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Comparison of measured backscatter factors with Monte Carlo simulations for low energy X-ray

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Abstract

Experimentally determined values of X-ray backscatter factors (BSFs) are presented and compared with Monte Carlo simulation results. Measurements were made using X-rays generated at voltages between 50 and 100 kVp and various phantoms that differed in shape and size. To study the influence of irradiation geometry on BSFs, measurements were performed for different photon beam field diameters at the phantom front face. The phantoms were placed on the irradiation bench of an X-ray unit at a fixed distance of 100 cm from the focal spot. In this paper, BSFs were determined experimentally by using a measuring technique that utilized an ionization chamber of volume 1 cm^3. The generalized particle transport program MCNPX code was used for Monte Carlo simulations. Measured results are analyzed and discussed in comparison with simulated values and we acquired phantom images using a 512 channel linear array photodetector.

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Keywords: Backscatter factor (BSF); Backscatter X-ray; Monte Carlo; X-ray imaging

1. Introduction

When X-rays impinge on a scattering medium photons are absorbed or scattered by different interaction processes. This means that any point on the surface of a human body or a phantom receives unattenuated primary radiation plus scattered radiation. In principle, the dose at any point of an exposed phantom can be calculated using, for example, the Monte Carlo method by estimating the primary radiation reaching the point of interest and the corresponding contribution made by scattered radiation. However, because of the complexities of such calculations, this problem has been largely addressed using empirical approaches [1].

These measurements involve the concepts of surface backscatter, tissue–air ratios, scatter–air ratios and so on. The quantity that characterizes the contribution of back-scattered radiation to the surface dose or kerma is called the backscatter factor (BSF) [2].

In this paper, the experimental determination of BSFs was based on a measuring technique that utilized an ionization chamber, and thus represents a somewhat different approach to that taken by Klevenhagen [1]. According to Grosswendt [3], bearing in mind the known relationship between kerma and exposure, the BSF can be defined as

$$\mathrm{BSF}^{(w)}_{(w)} = \frac{X^{(w)}(\mu_{\mathrm{tr}}/\rho)^{(w)}_{(w,a)}}{X^{(0)}(\mu_{\mathrm{tr}}/\rho)^{(0)}_{(w,a)}},$$

where $X^{(w)}$ is exposure at the surface of a water phantom, $X^{(0)}$ is exposure at the same point in space in the absence of the phantom, and $(\mu_{\mathrm{tr}}/\rho)^{(w)}_{(w,a)}, (\mu_{\mathrm{tr}}/\rho)^{(0)}_{(w,a)}$ are the ratios of the mass energy transfer coefficients for water and air, respectively, in the presence of scatter medium and in free space [2].

Theoretical calculations using the Monte Carlo method were performed by Doi and Chan [4], and Chan and Doi [5]. More general Monte Carlo computations were

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performed by Grosswendt [3]. In this paper, BSFs were simulated using Monte Carlo calculations using the generalized particle transport program MCNPX. Based on these Monte Carlo analyses and experimental values, we acquired phantom images using a homemade multichannel linear array photodetector and data acquisition system (DAS) [7].

2. Measuring equipment

The principal components of the measuring equipment were an ionization chamber, four different phantoms and an X-ray source. One of the primary requirements in the process of BSF determination is to reduce the perturbation of photon fluence around the detector, which depends mainly on the dimensions and shape of the photon beam, the ionization chamber, and the phantom. This is particularly critical for low-energy photons that may have small mean free path lengths even in material of low density [6]. Moreover, it is necessary for the ionization chamber wall to be thin, and for the cross-sectional area of the detector to be much less than the cross-sectional area of the phantom and to be less than the irradiated area of the phantom [2].

The forms, i.e., hexahedral or cylindrical, and sizes of phantoms are shown in Fig. 1. The phantoms A, B and C (hexahedral) represent a human torso, whereas the cylindrical phantom represents human limbs.

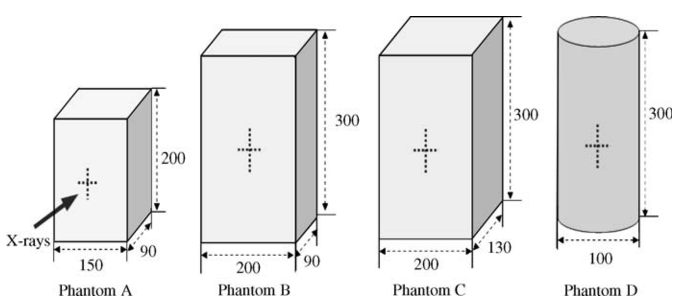

Fig. 1. Phantoms used in the experiments.

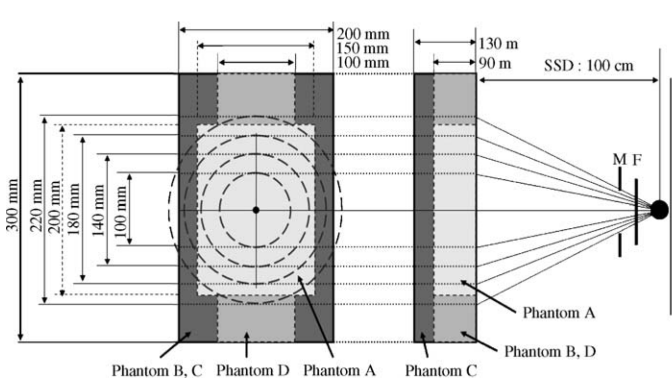

Fig. 2. Phantom surface exposed to irradiation at different diaphragm settings.

3. Experimental procedure

Backscatter radiation measurements require the careful optimization of experimental conditions. Phantoms were placed on the irradiation bench of an X-ray unit at a distance of 100 cm from the beam focus. The field size

Table 1
Backscatter factors

Constant potential (kV)	HVL (mm Al)	A	B	C	D
		Field size diameter $R = 10$ cm			
50	2.0	1.199888	1.200808	1.202583	1.164093
		1.171428	1.228571	1.264285	1.171428
80	2.5	1.190115	1.191572	1.195002	1.153369
		1.153225	1.201612	1.272580	1.177419
100	3.0	1.173586	1.175004	1.179151	1.140601
		1.161764	1.220588	1.288235	1.181372
		Field size diameter $R = 14$ cm			
50	2.0	1.256778	1.259090	1.261693	1.187333
		1.205128	1.230769	1.293333	1.153846
80	2.5	1.248613	1.251966	1.257616	1.177996
		1.229629	1.244444	1.308148	1.177777
100	3.0	1.227659	1.231607	1.238630	1.164186
		1.236607	1.258928	1.312678	1.178571
		Field size diameter $R = 18$ cm			
50	2.0	1.290175	1.302242	1.306041	1.200526
		1.230769	1.230769	1.318974	1.179487
80	2.5	1.290994	1.306973	1.314956	1.195149
		1.257352	1.279411	1.357058	1.183823
100	3.0	1.264625	1.279931	1.289246	1.179687
		1.259911	1.281938	1.352070	1.185022
		Field size diameter $R = 22$ cm			
50	2.0	1.304621	1.329043	1.334412	1.212200
		1.230769	1.256410	1.344615	1.179484
80	2.5	1.308711	1.342850	1.353001	1.209035
		1.262773	1.284671	1.361459	1.189781
100	3.0	1.282986	1.315226	1.326704	1.187030
		1.257641	1.288209	1.366113	1.187772

Monte Carlo simulation values using MCNPX.
Measured values.

Fig. 3. Si-photodiode detector.

Fig. 4. Data acquisition system.