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Shielding design calculation for SPring-8 beamlines using *STAC8*

Yoshihiro Asano

SPring-8 Project Team, Japan Atomic Energy Research Institute, Kamigori-cho, Hyogo-ken 678-12, Japan. E-mail: asano@spring8.or.jp

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The beamlines of SPring-8 are classified by synchrotron radiation source into undulator, wiggler and bending-magnet beamlines for safety analysis. The shielding design calculations for synchrotron radiation are performed with a new shielding design code, *STAC8*, taking into consideration the linear-polarization effect, the slant length of the shield hutch wall and the build-up effect as functions of scattering angle and azimuthal angle.

Keywords: shields; beamlines; SPring-8.

1. Introduction

Extremely high-brilliance and high-power-density synchrotron radiation is available at SPring-8 and therefore the shielding of the beamlines for radiation safety must be designed to withstand severe conditions. The main shielding components for beamline safety are a main-beam shutter, downstream shutter, gamma stop, beam stop, optics and experimental hutches. In the calculation, the following three kinds of radiation sources were considered: (*a*) neutrons, photons and muons due to stored electron beam loss; (*b*) *bremsstrahlung* from the residual-gas molecules in the straight section of the storage ring and associated photoneutrons generated at the gamma stop struck by gas *bremsstrahlung*; (*c*) synchrotron radiation. In the present paper we will focus on the shielding calculation for synchrotron radiation with respect to the hutch wall.

2. *STAC8* code

The *PHOTON* code (Chapman, 1988) was applied to the design calculations for the beamlines of the ESRF (Braeuer, 1992). However, in some cases it underestimated the doses outside the shield wall of the hutches. The *PHOTON* code has been validly created for calculations of the attenuation by filters, the isotropic scattering process by the optical elements, and the shielding by the walls of the hutches, ignoring the build-up effect of the synchrotron radiation emitted from the wiggler or bending magnet. The polarization effect is actually dominant in the synchrotron radiation and the code does not simulate the scattering process. Furthermore, with the considerably high-energy X-rays generated in third-generation synchrotron radiation facilities, the dose outside the shield wall strongly depends on the scattering angle. A new shielding design code, *STAC8* (Asano & Sasamoto, 1994), has been developed to account for the deficiencies in the *PHOTON* code and to be applicable to consistent calculations of the radiation emitted from the insertion devices, including undulators, the effect of linear polarization of photons on the scattering process, and the angular dependence of the coherent and incoherent scattering, as illustrated in Fig. 1. For dose estimation, the code can calculate each 1 cm depth dose, surface dose, skin dose and absorbed dose due to scattering photons by considering the build-up effect and slant length of the shield wall of a hutch. The doses by the scattered photons can be calculated with and without introducing self-shielding of the scatterer.

3. Dose calculation outside the shield wall

The beamlines of SPring-8 are classified by synchrotron radiation source into wiggler, undulator and bending-magnet beamlines for safety analysis. Table 1 shows the key parameters of those sources for the typical beamlines (JASRI, 1997). The BL08W wiggler beamline is designed for Compton-scattering spectroscopy with circular-polarized photons. BL47XU and BL45XU are undulator beamlines. The former is designed for optics and imaging R&D with horizontal linear-polarized photons generated by an in-vacuum-type undulator, and the latter is for research on structural biology with vertical linear-polarized photons generated by a tandem-type undulator. The BL02B1 bending-magnet beamline is designed for crystal structure analysis.

Sizes and lead thicknesses of the optics hutches are also indicated in Table 1. The shield is fundamentally constructed with the hutch wall and local shield of the scatterer. The thickness of the roof is the same as that of the side wall. In the calculations, a copper disk of thickness 10 mm was used as a scatterer in place of the optical element, such as a silicon crystal, for conservative analysis. The dose distributions outside the hutches due to scattered synchrotron radiation were calculated considering the build-up effect and self-shielding of the scatterer. The slant length of the shield wall is also considered to depend on both the azimuthal and the scattering angle to introduce the polarization effect. On the other hand, in the calculations without the polarization effect, the slant length of the shield wall is considered not to depend on the azimuthal angle.

4. Results and discussion

The dose distributions calculated outside the optics hutch side wall are shown in Fig. 2. This figure indicates that the dose strongly depends on the scattering angle. The doses calculated by *PHOTON* are 5.0×10^{-5} and 3.6×10^{-7} mGy h^{-1} mA^{-1} for the BL02B1 and the BL08W beamlines, respectively. The reason that *PHOTON* obviously underestimated the dose values is

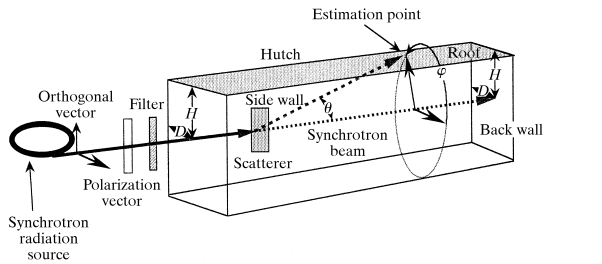

Figure 1
Illustration of the process of the shielding calculation for synchrotron radiation by using *STAC8*. The dose outside the hutch side wall, roof and back wall can be calculated consistently as a function of the scattering angle, azimuthal angle and the distance from the synchrotron radiation beam to the wall.

Table 1
Key parameters of synchrotron radiation sources and optics hutches for shielding calculations for typical beamlines of SPring-8.

Beamline	BL08W	BL47XU	BL45XU	BL02B1
Type of insertion device	Wiggler	Undulator (in-vacuum)	Undulator (tandem)	Bending magnet
Power (W mA^{-1})	180	110	27.5	2.25
Period length (mm)	120	32	37	39270 (bending radius)
Number of periods	37	140	40 × 2	–
Magnetic field (peak) (T)	1.0	0.78	0.5	0.68
Critical energy (keV)	42.7	–	–	29.0
Polarization	Circular	Linear (horizontal)	Linear (vertical)	(Linear)
Scatterer†	Cu (1 cm)	Cu (1 cm)	Cu (1 cm)	Cu (1 cm)
Optics hutch size				
Distance (m) from synchrotron radiation beam to side wall	2.35	1.7	1.03	0.6
Distance (m) from scatterer to back wall	4.0	7.5	8.0	1.75
Lead thickness‡ (mm)				
Side wall	15	15	10	10
Local shield	15	5	–	3
(Total)	30	20	10	15
Back wall	40	20	20	40
Local shield	45	30	–	10
(Total)	85	50	20	50

† A Cu scatterer is assumed instead of optical elements for safety analysis. ‡ The hutch wall is designed to be constructed with lead plate, sandwiched by iron plates of thickness 5 mm.

thought to be caused by neglect of the build-up effect and coherent scattering. Besides, isotropic scattering is assumed with the 90° scattered photon energy.

Fig. 3 indicates the azimuthal angle dependence of the dose distributions obtained by taking into consideration the linear-polarization effect and slant length at the side and the roof walls. The azimuthal angle is defined to be 0° on the horizontal plane. These distributions were calculated at the scattering angles 40, 50 and 60° to determine the maximum dose values and positions.

As shown in Figs. 2 and 3, the dose distributions strongly depend on the scattering angle and the azimuthal angle because of the anisotropic scattering process of photons and angular dependence of slant length. The dose is especially high in the scattering angle range 50–60° and azimuthal angle range 0–10° on the BL45XU beamline for vertical polarized photons, and in the azimuthal angle range 80–90° on the BL47XU and BL02B1 beamlines for horizontal polarized photons. The figures show that the highest dose outside the side wall should appear on the BL45XU beamline. The local shields, therefore, will be very

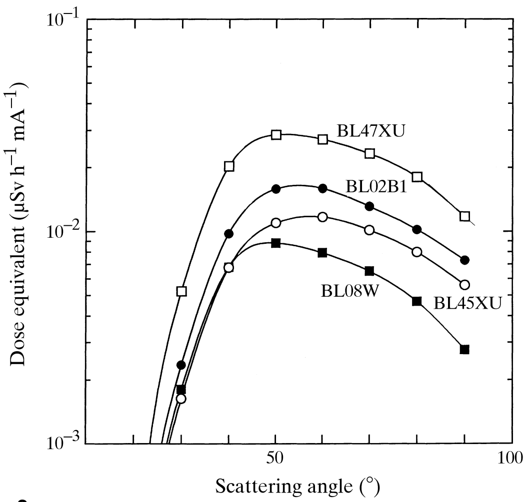

Figure 2
Calculated dose distributions outside the side wall of the optics hutch of the typical SPring-8 beamlines as a function of scattering angle. Black squares: BL08W; white circles: BL45XU; white squares: BL47XU; black circles: BL02B1.

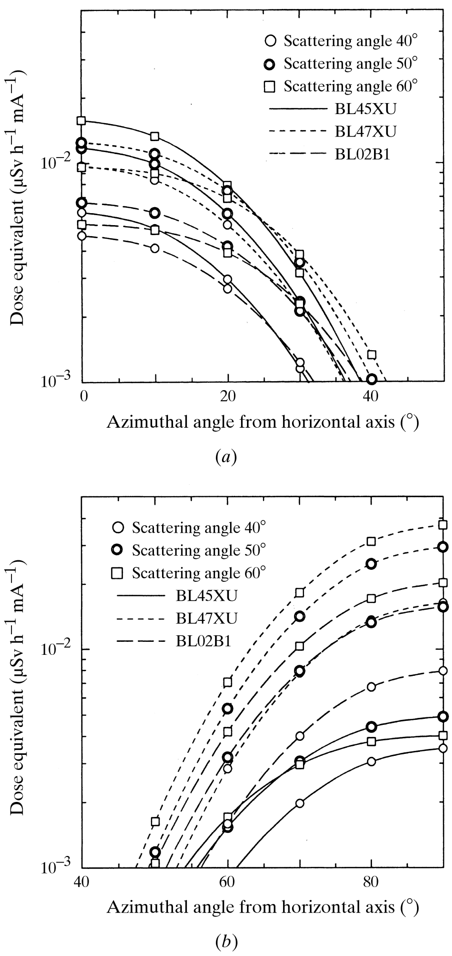

Figure 3
Dose distributions of the scattered photons outside the side wall (*a*) and the roof (*b*) of the optics hutches, calculated taking into consideration the linear-polarization effect. The slant length is considered to depend on both the azimuthal and the scattering angle to introduce the polarization effect. The side walls of the BL47XU and BL02B1 beamlines stand parallel to the beam path and perpendicular to the photon polarization vector, and parallel to the photon polarization vector for the BL45XU beamline. The roof walls of the BL47XU and BL02B1 beamlines are parallel to the plane expanded by the beam path and polarization vector, and perpendicular for the BL45XU beamline.

effective and also economical from the viewpoint of the shield weight.

5. Concluding remarks

To realize the characteristics of the shielding conditions of the beamlines in third-generation facilities, the dose distributions due to the synchrotron radiation of the typical beamlines in SPring-8 were calculated with the new shielding design code *STAC8*. The results showed that the dose distribution strongly depends on the scattering angle and the azimuthal angle.

To date, radiation checks on seven beamlines using synchrotron radiation have been performed within the 20 mA stored-current limit in the first stage of SPring-8, verifying that the shielding has performed satisfactorily and that with *STAC8* we can carry out shielding design calculations for the beamline easily and quickly with sufficient accuracy.

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