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MONTE CARLO SIMULATION ANALYSIS OF BACKSCATTER FACTOR FOR LOW-ENERGY X-RAY

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Abstract

The method for obtaining the patient skin dose by measuring the air kerma in the patient skin surface is being recommended.Back scatter factors (BSFs) which correspond to the radiation field in the patient skin surface and the quality of the X-ray are necessary in that time.Though it has been well used the backscattering coefficient published by Supplement17 of Brit.J.Radiol., there are some problems and man inspections are necessary.Because it is difficult that it is measured BSF included the each structure of the human internal organs and the body tissues for the patient skin dose.Then the backscattering coefficient was obtained using the Monte Carlo calculation code, and the usefulness was examined by comparing with the measured value of the TLD element. The results with EGS4 Monte Carlo code were similar to the results measured by using TLDs, so that we consider that it is effective in the x-ray equipment and under the experimental condition, which were used for this method. However, our results became the low valuses of 4$\sim$7% than those of Suplement 17, IPSM and AAPM. It is necessary to examine them including the characteristics of x-ray generators such as the x-ray spectrum.

1 Introduction

The measurement of air kerma at the patient's skin is the current recommended method for calculating x-ray dosimetry for low-energy x-ray. In order to make accurate calculations, the backscatter factor (BSF) of the x-ray beam is required. The BSF is typically measured using a thermoluminescence dosimeter (TLD), however there are known problems with this measurement technique with regard to the appropriate x-ray spectrum to be measured and the influence of the type of x-ray source.

It is therefore important to understand the effects of backscattering on the effective radiographic dosage to tissue, and transfer this knowledge to the parameters for calculating the BSF. The BSF should be calculated for every clinical system and tissue type, however actual measurement is often difficult. In this study, the BSF was calculated by Monte Carlo simulation using EGS4 code, and the result were compared with experimental measurements using a TLD at the authors' facilities.

2 Equipment

A low-energy x-ray dose was calculated by Monte Carlo simulation using the KEK-improve version of low-energy photon-scattering expansion EGS4 code with LSCAT[1]. The equipment employed for experimental analysis included a TLD (MSO-S, Kyokko, Japan), x-ray tube (CIRCLEX0.6/1.2P18DE, Shimadzu, Japan), x-ray source (UD150LC-R2, Shimadzu, Japan), and water phantom (JIS standard Z-4915).

3 Method

3.1 Monte Carlo simulation

The field was modeled in three-dimensional Cartesian geometry, and the x-ray source was assumed to be an isotropic point source (Fig. 1). The detection region was a 1-cm^3 volume that contained the incident surface, with assumed photon mono-energy E and photon fluence F(E), where e is the energy applied to the detection region. The calculated dose was converted into kerma K by

$$K = \int [(\mu_{tr}/\rho)(E) \times E \times \Phi(E)]\, de \tag{1}$$

The same calculation was made for air, and the BSF was calculated from the ratio K/K_{air}

The energy transfer coefficient (μ_{tr}/ρ) was calculated in reference to the photon attenuation coefficient data book and spline interpolated between calculations at 1 keV intervals.

X-ray scatter was simulated for International Commission on Radiation Units (ICRU) standard soft tissue, and for water, skin and bone[2]. The dimensions of the radiation field were increased in 5-cm increments from 5 cm $\times$ 5 cm, to 20 cm $\times$ 20 cm. The energy of the incident photons was set at between 8 keV and 100 keV, and the BSF was calculated in 1 keV intervals. The parameters for the simulation were NCASES: 10^7, and PCUT: 1 keV, and ECUT: lower limit.

The x-ray spectrum was specified according to the theory of Birch and Marshal[3], and the BSF was calculated over a continuous distribution of mono-energy x-rays. This spectral output is consistent with the experimentally observed output of the present x-ray tube (Fig. 2).[4]

3.2 TLD measurements

The measurement geometry is similar to that specified for the Monte Carlo simulation. The TLD was exposed to fields of 10 cm $\times$ 10 cm and 20 cm $\times$ 20 cm at tube voltages of 50 kV, 80 kV and 20 kV. The BSF was calculated from the ratio of the kerma at the phantom surface (i.e., with scatter) to the kerma in air.

4 Results

4.1 Simulation

The variation in BSF with mono-energy x-ray is shown in Fig. 3 for the 4 target types and the 4 radiation field sizes. In particular, the BSF of bone is relatively invariant with respect to field size. As shown in Fig. 4, the BSF increases smoothly with x-ray tube voltage. According to previous reports, the BSF increases when the radiation field is enlarged. However, as can be seen by comparing Fig. 4 (10 $\times$ 10 cm field) with Fig. 5 (20 $\times$ 20 cm field), the size of the radiation field does not affect the value of the BSF under the present conditions of mono-energy x-ray field saturated at 80 kVp. Even though no clear relationship between the size of the radiation field and the BSF value was identified in this study, it is considered that the size of the radiation field must in some way affect the calculations because the x-ray density changes with field size. We will continue our investigation on this topic. The BSF is conventionally taken as the peak value in the range 40 keV to 70 keV; in this case, the maximum value is 1.3.

4.2 Measurements

The BSF value measured using the TLD is shown in Fig. 6. Target material is water of 10 $\times$ 10 cm field and 20 $\times$ 20cm field. The calculated BSF fits the measured data very well over the entire range of field size and tube voltage examined in this study. In the lower energy region, the calculated BSF deviates from the measured results by less than 4%.

5 Discussion

Our calculations for mono-energy x-ray radiation by Monte Carlo simulation are compared in Fig. 7 with the results of other studies for water. The results obtained in the present study are appreciably smaller than previous values. With regard to British Journal of Radiology suppl 17(BJR-17)[5], this is because the previous results were obtained using a broad-spectrum x-ray radiation with filter for radiotherapy and not the mono-energy beam examined here. It is considered that the system characteristics such as the x-ray spectrum and the x-ray source affect the results considerably, and that the previous results apply to much more complex systems. A similar result demonstrating the smaller BSF values for mono-energy systems according to Monte Carlo simulation has been reported previously.

The largest discrepancy between the measured and calculated results in this study was in the lower energy region. It is considered that this is due to absorption by the glass wall of the water phantom in this energy region.

The values reported by the Institute of Physical Sciences in Medicine (IPSM)[6] and the American Association of Physicists in Medicine (AAPM)[7] are compared with the present results in Table 1. The present values are 4 to 7results using Monte Carlo code (Figs. 7 and 8)[8]. In practice, the x-ray intensity distribution in radiation fields is affected by heel effects, etc., and it is considered that the field will differ from the ideal results examined here. This topic will remain the subject of future analysis.

6 Conclusion

The backscatter factor calculated using EGS4 code was found to be very consistent with the BSF measured using a TLD. This calculation method is therefore considered to be highly applicable for the equipment and experimental conditions employed in the authors' facilities. The calculated values are 4 to 7% lower than those reported by the AAPM and IPSM, and for BJR, and in contrast to these existing values, takes into account the x-ray spectrum and diagnostic x-ray apparatus. It is important to obtain a model using EGS4 code and Birch and Marshal spectra that accurately reproduces the characteristics of practical x-ray spectra. A wider range of reports will need to be considered for further discussion. Based on the present findings, it is considered that the established BSF-calculation technique for low-energy x-rays may need to be revised.

References

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Table 1 Comparison of BSF from other reports.

AAPM		IPSM		Our Work	
HVL	r=10cm	HVL	10cm × 10cm	HVL	10cm × 10cm
2.0mm Al	1.245	2.0 mmAl	1.25	1.8mm Al	1.19
3.0mm Al	1.311	3.0 mmAl	1.29	3.0mm Al	1.23

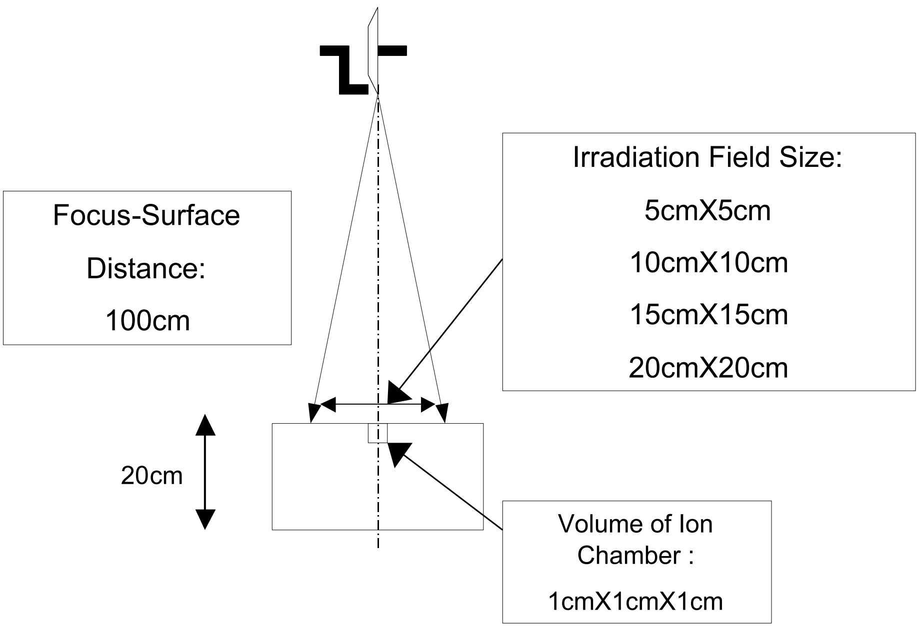

Figure 1: Assumed geometry for BSF calculation.

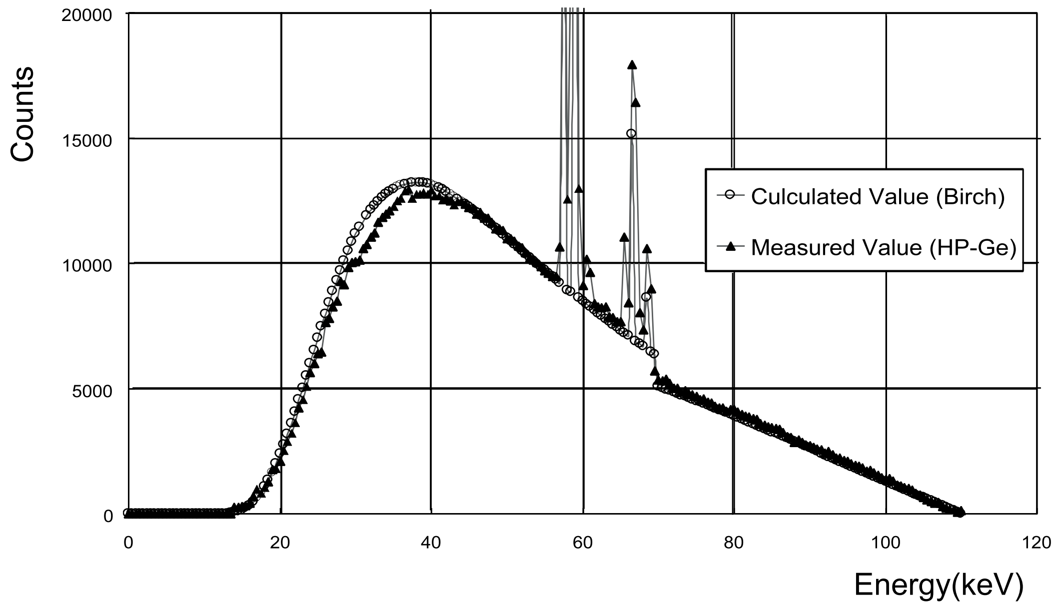

Figure 2: X-ray spectrum for BSF calculation in continuous monoenergy x-rat distribibition.

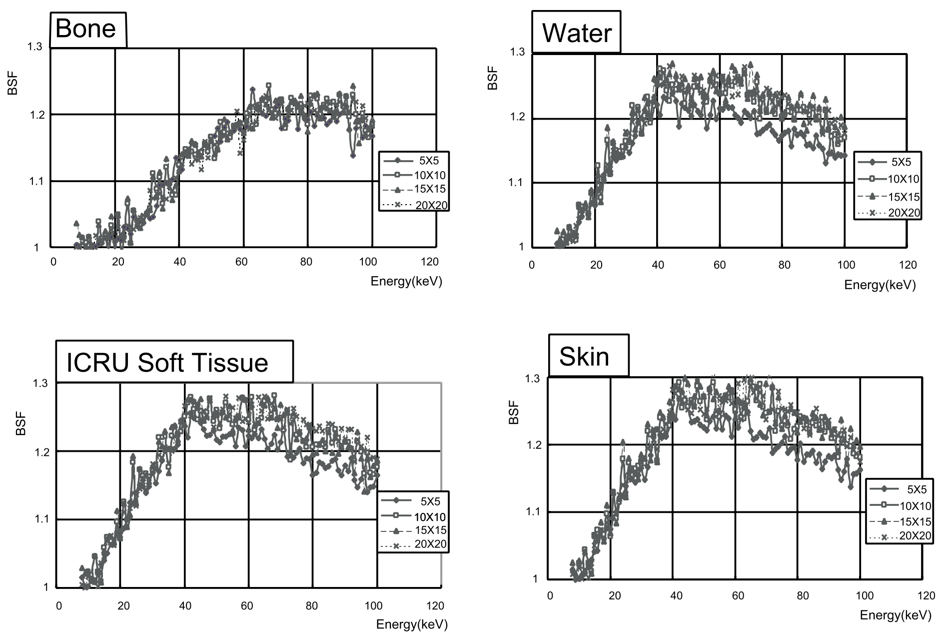

Figure 3: BSF for each 4 target types using monoenergy x-ray radiation.

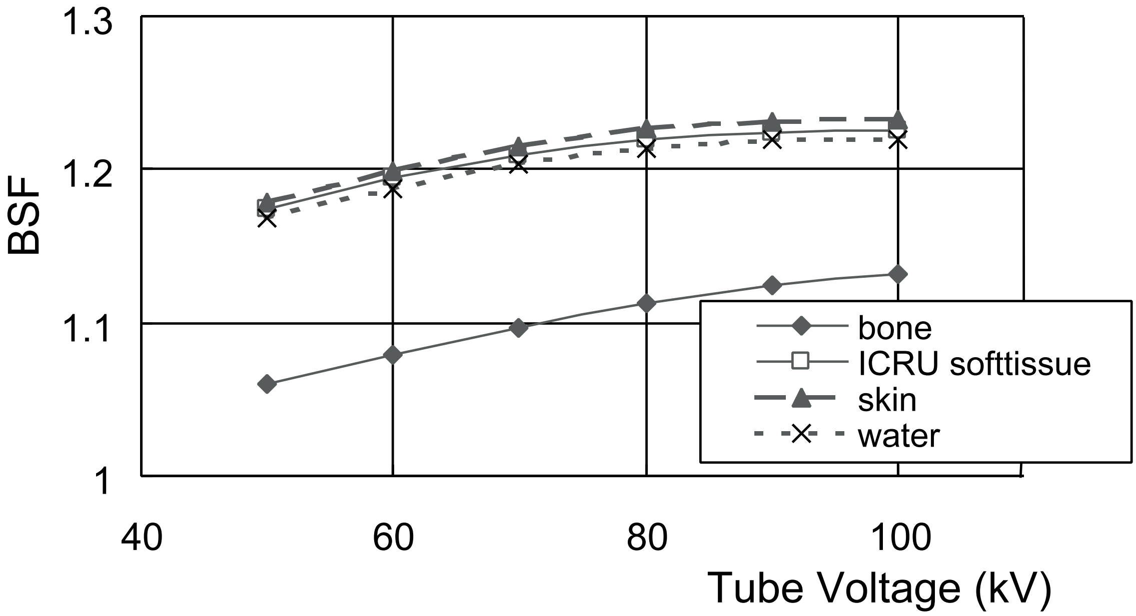

Figure 4: BSF for monoenergy x-ray radiation for field size 10 cm x 10cm.

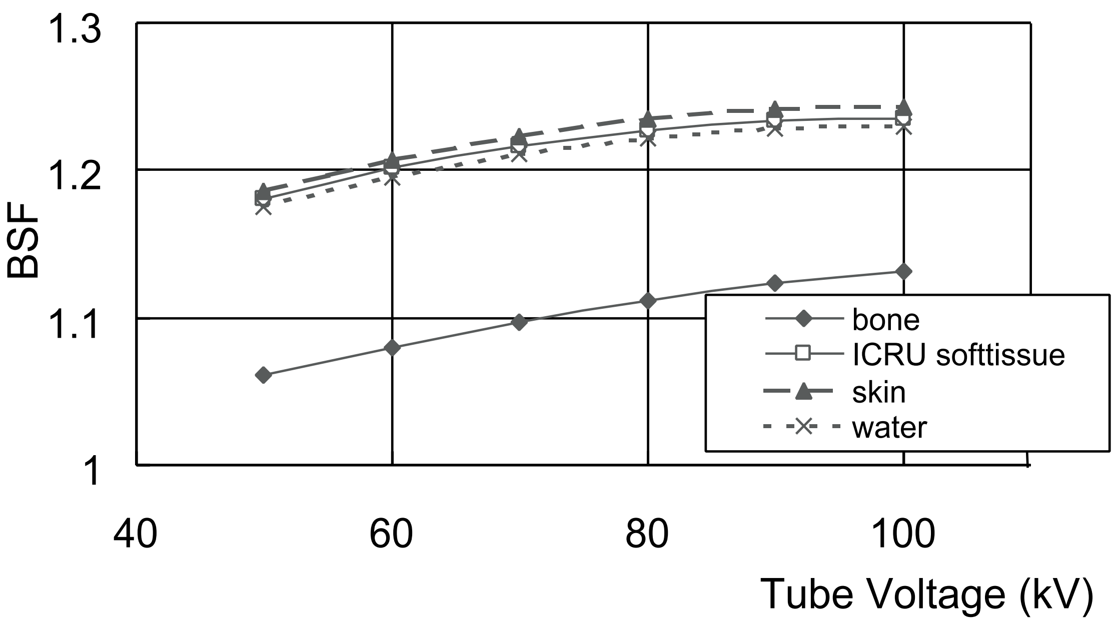

Figure 5: BSF for monoenergy x-ray radiation for field size 20 cm x 20cm.

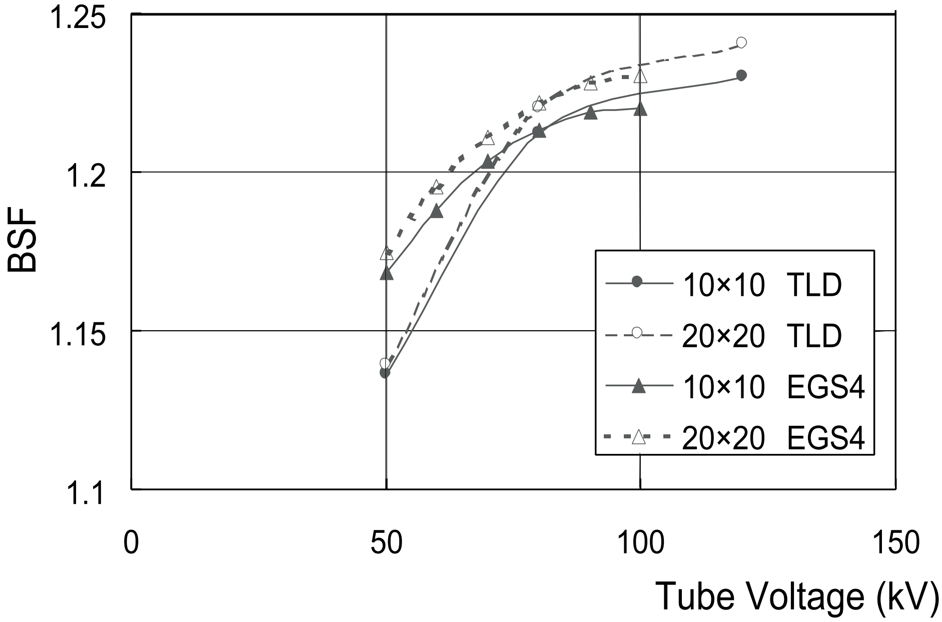

Figure 6: Comparison of BSF by EGS4 code and observation by TLD.

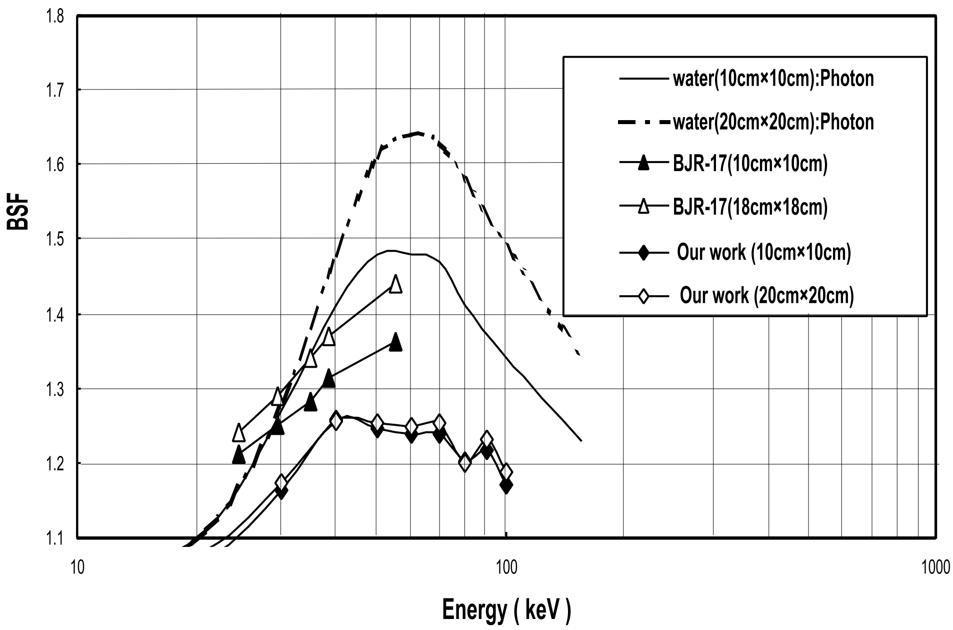

Figure 7: Comparison of BSF from other reports according to x-ray energy. (Photon:monoenergy x-ray. X-ray:effective spectrum.).

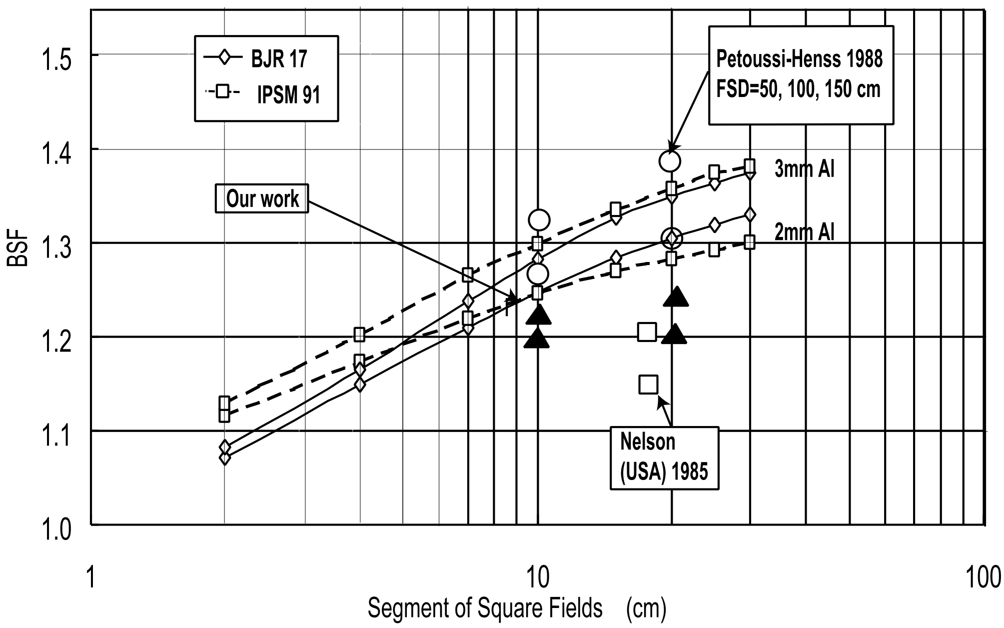

Figure 8: Comparison of BSF from other reports according to size of radiation field.