Estimation of shielding thicknesses for white beam enclosures

Thomas Wroblewski[1]

[1]Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, D-22607 Hamburg, Germany

Abstract

In the enclosure of synchrotron radiation experiments, secondary radiation arises from two effects, namely fluorescence and scattering. While the case for monochromatic radiation has already been treated (for lead enclosures) this contribution will deal with white radiation. Because the white beam is usually composed out of synchrotron radiation from insertion devices and high energy radiation arising from the interaction of high energy electrons with the residual gas (or the wall) in the accelerator. Therefore the enclosures are composed of barite. In the following, however, only the contribution of synchrotron radiation will be treated.

Introduction

At the PETRA III extension [1] new beam lines are planned with insertion devices of which the spectrum extends to higher energies then those at the existing beam lines. Especially beam line P61, dedicated to materials science and high pressure experiments, does not use undulators but radiation from ten so called damping wigglers. The high energy radiation arising from the interaction of high energy electrons with the residual gas (or the wall) in comparable long straight sections has been treated by A. Leuschner for the optics hutches in the Max von Laue hall [2] resulting in a thickness of heavy concrete of 300mm for roof and side walls and 500mm for the front walls. The doors consist of 20mm lead and 100mm polyethylene. This has proven to be sufficient for all existing beam lines.
The synchrotron radiation spectra from the ten damping wiggler were calculated using the XOP code [3]. A distance of 100m corresponding to that of the last wiggler to the first enclosure and a current of 200mA were assumed. Figure 1 shows that in the high energy regime the intensity from the damping wiggler (P61) even for a beam size of 1mm² far exceeds that of the standard undulator.

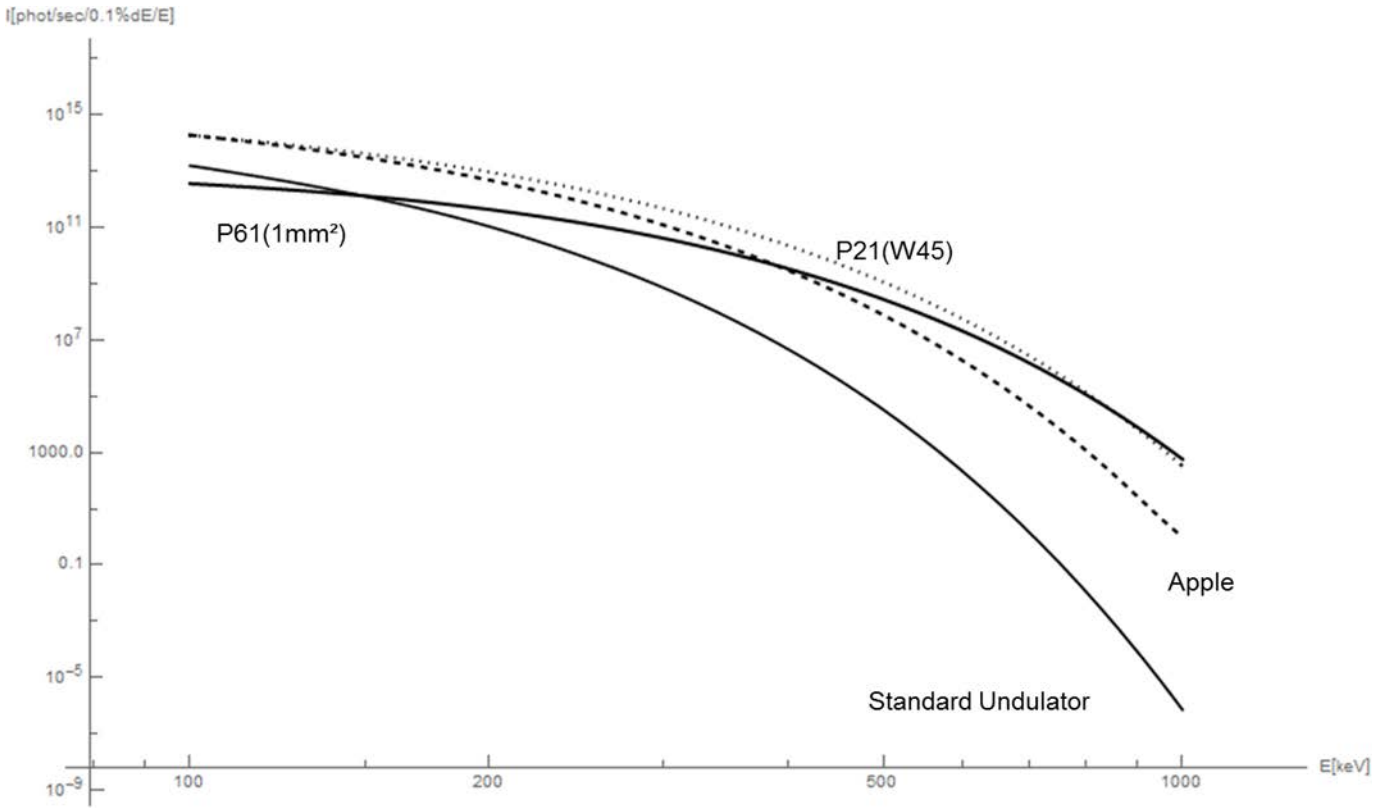

Fig.1: Spectrum from the damping wiggler (P61) compared to the standard undulator and two other devices

In recent publications [4,5] the shielding thicknesses for monochromatic radiation and photon energies below the pair production threshold have been calculated. The dose (rate) there is given by

$$D < n_0 E_S \frac{\sigma_\alpha + \sigma_\beta + Z r_e^2 C_{KN}}{A u \pi r^2} e^{-\mu_H t} \qquad (1)$$

Where n_0 is the number of incoming photons (per time) E_S the energy of the secondary photons, A the atomic mass number and u the atomic mass. σ_α and σ_β the cross sections for α and β fluorescence respectively while $Z r_e^2 C_{KN}$ describes Compton scattering with the number of electrons per atom Z, the classical electron radius r_e and the Klein-Nishima factor C_{KN}. μ_H is the attenuation coefficient of the hutch wall of (effective) thickness t and r is the distance between target and dose object.

Scattering

Below 150keV fluorescence dominates while above 150keV Compton scattering becomes dominant. Although C_{KN} depends on energy and scattering angle we will use its maximum value of unity. Furthermore we will set E_S to the energy of the incident radiation. This case corresponds to forward scattering. Scattering in other directions will yield lower intensities and lower energies (with higher attenuation coefficients.

Figure 2 shows the dose rate per energy band of 1keV attenuated by a wall of barite of thickness t. The distance between target and dose object is assumed to equal the wall thickness (worst case). Beam hardening with increasing thickness is clearly visible. Integration over all energies yields the dose rate given in figure 3. The dose rate due to scattering falls below the target of 0.5µSv/h (corresponding to 1mSV per working year of 2000h) at a thickness of about 300mm for beam sizes of 1mm² and also 9mm² (for a realistic inner distance to the target of 100mm). Due to the almost homogeneous intensity distribution of the damping wiggler thicknesses for other beam sizes can easily be deduced (dose rate proportional to beam area).

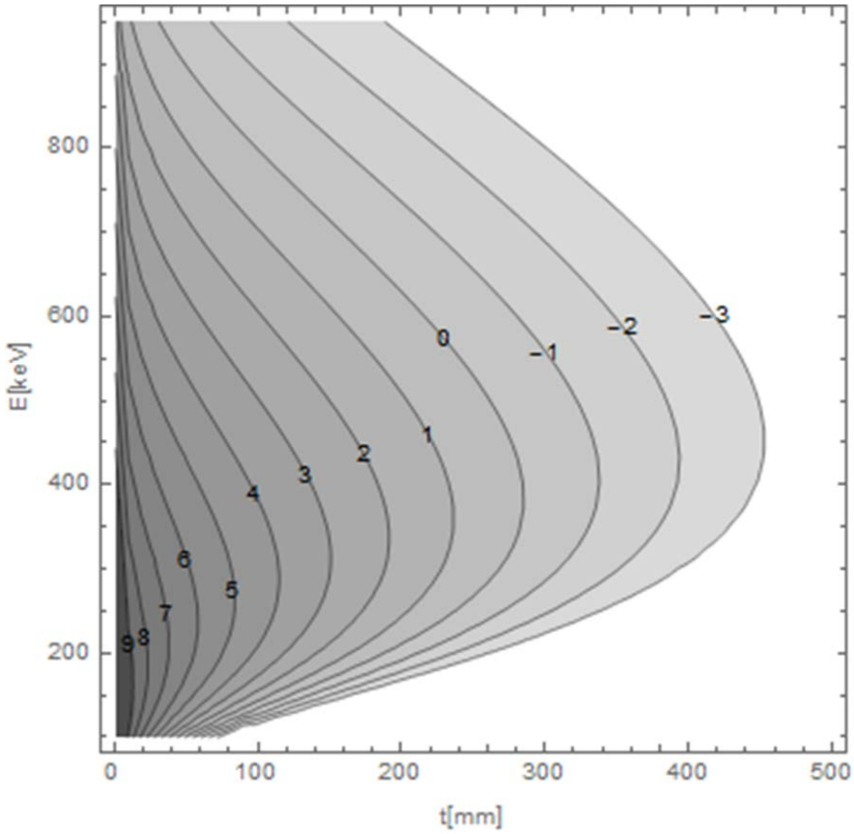

Fig.2: Common logarithm of the dose rate per 1keV energy band in units of nSv/keV/h as function of energy and wall thickness. The shift to higher energies is due to beam hardening with increasing shielding thickness.

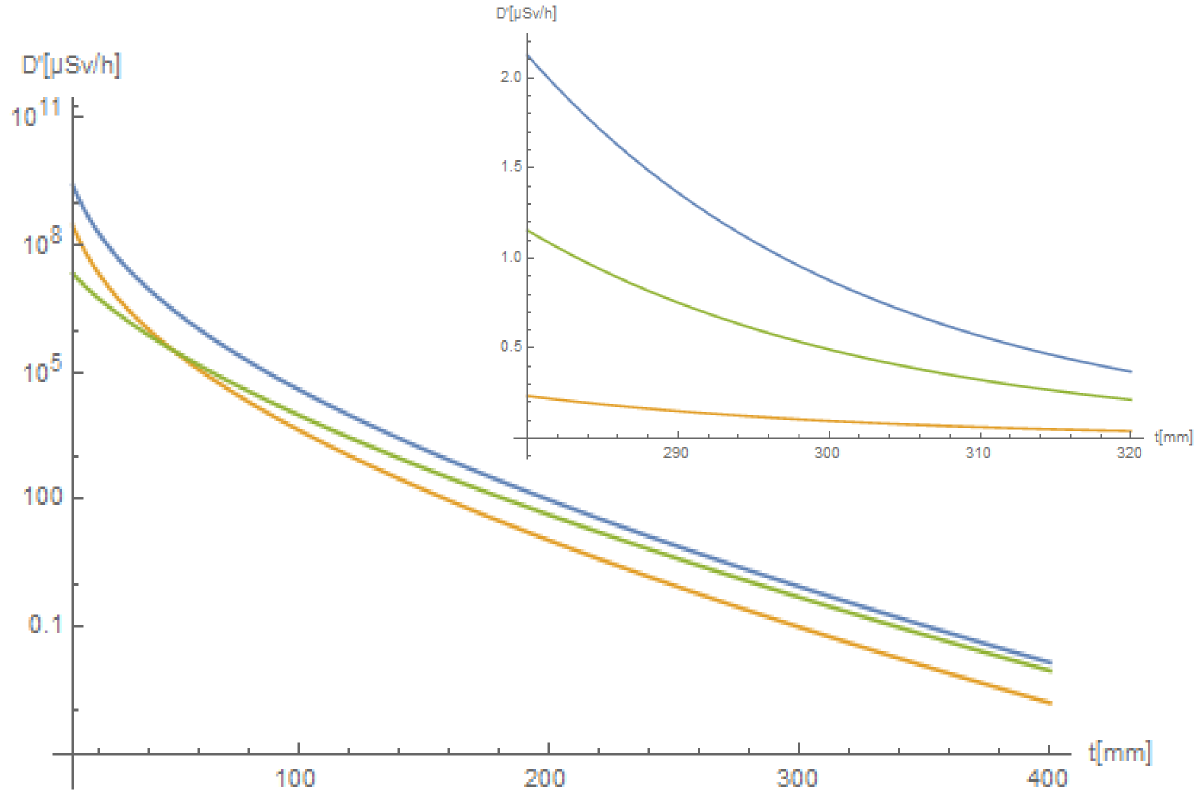

Fig.3: Dose rate due to scattering as function of wall thickness (equal to distance from target) for white radiation (yellow: beam size 1mm², blue: beam size 9mm², green: beam size 9mm² but with 100mm additional distance to target)

Fluorescence

Cross sections and the energy of fluorescence depend on the composition of the target. An (unrealistic) upper limit can however be given assuming the highest cross section (<10^4barn), highest energy of fluorescence lines (<100keV) and the lowest attenuation coefficient (at 100keV) for all photons. Even with this assumption the additional contribution of fluorescence stays well below that from scattering.

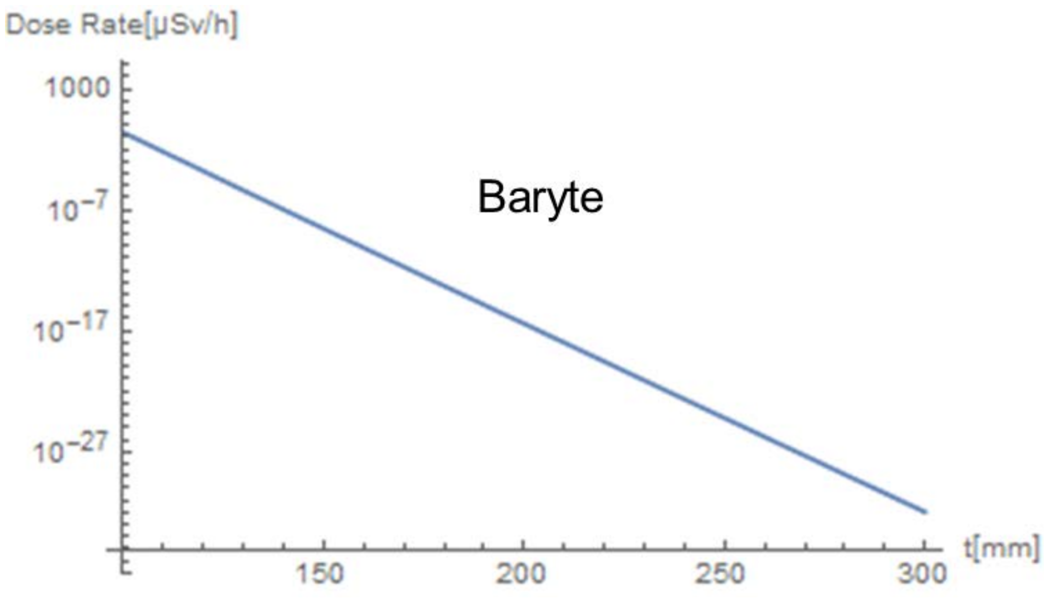

Fig.4: Dose rates due to fluorescence demonstrating that scattering is the dominant contribution.

Doors

The lead thickness of the doors for the existing optical enclosures is 20mm (plus 100mm of polyethylene for neutron shielding). Figure 5 clearly shows that this will not be sufficient in the case of forward scattering. Although the doors are motor driven they have to be opened manually in case of emergency and should, therefore, not be unnecessary heavy. Therefore, calculations taking the anisotropy and inelasticity of scattering into account have been performed.

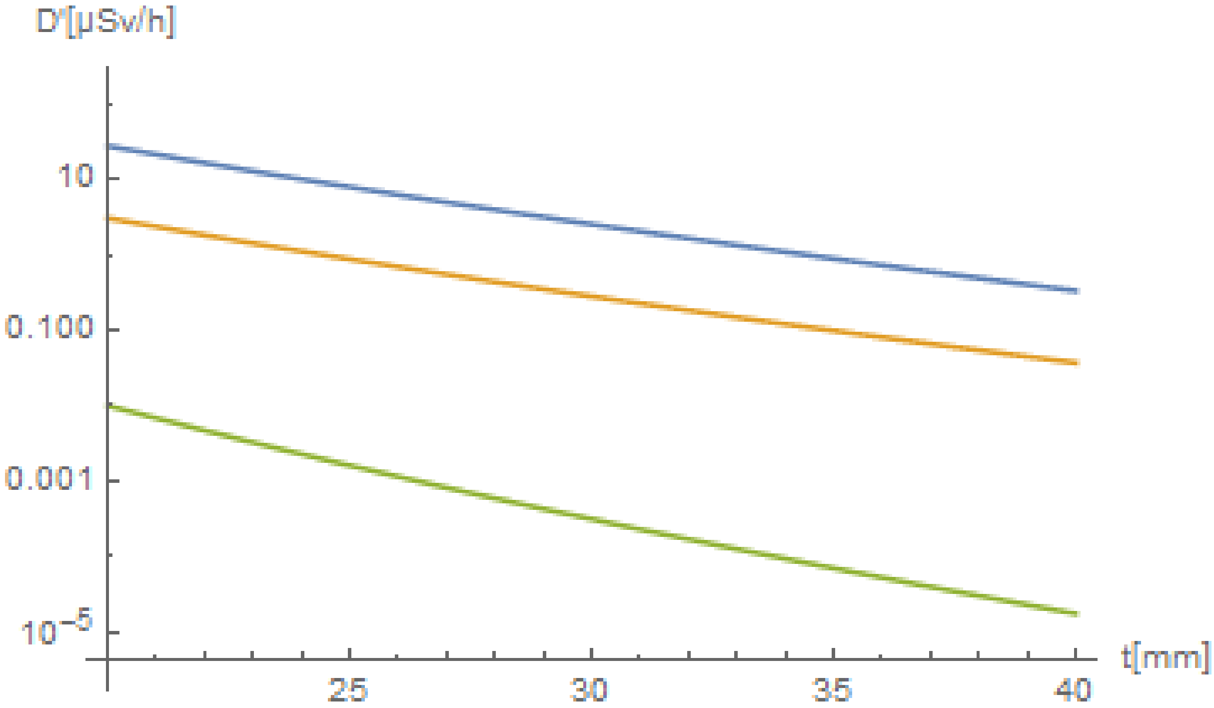

Fig.5: Dose rate as function of lead thickness for forward scattering and 1m distance from the target. (green: standard undulator, yellow and blue: P61 wiggler 1mm² and 9mm² beam size respectively)

Figure 6 shows the dose rate as function of angle and lead thickness for a beam size of 9mm² and 1m distance from the target. The angular dependence reflects the anisotropy in energy (and to a certain extend in intensity) of the scattered radiation and the fact that the effective thickness increases with decreasing angle of incidence. Furthermore it can be seen that due to the high energy of the radiation (beam hardening) a thickness of about 5mm is required to reduce the dose rate by an order of magnitude.
To have a certain safety margin it was decided to have 25mm lead thickness for the door of the first enclosure. In the following hutches the distance to the target is more than 2m reducing the dose rate by a factor of 4. Therefore 20mm of lead have been chosen for these doors.

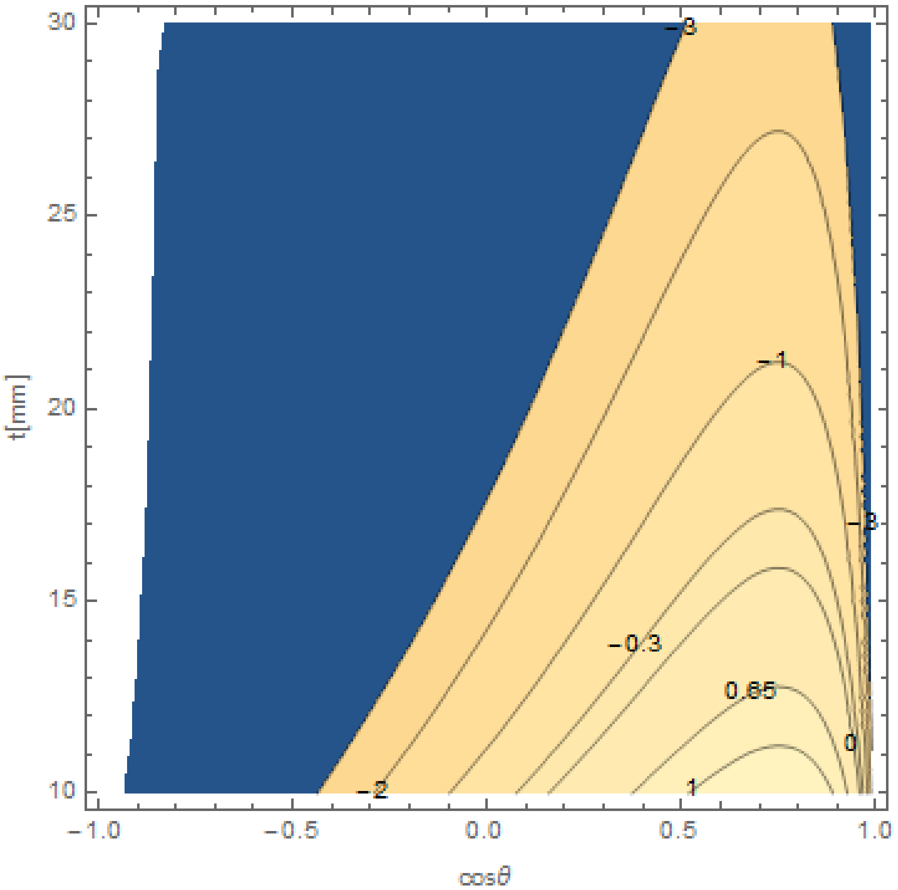

Fig.6: Dose rate as function of lead thickness and scattering angle for a beam size of 9mm² and a distance of 1m from the target.

Conclusion

All optics hutches built up to now at the PETRA III storage ring have wall thicknesses of 300mm (side) or 500mm (downstream). The calculations above clearly show that this is sufficient to shield the radiation originating from the damping wigglers for a beam size up to 9mm² (with the conservative estimate of 100mm inner distance to the target). For the first optical enclosure a lead thickness of 25mm for the door was chosen while due to the larger distance to the target 20mm were regarded as sufficient for the other doors. Contributions to the dose rate arise from high energy Bremsstrahlung and particles (neutrons) can be regarded as similar to other long straight sections where the wall thicknesses have been proven to be sufficient.

I would like to thank Wolfgang Caliebe for calculating the spectrum for the damping wiggler using the XOP code careful reading of the manuscript and further fruitful discussion. All calculations were made with Mathematica [6].

References

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