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XPD 28ID Radiation Shielding Analysis

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28-ID XPD Beamline Radiation Shielding Analysis	

1. Introduction:

This note documents the radiation shielding analysis of X-ray Powder Diffraction (XPD, 28 ID) beamline at 500 mA, including Gas Bremsstrahlung (GB) and Synchrotron Radiation (SR). Figure 1 shows the layout of XPD, which uses a damping wiggler (DW100) source.

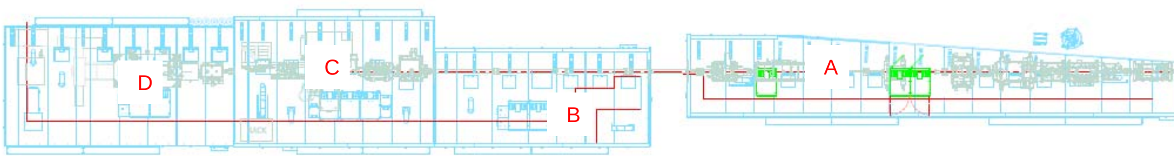

Figure 1 XPD layout

XPD-1 (hutch A, transport pipe and hutch C) will be commissioned in 2014; therefore the shielding analysis in this memo only covers XPD-1 beamline.

2. GB Shielding Calculation

For the evaluation of the GB shielding requirements, the wiggler 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 10 mm Pb and downstream wall 50 mm Pb.

The main scatterers considered in the Secondary Gas Bremsstrahlung (SGB) shielding analysis are: white beam fluorescence screen, white beam slits and white beam stop. The XPD FLUKA geometry is shown in Figure 2 and main parameters are listed in Table 1. (XPD mono is a 0.7 mm SiC crystal, which is considered transparent to GB source. The fixed mask's minimum aperture is 30 mmH × 3 mmV and it is immediately followed by a collimator.)

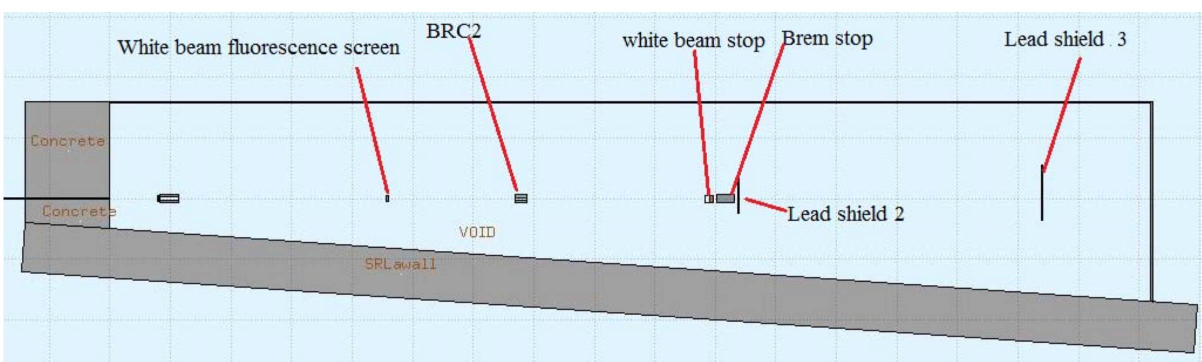

Figure 2 XPD main scatterers, collimators and shields

Table 1 Z locations and dimensions of main scatterers and shields

Scatterers	Components center Z location (Distance from straight section center)	Dimensions	Material
White beam fluorescence screen	3128 cm	8.5 cm W × 7.8 cm L × 2 cm H (rotate 6 degree)	Copper
White beam slits	3422.43 cm	1” cubic	Copper
White beam stop	3661.3 cm	11.4 W × 4 cm H × 13 cm L (6.37 degree cut on top)	Copper
Shields	Components center location (Distance from straight section center)	Dimensions	
BRC2 (second collimator)	3350 cm	13.1 cm W × 7.6 cm H × 20 cm L (aperture: 4.192 cm ×1.028 cm)	Tungsten
Bremsstrahlung stop	3687.7 cm	13.415 cm W × 9.06 cm H × 30 cm L	Lead
Lead shield 2	3709.7 cm	56 cm W × 90 cm H × 2 cm thick (aperture: 4.2 cm ×1.0 cm)	Lead
Lead shield 3	4210.85 cm	92 cm W × 96 cm H × 2.5 cm thick (aperture: 7.62 cm Radius)	Lead

2.1 White beam fluorescence screen as scattering target

White beam fluorescence screen is located 457 cm from FOE upstream wall. As shown in Figure 3, for white beam fluorescence screen scatterer, the dose rate downstream of FOE wall is < 0.05 mrem/h. The dose rates on roof and lateral wall are < 0.05 mrem/h too based on FLUKA calculation. (Note the roof and lateral wall dose rates are only plotted for white beam slits scatterer in this note.)

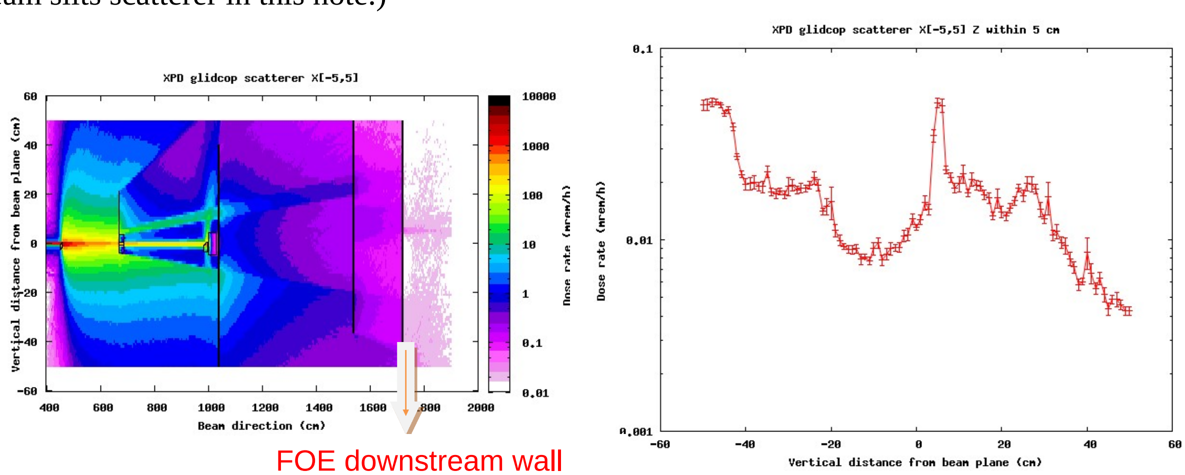

Figure 3 SGB dose rate plot - white beam fluorescence screen scatterer

2.2 White beam slits as scattering target

White beam slits are simulated by an optimum 1” cubic Cu target. The dose rates on the lateral wall and roof are both ~0.02 mrem/h, as shown in Figure 4.

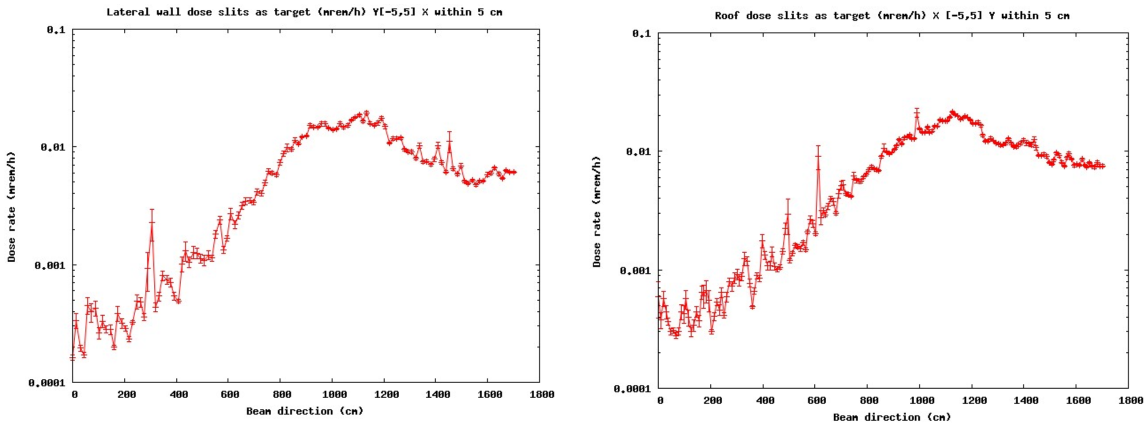

Figure 4 Dose rate on XPD lateral wall and roof – white beam slits scatterer

Figure 5 shows the dose rate on the vertical plane (where the apertures are located). There is radiation leakage on the FOE downstream wall due to the apertures in the shielding for the pipes going through. The penetration in the downstream wall used the photon shutter aperture size: 40 mm × 25 mm.

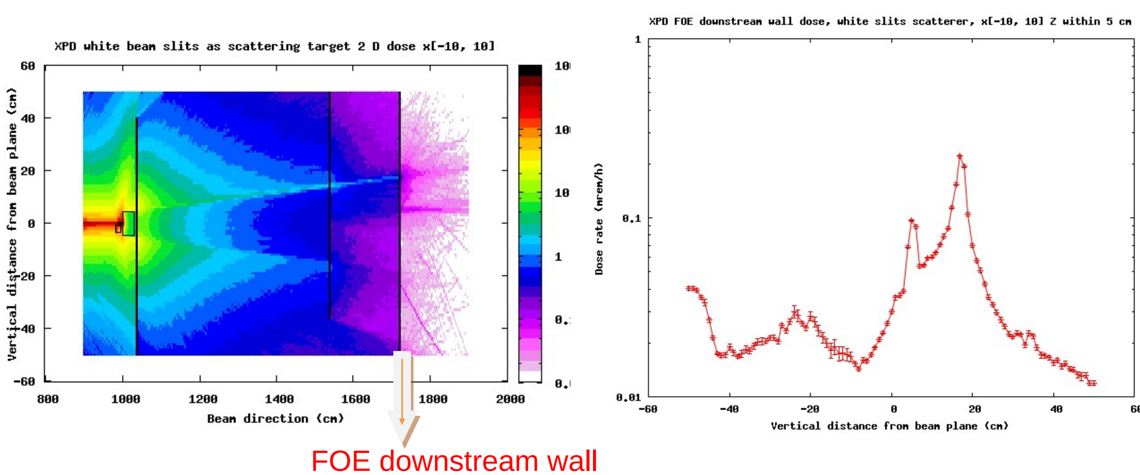

Figure 5 SGB dose rate – white beam slits scatterer

There are two leakages on the FOE downstream wall. The top plume has a contact dose of ~0.3 mrem/h and it drops to ~0.05 mrem/h at 30 cm distance. The lower leakage is ~0.1 mrem/h on contact, which is contained in beam pipe, not an occupied area.

The dose rate on horizontal beam plane (considering XPD2 aperture: 5.3 cm diameter hole at 13.2 cm from white beam center) is shown in Figure 6. The dose rate on the horizontal beam plane is < 0.05 mrem/h downstream of FOE wall.

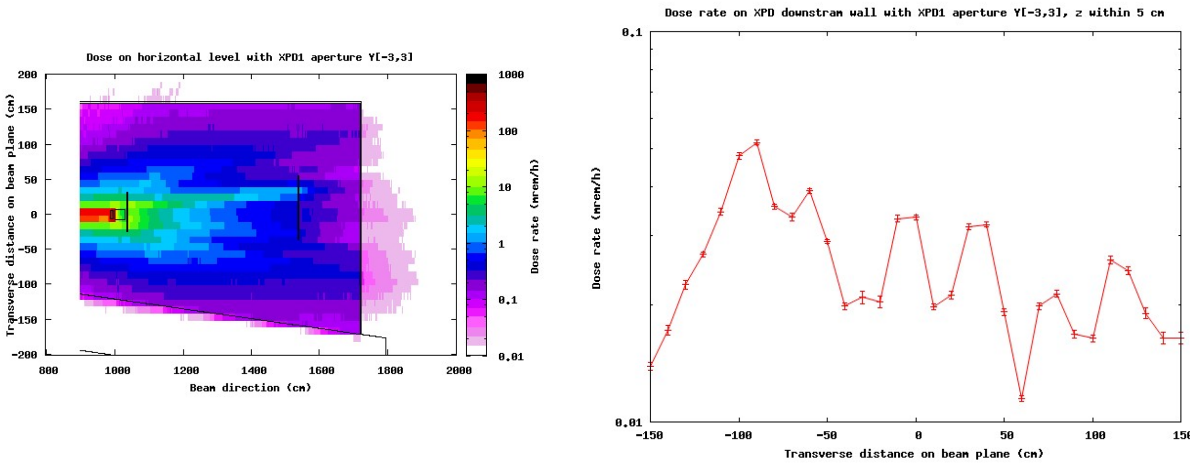

Figure 6 Dose rate on horizontal beam plan with XPD2 aperture

2.3 White beam stop as scattering target

White beam stop is a copper block with 6.37 degree slope on top, taking away synchrotron beam heat (immediately upstream of bremsstrahlung stop). The dose rates on the lateral wall and roof are both ~ 0.02 mrem/h from this scatterer too. Figure 7 shows the white beam stop geometry and dose rate on FOE downstream wall.

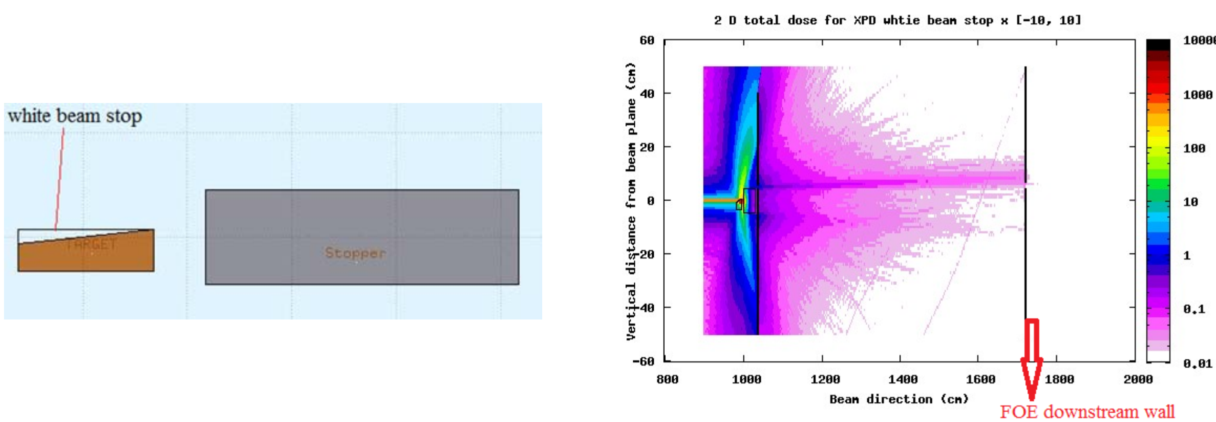

Figure 7 SGB dose rate – white beam stop scatterer

The white beam stop is immediately upstream of the bremsstrahlung stop, and the dose rate on FOE downstream wall is < 0.05 mrem/h for this scatterer.

3. SR Shielding Calculation

The XPD (28 ID) beamline is a DW100 source and the source parameters are listed in Table 2.

Table 2 Source Parameters for DW100

Source	Max. source opening	No. Of periods	Max. B_{eff} (T)	Period (mm)	E_c (keV)	Total power (kW)
DW 100	6.0 mrad-H	70	1.85	100	11	63

3.1 FOE wall / roof for white beam

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

3.2 Transport pipe

The transport pipe connecting hutch A to C is a 4” diameter pipe with 8 mm lead wrapping. The beam can operate in two modes: mirror IN and mirror OUT. When mirror is out, the higher energy harmonic (210 keV) also comes along with fundamental 70 keV photons.

The beam can travel as close as 16 mm to the pipe [2]. In the calculation, it is assumed to be 10 mm. The pipe shielding is calculated conservatively with STAC 8 for a compressed 10 m air target. The dose rates from 70 keV and 210 keV (with 0.5% bandwidth) are listed in Table 3. XPD is using a curved Laue crystal as monochromator, and the bandwidth is 0.1%, which is multiplied by 5 for conservative shielding calculation in this note. As shown in Table 3, the transport pipe shielding is sufficient.

Table 3 Dose rate from 70 keV and 210 keV photons (assuming 0.5% bandwidth)

Energy (keV)	Distance from beam to pipe (mm)	shielding	Dose rate (mrem/h)
70	10	8 mm PB	<0.001
210			0.01

3.3 Monochromatic beam in Hutch C

The mono hutch shielding calculation was done for 70 keV and 210 keV with 0.5% bandwidth too. The scattering target is assumed to be a silicon disk of 10 cm radius and 2 cm thick, with its axis horizontal, tilted by 0.155° with respect to the photon beam direction.

Note Hutch C shielding calculation takes credit of fixed mask apertures: XPD SR fan comes into beamline with a smaller size: 1.1 mrad (H) × 0.1 mrad (V) [3].

3.3.1 Mono hutch (hutch C) lateral wall and roof

The lateral walls are composed by 5 mm Pb and roof 3 mm Pb. The dose rates in Table 4 were calculated with the following assumptions: the scatterer is 1 m from lateral wall and 2 m from the roof.

Table 4 Dose rate on lateral wall and roof of mono hutch (0.5% bandwidth and 1.1 mradH SR fan)

	Distance from scatterer to shielding (m)	70 keV	210 keV
Lateral wall	1	< 0.001	< 0.001
Roof	2	0.07	0.003

3.3.2 Mono hutch (hutch C) downstream wall

A mono beam stop (20”×20”×1” thick Pb) is installed around the beam center in hutch C to prevent the monochromatic beam from direct hitting the downstream wall. Hutch C downstream wall is made of 5 mm Pb.

The dose rate is calculated for a tilted Si scatterer, 3 m upstream from the downstream wall. The dose rate from 70 keV is calculated by STAC 8, which is conservative for higher scattering angles on downstream wall. The dose rate is <0.006 mrem/h (1.1 mradH SR fan) when the scattering angle is > 5 degree. The smaller angles are covered by the mono beam stop.

The dose rate from 210 keV is calculated by FLUKA. The dose rate outside of mono beam stop area is < 0.0055 mrem/h (1.1 mradH SR fan). Note the dose rates in Figure 8 are normalized by 6 mradH. The dose rate from Figure 8 was scaled to 1.1 mradH to get Table 5.

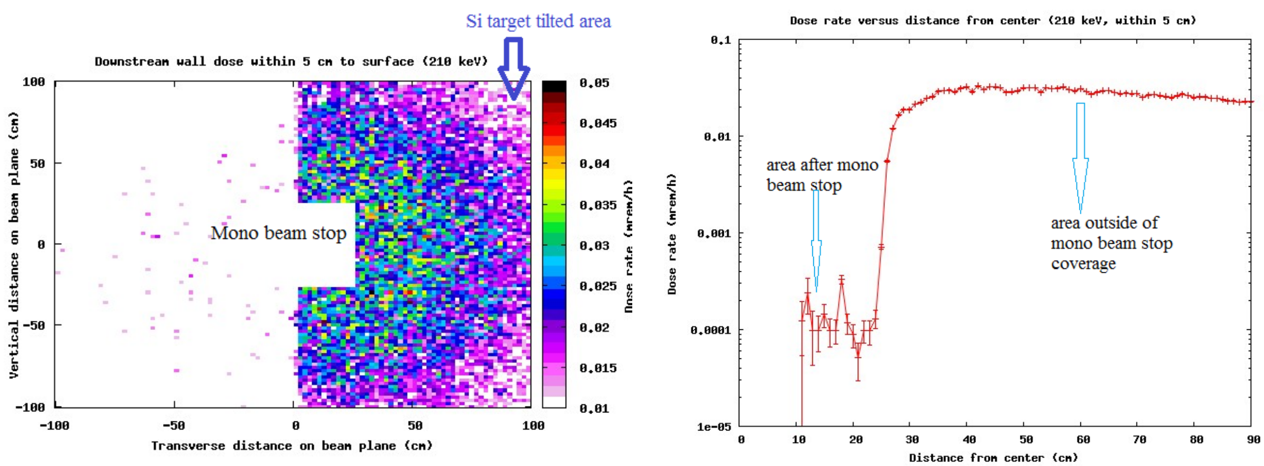

Figure 8 Dose rate on Hutch C downstream wall from 210 keV photons (6 mradH and 0.5% bandwidth)

The dose rates on hutch C downstream wall are listed in Table 5 for 70 keV and 210 keV mono beams.

Table 5 Dose rate on Hutch C downstream wall (0.5% bandwidth and 1.1 mradH SR fan)

	70 keV	210 keV
Area covered by mono beam stop (< 5 degree)	<0.001	<0.001
Area outside of mono beam stop coverage (>5 degree)	0.006	0.0055

4. 50 mA commissioning analysis

Currently XPD doesn't have lead shield 3 (Z ~ 4.2 m) installed (other shields already in place). The FLUKA calculation was done for the worst scatterer: white beam slits.

Figure 9 is the 2-D dose rate at 500 mA without lead shield 3 installed. In FLUKA simulation, the material of lead shield 3 was changed to air.

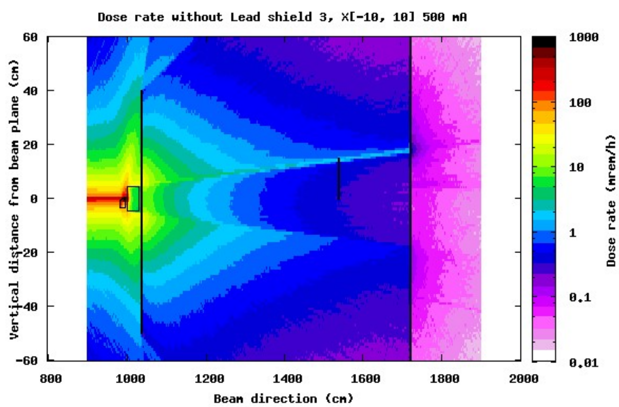

Figure 9 XPD dose rate without lead shield 3 installed.

Figure 10 shows the 1-D dose on FOE downstream wall and the dose rate at 30 cm from FOE downstream wall.

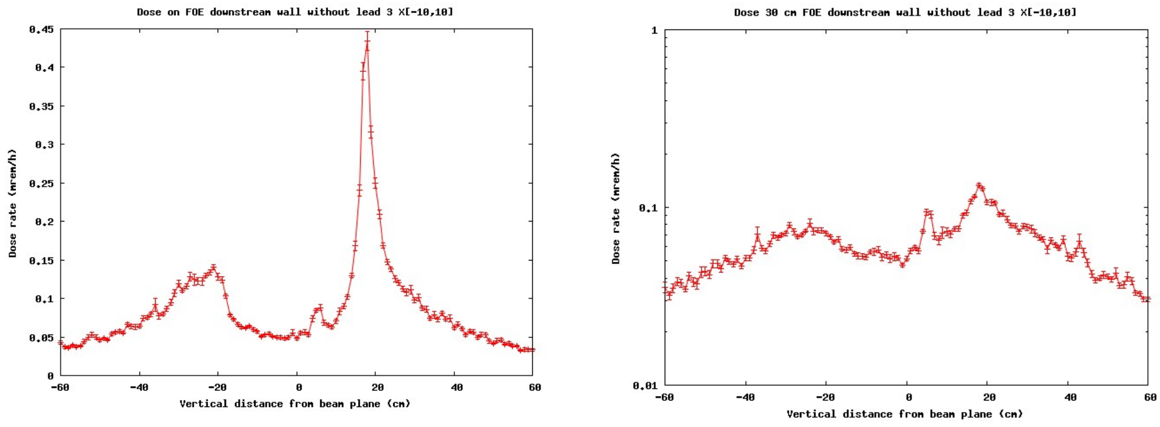

Figure 10 Dose rate at 500 mA without lead shield 3 installed

As shown in Figure 10, the dose rate at 30 cm from the downstream FOE wall is ~ 0.15 mrem/h. Therefore XPD is shielded up to 150 mA in this scenario.

5. Conclusions:

For 500 mA operation, with the two proposed SGB shields from XPD (Lead shield 2 and lead shield 3 in Table 1), the radiation level meets NSLS-II shielding policy.

1) The surface dose rate on FOE downstream wall is < 0.5 mrem/h, which decreases to < 0.05 mrem/h at 30 cm distance.
2) The dose rate on Hutch C roof is 0.07 mrem/h, which is acceptable since the roof occupancy rate is low.
3) The dose rate in all other areas is < 0.05 mrem/h.

If lead shield 3 (Z ~ 4.2 m) is not installed (all other shields in place), XPD is shielded up to 150 mA.

By comparing the shields in FLUKA calculation and ray trace, there are small differences in dimensions of the shielding components between Table 1 and the ones called out in the ray traces (e.g. the actual width of the bremsstrahlung stop is 137 mm instead of 131 mm. Lead shield 3 is 3 cm thick in reality, not 2.5 cm in FLUKA calculation). However, after the review, it was explained that these differences came out because the simulations used vendor design specifications, but the ray traces are based on as-fabricated dimensions. These differences are not making a problem; instead the dose rate should be lower due to larger dimensions/thickness in practice.

There may be small deviations between reality and simulated model due to practical difficulties. For example, there are small mounting holes on the lead shields, which are not included in FLUKA model. However, the holes are small (<1.5 cm diameter) and most of them are located at the edge and filled by dense material. In addition, lead shield 3 is going to be thicker in reality (30 mm Pb). So it is not expected to cause significant higher dose rate than the calculations. 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] Emails from E. Dooryhee to Z. Xia
[3] Email from H. Wang to Z. Xia