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COMPARISON OF SYNCHROTRON RADIATION CALCULATION BETWEEN EGS4, FLUKA, PHOTON AND STAC8

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Abstract

Doses due to scattered synchrotron radiation were calculated, in the case of thin shield or without shield as well as with and without considering linear polarization effect, by using shielding design codes for synchrotron radiation beamlines (STAC8 and PHOTON) and Monte Carlo simulation codes (EGS4 and FLUKA). The comparison of results shows reasonably agreements between codes.

1. Introduction

With constructing and operating the third generation facilities such as SPring-8, however, high energy synchrotron radiation of extremely high intense is available, and high accuracy should be required in the shielding and safety design for the beamline of synchrotron radiation. Furthermore, the middle size facilities, such as CLS (Canadian Light Source), are now under construction and the optimum design of shielding is desired strongly to construct the beamline with safety and compact. It is necessary to verify the detailed evaluation technique. Therefore, taking the SPEAR3 ring bending magnet and BL11-3 wiggler beamlines of SSRL as the examples, the characteristics of the synchrotron radiation shielding design codes PHOTON[1] and STAC8[2] were investigated by comparing with Monte Carlo simulation codes EGS4[3],[4] and FLUKA[5].

2. Characteristics of the Codes

For the shielding calculation, a computational capacity of the typical problems of synchrotron radiation such as polarization effect and strong attenuation is required as well as the calculating accuracy. Consequently, EGS4 and FLUKA were chosen for the Monte Carlo simulation codes. On the other hand, usability and conservativeness are required for the design code, strongly. The PHOTON code excels at usability. However, the code underestimated doses outside the shield wall of the hutches in some cases. The code has been validly created for calculations of attenuation and scattering by filters by considering the isotropic Compton scattering process by the optical elements, the shielding effect without the buildup effect. However, PHOTON dose not consider the polarization effect, coherent scattering process, and self-shielding effect of scatterer. On the basis of the PHOTON code, the STAC8 code was developed in order to overcome the above disadvantages. STAC8 is applicable to the calculations of the radiation emitted from the insertion devices including undulator and it considers the effect of linear polarization of photons on the scattering process and the angular dependence of the coherent and incoherent scattering. The buildup effect and self-shielding effect of inclined scatterer were also introduced into STAC8.

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Table 1 The key parameters of the SPEAR3 beamlines of SSRL at SLAC

		SLM	BL11-3
Light source		Bending magnet	Wiggler
Storage ring energy		3 GeV	3 GeV
Peak strength of magnetic field		1.28 T	1.8 T
Period (Bending radius)		7.85 m	0.175 m
Critical energy		7.662 keV	10.77 keV
Opening angle	Horizontal	3.5 mradian	1 mradian
Permanent filters	C	-	1.6 mm
Scatterer	Si (T)	3.8 mm	3.0 mm
	(R)	50 mm	50 mm
Shield wall	SiO_2	3.09 mm	-
Inclined angle of scatterer		9 degrees	24.2 degrees
Distance from scatterer		1.0 m	0.42 m
Maximum stored beam current		500 mA	
Polarization vector is on the horizontal plane			

3. Calculations and Discussions

The key parameters of synchrotron radiation sources of SPEAR3 SLM bending magnet and BL-11 wiggler are summarized in Table 1, including the shield parameters and the scatterer conditions. The geometry of calculations for SLM bending magnet is illustrated in Fig. 1. The target of silicon mirror was 9 degrees inclined, except for the calculations with PHOTON which can only use a cylinder as the target. Two thin silicon-oxide plates as the glass window were set as the shield wall. The source spectra of synchrotron radiation from the SPEAR3 bending magnet, which were calculated by PHOTON and STAC8, are shown in Fig.2, comparing to the results from the theoretical formula and the source sampling spectrum of FLUKA. The EGS4 code employed the source spectrum of STAC8. The dose distributions at the distance of 1 m away from the beam axis, with and without the considering polarization effect, are shown in Fig.3. As shown in this figure, both the results with and without considering the polarization effect of EGS4 closely agree with the FLUKA, except for a slightly difference at Z=0 with considering the polarization effect. The reason of the slight difference is the mismatched estimation points between the calculations of the codes. The sharp dip of STAC8 calculation at Z=0 is due to the consideration without multi-scattering. The STAC8 calculations overestimate by a factor of two to 10 in comparison with the Monte Carlo codes calculations.

In addition to the case of Fig. 3, inclined and cylinder mirror geometries were calculated to compare with the PHOTON calculations. The PHOTON code can calculate only the geometry of the cylindrical scatterer without self-shielding and it has only isotropic scattering. Therefore, the cylindrical geometry was also calculated by STAC8, and the results are shown in Fig.4 as a function of scattering angle, comparing to the FULKA results with and without the consideration of polarization effect. In the figure, the PHOTON result is close to the backscattered doses in the STAC8 calculations. However, the PHOTON dose is lower than the maximum dose of FLUKA in an inclined scatterer.

The calculated photon spectra at the scattered direction of 90^o from FLUKA, STAC8, and PHOTON are shown in Fig.5 with and without considering polarization effect and for various geometries of scatterer. As shown in the figure, it is evident that the overestimation of STAC8 in comparison with FLUKA is due to low energy photons. To confirm this overestimation, the cases of the monoenergetic photon injection into the scatterer were calculated using EGS4 and STAC8. The results in Table 2 indicates that the lower energy photon increases the level of the overestimation of STAC8. This fact does not contradict with the fact that that the STAC8 calculations for SPring-8 beamlines closely agree with the experiments with thick shield [6], in which case the low-energy photons do not exist outside the shield.

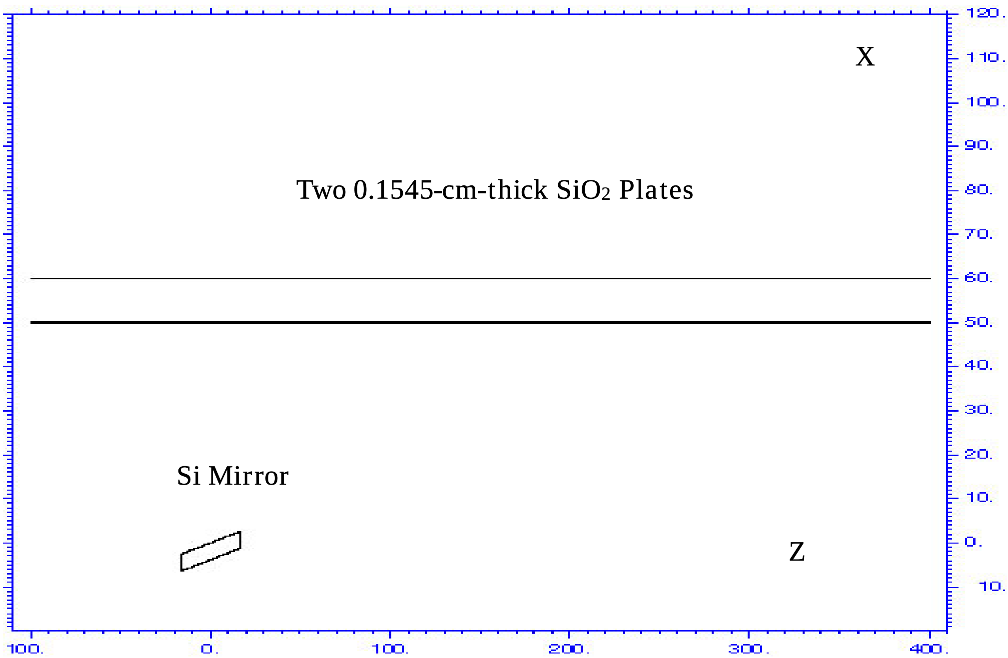

Fig 1. Geometry for the simulation of synchrotron radiation, emitted from the SPEAR3 bending magnet, hitting the Si mirror. The mirror is 9 degrees inclined relative to the beam direction (i.e., +Z axis). Polarization vector points toward +X. The shielding is two SiO_2 plates, parallel to the Z axis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

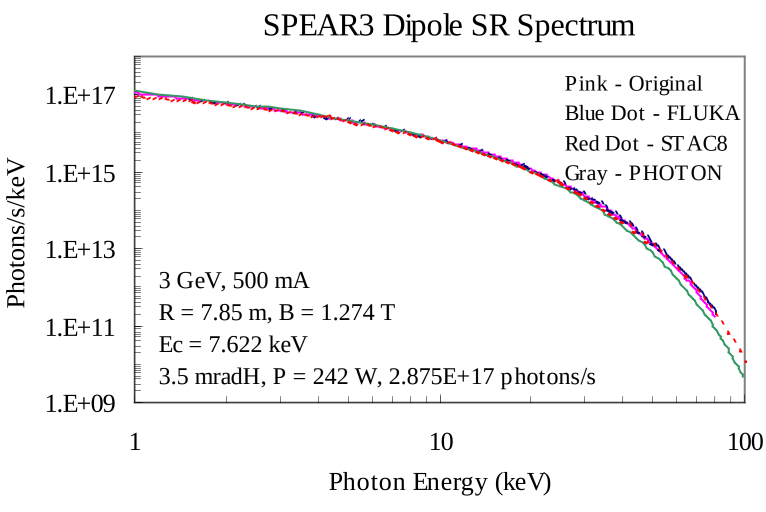

Figure 2. Comparison of SPEAR3 bending magnet SR spectra from the formula, FLUKA-sampled spectrum, and those given by PHOTON and STAC8 codes. The pink line is the spectrum given by the theoretical formula, red-dot line is STAC8, gray is PHOTON, and blue dot line is FLUKA.

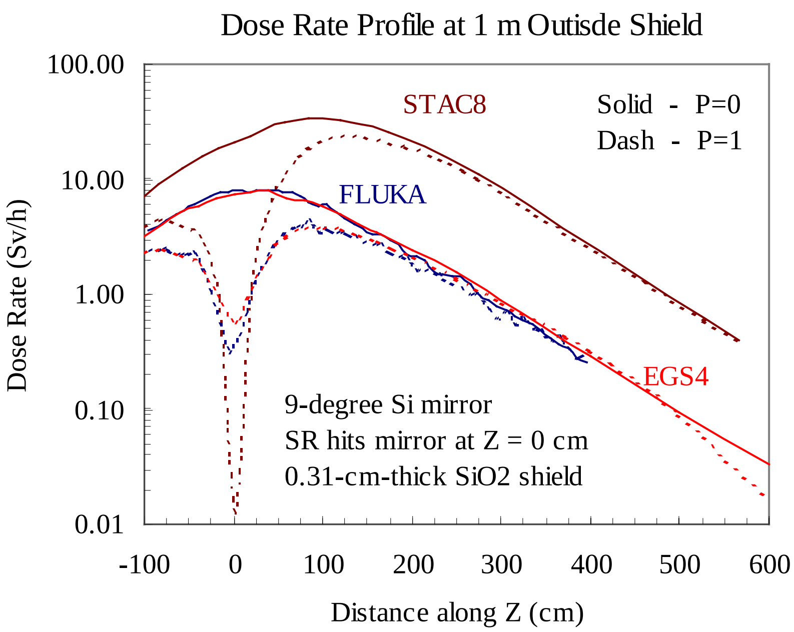

Figure 3. Comparison of photon dose equivalent rate profile at **1 m** away, parallel to Z-axis, outside the SiO_2 shields. Calculations using STAC8 (ICRP51 ambient dose equivalent), FLUKA (ICRP74 Effective Dose, worst geometry) and EGS4 (ICRP74 Effective Dose, AP geometry) with and without linear polarization (P=1 and P=0, respectively) are shown. FLUKA calculations also indicate a difference < 20% between Effective Dose and Ambient Dose Equivalent.

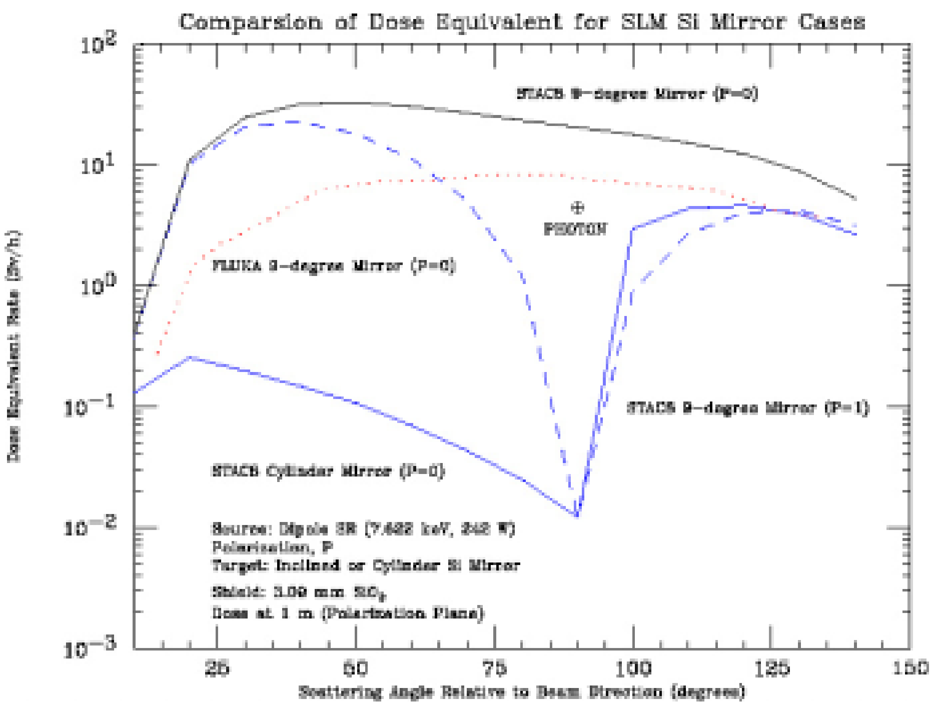

Figure 4. Comparison of dose equivalent rates, as a function of scattering angle, calculated using FLUKA, STAC8, and PHOTON codes for various mirror (inclined or cylinder) and polarization P conditions. The blue solid line shows the results of the cylinder geometry of STAC8 without polarization effect. The cross indicates the PHOTON calculation. Black solid and red dot lines are STAC8 and FLUKA with 9 degrees inclined target and without polarization effect. The dashed line is the SATC8 calculation with polarization effect.

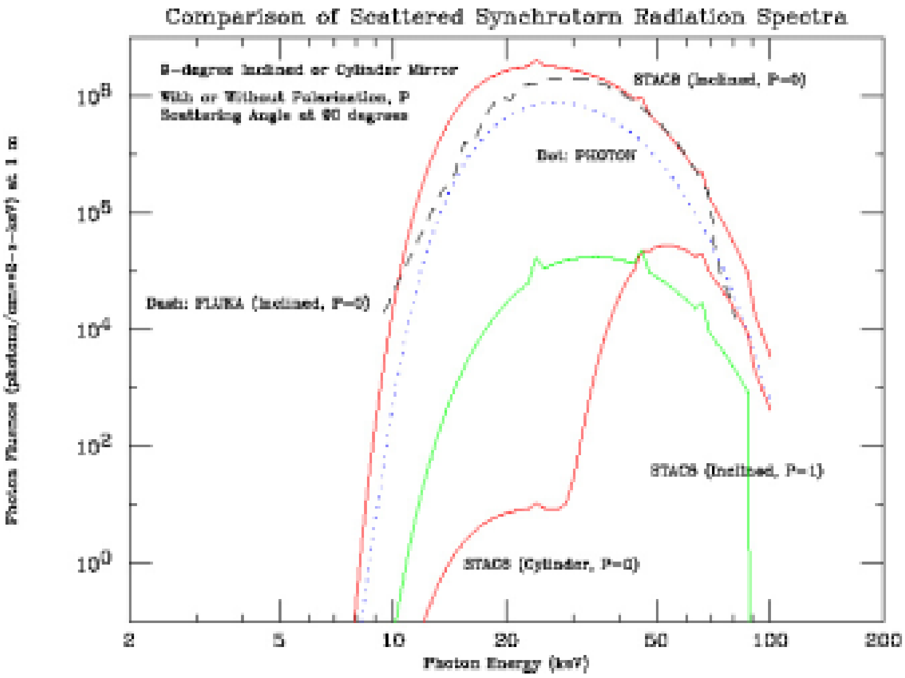

Figure 5. Comparison of 90-degrees scattered synchrotron radiation spectra, calculated using the FLUKA, STAC8, and PHOTON codes for various scatterer (inclined or cylinder) and polarization conditions. In the figure, inclined means the calculation with inclined scatterer, and P=1 means with considering polarization effect, P=0 without polarization.

Table 2 Comparison of dose rate due to injection of mono-energy photons between EGS4 and STAC8

Mono-energy	EGS4 (Sv/h)	STAC8 (Sv/h)	ratio (EGS4/STAC8)
20keV	0.211	1.01	0.19
40keV	0.126	0.322	0.39
58keV	0.0192	0.0310	0.62

For the BL11-3 wiggler beamline, the calculations were performed with and without the considering polarization effect in a similar way. The spectra of the wiggler, after the 1.6-mm thick carbon filter, are shown in Fig.6,. The scatterer is 24.2-degree inclined and the calculation results in Fig.7 shows the same tendency as the case of SPEAR 3 bending magnet.

4. Conclusion

In the case of thin shield or without shield, the dose distributions due to scattered synchrotron radiation of SPEAR 3 bending magnet and BL-11 wiggler beamlines at SLAC were simulated and calculated with Monte Carlo simulation codes EGS4 and FLUKA, and shielding design codes, PHOTON and STAC8. Their results are compared with each other. The EGS4 simulations show close agreements with the FLUKA in both cases of with and without linear polarization effect. The STAC8 calculations show clearly the distinctive features of the dose distributions, with and without considering linear polarization. Owing to the low energy photons, however, the absolute values of STAC8 overestimated by about 2 to 10 times in comparison with Monte Carlo simulations. In the case of cylindrical scatterer, the PHOTON calculation agrees with the maximum dose of the STAC8 calculation. However, it may be underestimated if the calculaitons are employed in the case of an inclined scatterer. There is no problem, however, for shielding design calculation using STAC8 in SPring-8 with thick shield. The effort to eliminate the overestimation is underway.

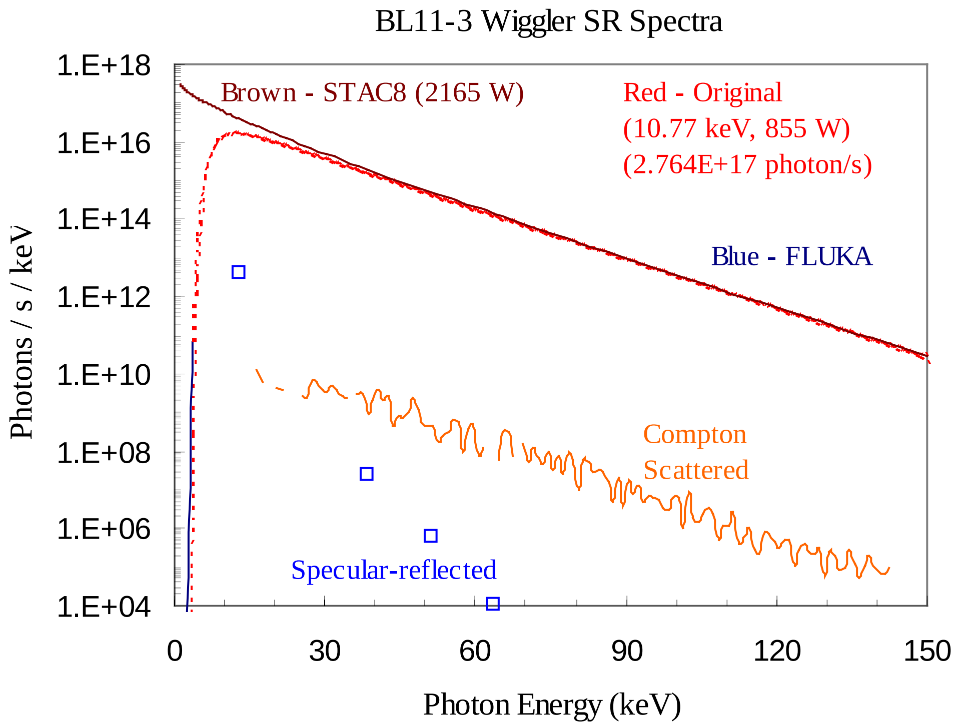

Figure 6. Comparison of SPEAR3 BL11-3 wiggler spectra from STAC8, FLUKA and the original formula. The wiggler has a period length of 17.5 cm, 13 periods, 1.8 T, a vertical angle of 0.16 mrad limited by Cu aperture, a 1.6-mm carbon filter and horizontal acceptance of 1 mrad.

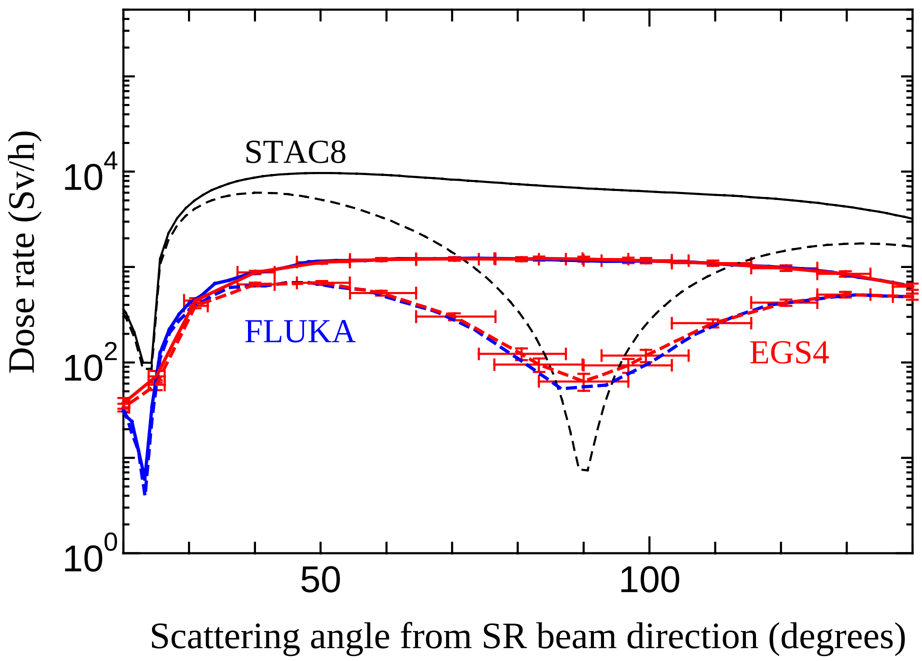

Fig.7 Comparison of dose calculations by suing EGS4, FLUKA and STAC8 for BL11-3 wiggler beamline of SLAC. Black dotted and solid ines indicate the results of STAC8 with and without polarization and red dotted and solid with error bars are EGS4 with and without polarization, blue dotted and solid lines are FLUKA with and without polarization.

Acknowledgment

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References

(1) D. Chapman, "PHOTON; A user's manual" BNL40822 (1988).

(2) Y. Asano and N. Sasamoto "Development of Shielding design code for synchrotron radiation beamline", Radiat Phys. Chem. **44**, 133 (1994).

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

(4) Y. Namito, and H. Hirayama, "LSCAT: Low-Energy Photon-Scattering expansion for the EGS4 code", KEK Internal 2000-3 (2000).

(5) A. Fasso, et al.,"FLUKA-99 manual", http://fluka.web.cern.ch/fluka CERN (1999).

(6) Y. Asano, "A study on radiation shielding and safety analysis for a synchrotron radiation beamline", JAERI-Research 2001-006 (2001).