NSLS-II Beamline Radiation Shielding Calculation

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Abstract

National Synchrotron Light Source II (NSLS-II) is a new state-of-the-art 3rd generation synchrotron. The NSLS-II facility is shielded up to 3 GeV electron beam energy at 500 mA. When the gas bremsstrahlung (GB) is scattered by the beamline components in the first optical enclosure (FOE), the scattered radiation will pose additional radiation hazard (bypassing PGB collimators and stops) and challenge the FOE shielding. The SGB radiation hazard can be mitigated by supplementary shielding or with an exclusion zone downstream of the FOE.

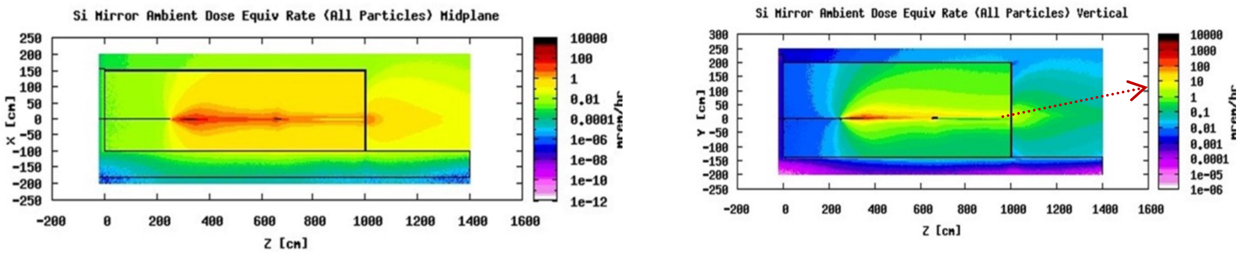
Figure 1. National Synchrotron Light Source II (NSLS-II)

1. Introduction

A synchrotron radiation (SR) beamline takes the SR light from an insertion device or a bending magnet in the ring through an optical hutch immediately downstream of the ratchet wall into one or more experimental stations. In addition to the low-energy, high-power SR, the high-energy, low-power gas bremsstrahlung (GB, photons from stored electron beam interacting with residual air inside ring chamber) also channels into the beamline. The SR hazard is generally mitigated with hutch wall shielding. The GB hazard needs to be mitigated with safety components (i.e.,collimators, hutch shutters, and beam stop) along the central beamline and local shielding around the optical components that are hit by GB.

FLUKA [1] Monte Carlo calculations have been performed to generate secondary bremsstrahlung scattering profile from a mirror, monochromator and a copper cube at the beamlines. At NSLS-II, the GB power is assumed to be 17 µW from 3GeV, 500 mA electron beam, with a 15.5 m straight source at 1 ntorr vacuum condition [2, 3, 4, 5]. In FLUKA simulation, the FOE is 10 m long, terminated by a 5 cm thick lead (Pb) downstream wall. The lateral wall is located 1.5 m from the beam axis and is constructed of 18 mm Pb. The roof of the enclosure is located 2.0 m above the beam plane and is made of 6 mm Pb. The target consists of a silicon (Si) mirror 3 cm × 4 cm × 100 cm at 0.25 degree incidence angle, located 3.5 m from upstream wall. The bremsstrahlung stop consists of a 6 cm diameter tungsten (W) cylinder, 20 cm long, located 3.04 m downstream of the Si mirror.

Figure 2 shows the dose rate pattern on horizontal beam plane and vertical beam plane when 17 µW GB is incident on a 1 meter long mirror. The GB has a nearly 1/k energy spectrum (with k denoted as the photon energy), which extends essentially from zero up to the kinetic energy of the stored electrons (3 GeV at NSLS-II) [6].



(a) (b)

Figure 2. Dose Rate from GB Scattering on a 1-m-long Si Mirror

As shown in Figure 2, the dose rate on the lateral wall and roof is acceptable (maximum dose rate is ~ 0.05 mrem/h). However the dose rate on downstream wall goes up to ~ 5 mrem/h on contact. An exclusion zone (~7 m downstream of FOE) will solve the problem. However most beamlines prefer to stop radiation in the FOE, so the required shielding is analyzed and discussed in this paper.

2. Shields needed to intercept SGB in FOE

A series of FLUKA calculations were performed to study the dose rate at different angles, after installing Pb shields in FOE. Figure 3 shows the dose rates on the white beam enclosure downstream wall, as a function of local shield location and thickness. The SGB was located at different z locations in FOE: 450 cm, 600 cm, 750 cm and 900 cm (distance from the FOE upstream wall). The highest dose rate occurs when the SGB shield is located at z of 900 cm (1 meter upstream of the FOE downstream wall). As shown in Figure 3, for downstream lateral location between 50 cm to 100 cm from the beam, 5 cm of additional Pb are needed. This corresponds to between 4 degree and 8 degree scattering angle from the mirror. Between 25 cm and 50 cm, 7 cm Pb is needed, which corresponds to between 2 degree and 4 degree. Below 25 cm (equivalent to about 2 degree), 9 cm Pb is needed. For W, the corresponding values are 4 cm, 5 cm and 6 cm (~ 2/3 of Pb thickness).

Similar calculations were performed for 1” cubic copper scatterer and 100 mm long Si monochromator. Based on the calculations, in order to mitigate the radiation on FOE downstream wall to < 0.05 mrem/h, the supplemental shielding needs to shield up to 8 degree for a 1-meter long Si mirror or the Cu scatterer, while up to 4 degree needs to be shielded for a 100 mm long Si monochromator. The recommended shields are listed in Table 1.

The complex dependence on shield location should be noted. It is recommended that the SGB shields should be installed at least 1 meter upstream of the FOE downstream wall. In the previous scenarios, all the neutrons are created from the shields and Pb is a poor attenuator of neutrons. With the deployment of SGB shielding located some distance upstream of the downstream wall, the neutrons are produced further and the distance help mitigate the neutron dose. Note that in the simulation geometry, the primary bremsstrahlung stop shields up to 0.56 degree.

Table 1. Recommended SGB shields for a variety of scatterers

Scattering angles/ Scatterers	**>8 degree**	**4 to 8 degree**	**2 to 4 degree**	**<2 degree**
1 m long Si mirror	-	5 cm Pb	7 cm Pb	9 cm Pb
0.1 m long Si monochromator	-	-	5 cm Pb	7 cm Pb
Copper (~1” cube)	-	5 cm Pb	7 cm Pb	9 cm Pb

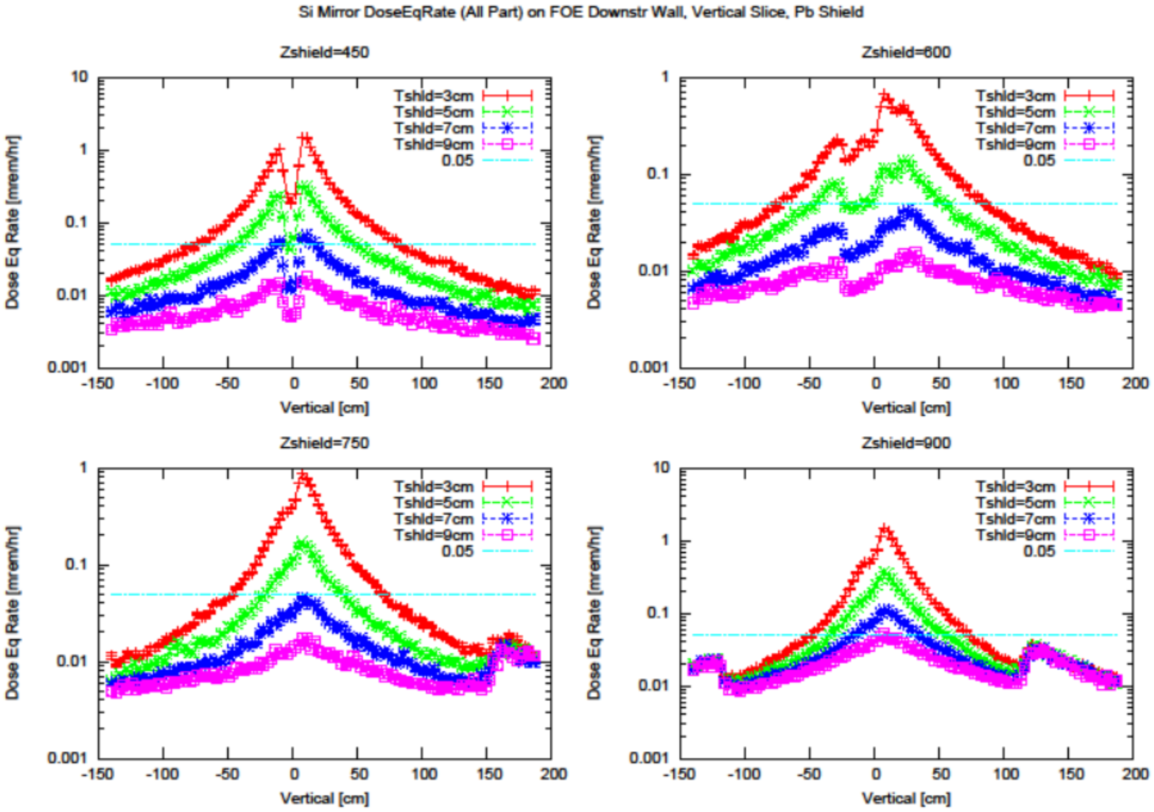


Figure 3: Dose rates on the white beam enclosure downstream wall, as a function of local shield location and thickness. The scatter is a 1 meter long Si mirror.

3. Implementation at different beamlines

Different scatterers were analyzed, including masks, slits, white beam stop, mirror and monochromator. For short scatterers (i.e. masks or white beam stops), a collimator or stop immediately downstream will mitigate the scattered radiation (the collimator shields up to 8 degree). Figure 4 shows the case of white beam stop immediately followed by a GB stop (XPD beamline). As shown in Figure 4, the SGB is well stopped by the GB stop and the dose rate on FOE downstream wall is minimal.

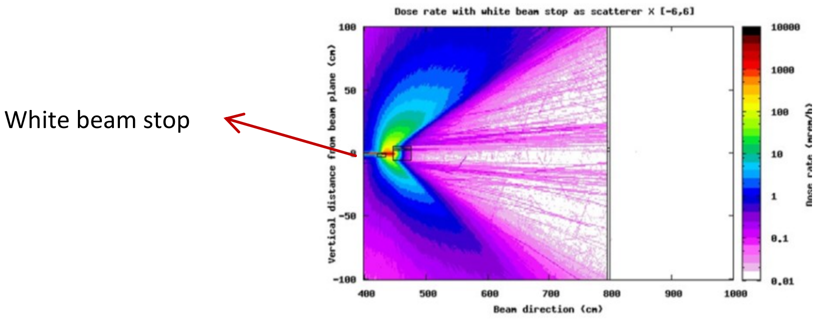
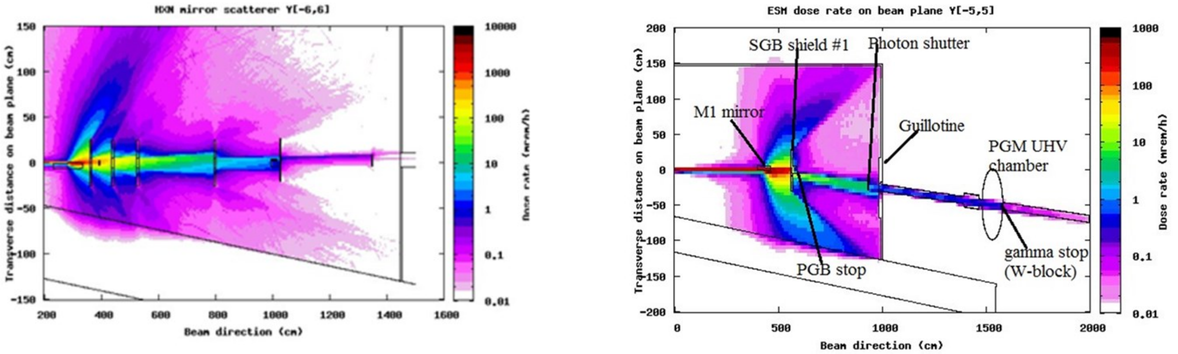


Figure 4. White beam stop immediately followed by a GB stop (XPD beamline)

For long scatterers (i.e. mirror), the 8 degree fan downstream of the long optical component becomes enormous. In this case the SGB shadow walls can be planned and installed. Figure 5 shows the shielding designs for a 1 meter long Si mirror scatterer (HXN and ESM beamlines). As shown in Figure 5, HXN (a) used a graded approach to shield 8 degree, 4 degree and 2 degree fans from the scatterer. For ESM (a soft Xray beamline) (b), one SGB shadow wall blocks the scattered radiation from the mirror up to 8 degree. A string of SGB leaks out from the aperture, which is blocked by a gamma stop at the downstream chamber.



(a) (b)

Figure 5. SGB Shields for Long Optical Components

4. Conclusions

Simulations show that significant amount of scattered bremsstrahlung is created when the primary bremsstrahlung is incident on substantial white beam components. Two approaches can be used to manage the secondary bremsstrahlung: the use of supplementary shielding or an exclusion area.

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