# SPECTRA, DIFFERENTIAL ALBEDO AND SHIELDING DATA FOR BREMSSTRAHLUNG SCATTERED FROM COMMON SHIELDING MATERIALS

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## INTRODUCTION

In the design of radiation shields for X-ray machines and electron accelerators not only the primary radiation but also the radiation scattered from irradiated material must be taken into account. The thickness of shielding barriers against secondary radiation can be calculated if the intensity and the quality of the radiation are known. For radiation protection purposes the scattered intensity is most conveniently described in terms of the differential albedo:

$$d\dot{J}_s = A_{JX}\,(E,\,\Theta_o,\,\Theta,\varphi)\;\dot{J}_o\;\frac{df\,\cos\Theta_o}{r^2}$$

$A_{JX}$ differential exposure albedo

$d\dot{J}_s$ scattered exposure rate at a distance r from the surface area df of the irradiated material

$E$ energy of incident photons

$\Theta_o$ angle of incidence; $\Theta$ polar angle of exit

$\varphi$ azimuthal angle of exit

$\Theta_s$ scattering angle $\Theta_s = \pi - \Theta_o - \Theta$ for $\varphi = 0$

In the case of very high energy photons it is more appropriate to replace the exposure by the absorbed dose in a tissue equivalent material.

Albedo data were measured for bremsstrahlung with maximum photon energies in the ranges from 100 keV to 400 keV and from 10 MeV up to 35 MeV. In the low energy region spectra of scattered radiation were measured with a semiconductor detector. From these spectra attenuation curves were calculated using known broad beam transmission factors for monoenergetic photons. For high energy bremsstrahlung (10 MeV to 35 MeV) the quality of scattered radiation was determined by direct attenuation measurements.

## EXPERIMENTAL

Bremsstrahlung with maximum photon energies between 100 keV and 400 keV was produced by means of a conventional industrial 400 kV X-ray machine (inherent filtration: 4 mm Al). The beam profile of the primary radiation was defined by a series of matched lead collimators.

The size of the irradiated area df was determined by exposing an X-ray film on the surface of the scattering material. Ion chambers with a flat energy response were used for measuring the exposure rate of primary and scattered radiation. The differential exposure albedo of ordinary concrete, barytes concrete, iron and lead was determined for normally incident radiation ($\Theta_o = 0$) as a function of the polar angle of exit $\Theta$ as well as for the special geometry $\Theta_o = 45^o$, $\Theta = 45^o$, $\varphi = 0^o$.

High energy bremsstrahlung was produced using a 35 MeV travelling wave linear accelerator. The electron beam is deflected by an achromatic magnet system and focused on a tantalum bremsstrahlung target (7 mm thick) where it is completely absorbed. The cross section of the photon beam is defined by several steel collimators which are coaxially mounted in a channel through the concrete wall (3 m thick) between the accelerator hall and the experimental area. The dose rate of the incident and the scattered radiation is measured with ion chambers surrounded by a sufficient amount of tissue equivalent buildup material.

## RESULTS AND DISCUSSION

Some selected albedo values are compiled in Fig. 1 to Fig. 3 and Table I for normally incident radiation.

In the low energy region there is a complicated relationship between the exposure albedo, the radiation energy and the scattering material (1), but for $\Theta_o = 0$ the scattered dose rate always increases with increasing scattering angle $\Theta_s$ (Fig. 1). Between 10 MeV and 35 MeV the differential albedo of materials with low mean atomic number (ordinary concrete, brick) decreases with increasing energy (Fig. 2). In the case of lead however (Fig. 3) higher scattering intensity is observed at higher energies because at high primary photon energies the main contribution to the albedo of high-Z material is due to the production of secondary bremsstrahlung which rapidly increases with energy (5).

Fig. 4 and Fig. 5 show photon spectra of low energy bremsstrahlung scattered from ordinary concrete. Whereas the quality of radiation scattered from low-Z material is determined by compton scattering, the spectra from high-Z materials (barytes concrete, lead) show a large contribution of characteristic X-radiation to the total scattered intensity. As an example calculated attenuation curves for low energy photons scattered from ordinary concrete are plotted in Fig. 6. They reasonably agree with measured values (3). Similar shielding data were calculated for several combinations of scattering and shielding materials.

TABLE I. Differential exposure albedo for low energy bremsstrahlung normally incident on common shielding materials ($\Theta_o = 0$)

| tube voltage U [kV] | $\Theta_s$[deg.] | scattering material | | |
|---|---|---|---|---|
| | | barytes concrete | steel | lead |
| 100 | 110 | $1,5 \cdot 10^{-2}$ | $2,6 \cdot 10^{-3}$ | $7,7 \cdot 10^{-3}$ |
| | 135 | $2,5 \cdot 10^{-2}$ | $5,2 \cdot 10^{-3}$ | $1,5 \cdot 10^{-2}$ |
| | 160 | $3,1 \cdot 10^{-2}$ | $7,5 \cdot 10^{-3}$ | $2,0 \cdot 10^{-2}$ |
| 200 | 110 | $1,3 \cdot 10^{-2}$ | $3,7 \cdot 10^{-3}$ | $9,5 \cdot 10^{-3}$ |
| | 135 | $2,2 \cdot 10^{-2}$ | $6,8 \cdot 10^{-3}$ | $1,7 \cdot 10^{-2}$ |
| | 160 | $2,9 \cdot 10^{-2}$ | $1,0 \cdot 10^{-2}$ | $2,1 \cdot 10^{-2}$ |
| 400 | 110 | $9,3 \cdot 10^{-3}$ | $6,1 \cdot 10^{-3}$ | $7,1 \cdot 10^{-3}$ |
| | 135 | $1,6 \cdot 10^{-2}$ | $1,1 \cdot 10^{-2}$ | $1,2 \cdot 10^{-2}$ |
| | 160 | $2,1 \cdot 10^{-2}$ | $1,5 \cdot 10^{-2}$ | $1,6 \cdot 10^{-2}$ |

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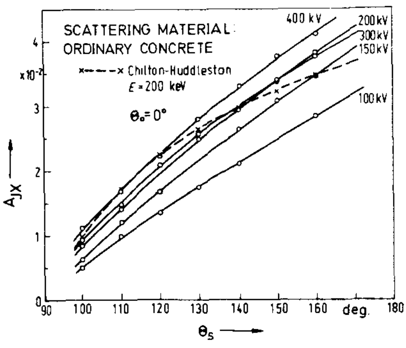


Fig. 1 Differential exposure albedo of ordinary concrete for low energy bremsstrahlung

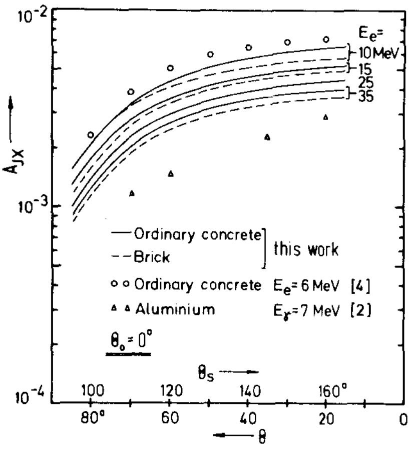


Fig. 2 Differential dose albedo of concrete and brick for high energy bremsstrahlung

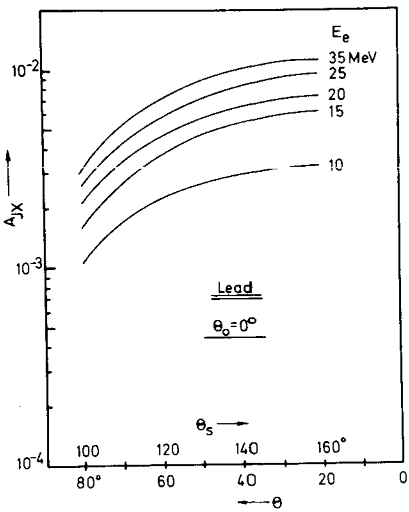


Fig. 3 Differential dose albedo of lead for high energy bremsstrahlung

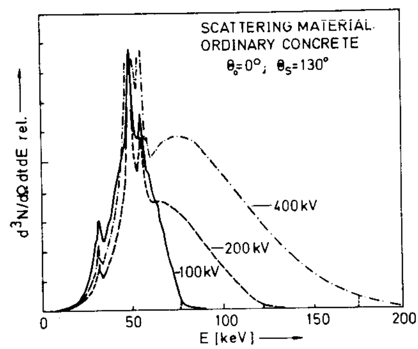


Fig. 4 Spectra of low energy bremsstrahlung scattered from ordinary concrete as a function of tube voltage

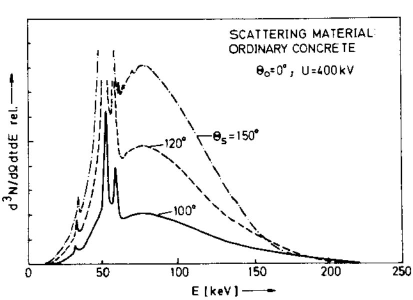


Fig. 5 Spectra of 400 kV bremsstrahlung scattered from ordinary concrete as a function of scattering angle

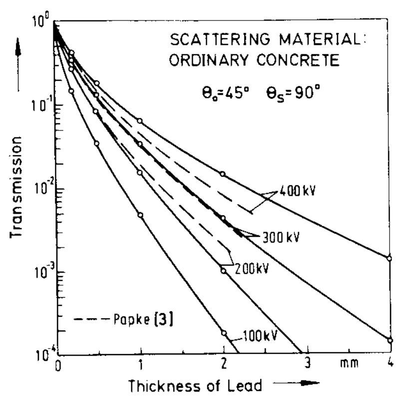


Fig. 6 Attenuation curves for scattered radiation. Scattering material: Concrete; shielding material: lead