Photo-nuclear reaction

T.K.Tuyet, et al, Nucl.Inst.Meth., A989 164965 (2021).
Y.Kirihara, et al., J.Nucl.Sci.Tech., 57, 444 (2020).

Estimation of thick target effect using multi-points kernel method in synchrotron radiation shielding calculation

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Shielding design for SR beamline (Introduction)

<u>Characteristics of SR beamline</u>

- SR beam is huge intensity
- Low energy and strong attenuation
- Components, placements and beam direction are usually variable

<u>Requirements of SR beamline shielding design</u>

- Rapid response & estimation easily
- Conservative

- **Point kernel with scattering methods**
- **Monte Carlo codes**

both are useful

each codes have some

important points to use

Shielding design can be carried out by using point kernel method under strong attenuation conditions.

Point kernel method

Leakage dose estimation

Build up effect

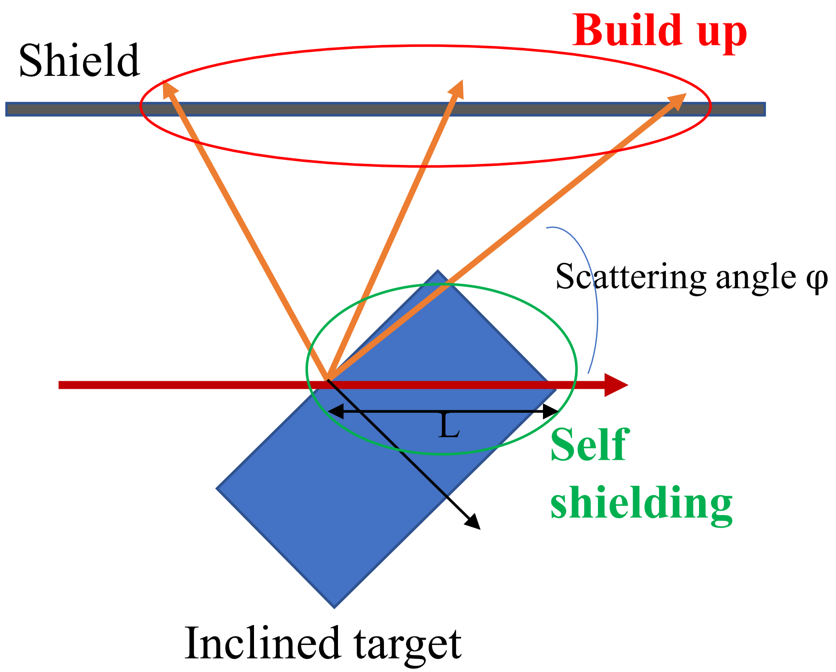
Self shielding

Today's theme

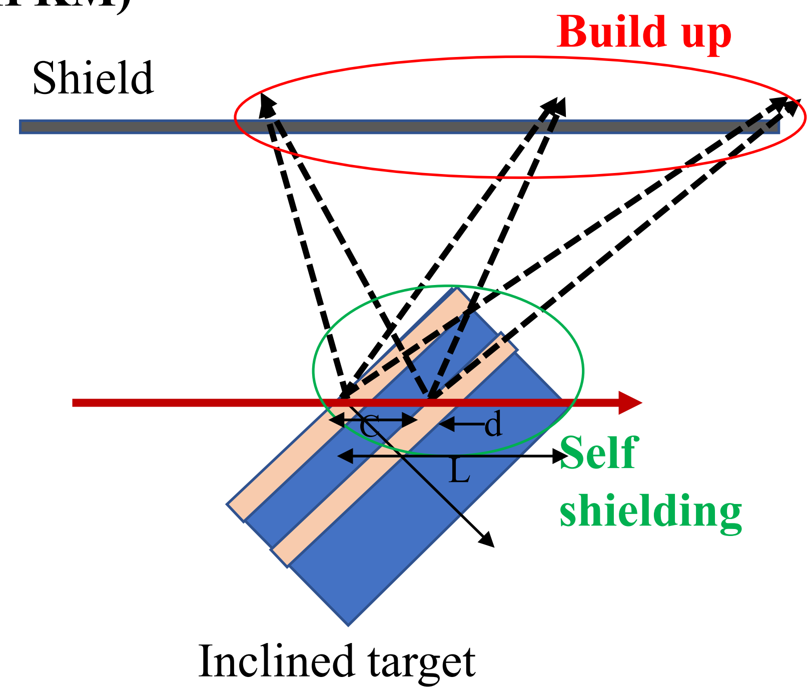
Usage limits of point kernel method and small improvement by using a multi-points kernel method.

SR beam shielding calculation model

Point kernel method



Multi-points kernel method (MPKM)



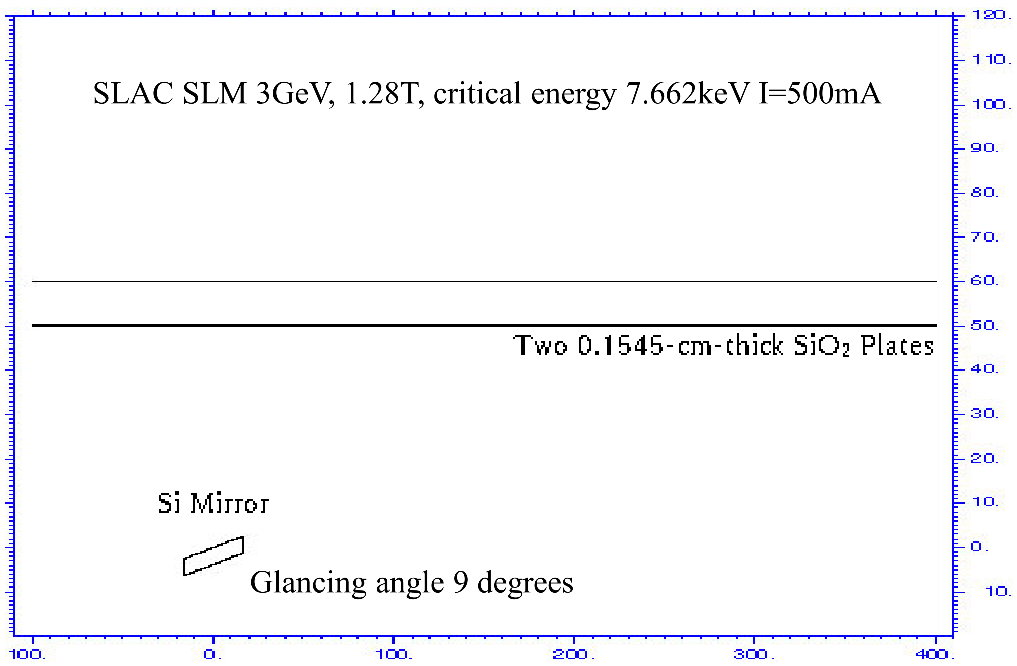
Two types of MPKM: uniform increase in small scattering angle
: uniform increase in segment target thickness

Fundamental formula for calculation of the leakage dose

$$\varphi_x(E,\theta,\varphi) = \int_0^L \frac{\Phi_s(E,\theta,\varphi)\cdot exp(-\mu_a(E)\cdot|\vec{r}|)}{|\vec{R}|^2} + \frac{\Phi^f_{\square}(E_k^n)\cdot exp(-\mu_a(E_k^n\cdot|\vec{r}|)}{4\pi|\vec{R}|^2} dr$$

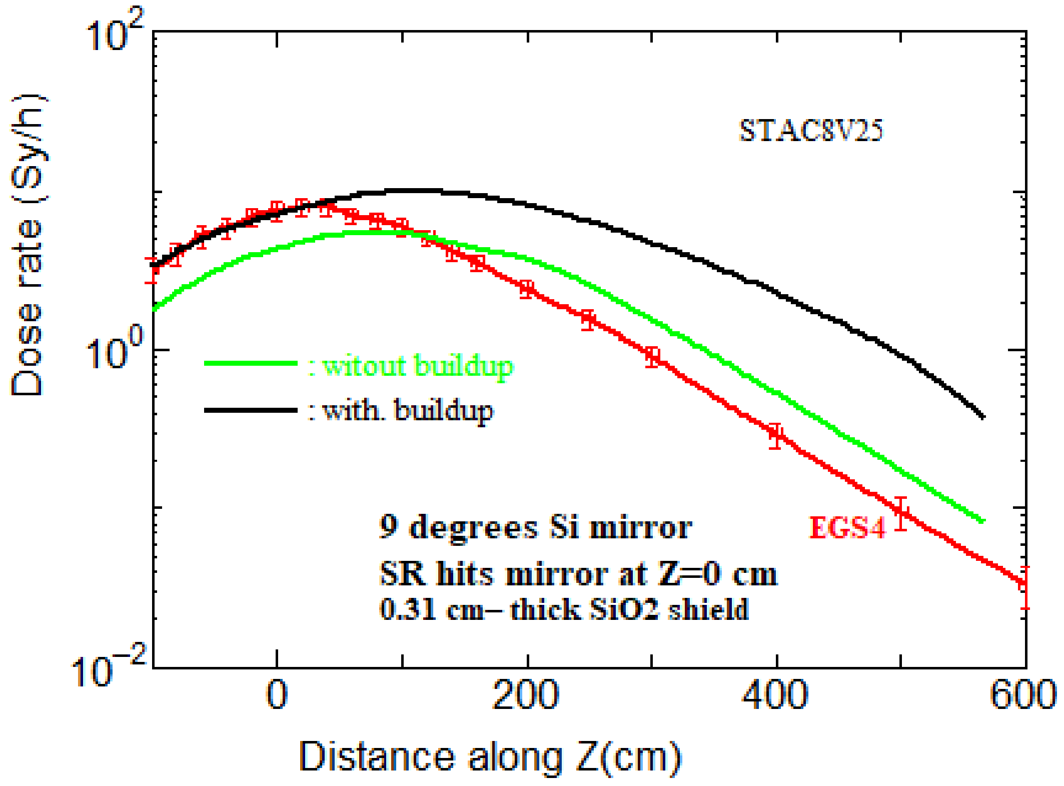
$$D_x = \sum_E f_x(E)\cdot B(E,\mu_a\cdot r)\cdot C(E)\cdot \varphi_x(E,\theta,\varphi)\Delta E$$

Example I, SLAC-PUB-10427 (April 26, 2004) ; Thin shield case



Geometry for the simulation of synchrotron radiation, emitted from the **SPEAR3 bending magnet**, hitting the Si mirror. The mirror is 9 degrees inclined relative to the beam direction (i.e., +Z axis). Polarization vector points toward +X. The shielding is two SiO_2 plates, parallel to the Z axis and each 0.1545 cm thick. The dose is scored at 1 m away from Z axis (i.e., X=100 cm).

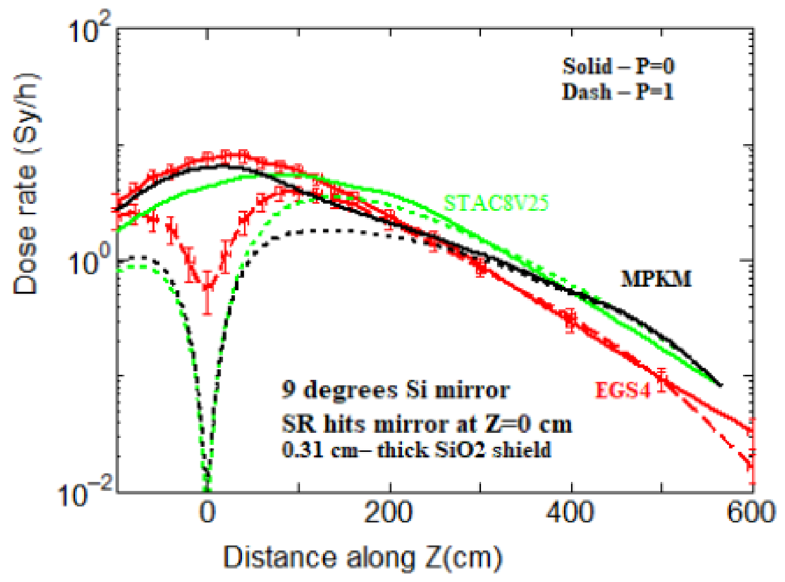
Build up effect



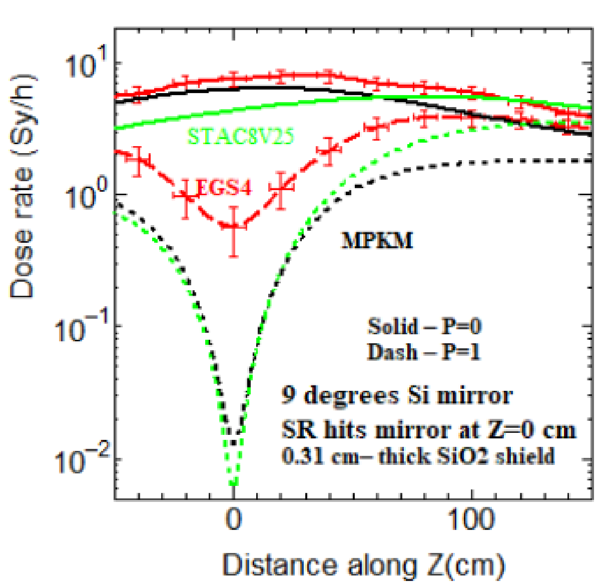
STAC8V25 with and without considering buildup effect

Ref: J.Liu, A.Prinz, S.Rokni and Y.Asano, SLAC-PUB-10427 (April 26, 2004)

Multi-points kernel vs point-kernel method without build up effect

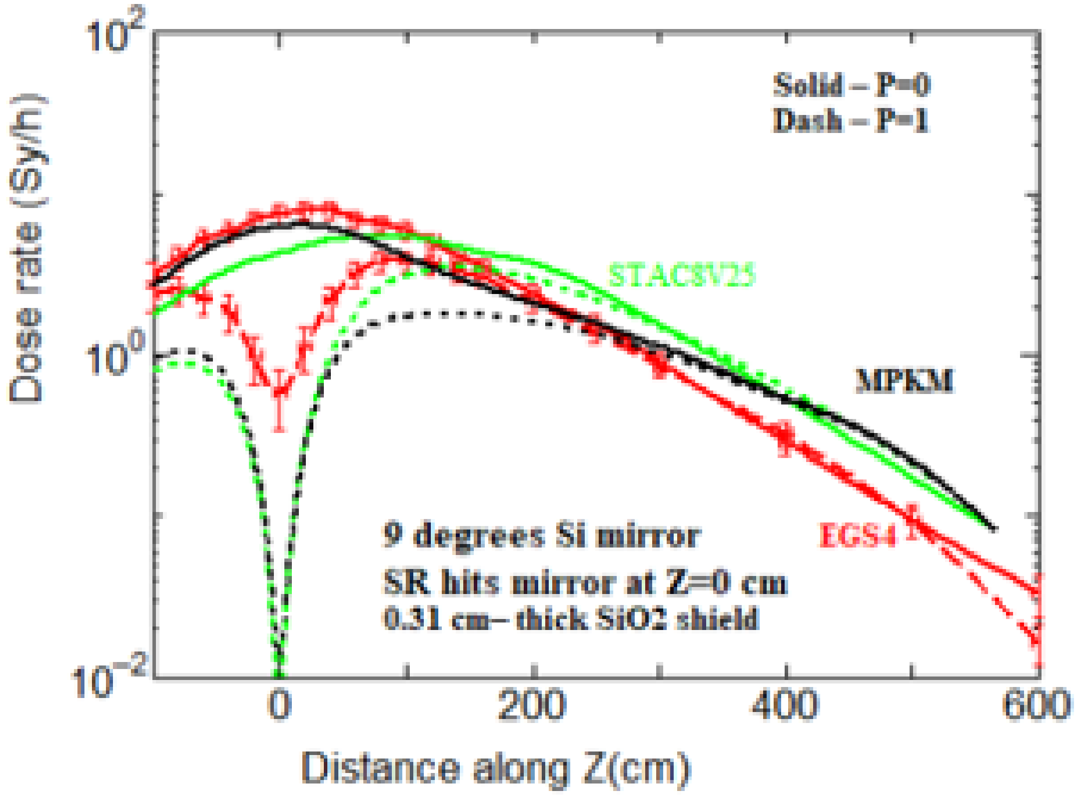


STAC8V25 and multi–points kernel method (MPKM) are without considering buildup effect

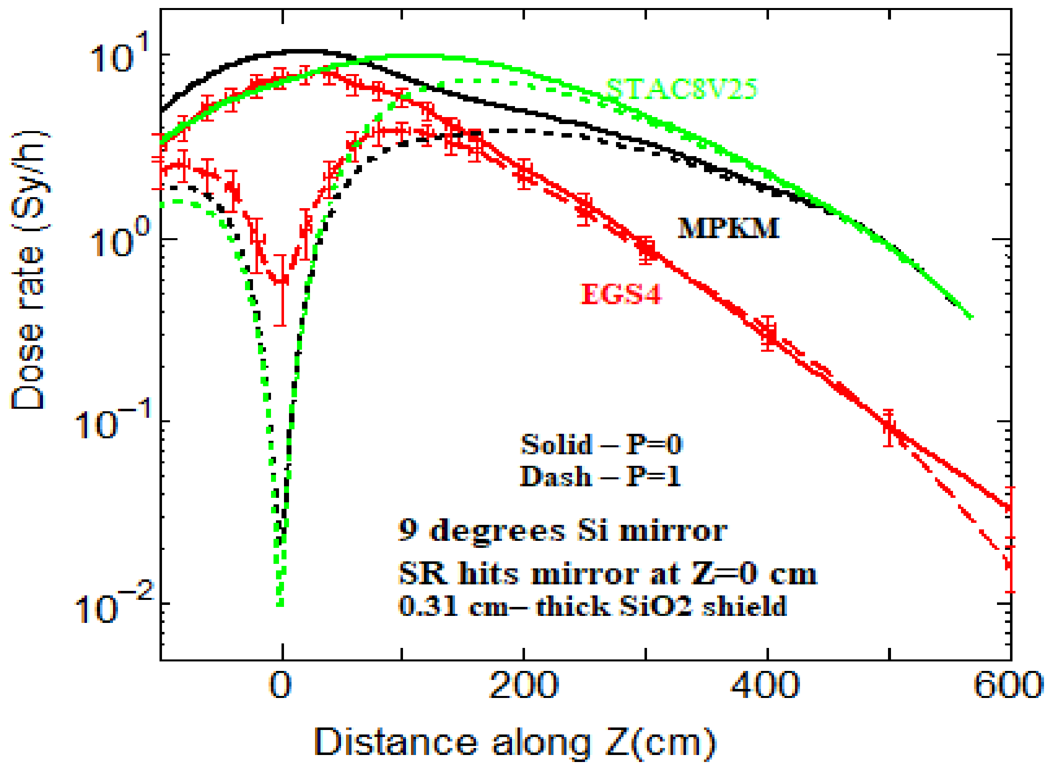


MPKM:1~22 segments
(depending on scattering angle)

Multi-points kernel vs point-kernel method with build up effect



STAC8V25 and multi–points kernel method (MPKM) are without considering buildup effect



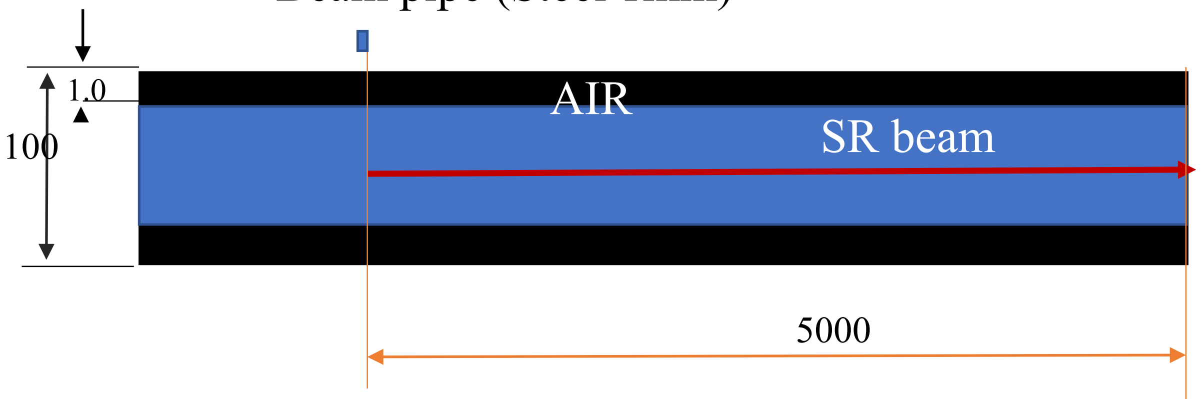
STAC8V25 and multi–points kernel method (MPKM) are with considering buildup effect

The Peak position of the leakage dose was improved.
The shape of the depression due to polarized photon was slightly improved.

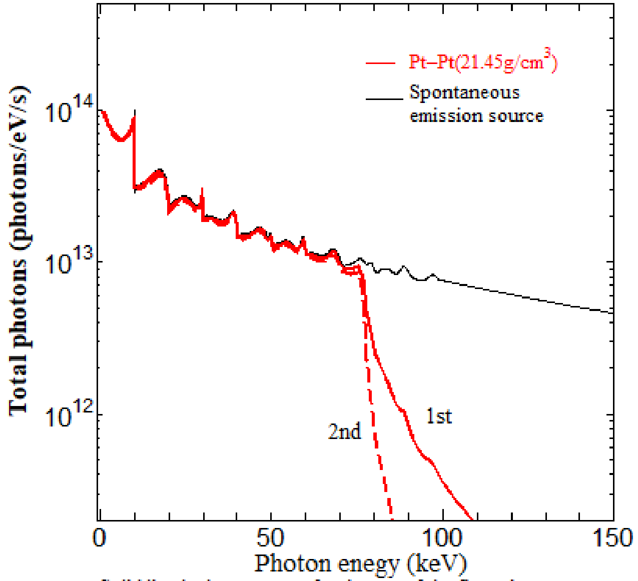
- Shielding calculation （long target: Virtually air 1.0 ~10^{-3}atm)

(Normally, vacuum inside the beam pipe with the interlock system)

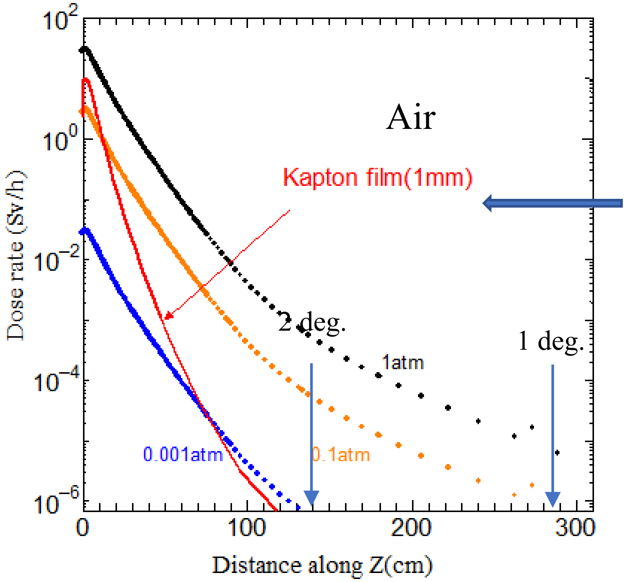
Beam pipe (Steel 1mm)



XFEL spontaneous emission (example)
Double mirror case
Glancing angle 1.1mradian

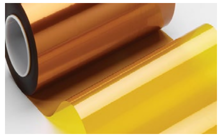


Solid line is the spectrum for the out of the first mirror
Dashed line is the spectrum for the out of the second mirror



Dose equivalent profile depending on air pressure at 5cm away pararell to Z axis,outside the 1mm steel beam pipe

Beam pipe 100 segments



Kapton film (point)

Application limit (Bad case for point kernel method)

long target & weak attenuation → to be improved if necessary

Monte Carlo code can be used easily.

- Example (mirror case)
- Comparison to measurements

→ Good cases (point kernel method)

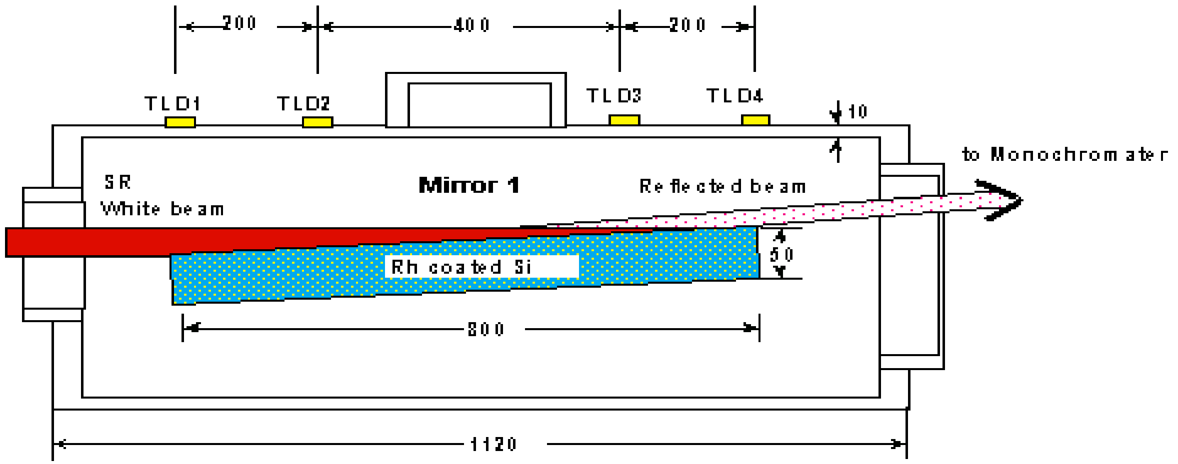
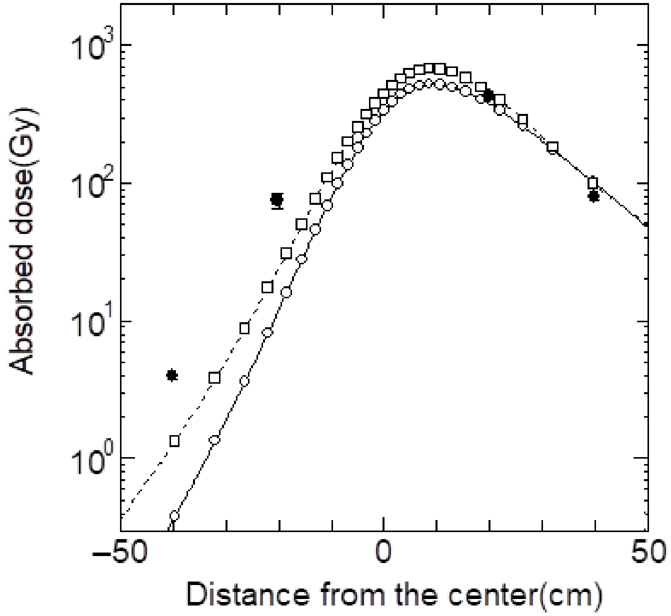
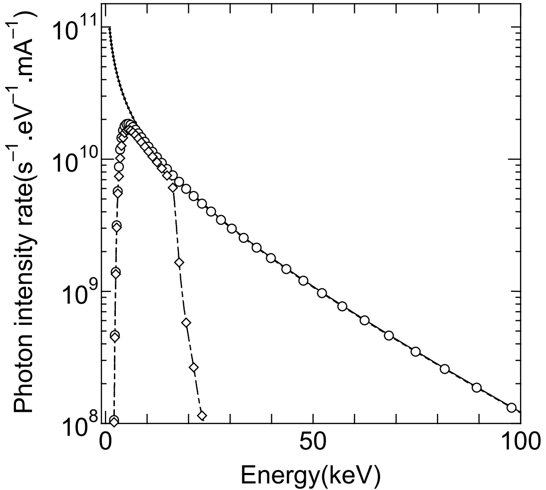


Illustration of the first mirror and the location of the four TLD dosimeters. The synchrotron radiation beam injected into the rhodium coated silicon body mirror. The soft X-ray component of synchrotron radiation is reflected and transmitted to the monochromator by the inclining mirror.



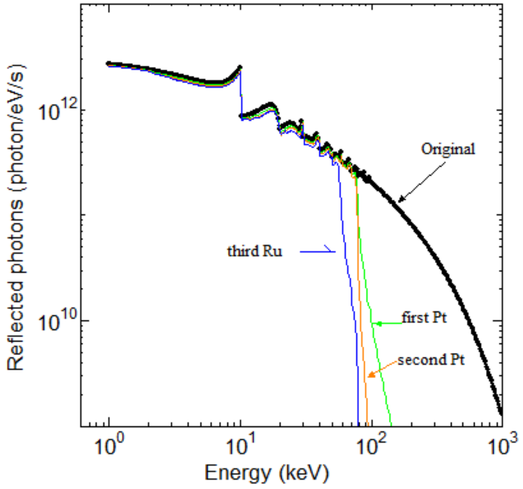
Dose distributions of the scattered photons outside the mirror box. The horizontal axis indicates the distance from the center of the top plane of the mirror box and the vertical axis indicates the absorbed dose in air. Full circles indicate the measurement data by using the TLD dosimeters. Open circle and solid line indicates the results of the STAC8 calculation by using the silicon scatterer. Open square and dot-dashed line indicates the STAC8 calculations by using the steel scatterer

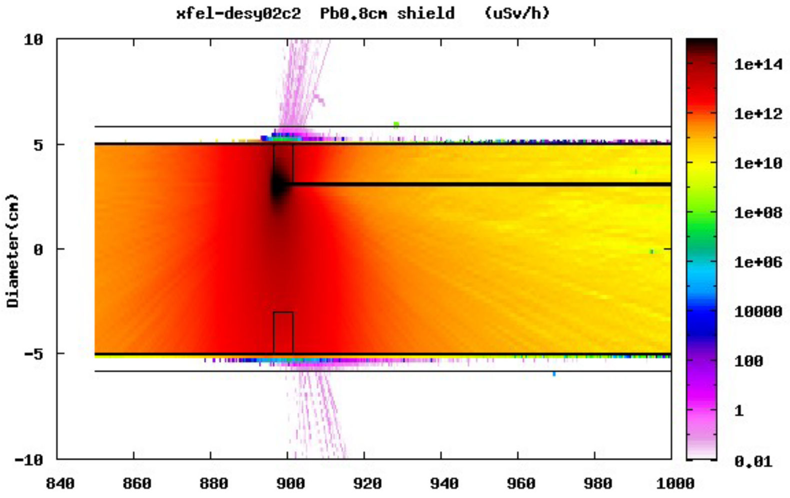


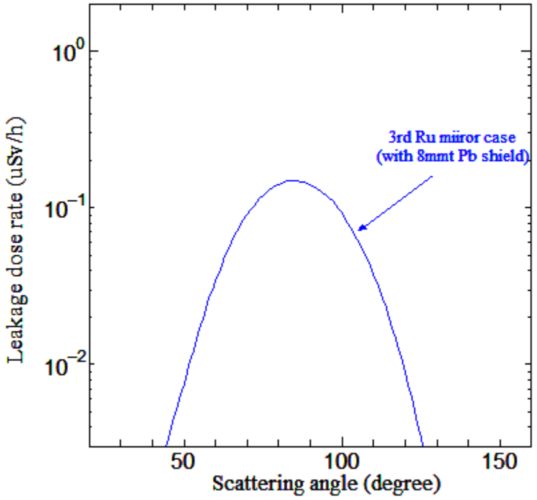
The solid line indicates the synchrotron radiation source emitted from the bending magnet. The open circle and dot line indicates the attenuated spectrum by beryllium filters. The open diamond and dot-dashed line indicates the reflected spectrum by inclining the rhodium coated silicon body mirror of 4 mradian

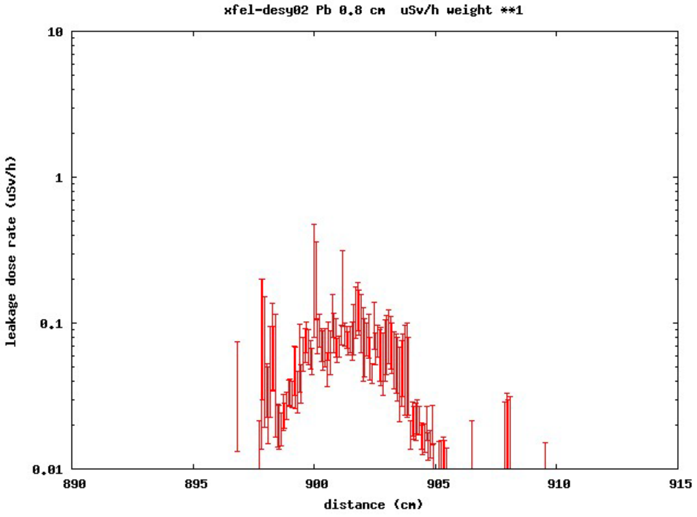
Example (beam pipe case)

Condition :vacuum & never hit the pipe wall (ex. set a collar); Normal safety design cases









Point kernel method(STAC8)

Monte Carlo cal. (FLUKA)

- Shield pipe (1mm steel+8mm Pb)
- Radiation source is 3rd reflected Ru mirror out
- Beam hits the B4C collar edge
- The calculation results by using STAC8 show good agreements to the FLUKA simulations.

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Conclusion

Using segment targets and multi-points kernel method, there are some improvements, such as the improvement of peak position due to leakage dose. Point kernel method is useful to design the shield of SR beamlines with strong attenuation cases, however these methods are not general-purpose code. The point kernel method with scattering has some limitation, even the multi-points kernel methods so that it is required to use it under well-known SR beamline systems, components and the radiation physics. Radsynch workshop, therefore, is useful and important to discuss about the safety engineering and the science.

Thank you for your attention

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