SLAC-PUB-12824

Shielding design aspects of SR beamlines for 3 and 8 GeV class synchrotron radiation facilities

Yoshihiro Asano[a,*], James C. Liu[b], Sayed Rokni[b]

[a]*Japan Synchrotron Radiation Research Institute, Sayo-cho, Hyogo-ken 679-5198, Japan*
[b]*Stanford Linear Accelerator Center, 2575 Stand Hill Road, M/S 48 Menlo Park, CA 94025, USA*

Abstract

Differences in synchrotron radiation beamline shielding design between the facilities of 3 GeV class and 8 GeV class are discussed with regard to SLAC SSRL and SPring-8 beamlines. Requirements of beamline shielding as well as the accelerator shielding depend on the stored electron energy, and here some factors in beamline shielding depending on the stored energy in particular, are clarified, namely the effect of build up, the effect of double scattering of photons at branch beamlines, and the spread of gas bremsstrahlung.

Keywords: Shielding design; Synchrotron radiation; Beamline; Build up; Gas bremsstrahlung; Double scattering

1. Introduction

Recently, many synchrotron radiation facilities with intermediate levels of stored electron energy such as Canadian Light Source in Canada and DIAMOND in UK are under construction or design. Some facilities such as SPEAR3 in USA have been upgraded. These facilities are required to be shielded more severely in keeping with growth of radiation power and the ring energy of about 3 GeV. Furthermore, strong shielding of insertion devices for the beamline is strictly required. On the other hand, large synchrotron radiation facilities with high stored electron energy such as ESRF in France, APS in USA, and SPring-8 in Japan are currently available, with stored electron energy of 6, 7, and 8 GeV, respectively. The shielding designs of these facilities were made independently. However, there are points in common as well as points of difference between the intermediate and the high stored electron energy facilities with regard to radiation shielding of the beamlines, and this information is very useful. Especially, the differences are very important for future designing. In this paper, therefore, we discuss the characteristics of the beamline shielding as they are affected by build up, spread of gas bremsstrahlung and double scattering of photons at branch beamlines, using the SLAC SSRL (Liu et al., 2005b) and SPring-8 (Asano, 2001) beamlines as examples to clarify the differences between the above two categories of the synchrotron radiation facilities.

2. Shielding calculation for synchrotron radiation

2.1. Typical beamlines of SPring-8 and SSRL

The typical beamlines of SPring-8 and SSRL are listed in Table 1 together with key parameters of the light sources and the hutch shield wall. For SPring-8, one bending beamline BL02B1, one wiggler beamline, BL08W, and two undulator beamlines, BL45XU and BL47XU, are given. For SLAC SSRL, we took one bending beamline and one wiggler beamline, BL11, and summarized the key parameters. The critical energy for a SPring-8 bending magnet with the stored electron energy of 8 GeV is 29 keV, and 7.7 keV for a SLAC SSRL bending magnet with 3 GeV stored energy. The “distance” in the table refers to the distance from the synchrotron beam axis to the hutch side wall. Making the thicknesses of the side wall (T_0) sufficient to prevent leakage due to scattered photons is a practical consideration for the shielding design of each optics hutch. The thicknesses given for SLAC SSRL beamlines

* Corresponding author. Tel.: +81 791 58 2705.
E-mail address: asano@spring8.or.jp (Y. Asano).

Submitted to Radiat.Meas.

Work supported in part by US Department of Energy contract DE-AC02-76SF00515

Table 1
Key parameters for build up calculation of the light sources of SPring-8 and SSRL

Beamline	Light source	Period	Period length (cm)	Magnetic field (Tesla)	Critical energy (keV)	Distance (cm)	Side wall thickness (optics hutch, T_0), (cm)
SPring-8 BL02B1	Bending	(0.5)	3930 (bending radius)	0.69	29.0	60	Pb 1.3 Fe 1.0
SPring-8 BL08W	Wiggler	37	12	1.0	42.66	235	Pb 3.0 Fe 1.0
SPring-8 BL45XU	Undulator (tandem)	74	3.7	0.5	(21.33)	103	Pb 1.0 Fe 1.0
SPring-8 BL47XU	Undulator (in vacuum)	140	3.2	0.78	(33.27)	170	Pb 2.0 Fe 1.0
SSRL SLM	Bending	(0.5)	785 (bending radius)	1.2772	7.70	100	Pb 0.3
SSRL	Wiggler	13	17.5	2.02	12.2	100	Pb 0.7

Target of the scatterer-SPring-8: Cu 1 cm disk; SLAC-SSRL: Si 2 cm thick disk, inclined 2°.

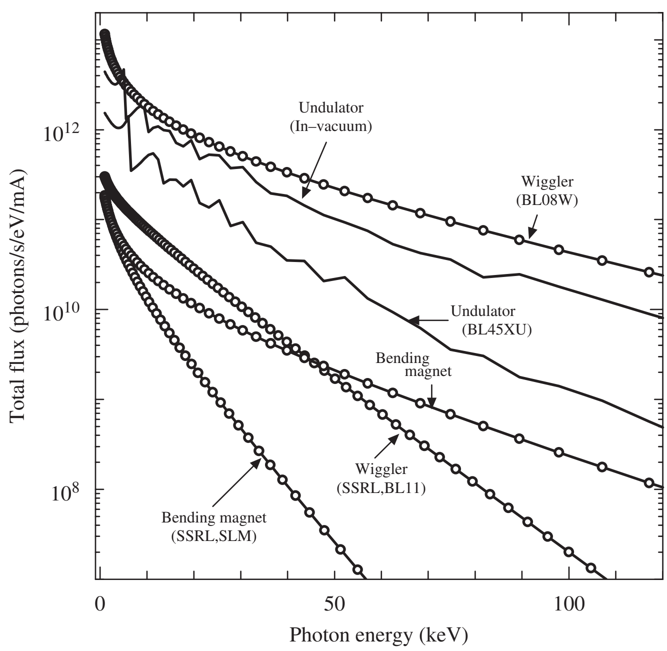

Fig. 1. Angle integrated photon flux for SPring-8 and SSRL typical beamlines.

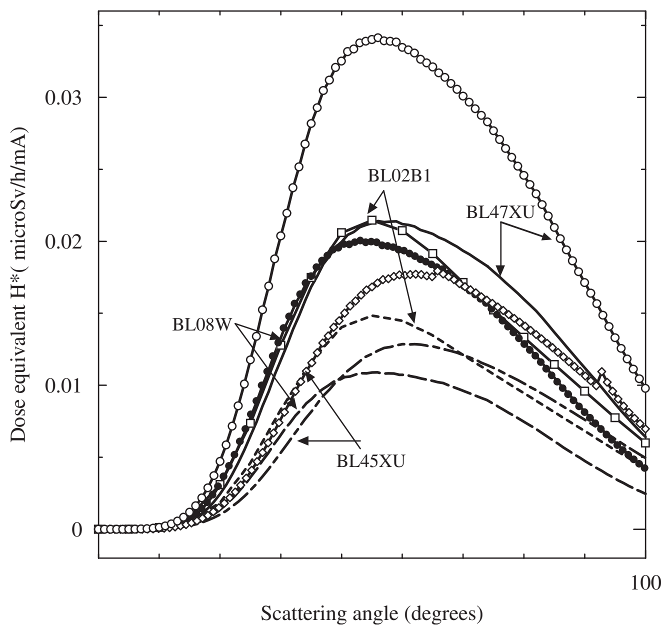

Fig. 2. Leakage dose distribution outside the hutches with and without consideration of build up effect. Solid and dashed lines are the dose distributions with and without consideration of the build up effect, respectively. The calculation conditions are those indicated in Table 1 for each beamline of SPring-8.

are tentative thicknesses for the upgraded SPEAR3 ring. The angle integrated photon spectra calculated by STAC8 (Asano and Sasamoto, 1994) are shown in Fig. 1 for each beamline, and it is clear that the SPring-8 beamlines have high intensities of high energy components in comparison with those of SSRL beamlines.

2.2. Shielding design code STAC8

A shielding design code, STAC8, was developed for synchrotron radiation beamlines at SPring-8. This code calculates the synchrotron radiation spectrum including angle integrated radiation from an undulator source, angular dependent coherent and incoherent scattering taking into consideration polarization effect and self-shielding of the scatterer, and the amount of leakage outside the hutch considering buildup effect, using the G-P method (Harima et al., 1984), with consistent accuracy. Now this code has been upgraded in the new STAC8 V2.1, so that it can calculate both the double scattering process of coherent and incoherent, and the specular reflection process. To verify the STAC8 calculations, several comparisons with results of experiments using beamlines of practical use were performed, and the calculations showed good agreement with these results. In addition, Monte Carlo simulations were performed and compared with the calculation of STAC8, showing reasonable agreement (Liu et al., 2005a; Asano and Liu, 2002).

In case of a thick shield to reduce the leakage dose outside the hutch to the allowable level, the STAC8 calculations considering the build up effect also show fairly good agreement with the Monte Carlo simulations (Prinz et al., 2003).

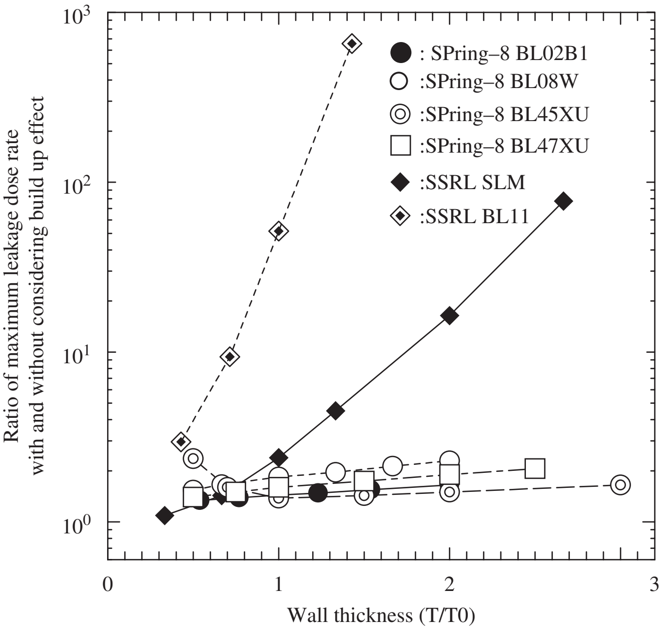

Fig. 3. Dependence of build up effect on the shield thickness of hutch side wall. T_0 means the thickness of the actual facility as indicated in Table 1. Solid circles, open circles, double circles and open squares are for SPring-8 BL02B1, BL08W, Bl45Xu, and Bl47XU beamlines, respectively. Solid diamonds and double diamonds are for SSRL SLM and BL-11 beamlines, respectively.

2.3. The need for consideration of build up effect

For hutch shielding design, one of the most important factors is the scattered synchrotron radiation. In case of the calculation of leakage dose due to scattered synchrotron radiation, the leakage dose outside the optics hutch is normally estimated considering the polarization effect, build up effect, and self-shielding effect of the scatterer. These effects depend strongly on photon energy, however, the build-up effect has the potential to cause misleading indications of serious conditions. For the SPring-8 beamline, leakage dose distributions outside the hutches are shown in Fig. 2 with and without consideration of build up effects. In comparing the SSRL with SPring-8 beamlines, the effect of the build up on the SSRL BL-11 beamline is obviously higher than that on SPring-8. In order to find the mechanism of the differences, the dependence of the build up effect on the wall thickness was investigated and the results are shown in Fig. 3 as the respective ratio of maximum leakage dose with and without consideration of build up effect. In this figure, the horizontal axis shows the shield thickness of the hutch wall relative to T_0 indicated in Table 1, and on this axis are the shield thickness of the actual facility of each beamline. The vertical axis shows the ratio of the maximum leakage dose considering the build up effect and the maximum leakage dose not considering the build up effect, calculated by using STAC8. It is clear that there are some build up effect in the SPring-8 beamline, but the effect is less than twice the dose calculated without considering the build up effect. However, the build up effect is obviously important in the SSRL beamline cases. This means that serious consequences may occur if the shielding

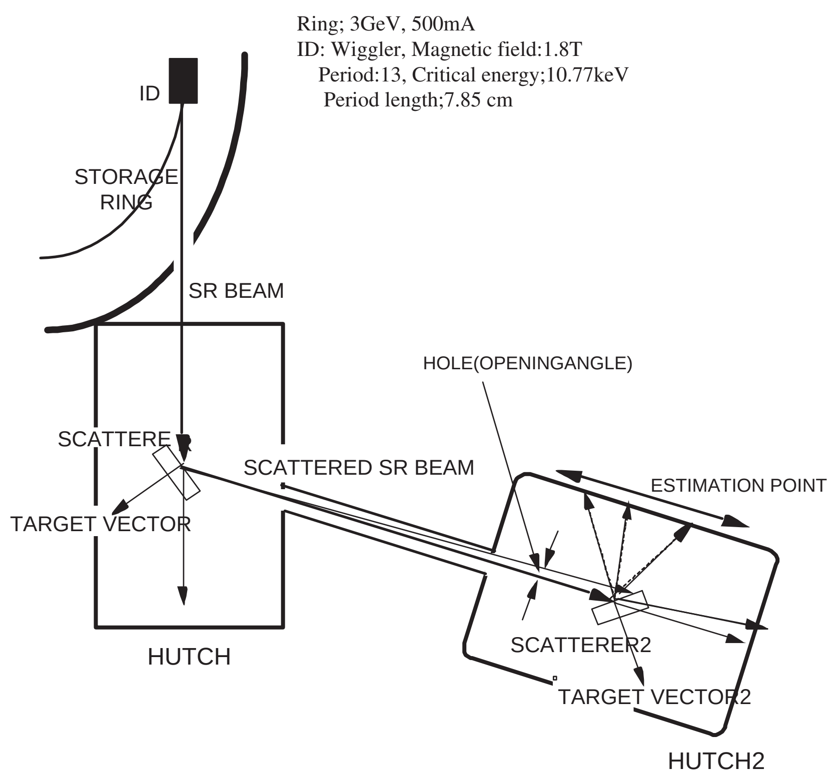

Fig. 4. Illustration of the SSRL BL-11 beamline with a branch beamline created using a mirror.

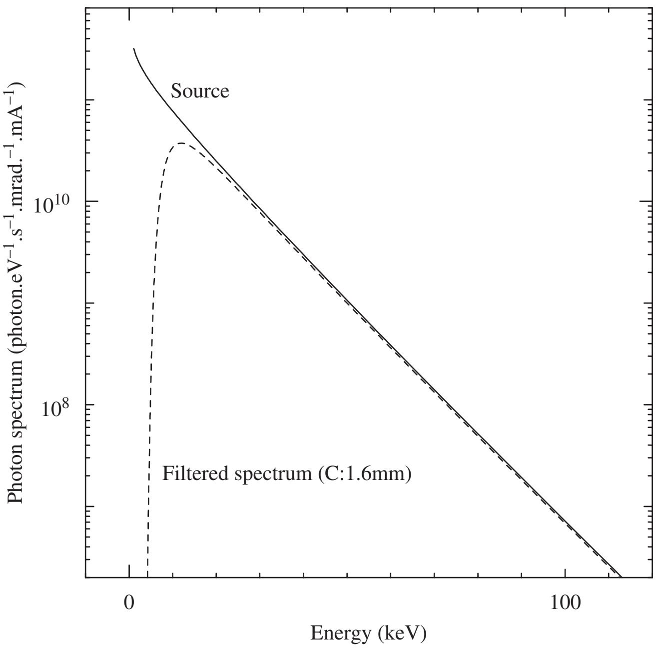

Fig. 5. Synchrotron radiation light source spectrum and spectrum filtered through graphite of 1.6 mm in thickness.

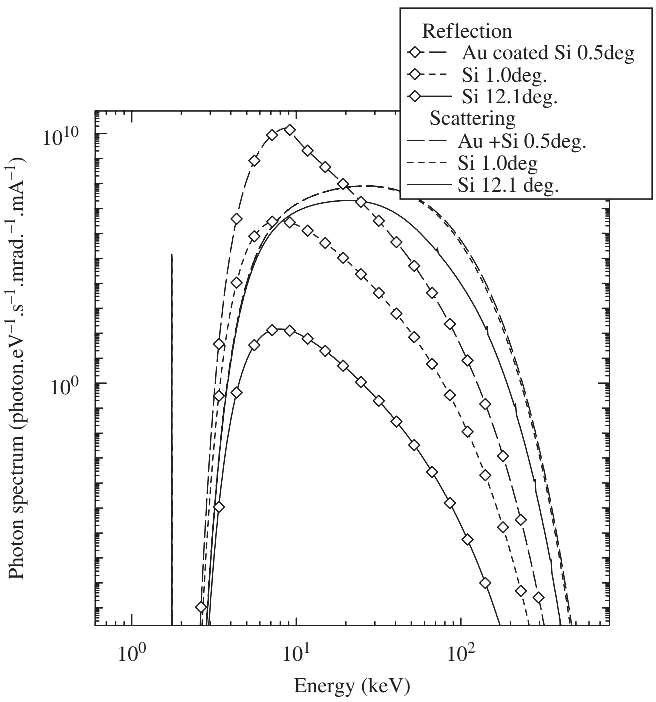

Fig. 6. Spectrum of specular reflected and scattered photons by the first scatterer in Fig. 7. Solid lines indicate the spectra from a silicon mirror with the glancing angle of 12.1°. Dashed lines are for the silicon mirror with the glancing angle of 1.0°, and dotted lines are for a gold coated silicon mirror with glancing angle of 0.5°. The aperture size which is defined by the beam transport pipe is 4.9 mrad. The lines with and without diamonds are the spectra of specular reflected and scattered photons, respectively.

designs of 3 GeV class beamlines are performed without considering the build up effect.

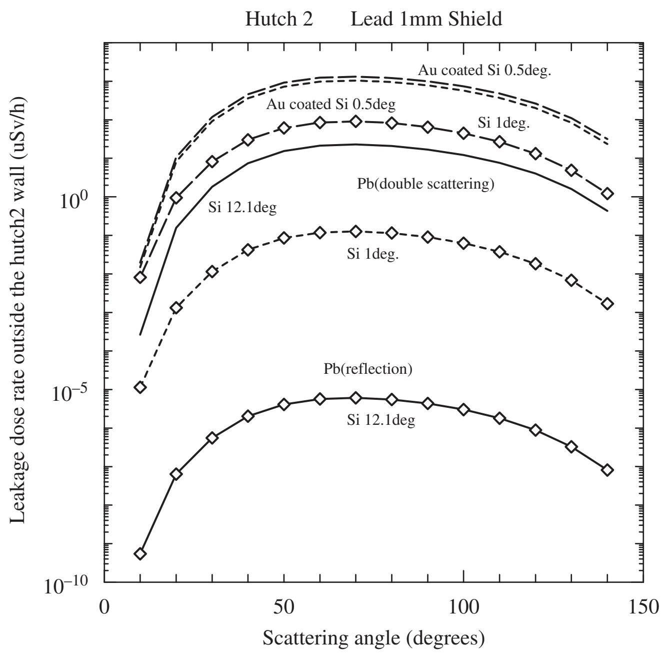

Fig. 7. Leakage dose outside the hutch 2 due to double scattering and due to specular reflected photons. The lines with and without diamonds indicate the leakage doses due to the specular reflected and double scattered photons.

2.4. *Double scattering photons*

Using a mirror, some beamlines are split to produce a branch beamline in order to perform synchrotron radiation experiments simultaneously or alternately. Fig. 4 is an illustration of the SSRL Bl-11 beamline with one branch beamline produced using a mirror. The spectrum of a synchrotron radiation beam filtered through graphite 1.6 mm in thickness is shown in Fig. 5. This beam hits the inclined first scatterer corresponding to the first mirror, and then specular reflected photons and scattered photons are collimated onto the second scatterer by the transport pipe. The leakage dose outside the hutch 2 due to the scattered photons of both the specular reflected and the scattered photons by second scatterer can be calculated accurately from the light source considering build up effect and polarization, by using STAC8. The specular reflected photons can be calculated based on the glancing angle and mirror material. Fig. 6 shows the specular reflected and scattered photon spectra using various materials for the mirror. The leakage dose distributions outside the hutch 2 due to photons specular reflected and scattered by each mirror material and the glancing angle are shown in Fig. 7 by using silicon scatterer 2 whose target angle inclines 89.9° and the shield wall of lead, 1 mm in thickness. The leakage dose due to the double scattering photons is dominant, as shown in this graph. The reason is that the scattered photons are dominant in the high energy regions in comparison with that of specular reflected photons, as shown in Fig. 6. The ratios of the maximum leakage dose due to the double scattering photons and maximum leakage due to specular reflected photons are indicated in Table 2 for each mirror material and glancing angle. In the table, the geometries and calculation configura-

Table 2
Ratio of the maximum leakage dose due to double scattering photons and that due to specular reflected photons

Mirror (material, glancing angle)	Ratio of maximum leakage dose (double scattering/specular reflection)		
	SLAC SSRL BL11	SPring-8 bending	SP8/SSRL
Silicon 12.1°	3.75E6	4.75E6	1.27
Silicon 1.0°	8.19E3	1.40E4	1.71
Gold coated Silicon 0.5°	1.45E1	2.32E1	1.60

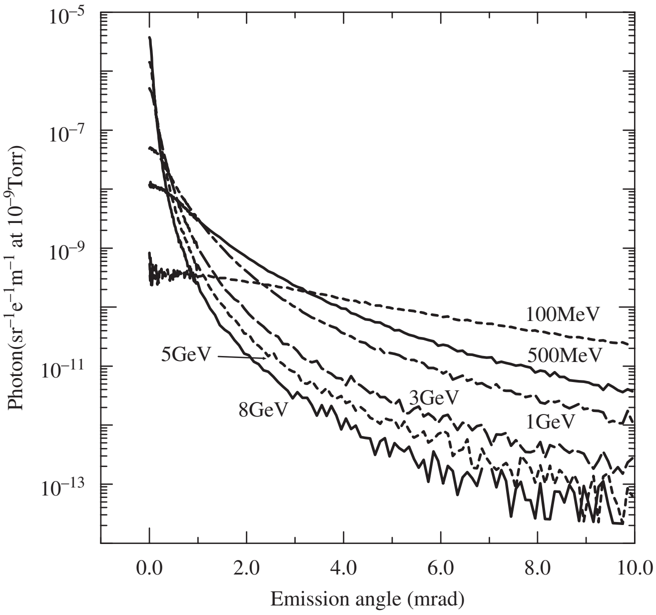

Fig. 8. Emission angle distribution of photons for various stored electron energies with path length of 1 m and gas pressure of 0.1 atm, allowing only a single interaction of the electrons.

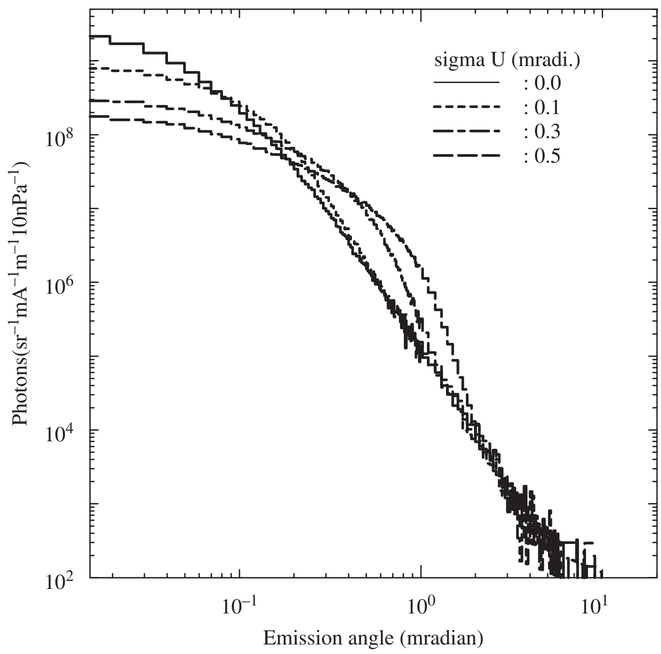

Fig. 9. Emission angle distribution of photons for various 8 GeV stored electron divergence distributions. Sigma U: 1 means the sigma of the Gaussian distribution of the divergence is one, and solid, dotted, dot-dashed, and dashed lines indicate U of 0.0, 0.1, 0.3, and 0.5, respectively.

tions are those of SSRL BL11, and "SPring-8 bending" means that the light source assumed the SPring-8 dipole magnet and others such as configurations assumed the same as SSRL BL-11 geometries and components. Table 2 shows that double scattering photons are the dominant consideration for the design of branch beamline shielding in all cases.

3. Distribution of gas bremsstrahlung

Information on gas bremsstrahlung intensity and its distribution is very important for synchrotron radiation beamline shielding. However, this intensity distribution has not been given much attention. In the case of a compact beamline, the distribution of gas bremsstrahlung has a critical impact on aspects of shielding design such as using a beam transport pipe. Therefore, dependence of the intensity distribution of gas bremsstrahlung on the stored electron beam conditions and magnetic field strength of insertion devices was investigated (Asano, 2002). As a result, it was clarified that the distribution of gas bremsstrahlung depends strongly on the stored electron beam divergence, and that the alternating magnetic field strength of the insertion device affects the intensity distribution. In addition to these influences, the dependence on the stored electron energy was investigated. The emission angle distributions of photons for stored electrons of various energies are shown in Fig. 8 by using the EGS4 (Nelson et al., 1985) Monte Carlo code. These simulations were performed without considering the stored electron beam divergence distributions or any fluctuations of the stored electrons. As shown in the figure, the gas bremsstrahlung due to 3 GeV electrons is more widely distributed than that of 8 GeV. Figs. 9 and 10 show the emission angle distributions as a function of the stored electron energy divergence distributions of 8 and 3 GeV stored electrons, respectively. In these cases, the parameter U is the sigma of the Gaussian distribution of the electron beam divergence. In these figures, the emission angle distributions of gas bremsstrahlung of 8 GeV electrons are sharper than that of 3 GeV. Besides, the emission angle distribution of 8 GeV electron beam is more

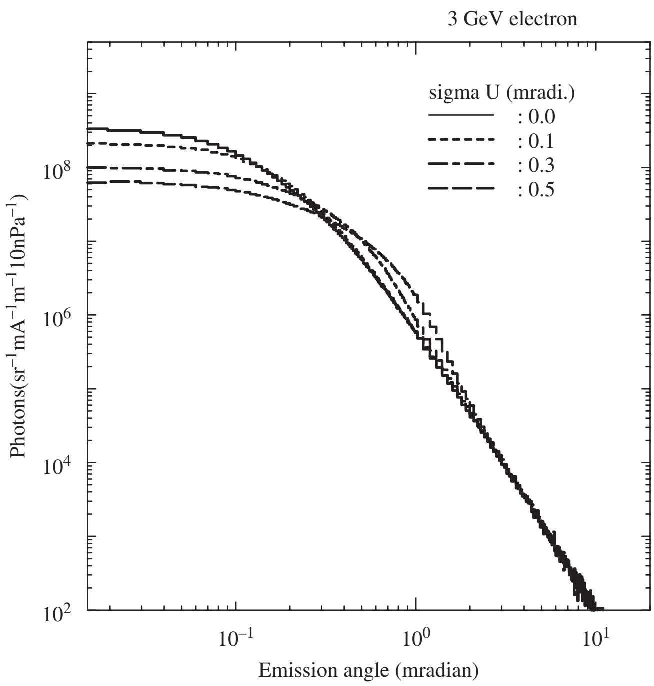

Fig. 10. Emission angle distribution of photons for various 3 GeV stored electron divergence distributions. Lines mean the same as in Fig. 8.

easily affected by the beam divergence distribution in comparison with that of 3 GeV case.

4. Conclusions

We investigated the differences between the intermediate and the high stored electron energy facilities with regard to the beamline shielding, using SLAC SSRL and SPring-8 as examples. As the results: (1) For the synchrotron radiation shielding, the build up effect is very important for an intermediate energy facility such as SSRL. (2) Double scattering photons have more effect than specular reflective photons on requirements of the branch beamline shielding. (3) For gas bremsstrahlung, the intensity distribution of intermediate facilities is wider, but the effect of the stored beam conditions is smaller than in an 8 GeV class facility.

References

Asano, Y., Sasamoto, N., 1994. Development of shielding design code of synchrotron radiation beamline. Radiat. Phys. Chem. 44.

Asano, Y., 2001. A study on radiation shielding and safety analysis for a synchrotron radiation beamline. JAERI-Research 2001–2006. JAERI (2001).

Asano, Y., Liu, J.C., 2002. Comparison of synchrotron radiation calculation between EGS4, FLUKA, PHOTON and STAC8. Proceedings of the 10th EGS4 Workshop on KEK Proceedings 2002–2018, Tukuba, SLAC-PUB-9507 (2002), pp. 48–54.

Asano, Y., 2002. Intensity distributions of gas bremsstrahlung depending on the stored beam conditions at SPring-8. Second Workshop of Radsynch ESRF France (2002).

Harima, Y., et al., 1984. Validity of the geometric-progression formula in approximating gamma ray build up factors. Nucl. Sci. Eng. 94.

Liu, J.C., Fasso, A., Prinz, A., Rokni, S., Asano, Y., 2005a. Comparison of synchrotron radiation calculations between analytic codes (STAC8, PHOTON) and Monte Carlo codes (FLUKA, EGS4). Radiat. Prot. Dosim. 116, 658–661.

Liu, J.C., Fasso A., Khater H., Prinz A., Rokni S., 2005b. Generic radiation safety design for SSRL synchrotron radiation beamlines, in this journal (2005).

Nelson, W.R., Hirayama, H., Rogers, D.W.O., 1985. The EGS4 code system, SLAC-265 (1985).

Prinz, A., et al., 2003. Private communication (2003).