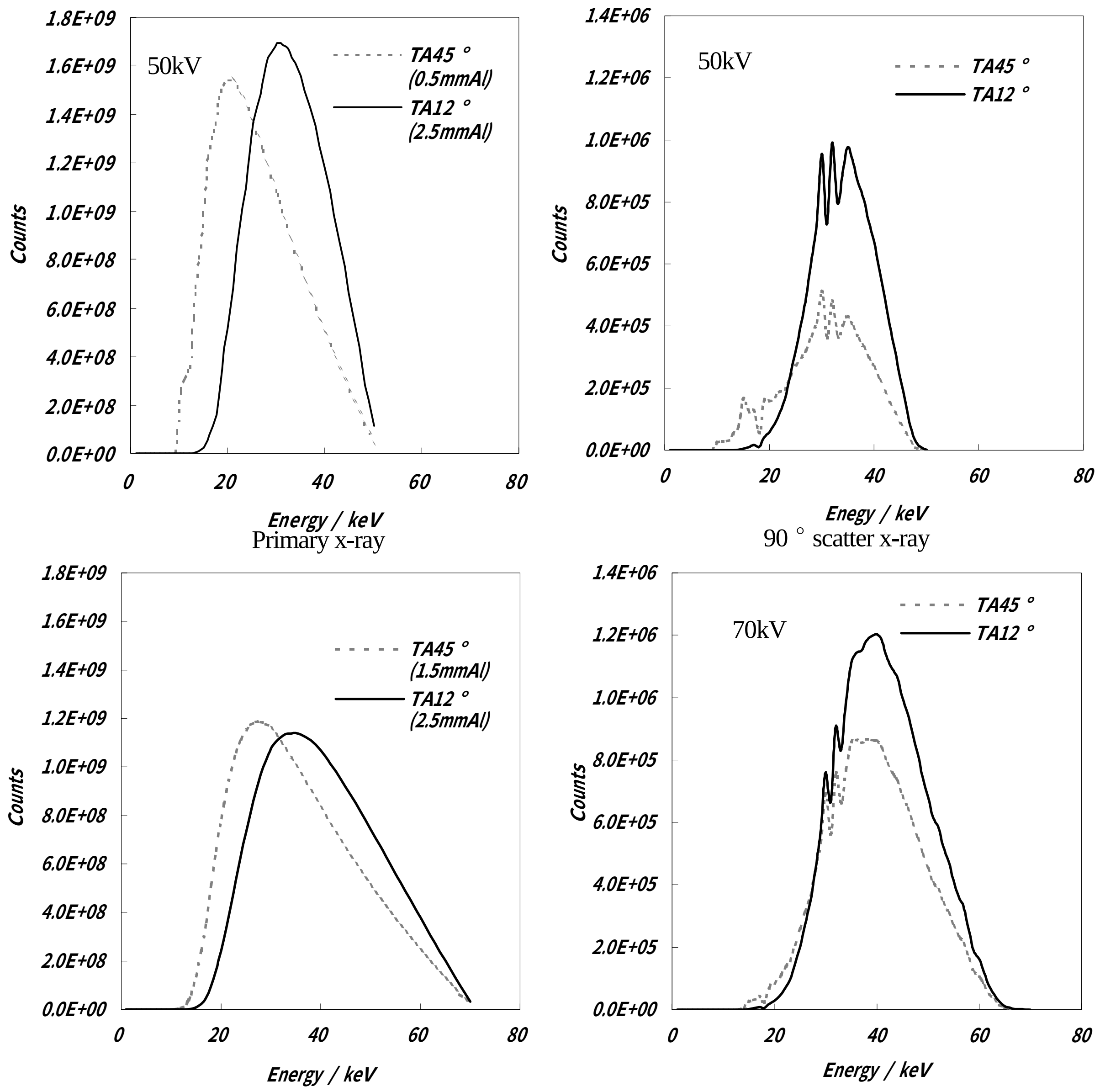

Fig.5 Comparison of primary and 90 ° x-ray spectrums at 50, 70kV

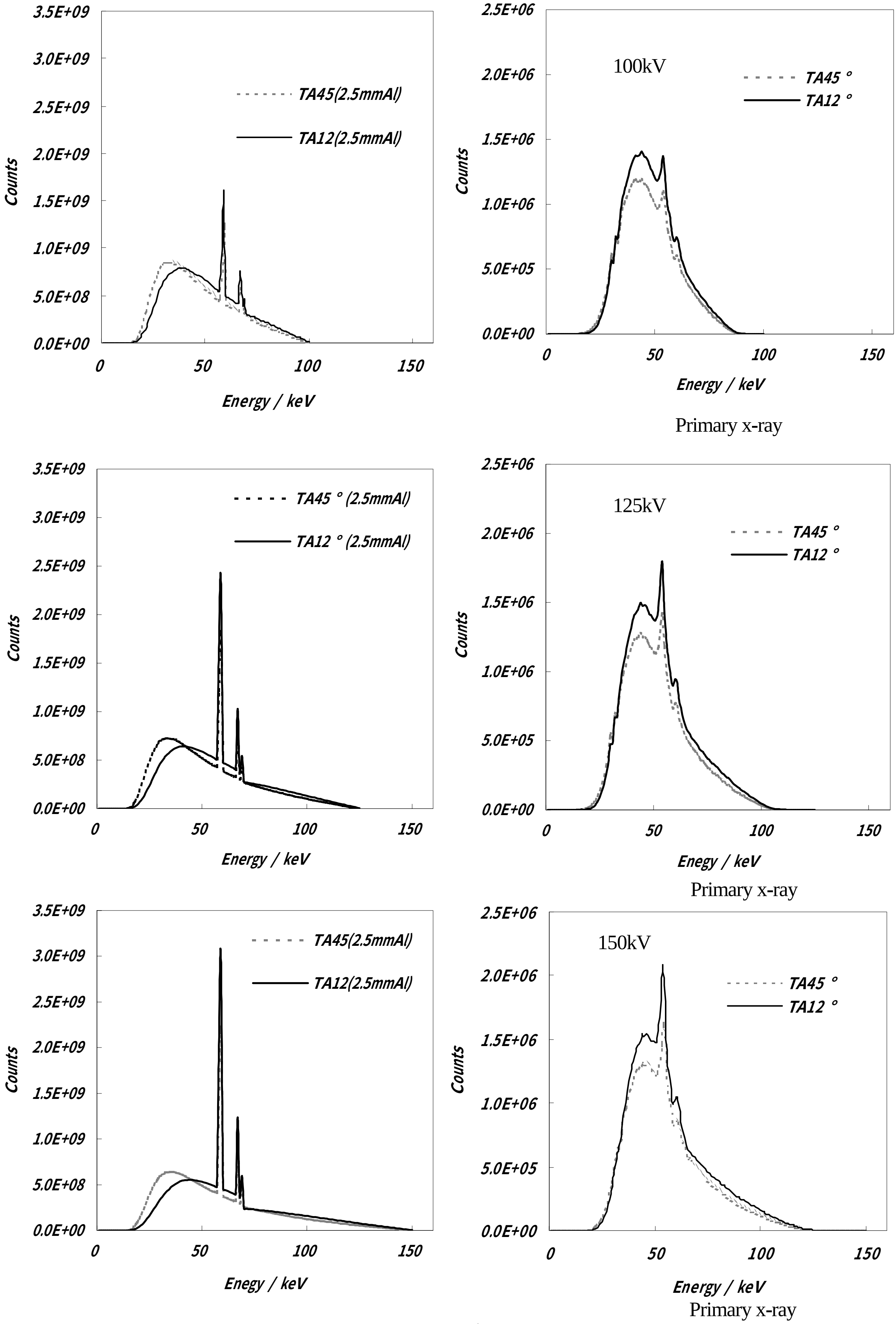

Fig.6 Comparison of primary and 90 ° x-ray spectrums at 100, 125, 150kV