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18-ID (FXI) Beamline Radiation Shielding Analysis	

1. Introduction

The 18-ID beamline is a Full Field X-ray Imaging (FXI) beamline capable of imaging 3D in-situ and in-operando dynamics of sample morphology and oxidation states at 30 nm spatial resolution. The source of this beamline is a high-flux hard x-ray damping wiggler (DW100). The radiation shielding analysis of this beamline is described in this report.

The NSLS-II Beamline Radiation Shielding Guidelines [1] states the following: Radiation exposure to staff and users resulting from National Synchrotron Light Source II (NSLS-II) operations must comply with Brookhaven National Laboratory (BNL) and Department of Energy (DOE) radiation requirements and must be maintained as low as reasonably achievable (ALARA). Per the Shielding Policy (PS-C-ASD-POL-005), in continuously occupied areas during normal operation the dose rate is ALARA, and shall be < 0.5 mrem/hr (based on occupancy of 2000 hours/year) or less than 1 rem in a year.

For a fault event, the dose to an individual shall be < 20 mrem in a non-radiation controlled area and < 100 mrem in a radiation controlled area. Although the experimental floor is initially designated as a Controlled Area – TLD Required, it is hoped that in the future, it can be declared a Controlled Area – No TLD Required. As such, beamlines should be shielded so that in the event of a fault, the total dose to an individual, integrated over the duration of the fault, is < 20 mrem.

In this report, the recommended shielding is based on calculations to achieve dose rates less than 0.05 mrem/hr at 30 cm from lateral wall and roof of the FOE and less than 0.5 mrem/hr on contact with the downstream wall of the First Optical Enclosure (FOE) [2] during normal operations.

This report consists of two parts, one dealing with the gas bremsstrahlung (GB) as the source and the other dealing with the scattering of the synchrotron radiation (SR). Both these cases are constant sources of radiation and the dose rates that are present represent the normal operating conditions. Section 2 describes the FLUKA Monte Carlo radiation transport calculations for the GB as the source and section 3 deals with the synchrotron radiation as the source of radiation.

Figure 1 shows the layout of the 18-ID (FXI) beamline FOE.

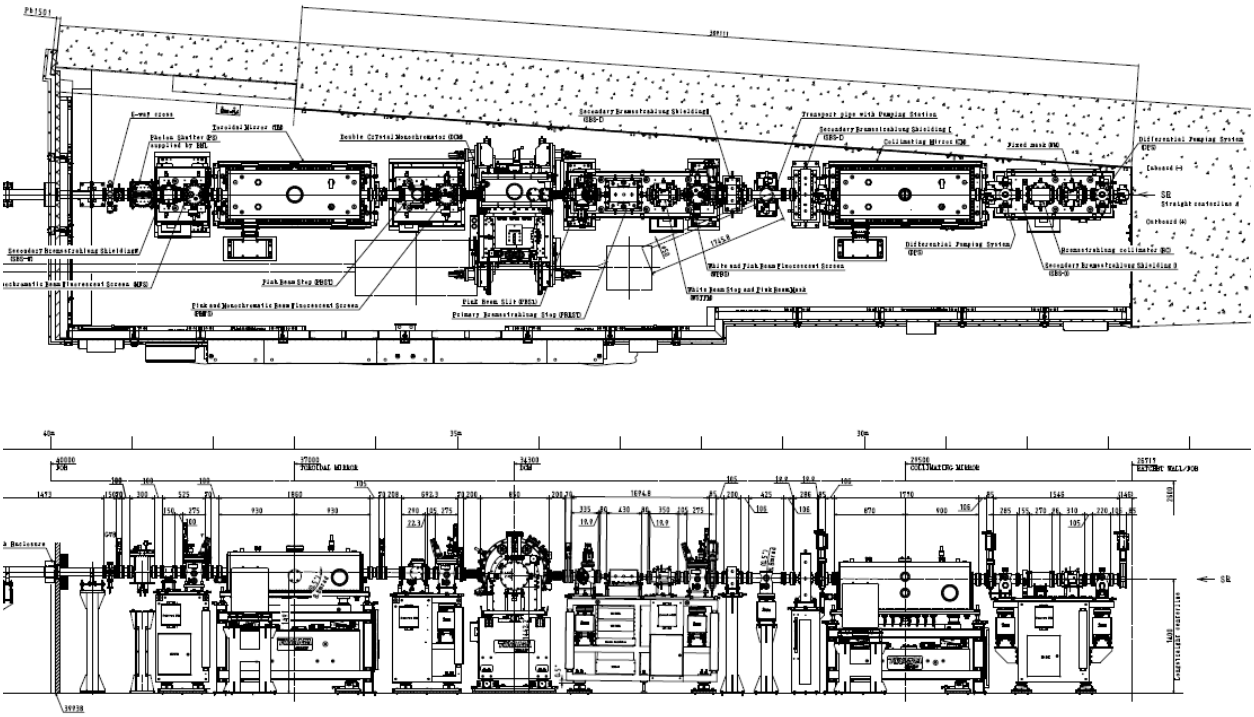

Figure 1. The layout of the FOE of 18-ID (FXI) Beamline

The FOE is made of lead with 5 cm thick downstream wall, 1.8 cm side wall and 1.0 cm roof thickness. The downstream wall has a lead guillotine 10 cm thick and 35 cm x 35 cm in the lateral and vertical directions. The beam transport pipe has 6.0 mm lead wrapped around the SS pipe and runs 19.5 m, separating the FOE from the End Station Enclosure (ESE). The ESE is also made of lead with 4 mm thick upstream, downstream and lateral walls and 3 mm thick roof. The white beam is centered along the horizontal (X) axis. It is tilted in the upward (+Y) direction by the collimating mirror (CM) which is placed at an angle of 4.4 mrad. The resulting pink beam is directed upward by 8.8 mrad.

2. FLUKA Monte Carlo radiation transport simulations

The radiation background in and around the FOE due to the GB produced in the long straight section of the 18-ID (FXI) beamline is modeled with the FLUKA Monte Carlo code. The source of GB is the long straight section in the storage ring where the primary electron beam interacts with the residual gas molecules in the beam pipe. The GB spectrum extends up to the primary electron energy of 3 GeV and is a constant source of radiation. When the front end safety shutters and photon shutter are open it enters the FOE and interacts with the beamline components inside the FOE producing an electromagnetic cascade that results in a radiation environment outside the FOE.

For the radiation transport simulation, the important radiation safety components are modeled in the geometry as shown in Figures 2 and 3. In Figure 2, the full layout of the FOE, the beam transport pipe and the ESE is shown.

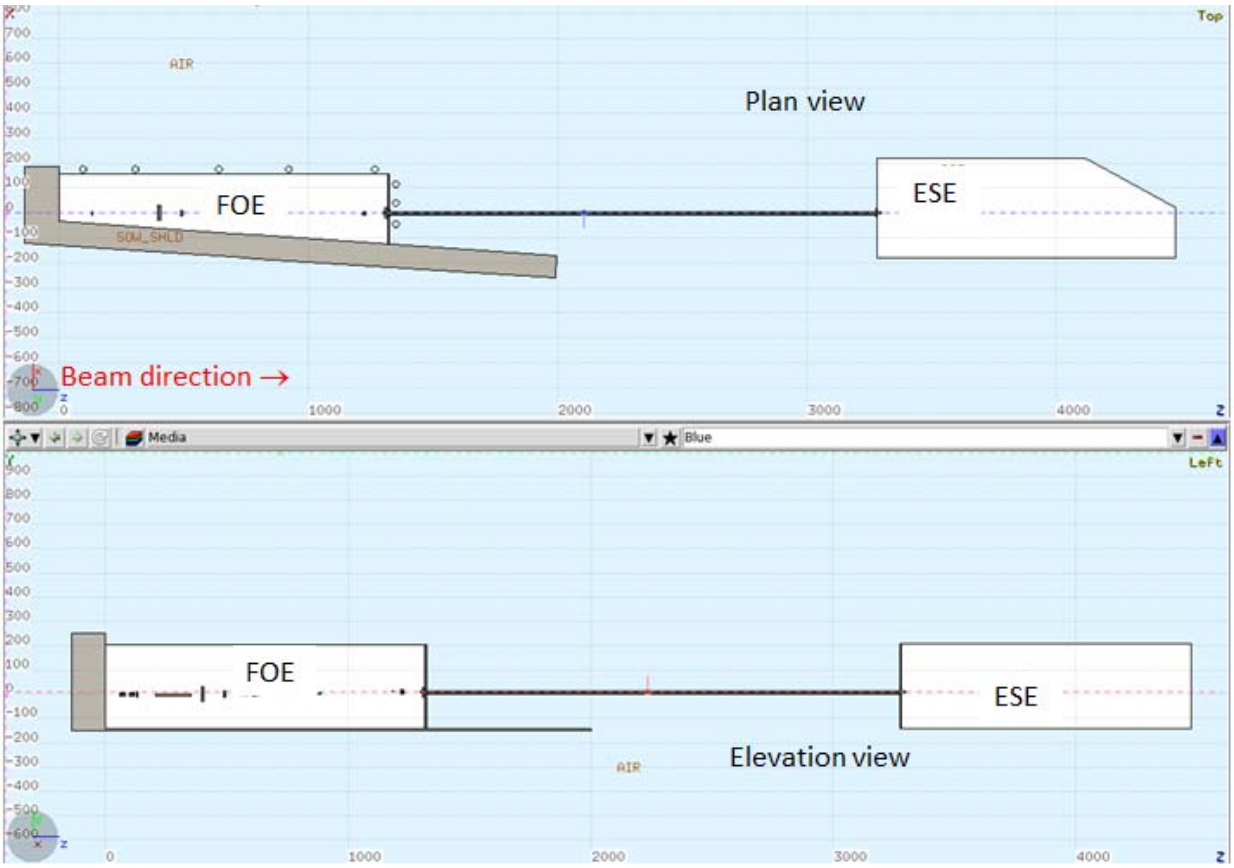

Figure 2. The FOE, Beam Transport Pipe and the ESE as Modelled for FLUKA Simulations

In Figure 3, the components in the FOE are shown. The details of the components are given in Appendix A. The major components are the fixed mask (FM) approximated as copper in this analysis as surrogate for the original Glidcop, a bremsstrahlung collimator (BC) made of tungsten, first three secondary bremsstrahlung shields (SBS-0, SBS-1, SBS-2) made of lead, white beam stop (WBS) modeled as copper, a primary bremsstrahlung stop (PBRS) made of lead, a pink beam stop (PBS) modeled as copper, two more tungsten secondary bremsstrahlung shields (SBS-3 and SBS-4), the photon shutter (PSH) modeled as layers of copper, tungsten and stainless steel and the rear wall guillotine made of lead.

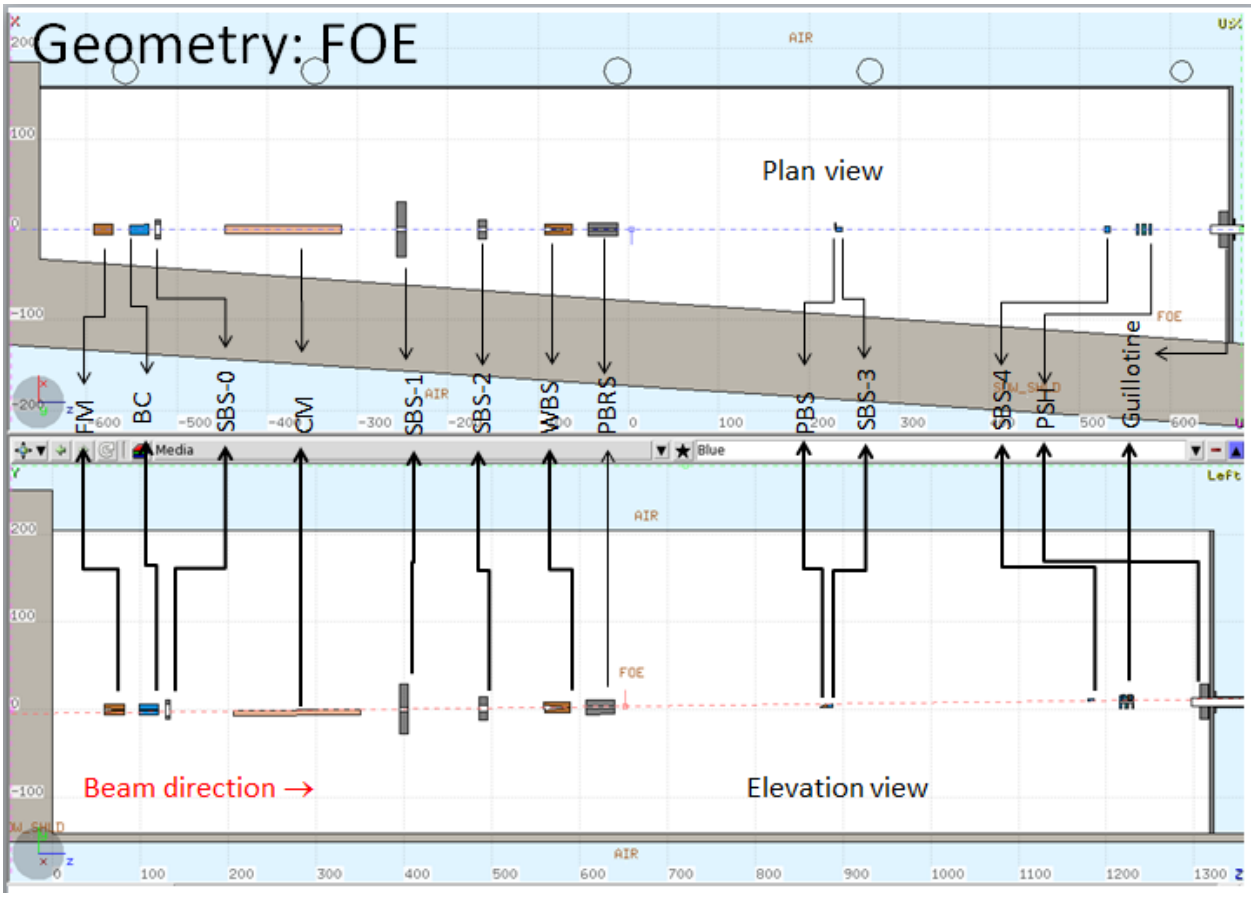

Figure 3. The plan and the elevation view of the FOE and the components modeled for radiation transport simulations.

2.1. Simulation details

The source of radiation is the GB spectrum that extends from 10 keV to 3 GeV, obtained from a previous simulation for the long straight section. A source routine is used to sample from the cumulative distribution function of the spectrum. Eight beam loss points are identified from the FXI beamline ray trace (Figure 4) and are listed here with the X and Y coordinates used in the FLUKA simulations. The full GB power is assumed to be incident on all these locations.

1. On the aperture of FM, inboard side (-0.58, 0.525) cm
2. On the aperture of FM, outboard side (0.58, 0.525) cm
3. On FM, top outboard point, normal incidence (3.13, 1.665) cm
4. On FM, outboard point, angled incidence (1.3 mrad)
5. Upstream edge of CM (0.58, -1.0) cm
6. Center of CM (0, 0) cm
7. Top center point on the WBS (0.0, 0.94) cm
8. Top outboard corner on the WBS (2.165, 0.94) cm

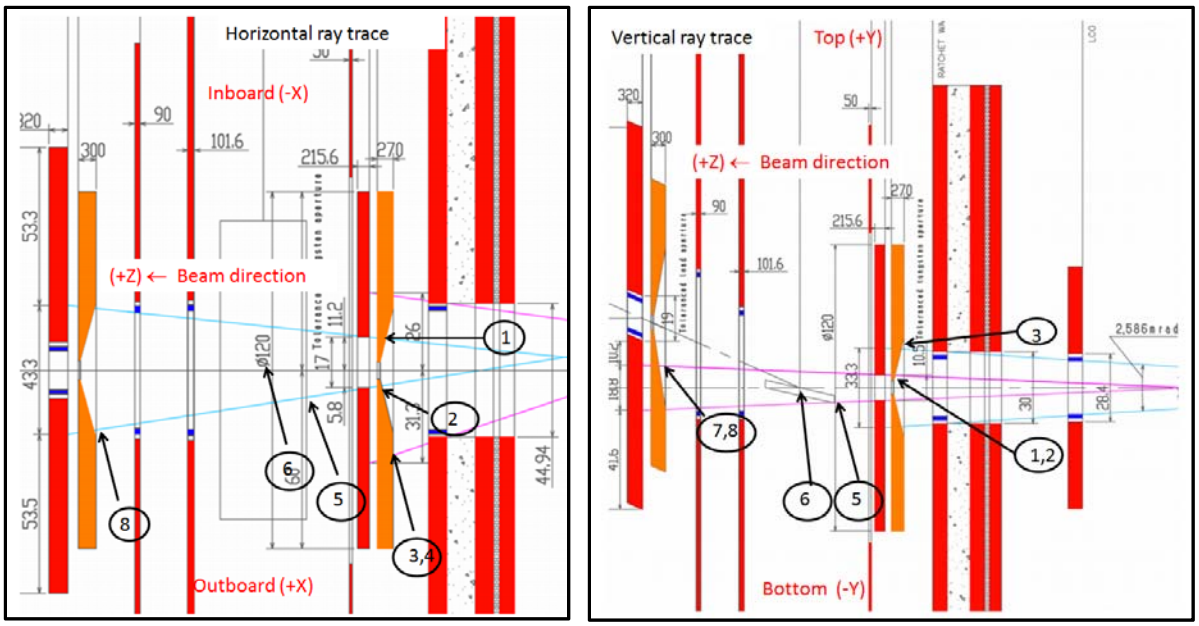

Figure 4. The horizontal (left) and vertical GB ray trace with the beam loss points shown.

The total ambient dose equivalent rates are estimated in a three dimensional mesh by (USRBIN in FLUKA) scoring the fluence and folding them with the fluence to ambient dose equivalent conversion coefficients. All the results given in these sections are on contact with the shield wall and in units of mrem/hr, normalized to 17μW bremsstrahlung power. This is the GB power generated by a 500 mA electron beam of 3 GeV striking the residual air in the 15.5 m long straight section, when the vacuum is 10^{-9} Torr.

2.2. Results

The various subsections discuss the results from the FLUKA simulations.

2.2.1. Case 1

In this case, the beam is striking the aperture of the FM, inboard side. The total ambient dose equivalent rate plots are given in Figure 5. The photon and the neutron contributions are shown in Figure 6. The total ambient dose equivalent rate on contact is 0.02 mrem/hr outside the side wall and the roof, and less than 0.01 mrem/hr outside the downstream wall. The neutrons can be seen to contribute more to the dose rates outside the side wall.

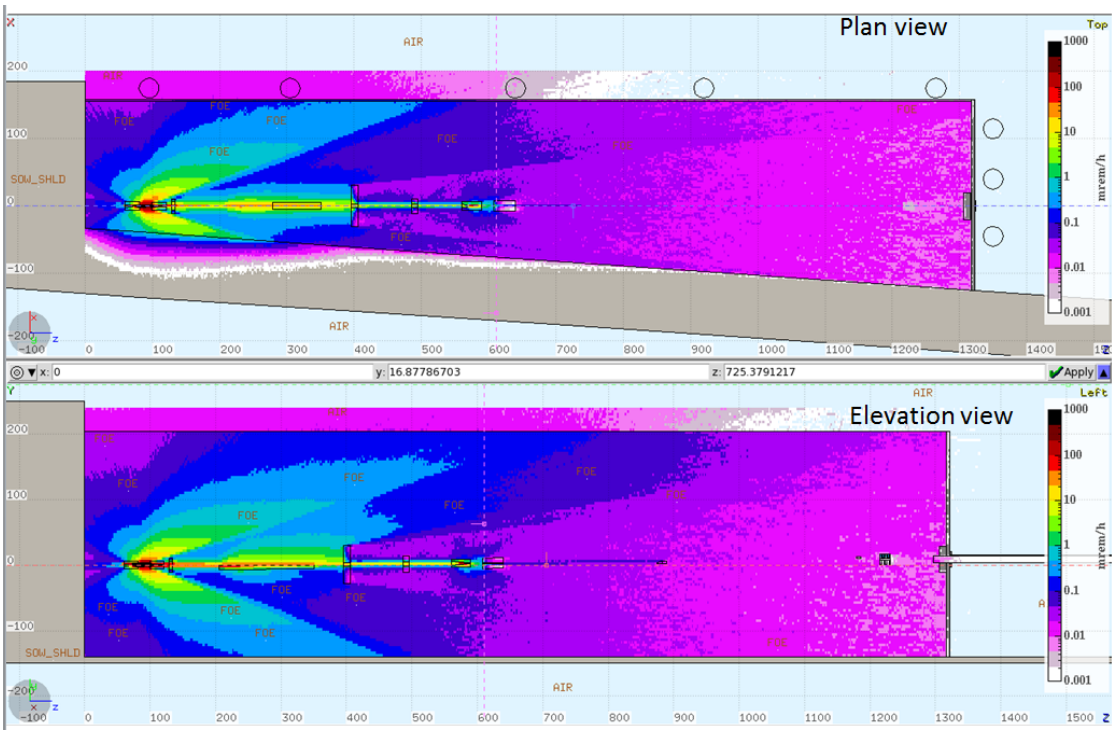

Figure 5. Total ambient dose equivalent rates in and around the FOE when the GB strikes the inboard side of the aperture of FM [case 1].

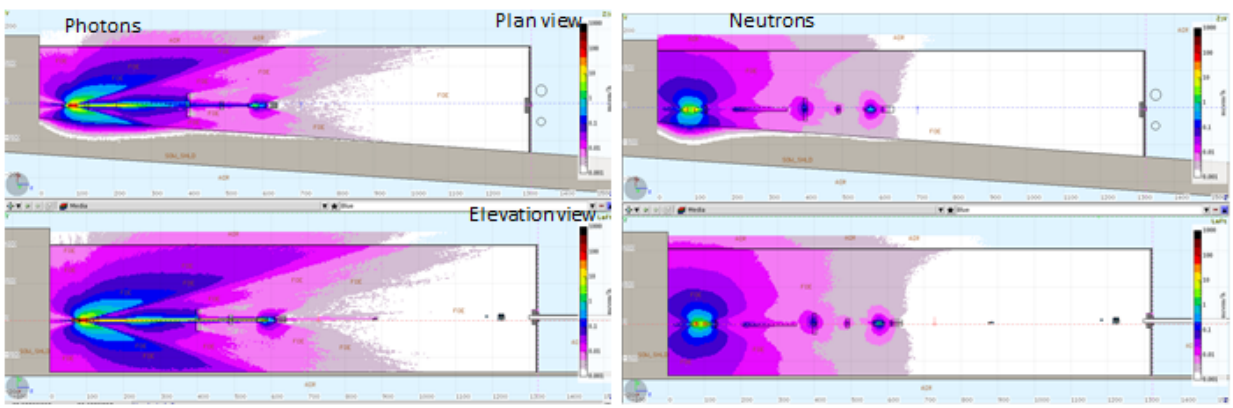

Figure 6. The photon (left) and the neutron ambient dose equivalent rates in and around the FOE when the GB strikes the inboard side of the aperture of FM [case 1].

2.2.2. Case 2

The GB is incident on the aperture of FM towards the outboard side. Figure 7 shows the total ambient dose equivalent rates while Figure 8 shows the photon and the neutron contributions.

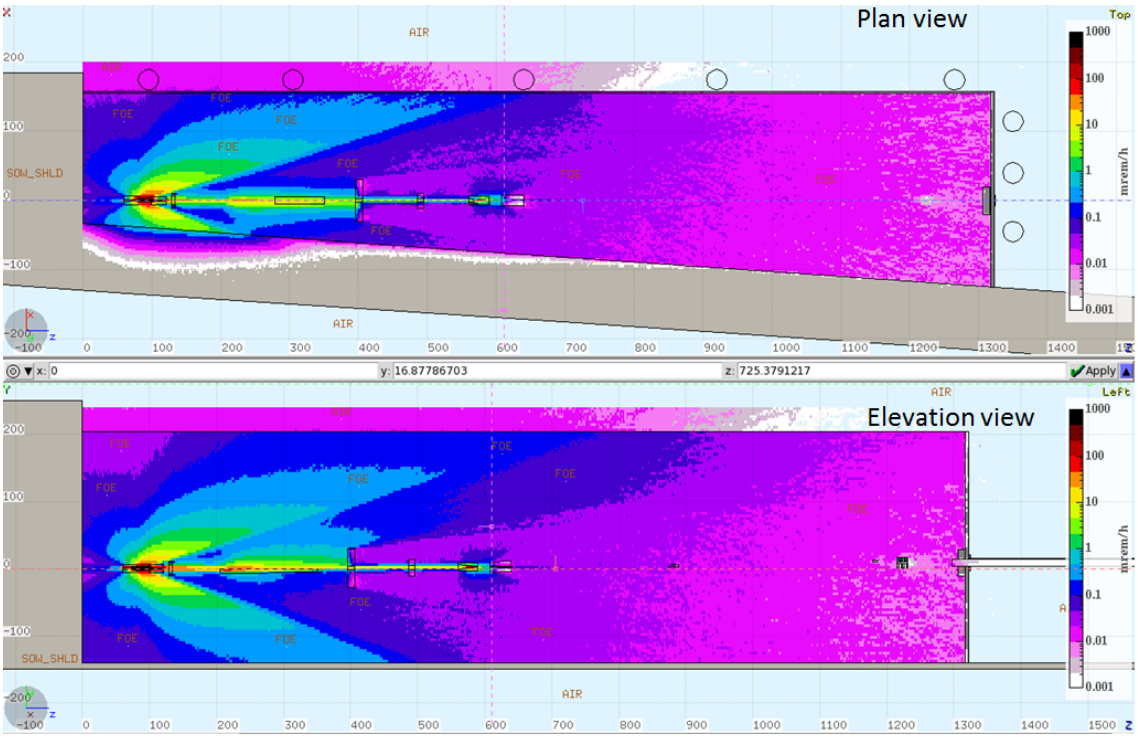

Figure 7. Total ambient dose equivalent rates in and around the FOE when the GB strikes the outboard side of the aperture of FM [case 2].

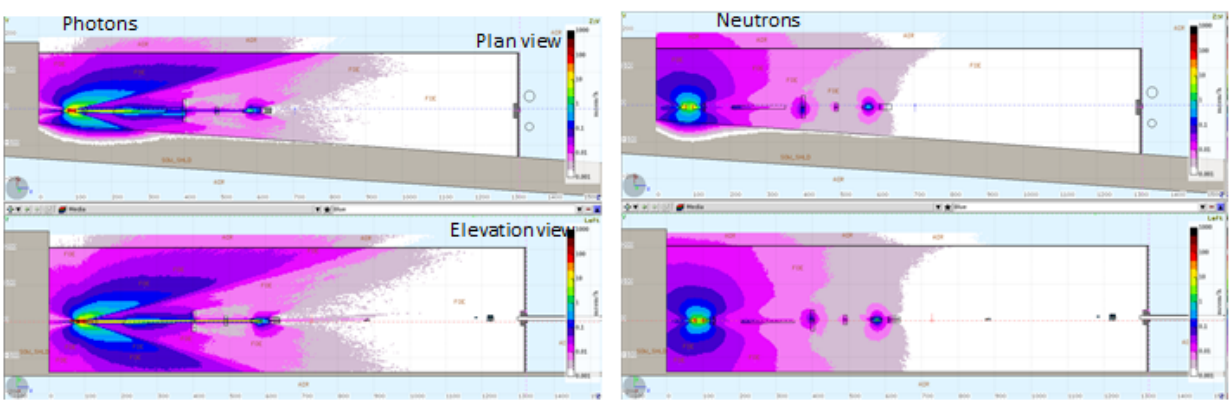

Figure 8. The photon (left) and the neutron ambient dose equivalent rates in and around the FOE when the GB strikes the outboard side of the aperture of FM [case 2].

The dose rates are found to be 0.02-0.03 mrem/hr outside the sidewall and the roof and is less than 0.01 mrem/hr outside the downstream wall. The neutron contribution to the total dose rates is seen to be marginally higher than the photons.

2.2.3. Case 3

The GB is incident on the top outboard point on FM. The total ambient dose equivalent rates are shown in Figure 9 and the photon and neutron contributions are shown in Figure 10.

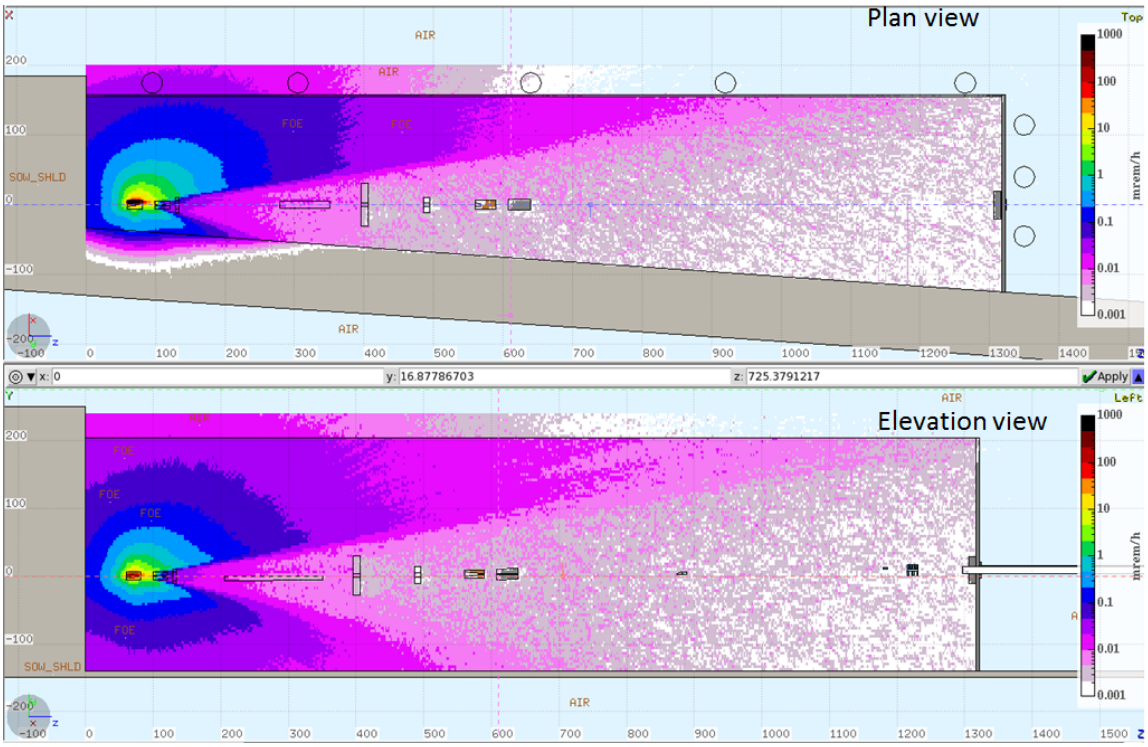

Figure 9. Total ambient dose equivalent rates in and around the FOE when the GB strikes the top outboard point of FM [case 3].

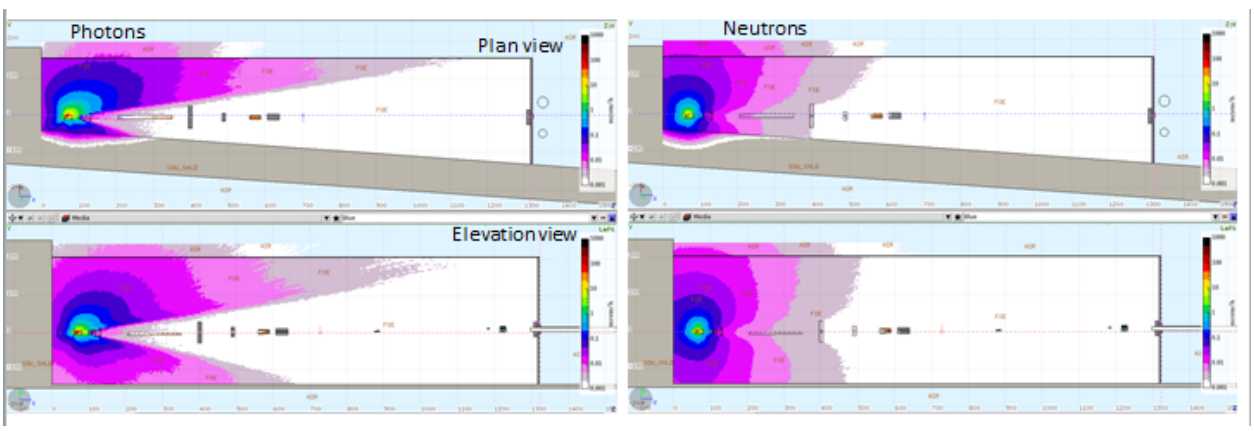

Figure 10. The photon (left) and neutron ambient dose equivalent rates in and around the FOE when the GB strikes the top outboard point of FM [case 3].

The total ambient dose equivalent rates are less than 0.03 mrem/hr outside the side wall, less than 0.02 mrem/hr on the roof and less than 0.01 mrem/hr outside the downstream wall. Contributions by neutrons dominate the dose rates outside the side wall as seen in Figure 10.

2.2.4. Case 4

Here the GB is made to strike the outboard point of FM at an angle as shown in the horizontal ray trace. Figure 11 shows the total ambient dose equivalent rates and Figure 12 shows the photon and neutron contribution.

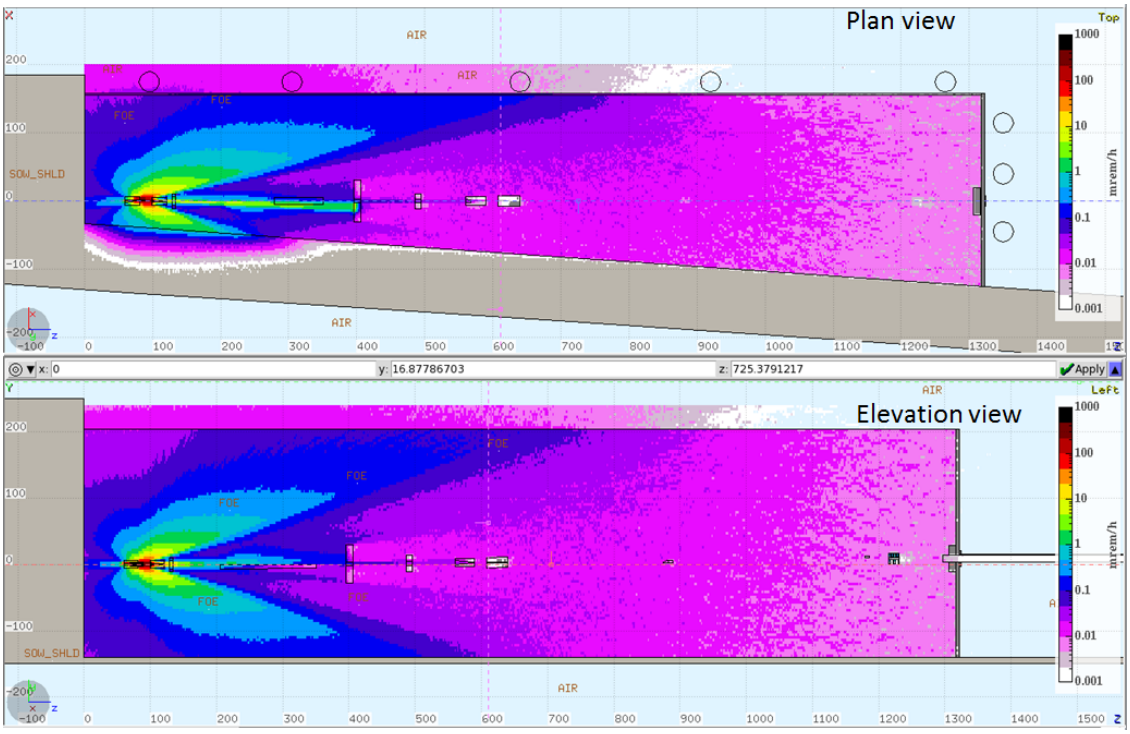

Figure 11. Total ambient dose equivalent rates in and around the FOE when the GB strikes FM at the outboard point at an angle [case 4].

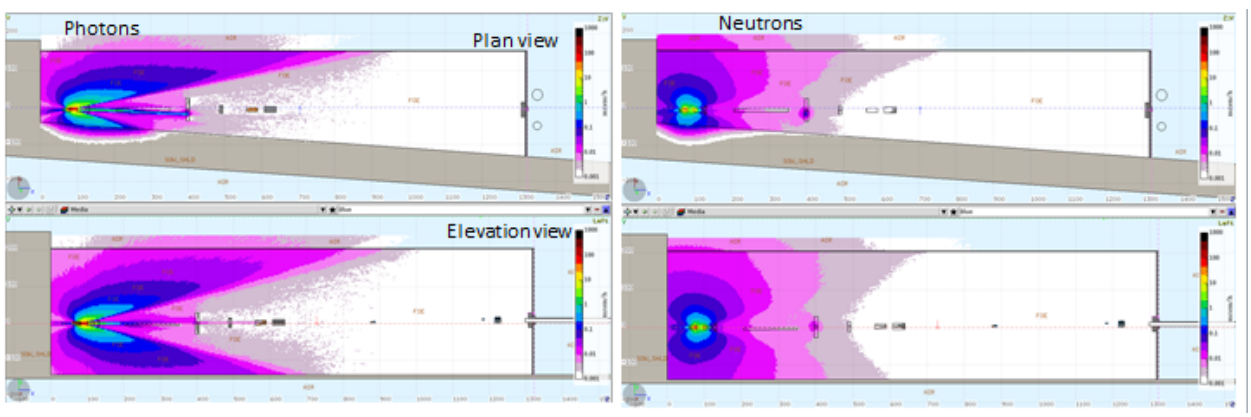

Figure 12. The photon (left) and the neutron ambient dose equivalent rates in and around the FOE when the GB strikes FM at the outboard point at an angle [case 4].

The dose rates outside the side wall are less than 0.03 mrem/hr and less than 0.02 mrem/hr on the roof. Outside the downstream wall the dose rates are less than 0.01 mrem/hr. Here too, neutrons contribute more to the total ambient dose equivalent rates.

2.2.5. Case 5

Here the GB is incident on the upstream edge of the CM. Figure 13 shows the total ambient dose equivalent rates in and around the FOE and Figure 14 shows the photon and neutron contribution.

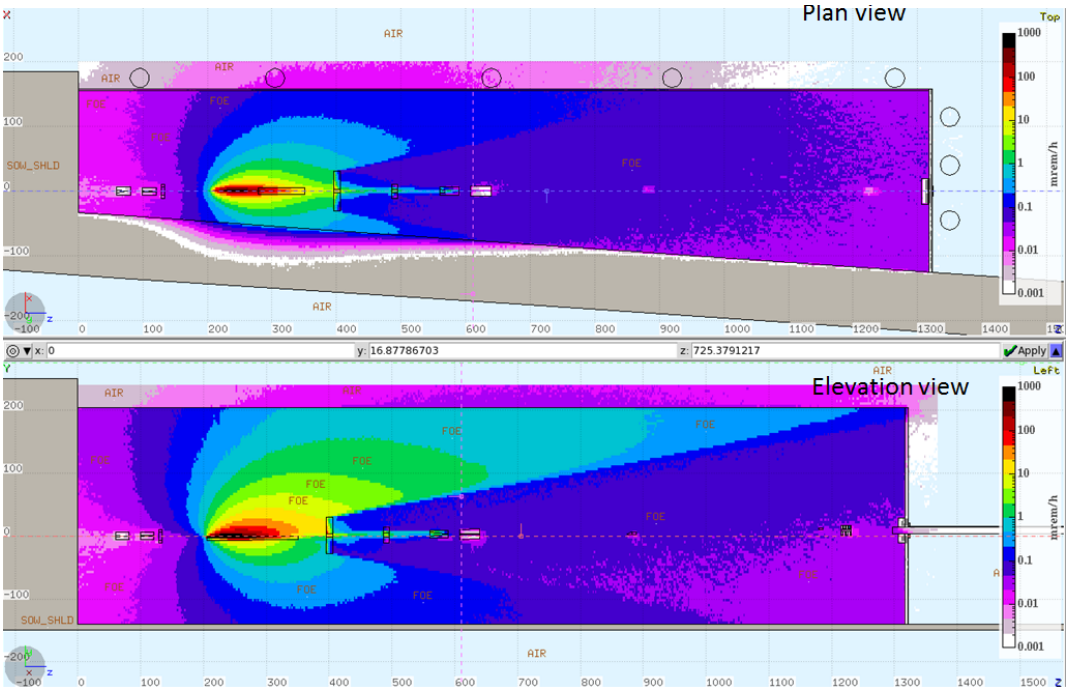

Figure 13. Total ambient dose equivalent rates in and around the FOE when the GB strikes upstream edge of CM [case 5].

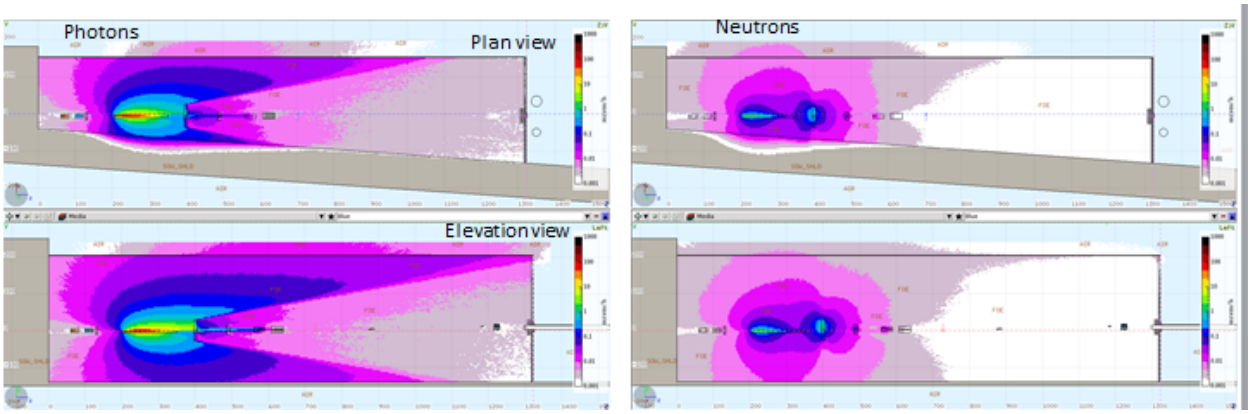

Figure 14. The photon (left) and neutron ambient dose equivalent rates in and around the FOE when the GB strikes upstream edge of CM [case 5].

The dose rates are 0.02 - 0.03 mrem/hr outside the side wall and the roof and less than 0.01 mrem/hr outside the downstream wall. The photons have a larger contribution to the total dose rates in this case.

2.2.6. Case 6

The GB strikes the center of the CM in this scenario. The total ambient dose equivalent dose rates are shown in Figure 15 and the photon and neutron contribution are given in Figure 16.

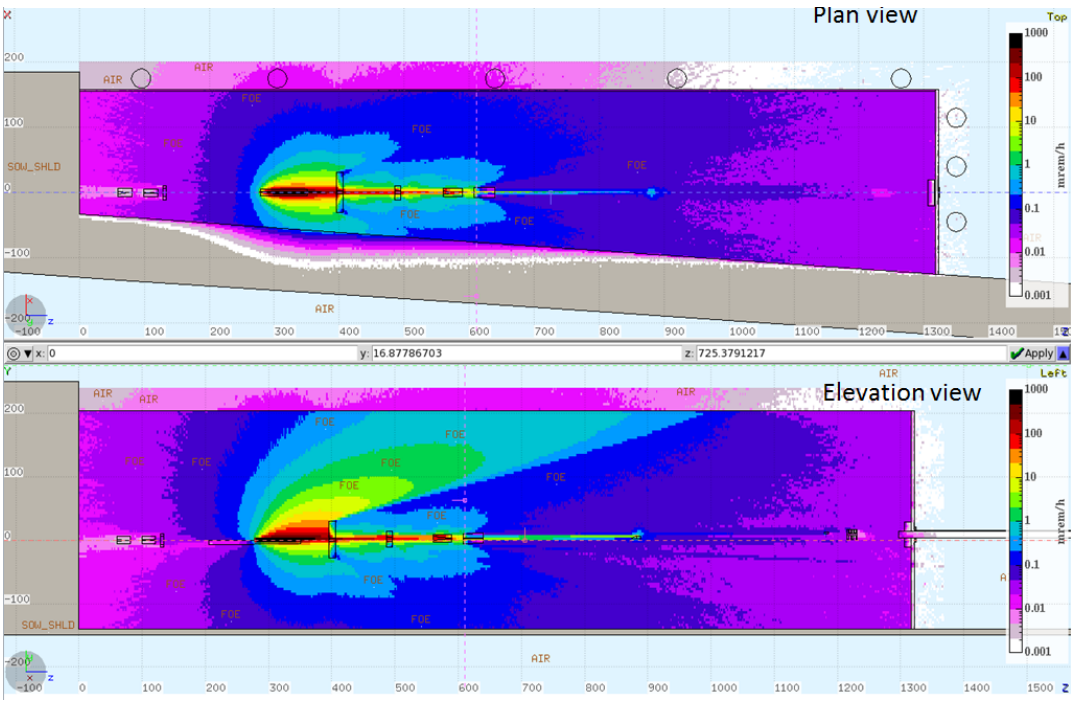

Figure 15. Total ambient dose equivalent rates in and around the FOE when the GB strikes the center of CM [case 6].

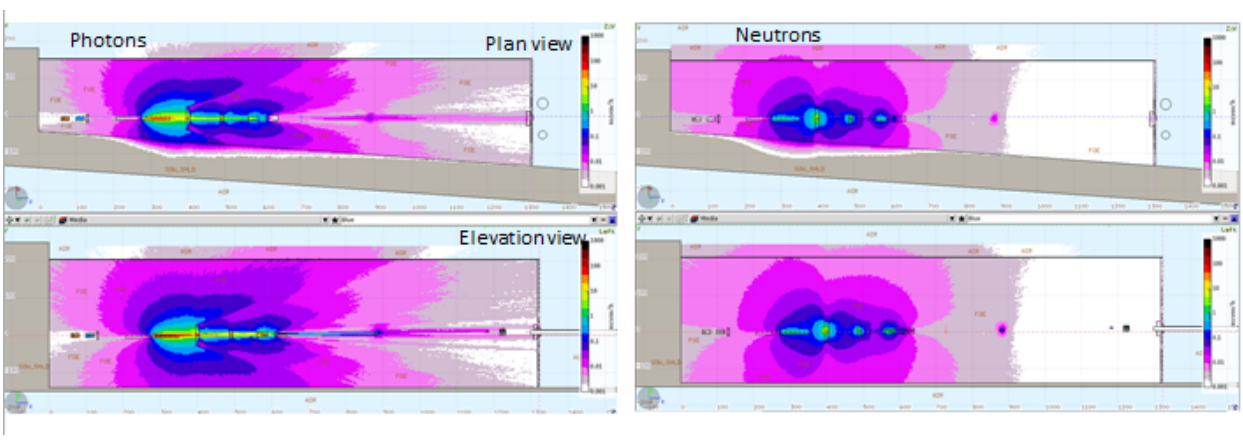

Figure 16. The photon (left) and neutron ambient dose equivalent rates in and around the FOE when the GB strikes center of CM [case 6].

The total ambient dose equivalent rates outside the side wall and the roof of the FOE are estimated to be less than 0.02 mrem/hr and less than 0.01 mrem/hr outside the downstream wall. Neutron contribution is marginally higher than the photon outside the side wall of the FOE.

2.2.7. Case 7

Here, the GB strikes the top center point on the WBS. This is below the center of the aperture. Figure 17 shows the total ambient dose equivalent rates and Figure 18 shows the photon and neutron contribution.

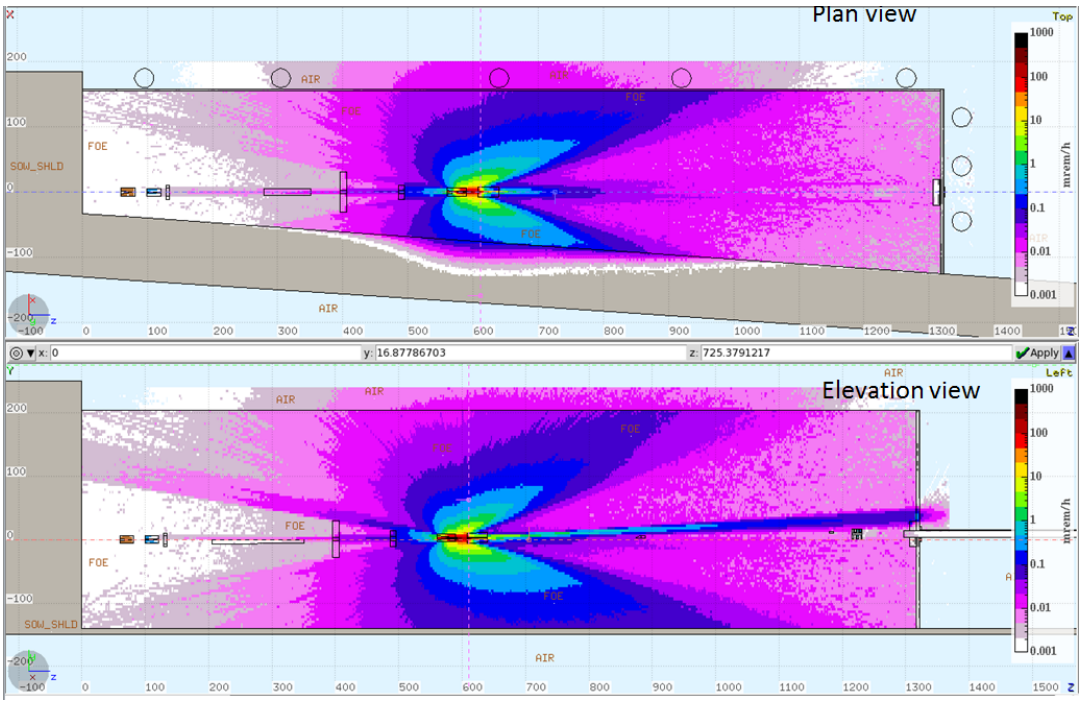

Figure 17. Total ambient dose equivalent rates in and around the FOE when the GB strikes the top center point on the WBS [case 7].

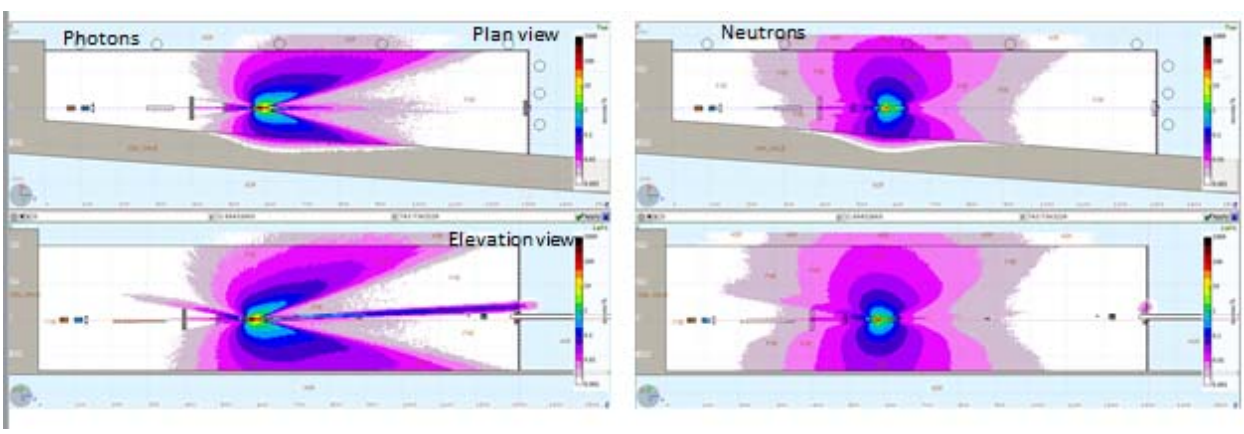

Figure 18. The photon (left) and neutron ambient dose equivalent rates in and around the FOE when the GB strikes the top center point on the WBS [case 7].

The dose rates outside the side wall is estimated to be less than 0.02 mrem/hr and less than 0.01 mrem/hr on the roof. The dose rates outside the downstream wall on contact is found to be less than 0.06 mrem/hr and consist mostly of photons. Figure 19 shows the cutaway view of the dose rates outside the downsteam wall on contact. In this figure the beam is directed out of the paper towards the reader.

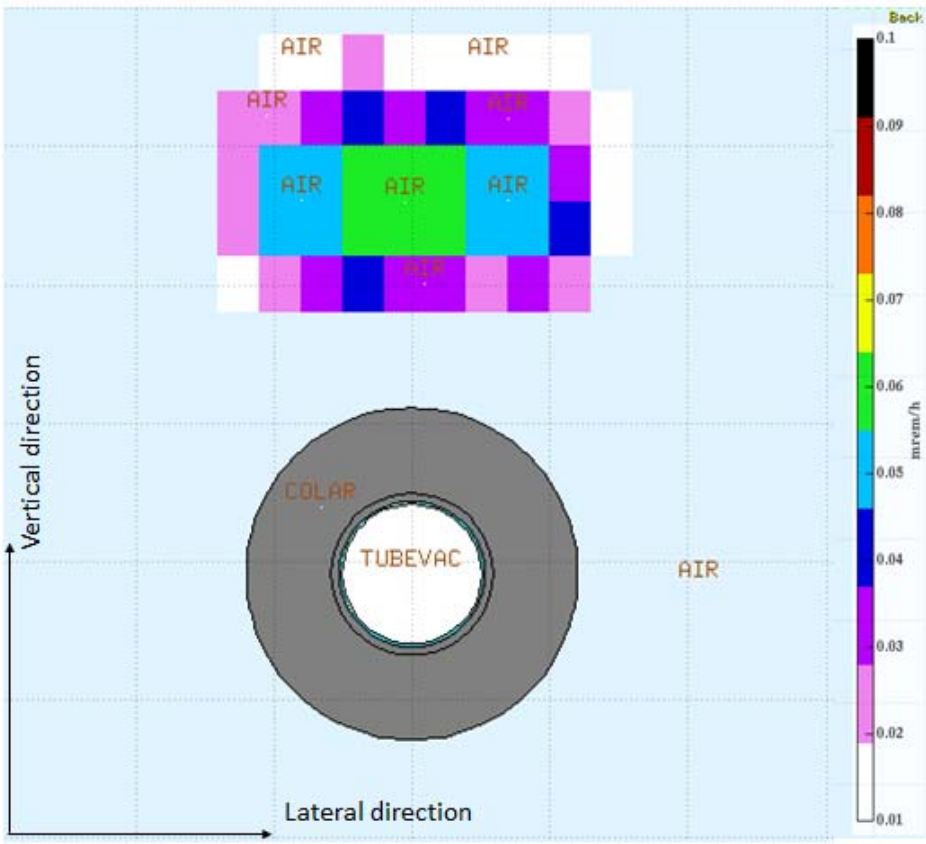

Figure 19. The cutaway view of the region right outside the FOE downstream wall showing the dose rates.

At 4 cm from the wall, this reduces to 0.05 mrem/hr and at 30 cm it is 0.01 mrem/hr. It should be noted that the USRBIN resolution in Z direction in these simulations is 2 cm. In Figures 20 and 21, the total ambient dose equivalent rates outside the beam transport pipe and in and around the ESE are shown. The dose rates can be seen to be well below 0.05 mrem/hr in and around the pipe and the ESE. For the ESE, the scoring is carried out for one bin in the Z direction that is about 21 cm from the inner face of the upstream wall.

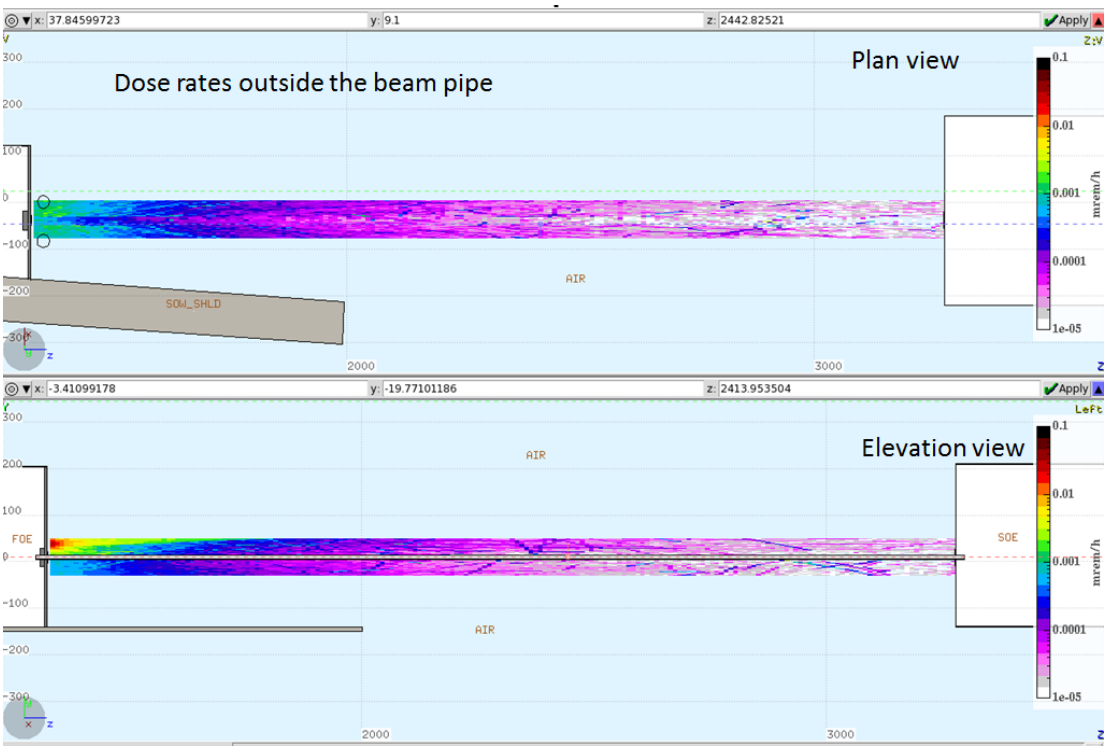

Figure 20. Total ambient dose equivalent rates in and around the beam transport pipe, when the GB strikes the top center point on the WBS [case 7].

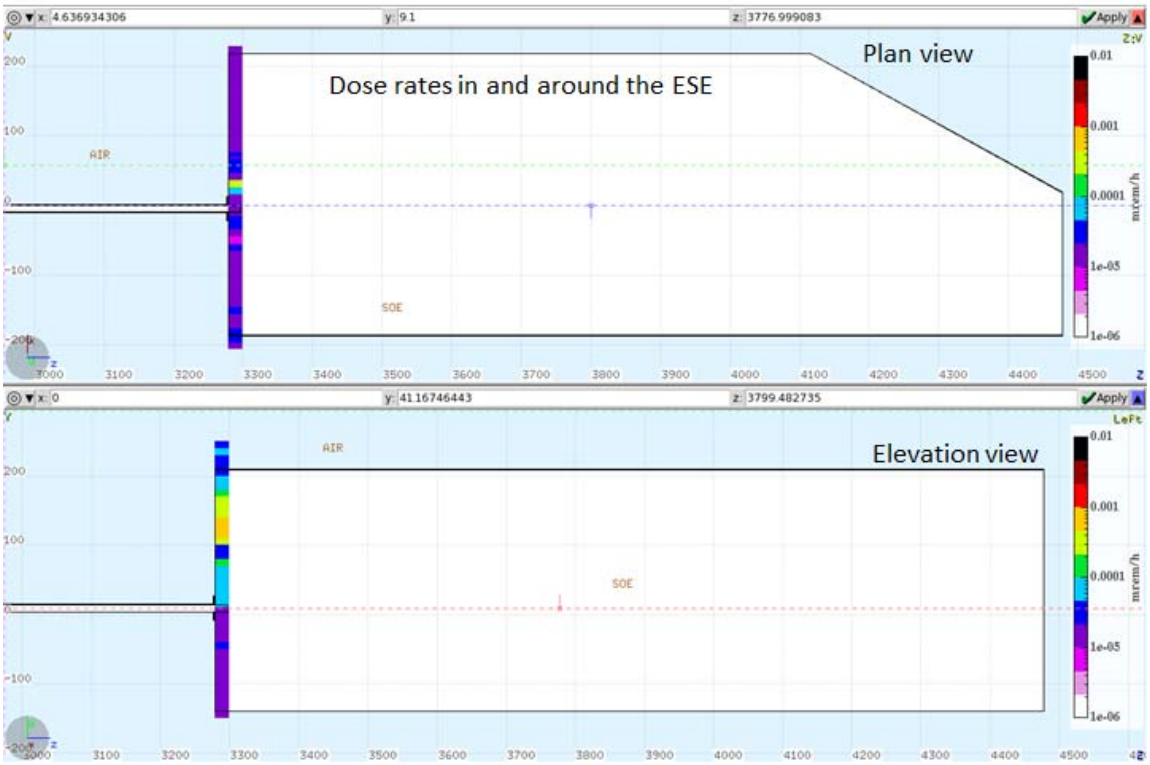

Figure 21. Total ambient dose equivalent rates in and around the ESE, when the GB strikes the top center point on the WBS [case 7].

2.2.8. Case 8

The GB is incident on the top outboard point on the WBS/pink beam mask as shown in Figure 4. The total ambient dose equivalent rates are shown in Figure 22 and the photon and neutron contribution are given in Figure 23.

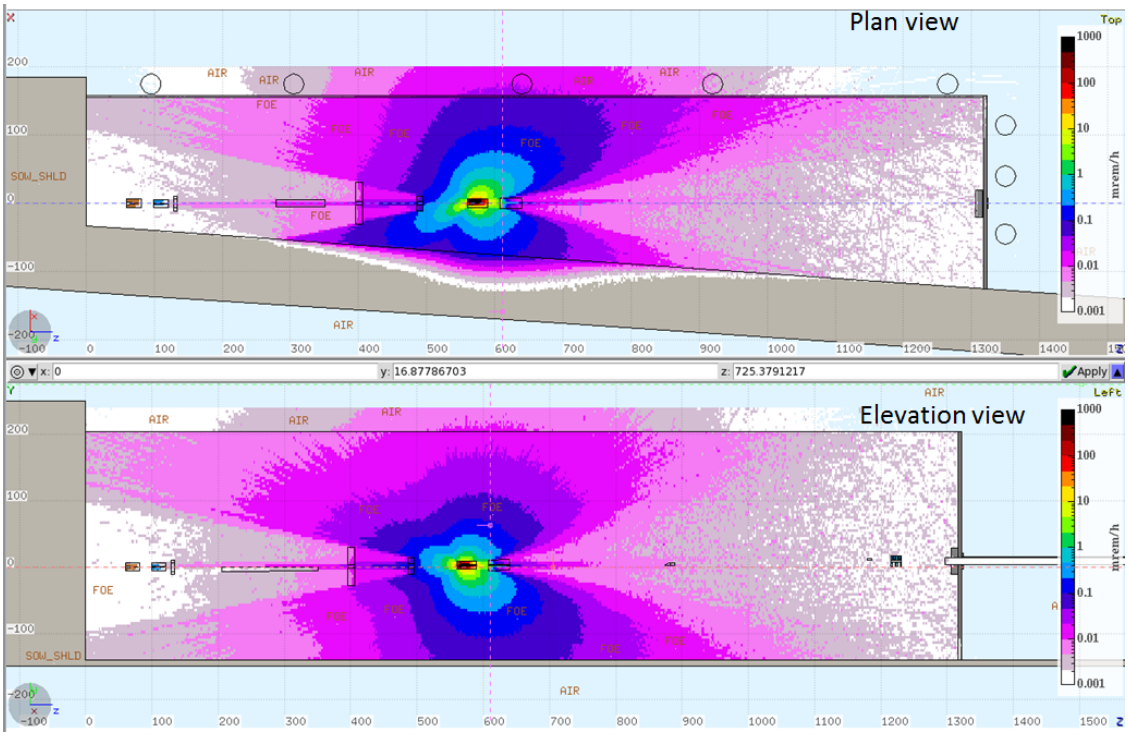

Figure 22. Total ambient dose equivalent rates in and around the FOE, when the GB strikes the top outboard point on the WBS [case 8].

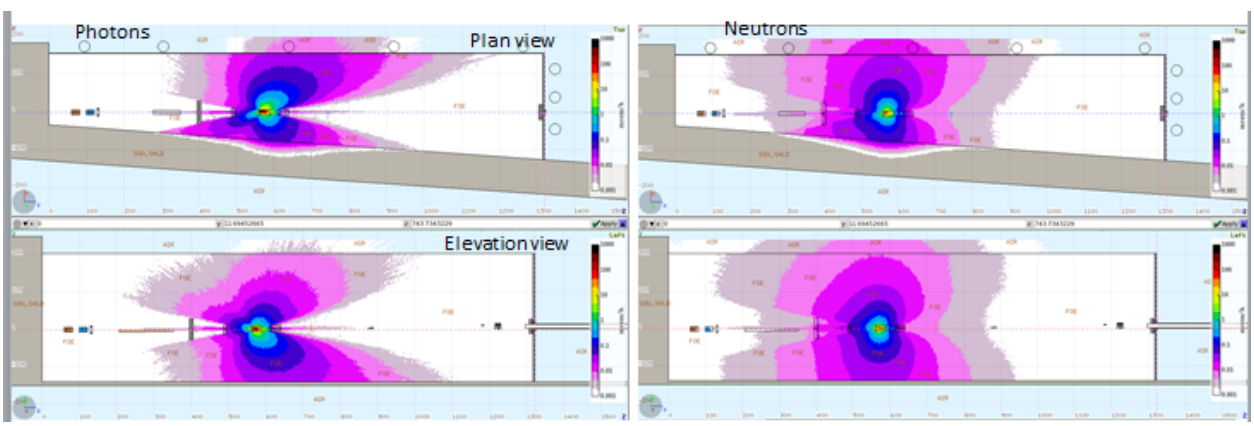

Figure 23. Photon (left) and neutron ambient dose equivalent rates in and around the FOE, when the GB strikes the top outboard point on the WBS [case 8].

The total ambient dose equivalent rates outside the side wall is estimated to be less than 0.02 mrem/hr and less than 0.01 mrem/hr outside the roof and the downstream wall. Neutrons contribute a significant part of the dose rates outside the side wall.

2.3. Summary

Table 1 gives the summary of the results from the radiation shielding analysis with GB as the source.

Table 1. Summary of the Contact Dose Results in and Around the FXI Beamline with GB as Source

	Source	**Total ambient dose equivalent rate on contact mrem/hr**				
		Side wall (FOE)	Roof (FOE)	Downstream wall (FOE)	Transport pipe	ESE
1	On aperture of FM, inboard side	<0.02	<0.02	< 0.01	< 0.01	< 0.01
2	On aperture of FM, outboard side	<0.03	<0.02	< 0.01	< 0.01	< 0.01
3	On FM, top outboard point	<0.03	<0.02	< 0.01	< 0.01	< 0.01
4	On FM, outboard point, angled incidence	<0.03	<0.02	< 0.01	< 0.01	< 0.01
5	Upstream edge of CM	<0.02	<0.03	< 0.01	< 0.01	< 0.01
6	Center of CM	<0.02	<0.02	< 0.01	< 0.01	< 0.01
7	Top center point on WBS	<0.02	< 0.01	<0.06	< 0.01	< 0.01
8	Top outboard corner on WBS	<0.03	< 0.01	< 0.01	< 0.01	< 0.01

From the results, the estimated ambient dose equivalent rates outside the FOE, beam transport pipe and the ESE are below the levels stipulated by the NSLS-II Shielding Guidelines and the ALARA policy.

3. Synchrotron radiation scattering analysis

The various locations of the synchrotron radiation losses are obtained from the ray trace. The relevant portions of the vertical and horizontal ray traces (Figure 24) and the components are shown in Figure 25. A mis-steered condition is not analyzed here as such a scenario has been ruled out by a separate simulation by the Lead Beamline Scientist [3].

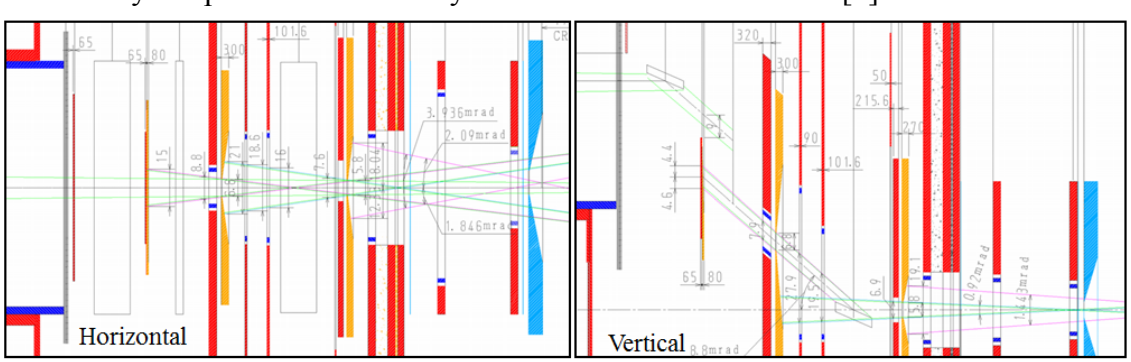

Figure 24. The horizontal and vertical synchrotron radiation ray traces

The following cases are considered for the synchrotron calculations:

1. Full power white beam on FM
2. Trimmed white beam on CM
3. Trimmed white beam on WBS
4. Pink beam on Double Crystal Monochromator (DCM)
5. Pink beam on the PBS
6. Monochromatic (Mono) beam in air inside the transport pipe (loss of vacuum)
7. Mono beam on a Silicon (Si) scatter target in ESE
8. Mono beam on the beam stop inside ESE

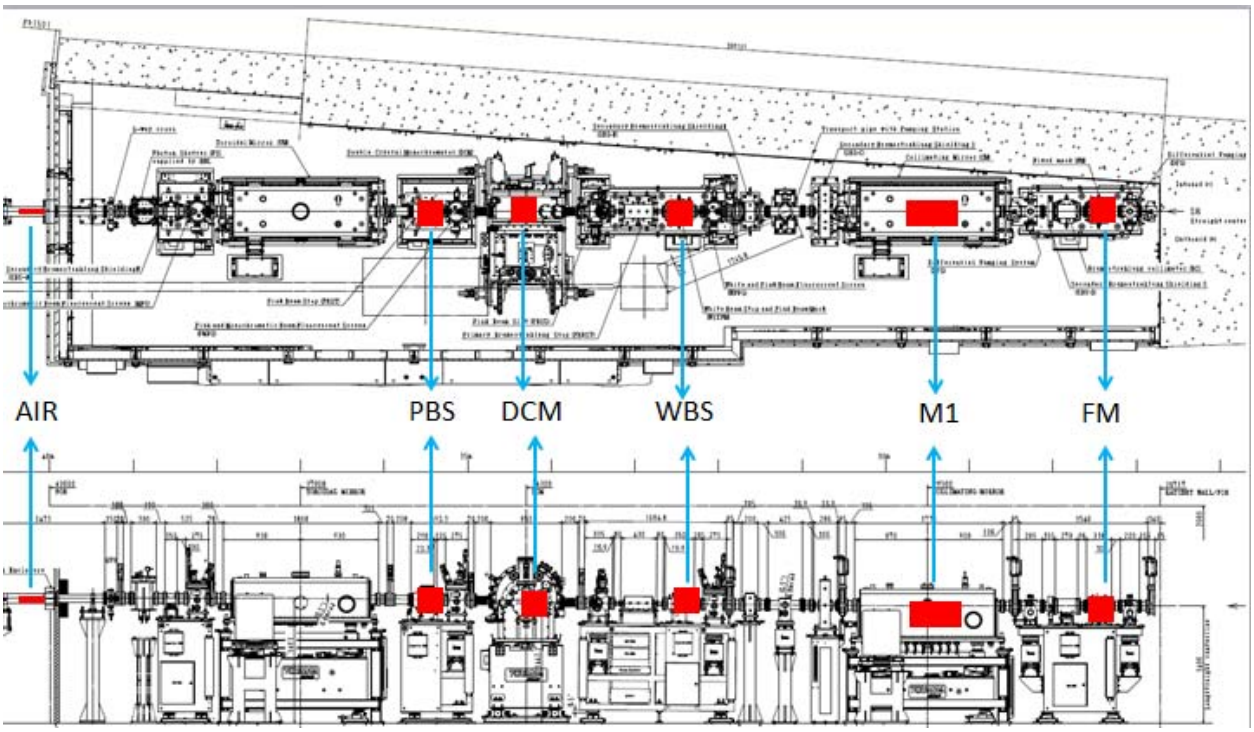

Figure 25. The layout of the FXI beamline showing the scatter components in the FOE and the air column in the beam transport pipe.

The synchrotron beam is centered horizontally with a distance of 179.4 cm to the side wall including the 18 mm lead (Pb) shield. The distance to the roof from the mirror is 200.9 cm including the 10 mm Pb. The vertical inclination of the beam introduces a vertical offset which reduces this distance by 2.48 cm from the WBS, 2.94 cm from the PBS and 9.1 cm from the DCM. The distance from the scattering target considered in the ESE is taken to be 180 cm to the side wall. The vertical offset here is assumed to be the same as that of the DCM.

3.1. Results

The white beam spectrum is calculated using the XOP software [4]. The calculation parameters are shown in Figure 26. The spectrum is calculated in steps of 1 keV from 1 keV to 500 keV. Two different slit openings are used for the calculations. For the full power white beam that

enters the FOE and falls on the FM, the slit openings are 0.83 mrad × 0.62 mrad. For the trimmed beam after FM, the slit openings are 0.21 mrad × 0.21 mrad as shown in the figure. Figure 27 shows the full power and the trimmed white beam spectra. The integrated (from 1 keV to 500 keV) beam powers are 10.9 KW and 1.9 KW before and after the FM. It also shows the pink beam spectrum as calculated by the STAC8 code with a Rhodium (Rh) coated mirror at 4.4 mrad. When the mirrors are considered as Si scatters, their reflective properties are neglected. When they are considered as mirrors for reflection (for obtaining the pink beam from the white beam), the loss of reflectivity due to the inherent roughness is not considered.

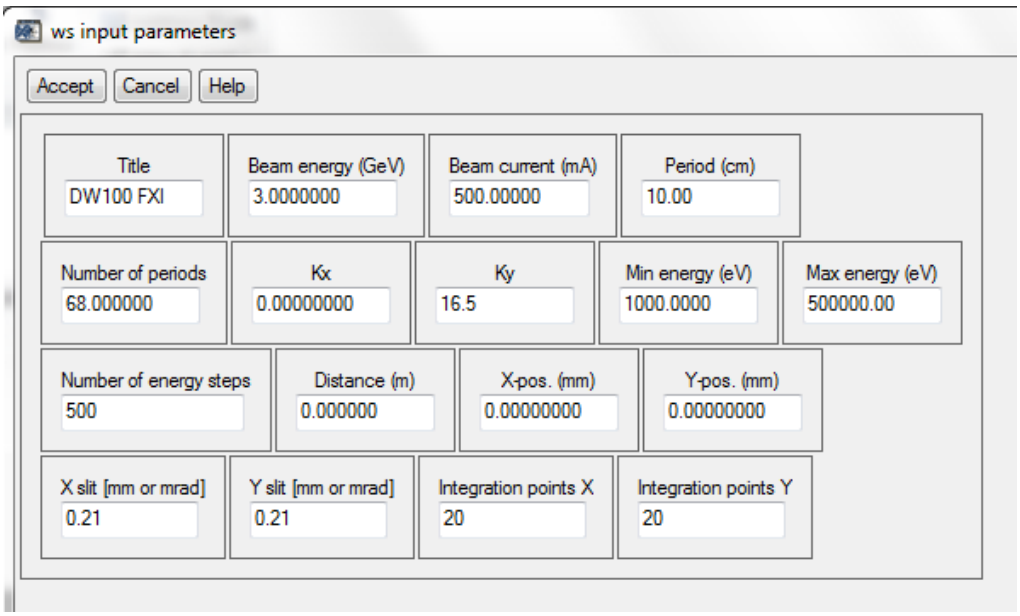

Figure 26. The XOP input parameters used to obtain the trimmed white beam spectrum

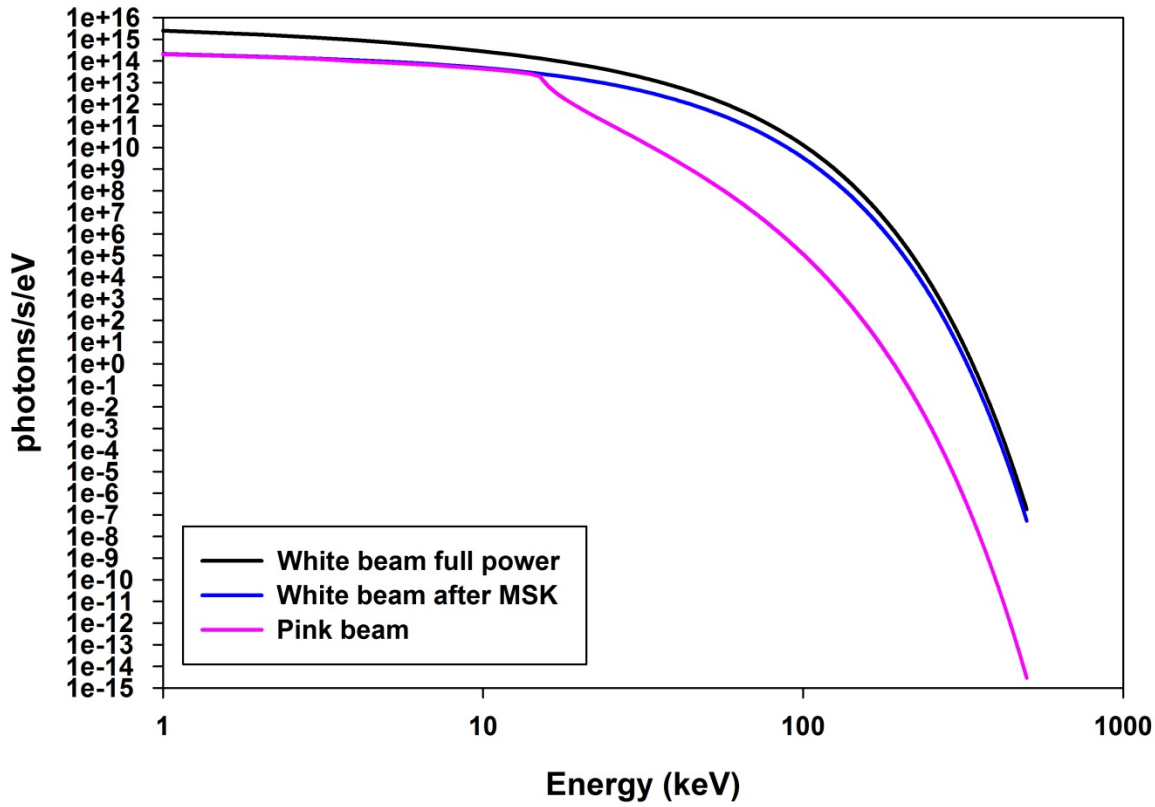

Figure 27. The white beam spectrum before and after the FM, obtained from XOP for the FXI DW100 source and the pink beam obtained from the STAC8 code with the white beam after the FM as the input.

3.1.1. Dose rates outside the FOE

The ambient dose equivalent rates are estimated by the STAC8 code with the white beam as given in Figure 27 as the starting point. This is incident on the CM and the WBS and made to scatter. Here, the mirror is considered as a scattering target. The dose rates on contact outside the side wall, downstream wall and the roof from these two scatter sources are found to be less than 0.01 mrem/hr.

For the pink beam calculations, the white beam is incident on the CM at 4.4 mrad with Rh as the reflecting medium. The mirror here is a reflecting device. The resulting beam (shown in Figure 27) is incident on the PBS and the DCM. The dose rates from these targets, on contact outside the side wall, downstream wall and the roof are found to be less than 0.01 mrem/hr.

3.1.2. Dose rates outside the beam transport pipe

The mono beam option of STAC8 is invoked to carry out all analyses for targets that are downstream of the DCM. In this case, the mono beam is scattered off an air column with 6 mm

lead beam transport pipe at a distance of 5.86 cm to simulate a vacuum loss condition. The beam consists of the fundamental and the higher harmonics at energies. These are given in Table 2. This maximizes the 87 keV photons (K edge of Pb) where it has the lowest attenuation factors in the energy domain considered here.

Table 2. Mono Beam Parameters used in the STAC8 Calculations

Energy (keV)	Bandwidth	Flux (photons/s)
29.0	3.857E-03	2.071E+13
87	7.012E-04	8.765E+09
116	5.464E-04	3.764E+08
145	2.015E-04	7.901E+06
203	6.557E-05	8.917E+03

The dose rate on contact with the beam transport pipe is found to be less than 0.01 mrem/hr.

3.1.3. Dose rates outside the ESE

Synchrotron radiation (SR) scattering off a Si target placed in the beamline is used to estimate the dose rates outside the side walls and the roof with the mono beam given in Table 2 as the source. The side walls and the upstream and the downstream walls are constructed of lead 4 mm thick and the roof is 3 mm thick. The minimum distance to the side wall is 180 cm and 191.8 cm to the roof. For the upstream and the downstream wall, the target is assumed to be at a distance of 1 m from the walls. The ambient dose equivalent rates are estimated to be less than 0.01 mrem/hr on contact with all the walls and the roof of the ESE.

3.1.4. FLUKA simulations to rule out a direct path to the beam transport pipe

Two separate FLUKA Monte Carlo simulations are carried out with 100 keV isotropic source photons originating from the CM and the DCM to understand the possibility of the photon path to the beam transport pipe either directly or through the Compton scattering process. The FLUKA geometry (Figure 3) used for the GB calculations is used for these simulations. The source starting points are located on the center of the mirror and at the DCM location, though the DCM itself is not modelled in the geometry. The lead walls and the guillotine of the FOE are configured to completely absorb the photons to prevent scatter from these reaching the beam transport pipe. The results then will show the photons that will reach the beam transport pipe after they have interacted with the beamline components only. This will show the effectiveness of the PBS and the SBS-3 as shadows. Figures 28 and 29 show the results from these simulations. The scoring is carried out in a smaller region in X and Y directions. They indicate the PBS and SBS-3 effectively shadow the scattered photons from CM and DCM.

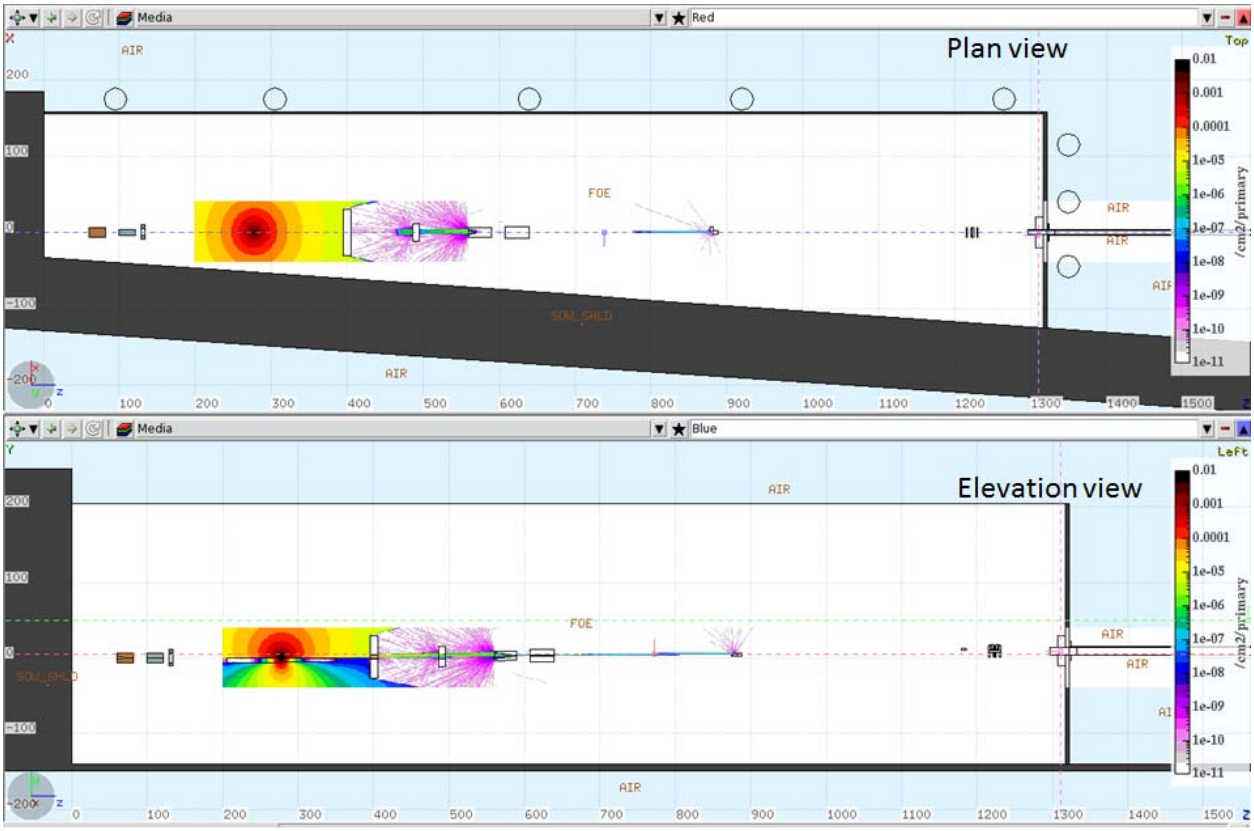

Figure 28. Study indicating the effectiveness of the PBS as a shadow for blocking the pink beam from CM reaching the beam transport pipe

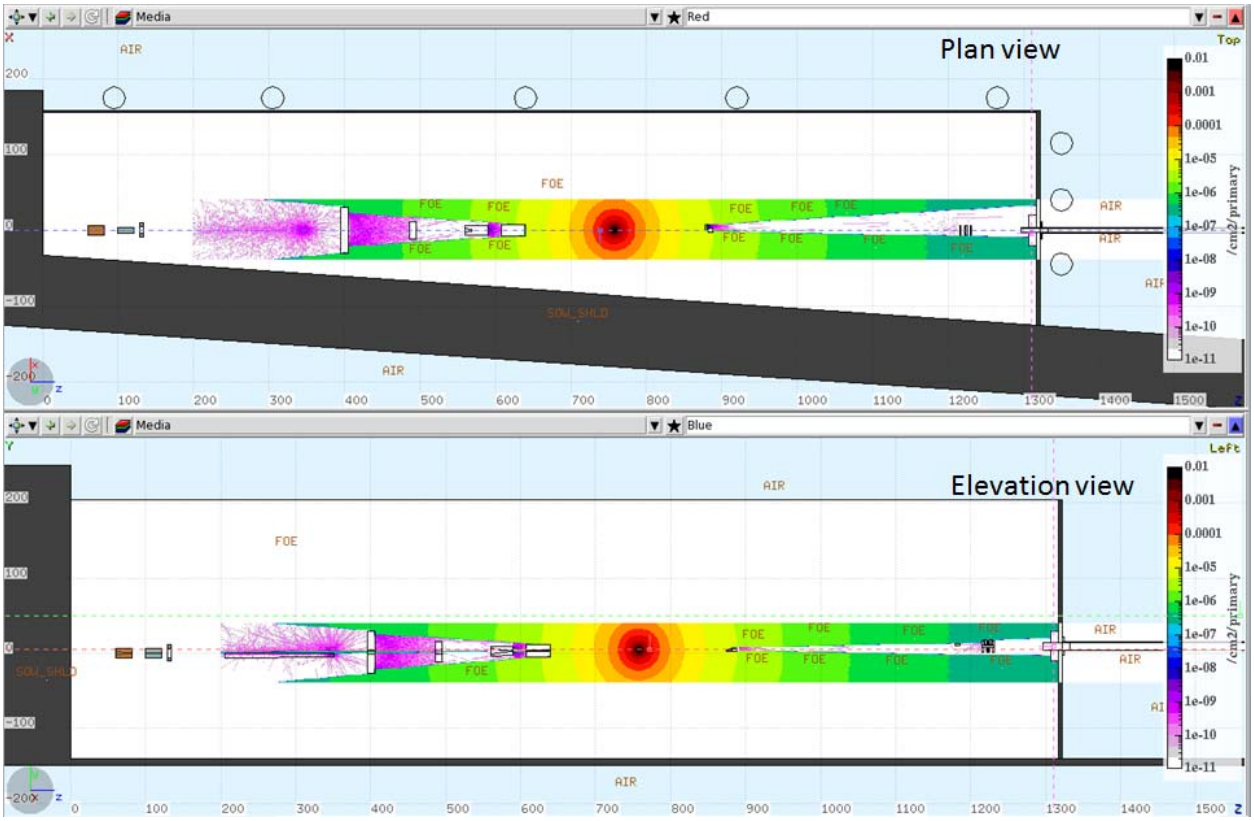

Figure 29. Study indicating the effectiveness of the PBS as a shadow for blocking the pink beam from DCM reaching the beam transport pipe

3.2. Summary

Table 3 shows a summary of the dose rates at various locations, all reported on contact with the shield surface. The results indicate that the ambient dose equivalent rates outside the FOE, the beam transport pipe and the ESE are well below 0.01 mrem/hr.

Table 3. Summary of the Dose Rates around the FXI **b**eamline with SR as Source

Location	Scattering target	Source	Ambient dose equivalent rates on contact (mrem/hr)		
			Side wall	Roof	Downstream wall
Outside the FOE	FM	Full white beam	< 0.01	< 0.01	< 0.01
Outside the FOE	CM	Trimmed white beam	< 0.01	< 0.01	< 0.01
Outside the FOE	WBS	Trimmed white beam	< 0.01	< 0.01	< 0.01

Outside the FOE	PBS	Pink beam	< 0.01	< 0.01	< 0.01
Outside the FOE	DCM	Pink beam	< 0.01	< 0.01	< 0.01
Outside beam transport pipe	Air	Mono beam	< 0.01	-	-
Outside the ESE wall	Silicon	Mono beam	< 0.01	< 0.01	< 0.01
Outside the beam stop in ESE	-	Mono beam	-	-	< 0.01

The estimated results indicate that the ambient dose equivalent rates are well below 0.01 mrem/hr at all locations for all sources and scattering targets.

4. Overall summary

The radiation shielding analysis of the 18-ID (FXI) beamline indicates the dose rates outside the FOE, beam transport pipe and the ESE meet the NSLS-II Shielding Guidelines and ALARA policy.

5. References

1. Guidelines for the NSLS-II Beamline Radiation Shielding Design LT-C-ESH-STD-001, November 7, 2014.
2. R. Lee, NSLS-II Issue and Decision Paper: ALARA Analysis for Installations of Secondary Bremsstrahlung Shields in the First Optics Enclosure, PS-C-ESH-STD-005, (06/01/2016).
3. FXI Mis-steered Pink Beam, W. Lee, NSLS-II TECHNICAL NOTE 265 https://ps.bnl.gov/sites/tn/TechNotes/FXI%20Mis-steered%20Pink%20Beam.pdf
4. https://www1.aps.anl.gov/science/scientific-software/xop

6. Abbreviations

ALARA	As Low as Reasonably Achievable	FOE	First Optical Enclosure
BC	Bremsstrahlung Collimator	FXI	Full Field X-ray Imaging
BNL	Brookhaven National Laboratory	GB	Gas Bremsstrahlung
CM	Collimating Mirror	ID	Inside Diameter
DW	Damping Wiggler	m	Meter
DCM	Double Crystal Monochromator	mrad	Millirad
DOE	Department of Energy	mrem/hrr	Millirem per hour
ESE	End Station Enclosure	NSLS-II	National Synchrotron Light Source II
FM	Fixed Mask	OD	Outside Diameter

PBRS	Primary Bremsstrahlung Stop	SR	Synchrotron Radiation
PBS	Pink Beam Stop	SS	Stainless Steel
PSH	Photon Shutter	TLD	Thermo Luminescent Dosimeter
SBS	Secondary Bremsstrahlung Shield	WBS	White Beam Stop

Appendix A

FXI components modeled in radiation safety simulation

Coordinate system: (x,y,z) where z is the beam direction (+ve is downstream), y is vertical (+ve is up); x is horizontal (+ve is outboard). z is measured from center of the straight section, x and y are measured from the white beam center line.

18-ID-A (FOE): see drawing. Side walls are 18 mm Pb, roof is 10 mm Pb, downstream wall is 50 mm Pb. The A hutch downstream side of the downstream wall is about 39938 mm from the center of the straight section.

18-ID-B: see drawing. All walls are 4 mm Pb, roof is 3 mm Pb. The B hutch upstream side of the upstream wall is about 59500 mm from the center of the straight section.

Transport pipe between 18-ID-A and 18-ID-B: 101.6 mm OD SS tube, wrapped with 6 mm thick Pb. Centered at (x,y)=(0,91)

Drawings for these are included. You will see some differences in dimensions given here compared with the drawings – the dimensions here are conservatively simplified.

1. Fixed Mask (Glidcop): Sloped surfaces with aperture

Size 120 mm x 120 mm x 220 mm

Upstream entrance centered at (x,y,z)=(0,0,27313). Size of sloped opening = 42 mm H x 28 mm V.

Downstream exit centered at (x,y,z)=(0,0,27533). Toleranced aperture size at exit = 6.6 mm x 6.6 mm

2. Bremsstrahlung collimator (W): 120 mm diameter W cylinder, 215 mm long with aperture.

Upstream aperture centered at (x,y,z)=(-2.7,0,27711) ; note horizontal offset.

Downstream aperture centered at (x,y,z)=(-2.7,0,27926)

Toleranced aperture size = 10.5 mm V x 17 mm H.

3. Secondary Bremsstrahlung shielding – 0 (Pb): Lead donut

OD = 220 mm; ID=130 mm

Thickness = 50 mm

Upstream centered at (x,y,z)=(0,0,28002)

Downstream centered at (x,y,z)=(0,0,28052)

ID=132 mm and OD 218 mm.

4. Collimating mirror (Si):

1450 mm long x 100 mm wide x 60 mm high

Centered at (x,y,z)=(0,0,29500)

Nominal angle: 4.4 mrad; reflects upwards.

5. Secondary Bremsstrahlung shielding – I (Pb): Lead wall with aperture

Wall size is 609.6 mm H x 570.8 mm V x 101.6 mm thick

Upstream aperture centered at (x,y,z)=(0,10.3,30672)

Downstream aperture centered at (x,y,z)=(0,10.3,30773.6)

Toleranced aperture size = 47 mm H x 47 mm V

6. Secondary Bremsstrahlung shielding – II (Pb): Lead wall with aperture

Wall size is 220 mm H x 260 mm V x 90 mm thick

Upstream aperture centered at (x,y,z)=(0,18.3,31578)

Downstream aperture centered at (x,y,z)=(0,18.3,31668)

Toleranced aperture size = 46 mm H x 63 mm V

7. White beam stop/pink beam mask (Glidcop): Sloped surfaces with aperture. Tilted at 8.8 mrad.

Size 120 mm x 120 mm x 300 mm

Upstream entrance centered at (x,y,z)=(0,24.8,32317). Size of sloped opening = 46 mm H x 68 mm V.

Downstream exit center at (x,y,z)=(0,27.4,32617). Toleranced aperture size at exit = 7.6 mm x 7.6 mm

8. Primary Bremsstrahlung stop (Pb): Lead wall with pink beam aperture. Tilted at 8.8 mrad.

Wall size is 150 mm H x 160 mm V; 320 mm thick.

Upstream entrance aperture centered at (x,y,z)=(0,29.0,32797)

Downstream exit aperture centered at (x,y,z)=(0,31.8,33117)

Toleranced aperture size = 19 mm H x 19 mm V

9. Pink beam stop (Glidcop): Wedge shape

Size: Downstream end is 34 mm high; upstream end is zero high

Width = 70 mm; Angle = 23.8 degree; Length = 34/tan(23.8) = 77 mm

Downstream is centered at (x,y,z)=(0,51.4,35537) (ie; goes from y=34.4 mm to y=68.4 mm)

10. Secondary Bremsstrahlung stop III (W): W block downstream of the pink beam stop

Size = 45 mm wide x 40 mm high x 65 mm thick

Upstream edge is centered at (x,y,z)=(0,48.4,35537)

11. Secondary Bremsstrahlung stop IV (W): W block

Size = 75 mm wide x 28 mm high x 75 mm thick

Upstream edge is centered at (x,y,z)=(0,116,38512)

12. 'Standard' NSLS-II Photon shutter. 25 mm V x 40 mm H aperture. Aperture centered at (0, 91,38869). Drawing PD-COM-PSH-1000.

13. 18-ID-A guillotine: Lead plates

Size = 40 cm x 40 cm x 10 cm thick (total).

Aperture for pipe is about 100 mm diameter

Upstream edge is centered at (x,y,z) =(0, 91,39788) (39938 minus 50 mm wall thickness minus 100 mm guillotine thickness).

14. 18-ID-B guillotine: Lead plates

Size = 35 cm x 35 cm x 1 cm thick (total)

Aperture for pipe is about 170 mm diameter

It is in two pieces: upstream piece is on upstream side of upstream wall (about z=59500); downstream piece is on downstream side of upstream wall (about z=59506).