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CHX 11ID Radiation Shielding Analysis

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11-ID CHX Beamline Radiation Shielding Analysis	

1. Introduction:

The radiation shielding analysis of Coherent Hard X-ray Beamline (CHX, 11 ID) at 500 mA is documented in this technical note, including Gas Bremsstrahlung (GB) and Synchrotron Radiation (SR). Figure 1 shows the layout of CHX, which uses an in vacuum undulator (IVU20) beam line.

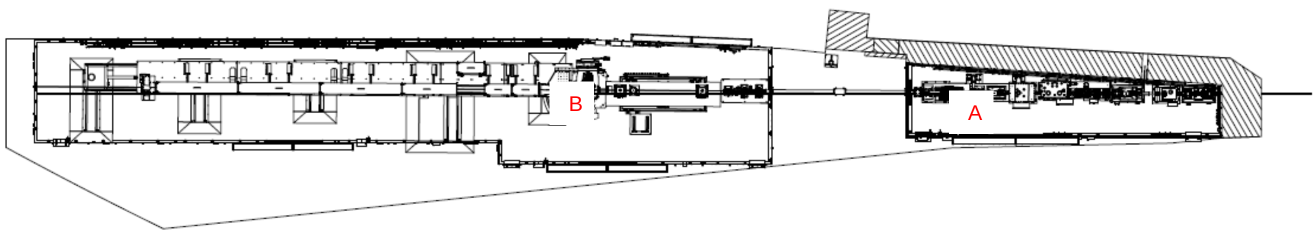

Figure 1 CHX layout

2. GB Shielding Calculation

For the evaluation of the GB shielding requirements, the undulator source is assumed to have a 15.5-m-long air section at 10^{-9} torr. The FLUKA results are normalized to the power of 17 µW, which is the GB source for 3 GeV, 500 mA electron beams at 1 ntorr of Storage Ring Vacuum [1]. The First Optical Enclosure (FOE) shielding is dominated by GB. The FOE lateral panel is made of 18 mm Pb, roof 6 mm Pb and downstream wall 50 mm Pb. As shown in Figure 2, the FLUKA calculation was done for three main scattering targets: fixed mask, mirror and white beam stop. Based on the calculation, the dose rates on the lateral wall and roof are less than 0.05 mrem/h from all scattering targets with current FOE shielding. The dose rate on beam plane, especially on FOE downstream wall is analyzed in this note.

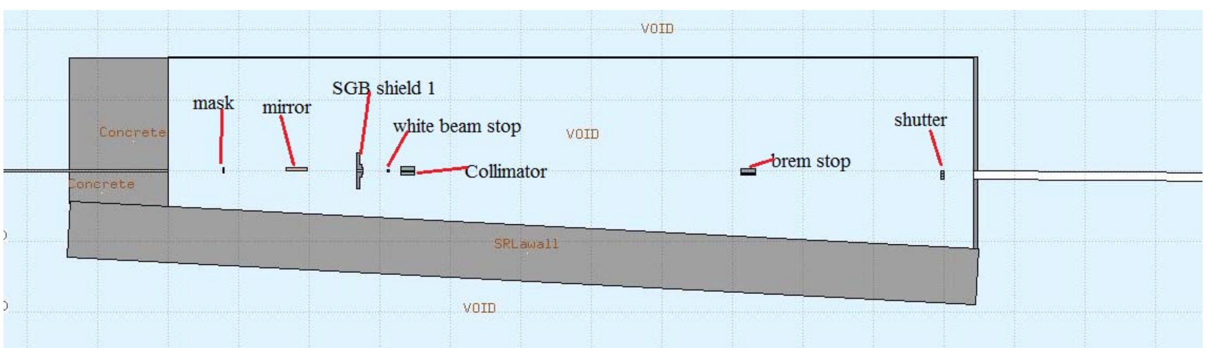

Figure 2 Horizontal cut of CHX FLUKA geometry

The objects in the simulation from upstream to downstream are: Fixed mask, Mirror, SGB shield 1, white beam stop, collimator, bremsstrahlung stop and photon shutters. The Z location, dimensions and material of the main components are listed in Table 1.

Table 1 Z locations and dimensions of main scatterers and shields

Scatterers	Upstream Z location (Distance from straight section center)	Dimensions	Material
Fixed mask	2635 cm	7.6 cm × 7.6 cm × 2.54 cm thick (aperture: 3.9 mm × 3.9 mm)	Copper
Mirror	2724.9 cm	5 cm × 5 cm × 30 cm Long (rotated at 0.18 degree)	Silicon
White beam stop	2868.35 cm	1” cubic (optimum target)	Copper
Shields	Center Z location (Distance from straight section center)	Dimensions	
SGB shield 1	2825 cm	First layer: 50 cm × 50 cm × 5 cm thick Second layer: 17 cm × 17 cm × 2 cm thick Third layer: 8.7 cm × 8.7 cm × 2 cm thick (aperture: 2.7 cm × 2.1 cm)	Lead
Collimator	2887.5 cm	11 cm W × 9 cm H × 20 cm Thick (aperture: 1.92 cm × 0.8 cm)	Tungsten
Bremsstrahlung stop	3370 cm	9.5 cm W × 7.4 cm H × 20 cm thick (aperture: 1.5 cm ×1.5 cm)	Tungsten
Shutter	3653.1 cm	12.5 cm W × 15 cm H × 3.8 cm thick (aperture: 40 mm × 25 mm)	Tungsten
Second Bremsstrahlung stop at end of Hutch B	6881 cm	30.5 cm × 30.5 cm × 5 cm thick	Lead

2.1 Fixed mask as scattering target

The CHX fixed mask has a minimum aperture size of 3.9 mm × 3.9 mm, located ~ 1 meter upstream of the mirror. The target simulated in FLUKA is a 1” long copper target (optimum length) with a 3.9 mm × 3.9 mm aperture.

The FLUKA simulation was done in a conservative approach for mask scatterer: GB is uniformly spread along Z in a 0.17 mrad cone (in reality GB is peaked around center). Two scenarios were simulated: Shutter A (in hutch A) open and shutter A closed. The FLUKA simulations were done with SGB shield 1 and SGB stop (at end of Hutch B) installed unless specifically noted.

2.1.1 Shutter A closed, Fixed mask scatterer

Figure 3 shows the dose rate on beam plane. On the downstream wall of FOE, it is seen the dose rate is < 0.5 mrem/h on contact and decrease to < 0.05 mrem/h at 30 cm.

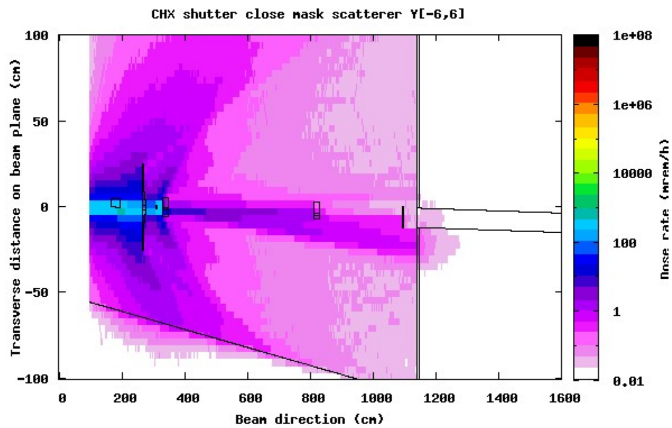

Figure 3 Fixed Mask scatterer, dose rate on beam plane, shutter A CLOSED

2.1.2 Shutter A open, Fixed mask scatterer

When shutter A is open, hutch B is unoccupied. The dose rates downstream of FOE and hutch B are analyzed.

Figure 4 shows the dose rate with “shutter open” scenario. On the downstream wall of FOE, the dose rate is < 0.5 mrem/h on contact and decrease to < 0.1 mrem/h at 30 cm (<0.05 mrem/h at 60 cm). Note the assumption is conservative (GB uniformly spread along Z in a 0.17 mrad cone) and the mask is simulated with optimum length and minimum aperture. In practice the dose rate could be lower.

The dose rate downstream of Hutch B is < 0.05 mrem/h with additional 5 cm secondary bremsstrahlung stop at the end of Hutch B.

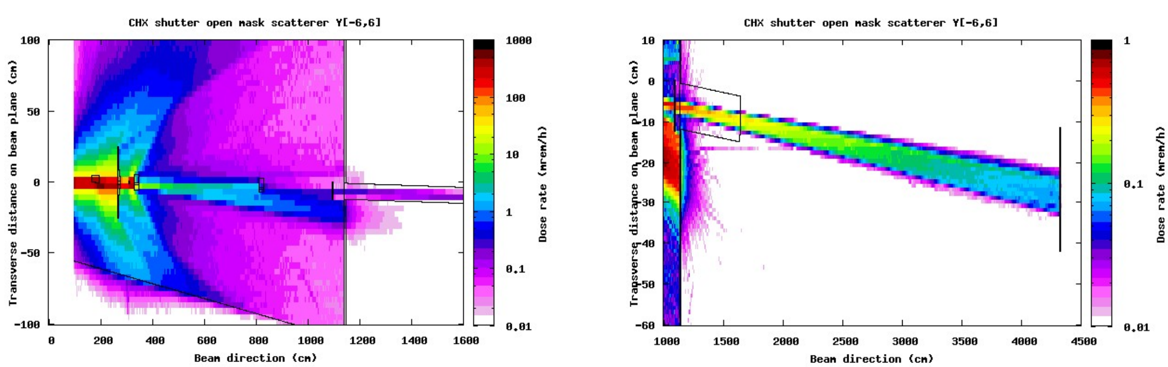

Figure 4 Fixed Mask scatterer, dose rate on beam plane, shutter A OPEN

2.2 Mirror as scattering target

CHX has a 5 cm × 5 cm × 30 cm Long (rotated at 0.18 degree) Silicon mirror coated with Rhodium, kicking beam inboard. The dose rates on beam plane are plotted for “Shutter Open” and “Shutter Closed” scenarios for mirror scatterer.

2.2.1 Shutter A closed, Mirror scatterer

Figure 5 shows the dose rate on beam plane. On the downstream wall of FOE, it is seen the dose rate is < 0.5 mrem/h on contact and decrease to < 0.05 mrem/h at 30 cm.

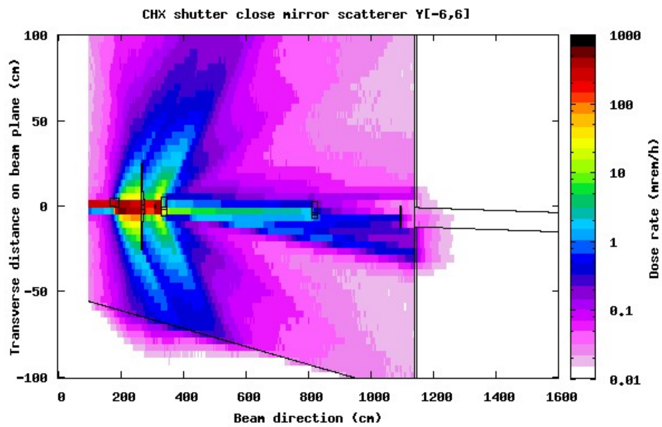

Figure 5 Mirror scatterer, dose rate on beam plane, shutter CLOSED

2.2.2 Shutter A open, Mirror scatterer

Figure 6 shows the dose rate with “shutter open” scenario. On the downstream wall of FOE, the dose rate is < 0.5 mrem/h on contact and decrease to < 0.05 mrem/h at 30 cm. The dose rate downstream of Hutch B is < 0.05 mrem/h with additional 5 cm secondary bremsstrahlung stop installed at the end of Hutch B.

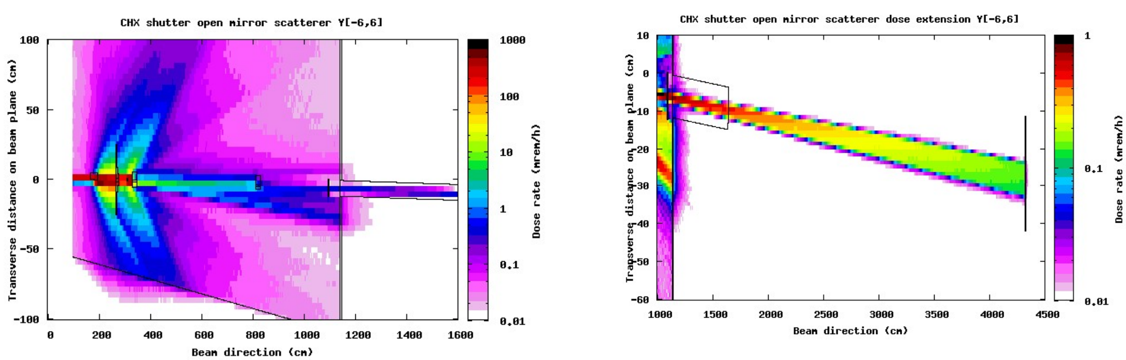

Figure 6 Mirror as scatterer, dose rate on beam plane with shutter OPEN

2.3 White beam stop as scattering target

White beam stop is simulated by a 1” copper cubic in the FLUKA calculation. Figure 7 shows the dose rate from white beam stop scatterer on beam plane.

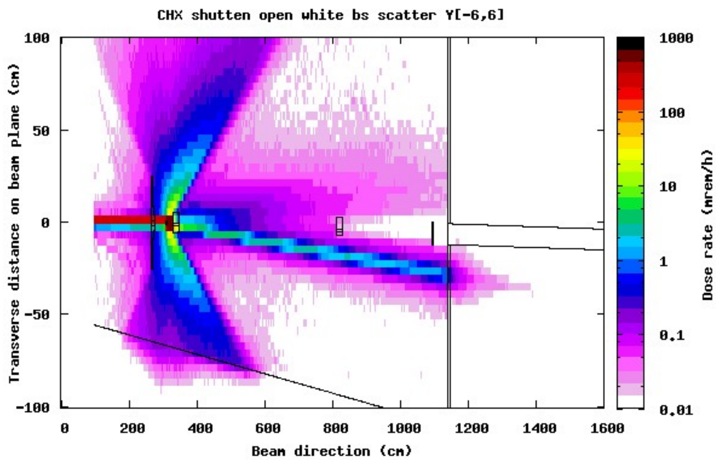

Figure 7 White beam stop scatterer, dose rate on beam plane with shutter OPEN

The white beam stop is immediately followed by a bremsstrahlung stop, so the dose rate on downstream wall is acceptable during both “shutter open” and “shutter closed” scenerio. The dose rate is < 0.5 mrem/h on contact and decrease to < 0.1 mrem/h at 30 cm (<0.05 mrem/h at 60 cm). Considering mirror is “in” during most time (full power GB will NOT stop at white beam stop), this dose level is acceptable.

3. SR Shielding Calculation

The CHX beamline is an IVU 20 source and the source parameters are listed in Table 1.

Table 1 Source Parameters for IVU 20 [2].

Source	Max. source opening	No. Of periods	Max. B_{eff} (T)	Period (mm)	E_c (keV)	Total power (kW)
IVU 20	1.0 mrad-H	148	1.03	20	6.65	9.4

3.1 FOE wall / roof for white beam

The FOE shielding is dominated by GB. The dose rate from SR is negligible on lateral wall, roof and downstream wall with current FOE shielding.

3.2 Transport pipe and Hutch B

The SR energy in transport pipe and hutch B is limited by Rh coated mirror with cut-off energy at 20 keV. Table 2 lists the photon spectrum transmitted to transport pipe and hutch B.

Table 2 Photon sources in transport pipe and hutch B [3] [4]

Energy (keV)	BW (keV)	Photons/sec
1.6	0.0107	2.00E+16
3.2	0.0107	1.51E+16
4.8	0.0107	9.50E+15
17.6	0.0107	4.57E+14

The transport pipe is wrapped by 3 mm Pb and hutch B is shielded by 6 mm Stainless steel. The dose rate outside of shielding is negligible (< 0.001 mrem/h) from CHX monochromatic beam.

4. 50 mA commissioning analysis

This session analyzes whether an exclusion zone is needed for 50 mA commissioning if the SGB shields are not in place (SGB shield 1 and second Bremsstrahlung stop at end of Hutch B in Table 1). Figure 8 shows the 2-D dose rate at 50 mA without SGB shields for mirror scatterer. In FLUKA simulation, the material of SGB shields was changed to air. Figure 8 (right) shows the 1-D dose on FOE downstream wall without SGB shields at 50 mA. The dose rate on FOE downstream wall is < 0.02 mrem/h (the middle peak is contained in pipe).

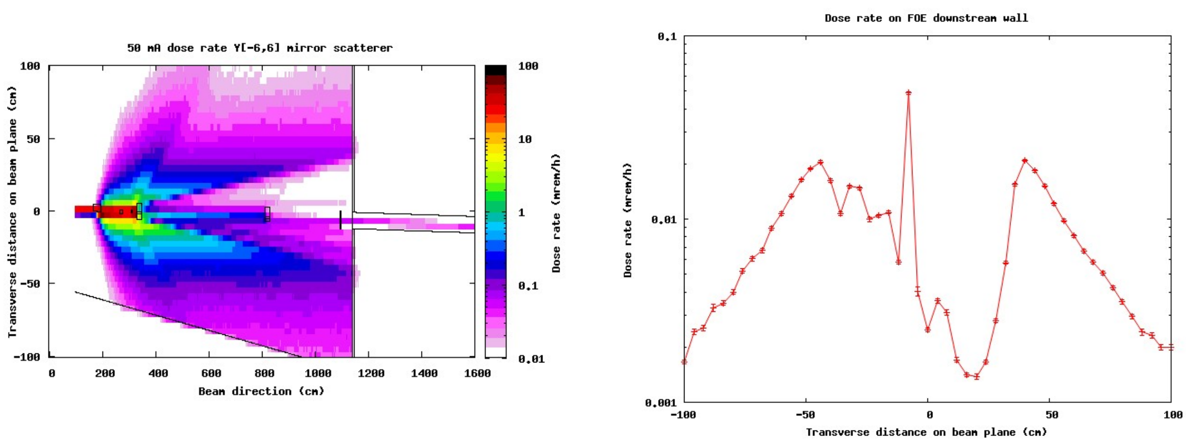

Figure 8 CHX dose rate without SGB shields at 50 mA

The dose rate with current mono beam stop (1” lead on Hutch B downstream wall, no additional secondary bremsstrahlung stop installed) was also studied; the dose rate on contact of hutch B downstream wall is ~0.05 mrem/h as shown in Figure 9. So CHX is shielded for 50 mA commissioning without additional SGB shields.

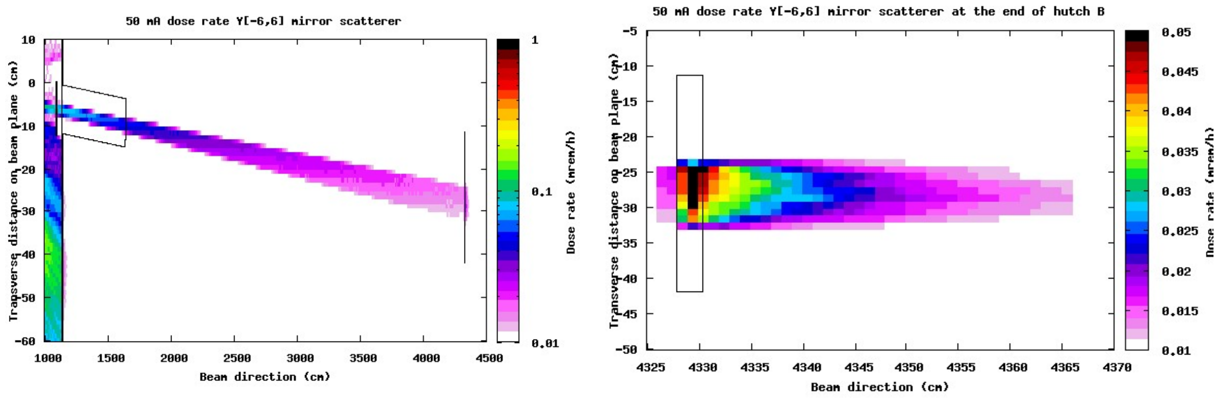

Figure 9 Dose rate at 50mA without SGB shields at the end of hutch B

Figure 9 (right) shows the dose rate downstream of Hutch B mono beam stop (without additional 5 cm SGB stop). Note the dose rate is higher downstream of mono beam stop compared with upstream of shielding. This is due to the shower build-up effect, which causes the dose at thin shield higher than the doses at the no-shield case.

5. Conclusions:

For CHX 500 mA operation, with the proposed shielding (SGB shield 1 downstream of mirror, SGB stop at the end of hutch B), the radiation level meets our shielding policy.

1) The dose rate on contact of FOE downstream wall is less than 0.5 mrem/h, which decreases to 0.05 mrem/h at 30 cm when full power GB (17 µW) interacts with mirror scatterer.
2) The dose rate on contact of FOE downstream wall is less than 0.5 mrem/h, which decreases to 0.1 mrem/h at 30 cm when full power GB (17 µW) interacts with mask or white beam stop. However these two scenarios are either based on very conservation assumption or simulating non-normal operation. In practice the dose level should be lower.
3) The dose rate is < 0.05 mrem/h in all other occupied areas.

If CHX doesn't install SGB shields (SGB shield 1 downstream of mirror and SGB stop at the end of hutch B), it is shielded for 50 mA commissioning. Both SGB shields must be installed before the current goes up.

The following shielding is recommended to be installed for ALARA practice when beam current goes higher than 250 mA: an additional 2 cm lead on the inboard side of beam pipe on FOE downstream wall, and the size can be decided by SGB ray trace. Note this recommendation may be adjusted by future measurement results.

All shielding will need to be verified by radiation survey during commission. If a radiation leakage is observed during the measurement, shielding shall be installed to mitigate the radiation level outside of the enclosure to acceptable level.

Reference:

[1] P.K. Job, Shielding Guidelines for Secondary Bremsstrahlung at NSLS-II Beamlines with Mirror as the First Optical Element, September 11, 2012.
[2] P.K. Job, LT-C-ESH-STD-001, Revised Guidelines for the NSLS-II Beamline Shielding Design, September 17, 2013.
[3] Emails from A. Fluerasu to Z. Xia.
[4] Private communication between A. Fluerasu and Z. Xia.