# PROTECTION AGAINST SCATTERED X-RAYS AT ELECTRON ACCELERATOR INSTALLATIONS

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## INTRODUCTION

At accelerator installations those areas towards which the useful beam cannot be directed must be protected against scattered radiation. Shielding requirements for secondary X-rays may be calculated if data describing the intensity and the quality of scattered radiation are available. The intensity of scattered photons is conveniently described in terms of the differential albedo of the scattering material. The attenuation of secondary X-rays in shielding materials may be computed from the energy spectrum of the scattered photons using attenuation factors for monoenergetic photons. Albedo data of common shielding materials, photon spectra of scattered radiation and effective attenuation curves for shielding against scattered radiation were evaluated for 10 MeV to 35 MeV X-rays.

## EXPERIMENTAL

The electron beam from the linear accelerator was completely absorbed in a tantalum target. The resulting X-ray beam was well collimated by a series of matched steel disks (total thickness : 1 m) inside a channel through the concrete wall (3 m thick) which shields the experimental area against the accelerator. The intensity of the primary and of the scattered photons was measured with ionisation chambers. A well shielded 5"x5"-NaI-scintillation detector was used for measuring the energy spectra of the scattered radiation.

The differential albedo and the spectra of scattered photons were measured as a function of the following parameters:

a.) scattering material: ordinary concrete, brick, barytes concrete, lead, water slab and a cylindrical water phantom
b.) scattering angle $\Theta s$
c.) angle of incidence: $\Theta_0 = 0^\circ$ and $\Theta_0 = 45^\circ$
d.) endpoint energy of the primary X-rays (electron energy $E_e$): 10 MeV to 35 MeV

## RESULTS AND DISCUSSION

### Differential Exposure Albedo

The differential exposure albedo can be expressed in terms of readily measurable quantities:

$$A_{JX}(E_0,\Theta_0,\Theta_S,\varphi) = \frac{\dot{J}_D(\Theta_S,\varphi)}{\dot{J}_0(E_0,\Theta_0)} \cdot \frac{r^2}{\Delta f \cdot \cos\Theta_0} \qquad (1)$$

$\dot{J}_D$ exposure rate of the scattered radiation at the distance r from the scattering surface

$\dot{J}_0$ exposure rate of the incident radiation at the scattering surface

$\Delta f \cdot \cos\Theta_0$ cross section of the incident beam

The definition of the angles is seen from Fig. 1. The differential albedo was calculated from the measured dose rates at the scatterer and at the detector according to equ. (1). The albedo data were corrected for the contribution of secondary electrons emitted by the irradiated scattering material. Some typical results are presented in Fig. 2 to Fig. 4.

## Photon Spectra

The measured pulse height spectra were converted into photon energy spectra using the appropriate response matrix of the 5"x5" NaI-crystal. Four contributions to the total spectrum are clearly discernible:

a.) a broad continuum caused by Compton-scattering of the continuous X-ray photons,
b.) an isolated 511 keV line, due to the annihilation of positrons produced by high energy photons via pair formation,
c.) characteristic X-rays of the scattering material (lead),
d.) a high energy "tail" beyond the Compton-transformed maximum energy of the primary X-ray spectrum. This component is due to secondary bremsstrahlung produced by electrons and positrons from pair formation interactions.

## Attenuation of Scattered Radiation

From the photon spectra effective attenuation factors of typical shielding materials for scattered X-rays were computed by folding the product of the flux-to-dose conversion factor and the photon spectrum with the energy dependent dose attenuation factor of the material for monoenergetic photons. Since in practice large areas of the shielding material are irradiated by scattered photons the attenuation factors for maximum build up must be used for a conservative shield design. In Tab. I some selected data for the shielding from a broad beam of scattered X-rays are presented. The results show that for all scattering materials the tenth value layer weakly increases with increasing X-ray energy and with decreasing scattering angle. The dependence on the scattering angle is most pronounced for scattering materials with low atomic number. For the same energy of the incident X-rays and the same scattering geometry the tenth value layer increases with the atomic number of the scatterer.

Tab. I Tenth value layers (TVL in cm) for the shielding from a broad beam of scattered X-rays. The scattering angle $\Theta_s$ varies between 140° and 40° in the case of the water phantom and between 140° and 60° for all other materials:

| $E_e$ in MeV | scattering material | shielding material | | | |
|---|---|---|---|---|---|
| | | ordinary concrete | | lead | |
| | | $TVL_1$ | $TVL_2$ | $TVL_1$ | $TVL_2$ |
| 10 | water phantom | 20---28 | 16---24 | 1,3---4,1 | 2,5---4,1 |
| | ordinary concrete | 20---23 | 17---20 | 1,4---2,6 | 2,5---3,0 |
| | barytes concrete | 24---26 | 21---23 | 2,8---3,4 | 3,8---3,9 |
| | lead | 27---28 | 24---25 | 3,5---4,0 | 4,3---4,4 |
| 35 | water phantom | 24---28 | 21---25 | 2,8---4,4 | 4,0---4,9 |
| | ordinary concrete | 21---24 | 17---20 | 1,6---2,8 | 2,6---3,1 |
| | barytes concrete | 27---27 | 24---25 | 3,6---3,9 | 4,0---4,8 |
| | lead | 29---30 | 26---28 | 4,3---4,6 | 4,3---4,9 |

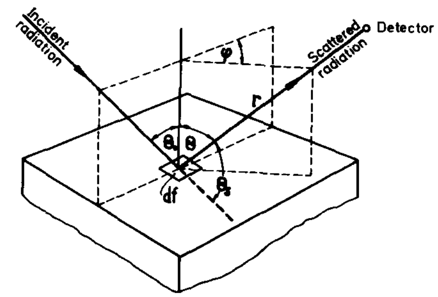


Fig. 1 Scattering geometry

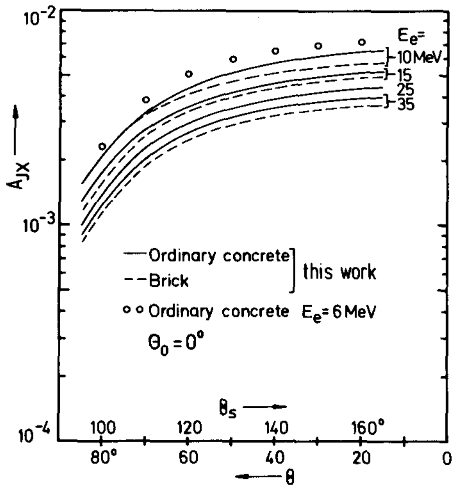


Fig. 2 Differential X-ray exposure albedo of ordinary concrete and brick. ($E_e$ = 6 MeV:Karzmark et al. ; without secondary electrons from the scatterer)

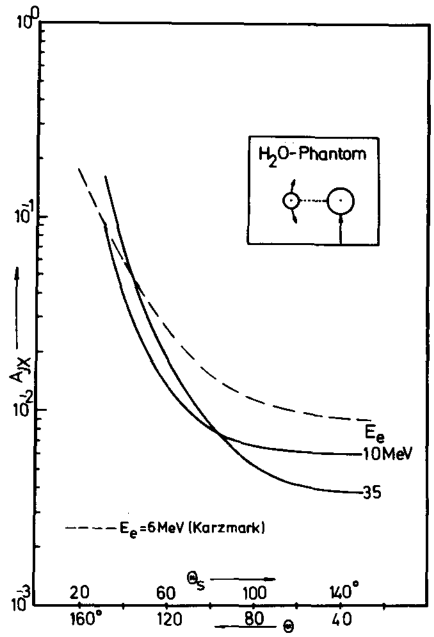


Fig. 3 Differential X-ray exposure albedo for a cylindrical 30 cm diam water phantom (without secondary electrons from the scatterer).

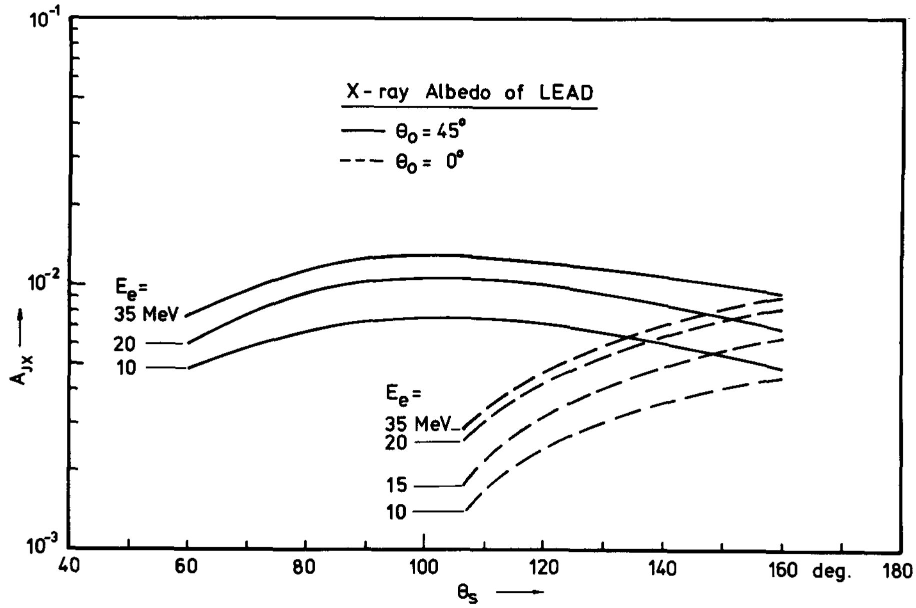


Fig. 4 Differential X-ray exposure albedo of lead (without the contribution of secondary electrons from the scatterer).

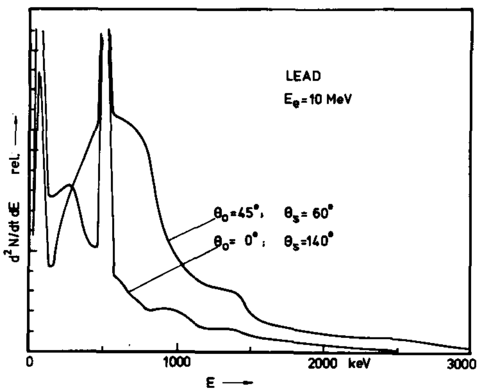


Fig. 5 Photon spectra of 10 MeV X-rays scattered from lead.

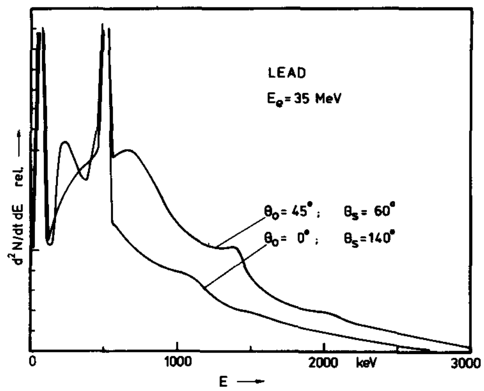


Fig. 6 Photon spectra of 35 MeV X-rays scattered from lead.