21ID (ESM) TOP-OFF RADIATION SAFETY ANALYSIS

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21ID (ESM) Top-Off Radiation Safety Analysis	

1. Introduction

The primary radiological safety concern for Top-Off injection, with the front end (FE) safety shutters open, is the scenario where injected electrons could be transported down to the beamline through the FE due to an erroneous combination of lattice magnetic field settings and beam energy. These electrons will scatter off the First Optics Enclosure (FOE) components, thereby leading to high dose rates on the FOE walls. The radiological consequences of this fault condition specifically for 21-ID (ESM) are analyzed and discussed in this report. For this beamline, all FE comonents, the ratchet wall collimators and many FOE components lie along the short straight (SS) centerline. The goal of the simulations documented here was to estimate the radiation dose levels generated outside the FOE during this Top-Off fault condition, thus evaluating the efficacy of the FE radiation safety components and the FOE shielding. This beamline was not covered by the Top-Off design report issued in 2014 [1].

The layout of the 21-ID (ESM) FE components is presented in Figure 1 and the layout of the FOE components is presented in Figure 2(a). One ARM is located near the sliding door of the FE. Another ARM is located on the sidewall of the FOE near the hutch door as shown in Figure 2(b).

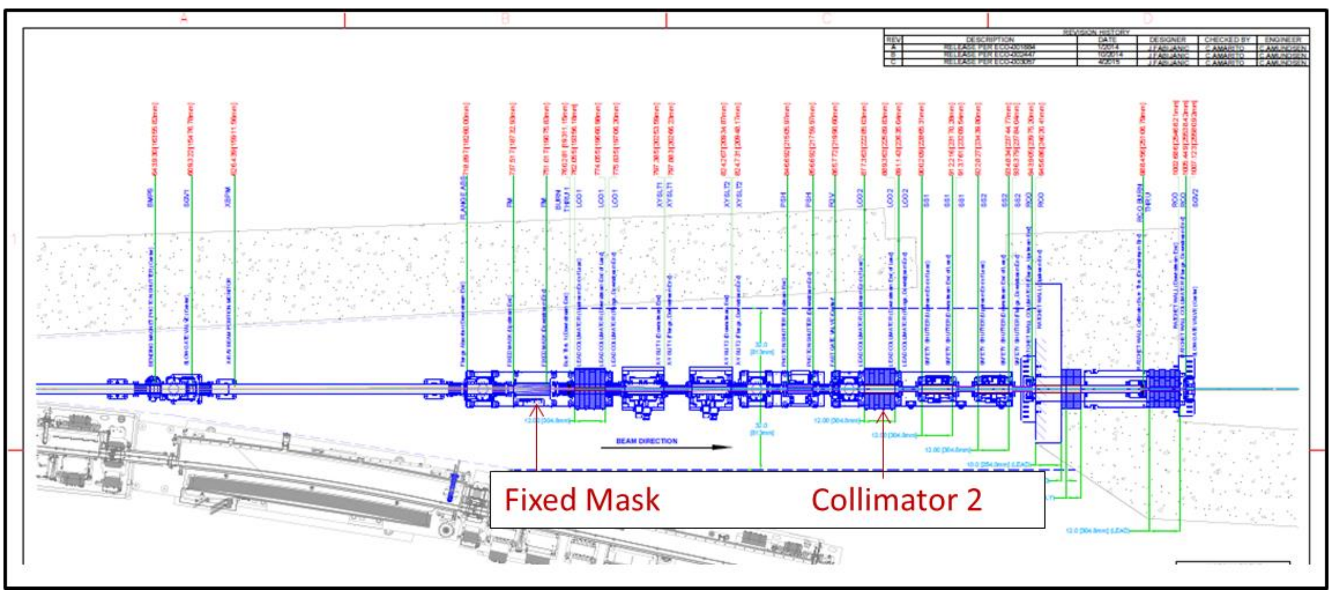

Figure 1: Layout of 21-ID (ESM) FE showing major components consisting of Masks, Collimators, Safety Shutters, and Ratchet Wall Collimator

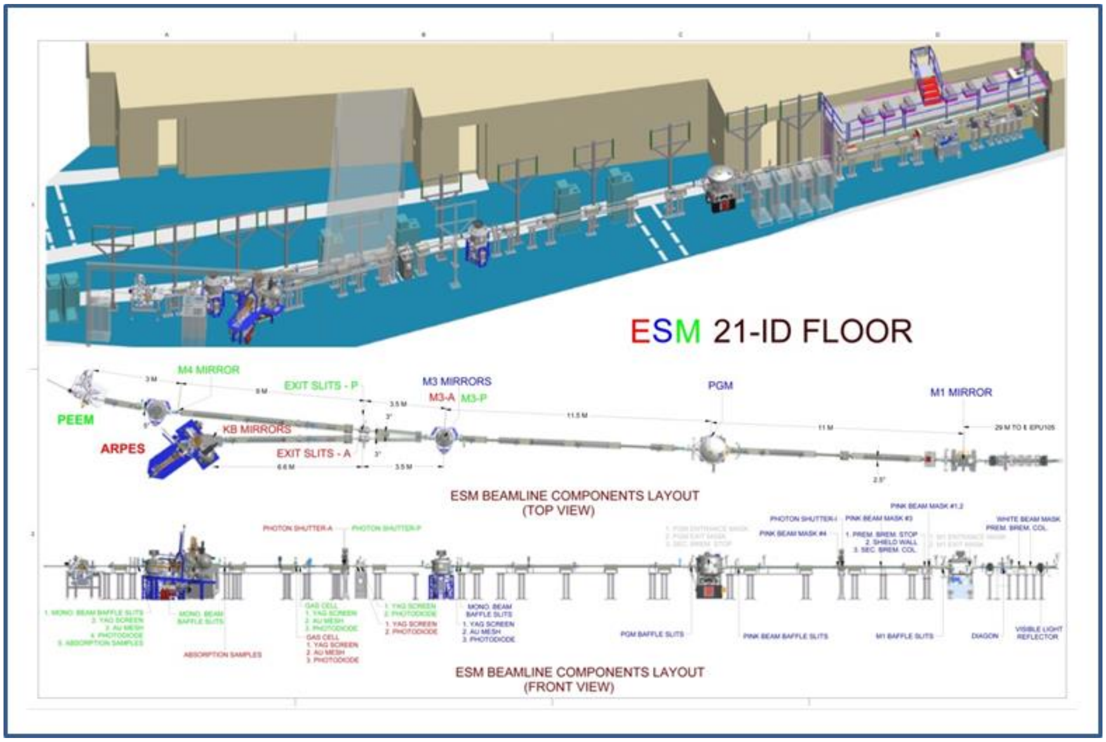

Figure 2(a): Layout of 21-ID (ESM) Beamline

Figure 2(b): ARM installed on the side wall of the 21-ID (ESM) FOE near the hutch door

Backward particle tracking analysis was performed for 21-ID (ESM) and has determined that the injected electrons will not travel beyond the lead collimator 2 (LCO2) in the FE. FLUKA simulations were performed with a pencil beam of electrons striking the upstream face of LC02, both inboard and outboard at 5mm from the aperture edge. Simulations were also performed for the electron pencil beam hitting the inside of the beampipe 40cm upstream of LC02.

The Top-Off backward particle tracking analysis for 21-ID (ESM) is discussed in Section 2, the FLUKA model is described in Section 3 and the results of the simulations are discussed in Section 4. A summary and conclusions are presented in Section 5.

This report can be used as a basis to approve the Top-Off Operation of the 21-ID (ESM) beamline, provided that the beamline and shielding configuration are not changed. The Top-Off Operation of new beamlines and the approval process shall be in accordance with procedure PS-C-ASD-PRC-183 [2].

2. Top-Off Particle Tracking Analysis

At NSLS-II, the Top-Off Safety System guarantees that the injected electron beam does not channel down the FE and into the beamline FOE. Particle tracking analysis for the 21-ID (ESM) FE has shown that the safe endpoint for the injected electron beam is the lead collimator 2. To ensure this safe point for 21-ID (ESM), the apertures and tolerances are exactly the same as those called out in the TOSS interlock specification [1]:

- Collimator 2, +/-2 mm horizontally
- Fixed mask, +/-2 mm horizontally
- S2 chamber, +/-5 mm horizontally
- Undulator Absorber, +/-5 mm horizontally
- Blank off in place.

Figures 3(a), (b) and (c) show the particle tracking simulations for 21-ID (ESM). The two apertures shown in the figures at positions ~19 m and ~22 m from the source point represent the apertures through the fixed mask and collimator 2, respectively. In these simulations, the aperture of the fixed mask was assumed to be 13.14 mm and the aperture of collimator LC02 was assumed to be 70.1 mm. Based on the backward particle tracking simulation [1], the electron beam will have a distance of at least 5 mm from the LC02 aperture edge.

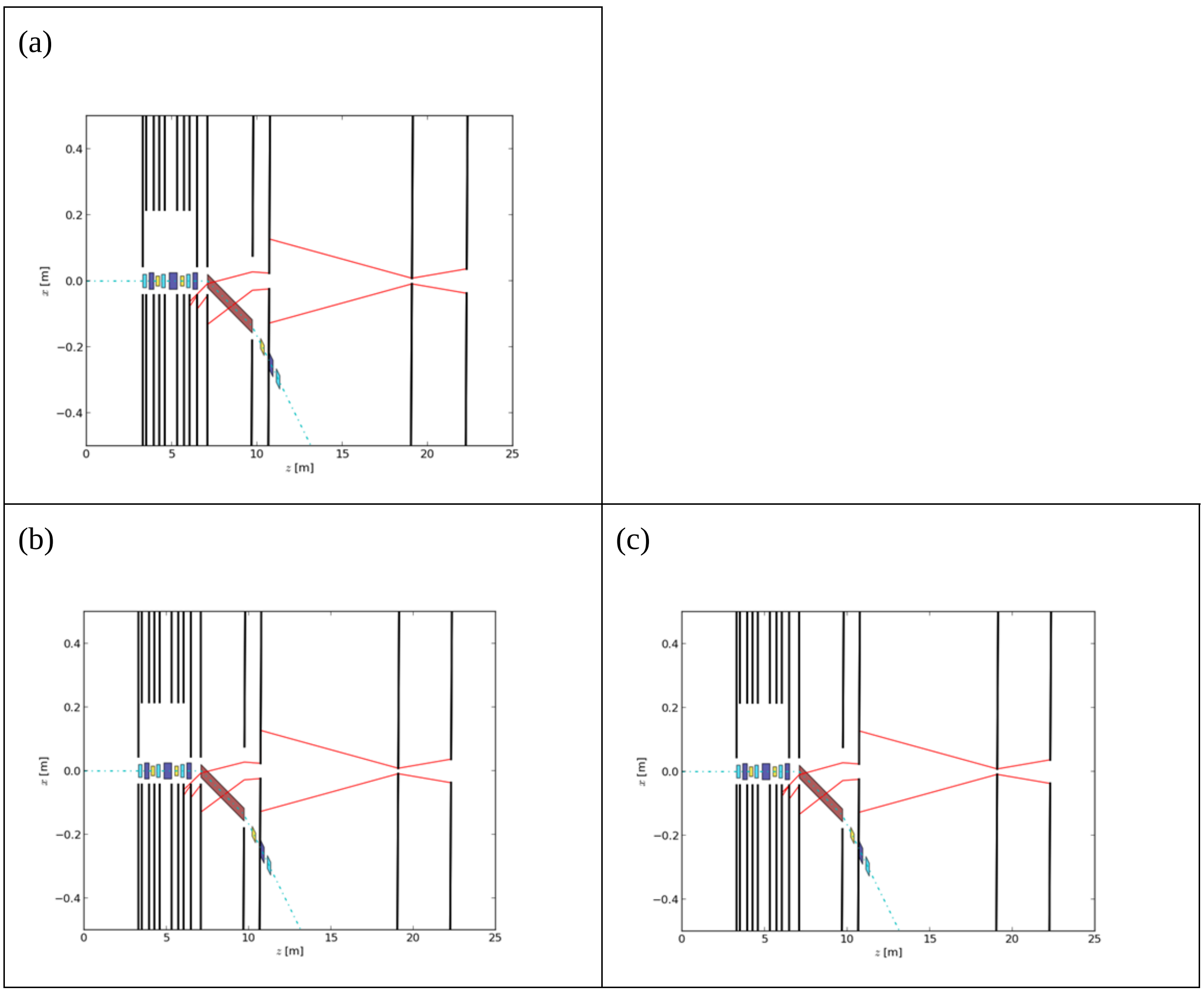

Figure 3. The envelopes of backward particle tracking trajectories for the 21-ID (ESM) beamline assuming a distance of 5 mm from the aperture of LC02 with 2 mm tolerance included. 3(a): On momentum, 3(b): Off momentum (+3%) 3(c): Off momentum (-3%)

3. Description of the FLUKA Model

The plan and elevation views of the FLUKA geometry used for the Top-Off simulations of the 21-ID (ESM) beamline are shown in Figures 4(a) and (b). The input used to generate the FLUKA model is listed in Appendix 1. The FLUKA input file has not been attached but can be provided on request.

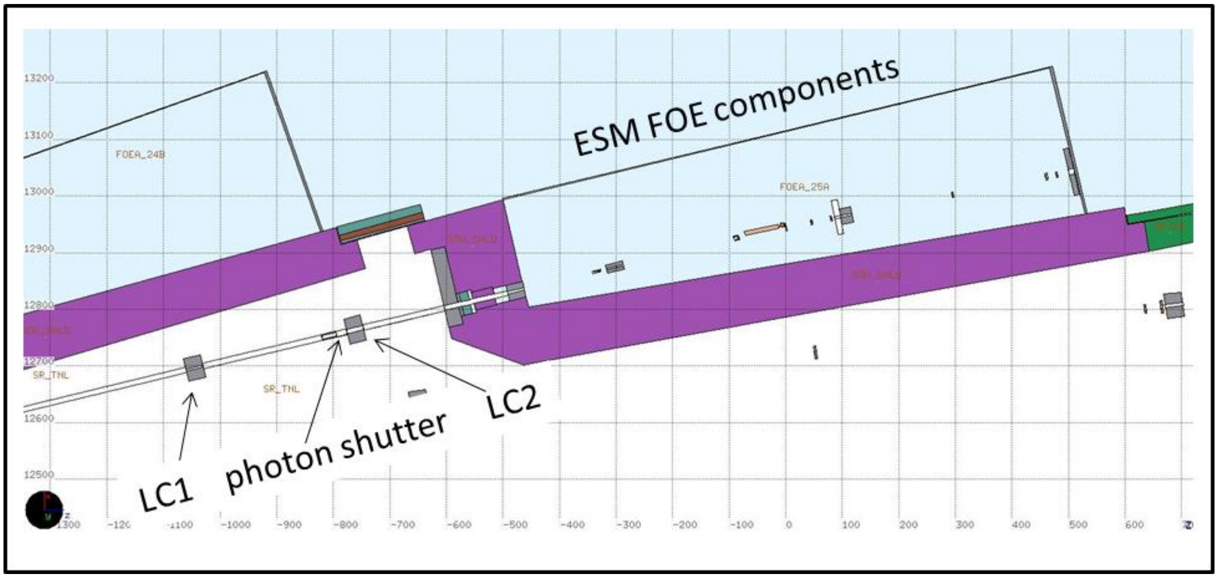

Figure 4(a): Plan view of the FLUKA geometry used in Top-Off simulation of the 21-ID (ESM) Beamline

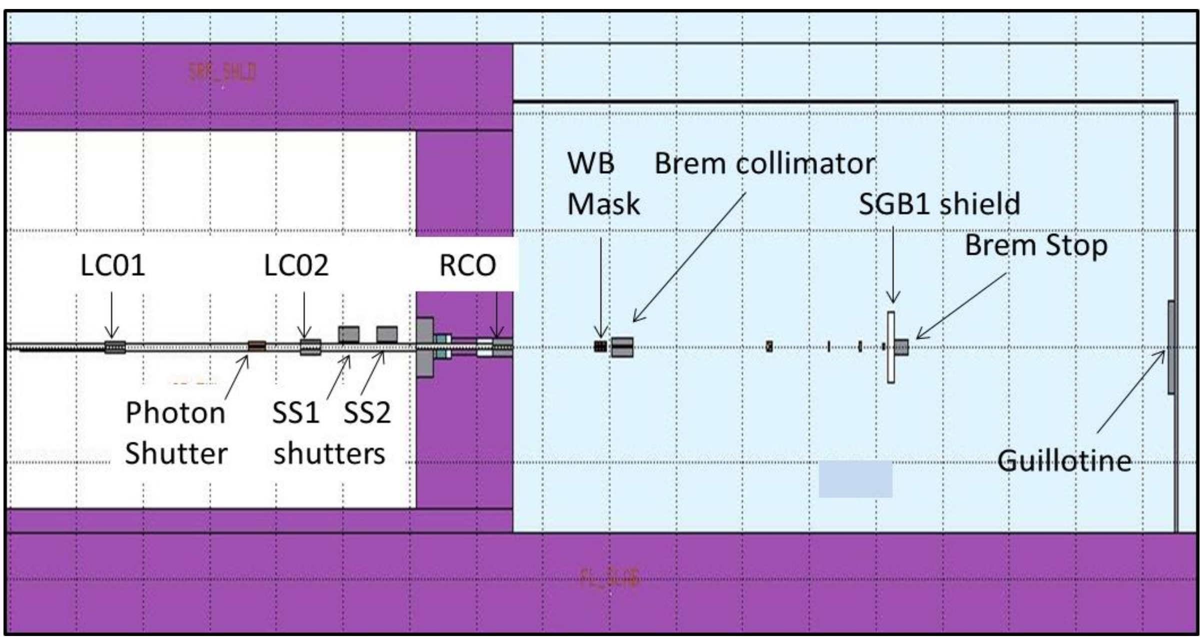

Figure 4(b): Elevation view of the FLUKA geometry used in Top-Off simulation of the 21-ID (ESM) Beamline

A plane view of the view with all components is provided in Figure 4(c).

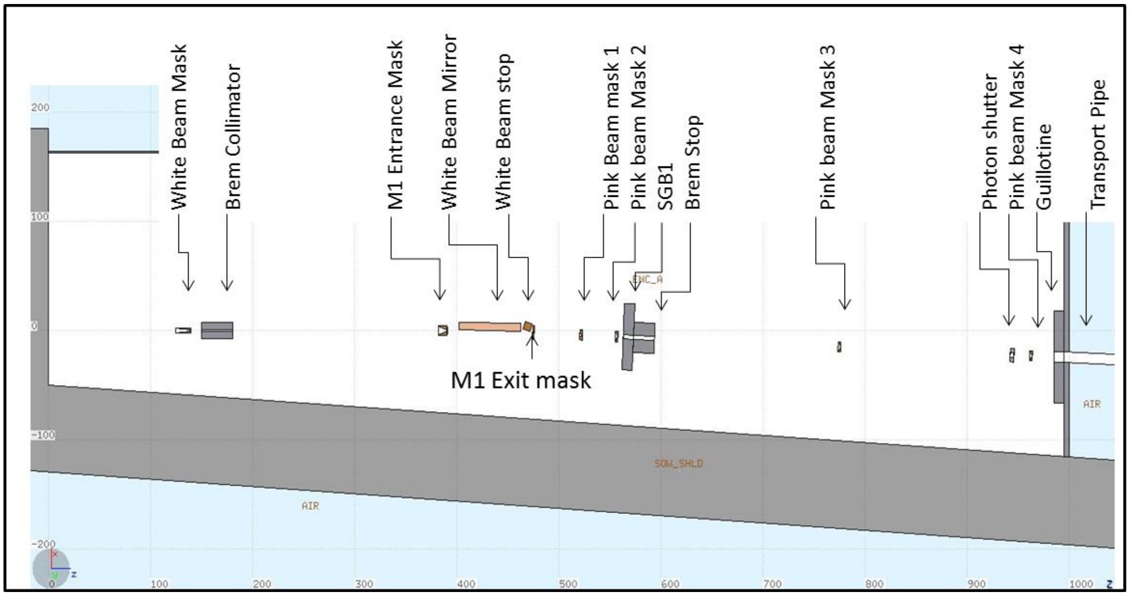

Figure 4(c): Plane view of the ESM Beamline components in the FOE

4. Results for Top-Off FLUKA Simulations

In all FLUKA simulation, a pencil beam of 3 GeV electrons is assumed for the injected beam and all dose rates are normalized to a booster to storage ring injection charge rate of 45 nC/min. Based on the backward particle tracking analysis described in section 2, the beam is assumed lost at the safe endpoint (5 mm from the upstream aperture edge of LC02).

The amount of radiation transmitted into the FOE is primarily determined by the aperture of the FE collimator LC02 and the ratchet wall collimator RCO. The aperture dimensions for 21-ID (ESM) are compared to those of other NSLS-II beamlines in Table 1. Table extracted from *Top-Off Safety Analysis for ISR, ISS and SMI Beamlines*, **Z. Xia and Y. Li, 7/21/2015**.

Table 1. CO2 and RWC aperture dimensions

	LCO2 Dimensions X (mm)	LCO2 Dimensions Y (mm)	RCO Dimensions X (mm)	RCO Dimensions Y (mm)
08-ID-ISS	**79.2**	**28.4**	**44.74**	**17.03**
04-ID-ISR	**79.33**	**28.22**	**88.16**	**30.56**
12-ID-SMI	**83.88**	**27.24**	**95.29**	**31.09**
5-ID-SRX	**79.2**	**28.4**	**78.44**	**21.80**
21-ID-ESM	**53.79**	**41.08**	**40.14**	**36.19**

The horizontal dimensions of the 21-ID (ESM) LC02 and RCO apertures are smaller than those for 12-ID (SMI), but the vertical dimensions are somewhat larger. The ESM simulations were undertaken to ensure that the larger vertical apertures do not result in high dose rates on the FOE walls and roof.

The following four scenarios were considered in the FLUKA simulation analysis and the radiation dose results are reported in this note:

1. Injected beam lost at the front face of LC02 at 5 mm from the inboard side of the aperture.

2. Injected beam lost at the front face of LC02 5 mm from the outboard side of the aperture.
3. The injected electron beam impinges on the inboard inside surface of the beampipe at an angle of 5 mrad, 40 cm upstream of the collimator LC02.
4. The injected electon beam impinges on the outboard inside surface of the beampipe at an angle of 5 mrad, 40 cm upstream of the collimator LC02.

The dose rates on the downstream FOE wall were found to be much larger for cases 3 and 4 than for cases 1 and 2, therefore cases 3 and 4 are described in more detail in this report.

4.1 Injected Electron Beam incident on the Front Face of Collimator LC02 at 5 mm from the Inboard Side of the Aperture

In this simulation, the injected electron beam was started just upstream of the selected point of contact and impinges on the front face of LC02 5mm from the aperture.

The total dose distributions (mrem/h) in the FE and FOE are shown in Figure 5.

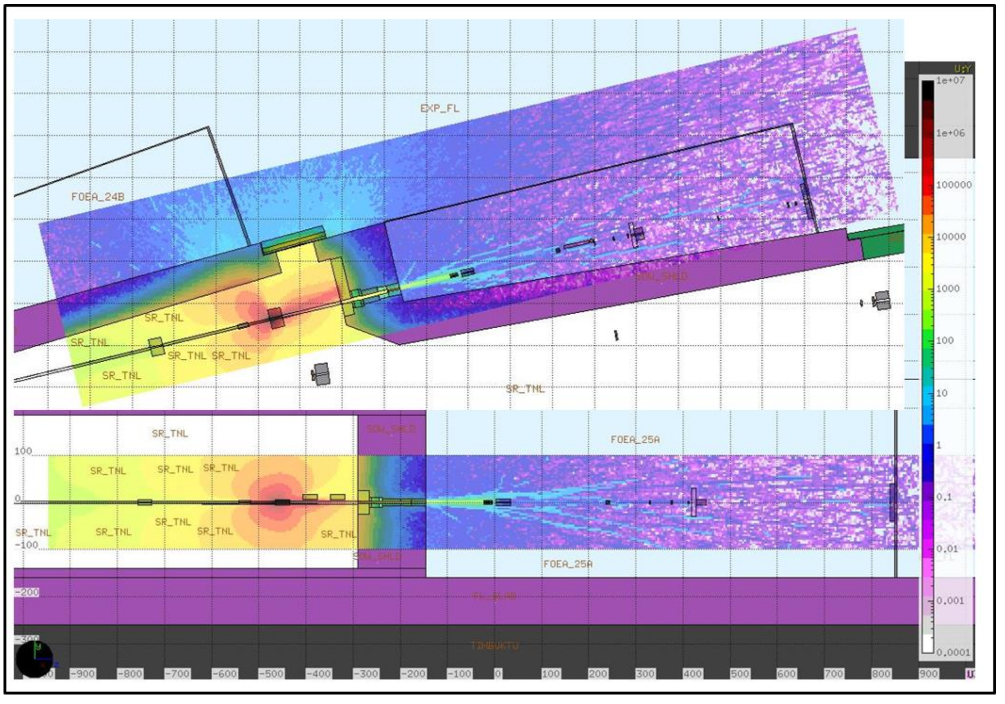

Figure 5: Total dose rate distributions (mrem/h). The Top view at y=0 is shown in the top figure and the elevation view in the bottom figure.

Total dose rates on the roof, sidewall and the downstream wall of the FOE were plotted and found to be well below 100 mrem/h.

4.2 Injected Electron Beam Incident on the Front Face of Collimator LC02 at 5 mm from the Inboard Side of the Aperture

In this simulation, the injected electron beam was started just upstream of the selected point of contact and impinges on the front face of LC2, 5 mm from the outboard edge of the aperture. Figure 6 show the dose rates distributions (mrem/h) in the FE and the FOE. These dose rate distributions are very similar to those for case 1. In both cases, the total dose rates on the FOE walls and roof are below 100 mrem/h for this fault condition.

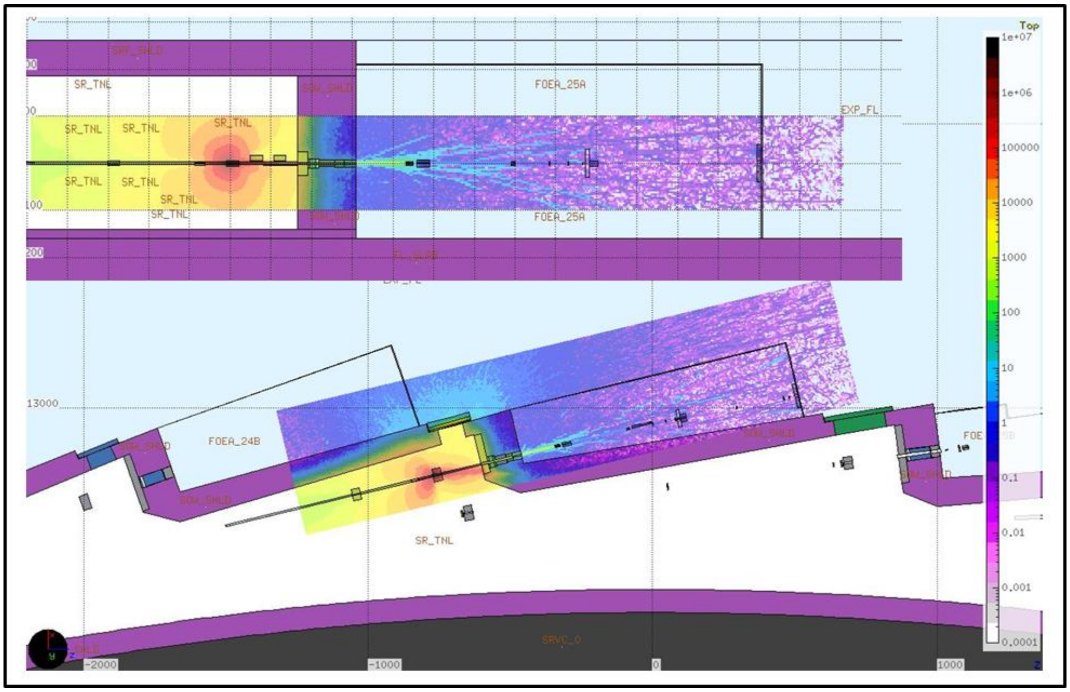

Figure 6: Total dose rate distributions (mrem/h). The Top view at y=0 is shown in the top figure and the elevation view in the bottom figure.

4.3 Electron Beam is Incident on the Inboard Inside Surface of the Beampipe at an Angle of 5 mrad 40 cm Upstream of the Collimator LC02

In this simulation, the injected electron beam was started just upstream of the selected point of contact and impinges on the inboard inside surface of the beampipe 40 cm upstream of the collimator LC2. The total dose rate distributions are shown in Figure 7.

Figure 7 shows that dose rates as high as 100 mrem/h can be found near the FE sliding door, parts of the FOE sidewall and the FOE downstream wall. To obtain these plots, very coarse spatial binning was used, resulting in the averaging of the dose rates over 10cm x 5cm x 5cm bins. To obtain a more accurate estimate of dose rates near the FOE walls and roof, the size of the spatial bins was reduced to 1cm in these regions. The results of these better estimates are shown in Figure 8.

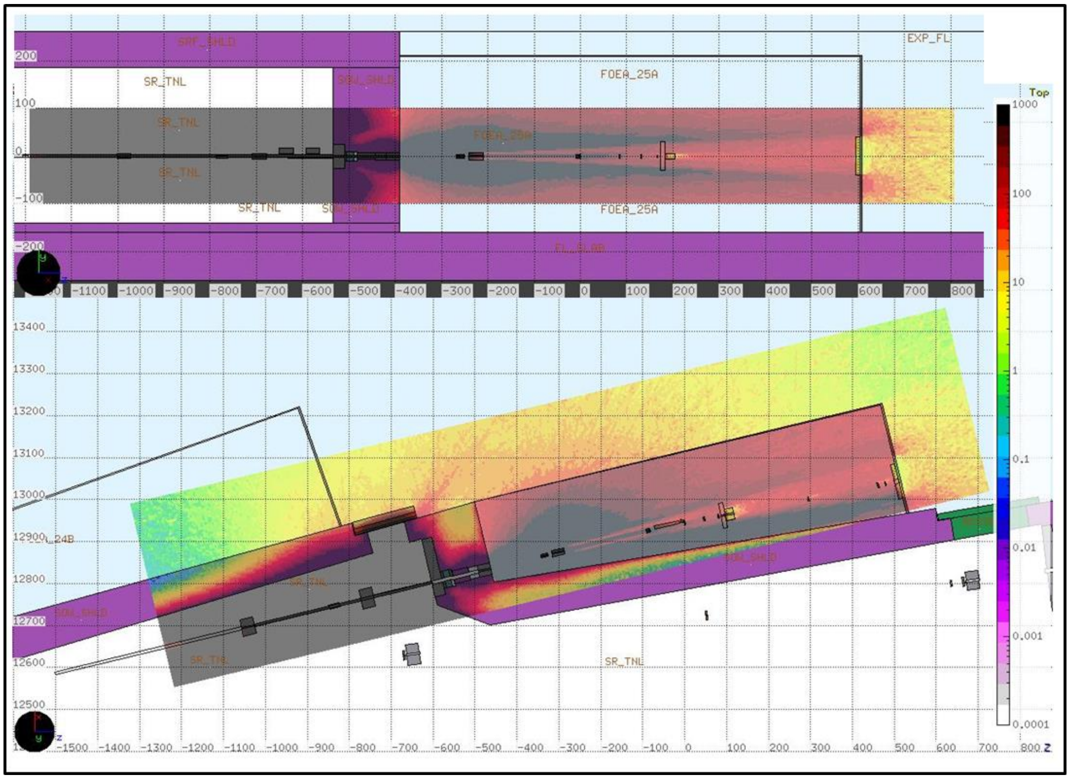

Figure 7: Total dose rate distributions (mrem/h). The elevation view at y=0 is shown in the top figure and the plane view in the bottom figure.

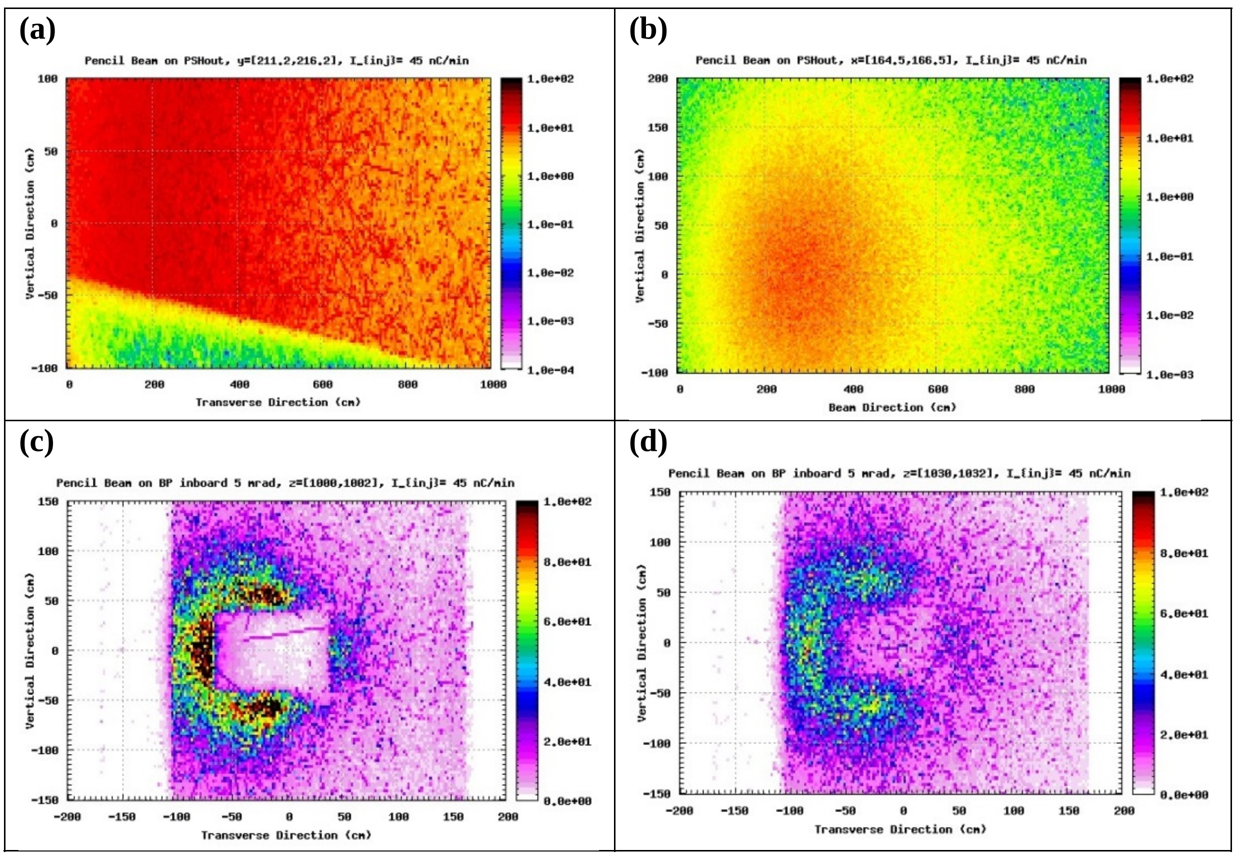

Figure 8: Total dose rate distributions (mrem/h) (a) on the roof, (b) on the sidewall, (c) on contact with the downstream FOE wall and (d) 30cm downstream of the FOE wall.

The dose rate on the roof [Figure 8(a)] and the sidewall [Figure 8(b)] were well below 100 mrem/h. The dose rate on contact with the downstream FOE wall is somewhat higher than 100 mrem/h but goes down to ~70 mrem/h at 30cm downstream of the wall.

4.4 Electron Beam is Incident on the Inboard Inside Surface of the Beampipe at an Angle of 5 mrad 40 cm Upstream of the Collimator LC02

In this simulation, the injected electron beam was started just upstream of the selected point of contact and impinges on the inboard inside surface of the beampipe 40cm upstream of the collimator LC2.

The total dose rate distributions are shown in Figure 9, and dose rates on the roof, sidewall and downstream FOE wall are shown in Figure 10. The dose rate distributions in this case (Figure 9) are very similar to the dose rate distributions in Figure 7, except for the positions of the high-dose spots on the downstream wall, which is now on the outboard side of the guillotine instead of the inboard side. However, the maximum values of the dose rates are approximately the same.

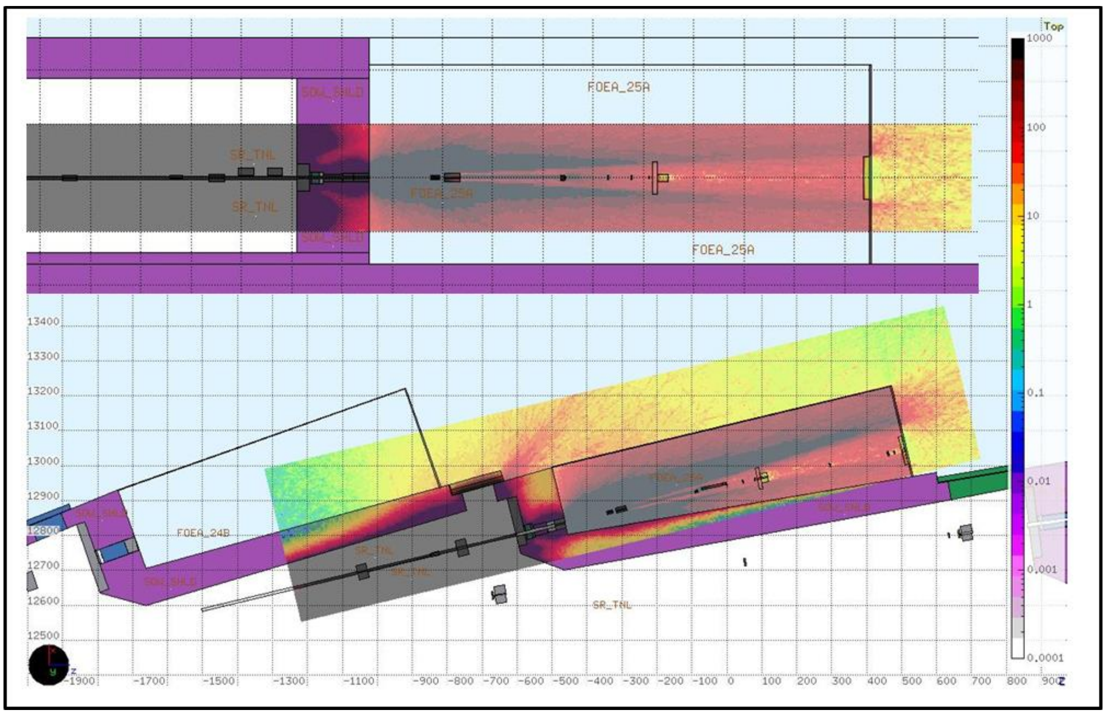

Figure 9: Total dose rate distributions (mrem/h). The elevation view at y=0 is shown in the top figure and the plane view in the bottom figure.

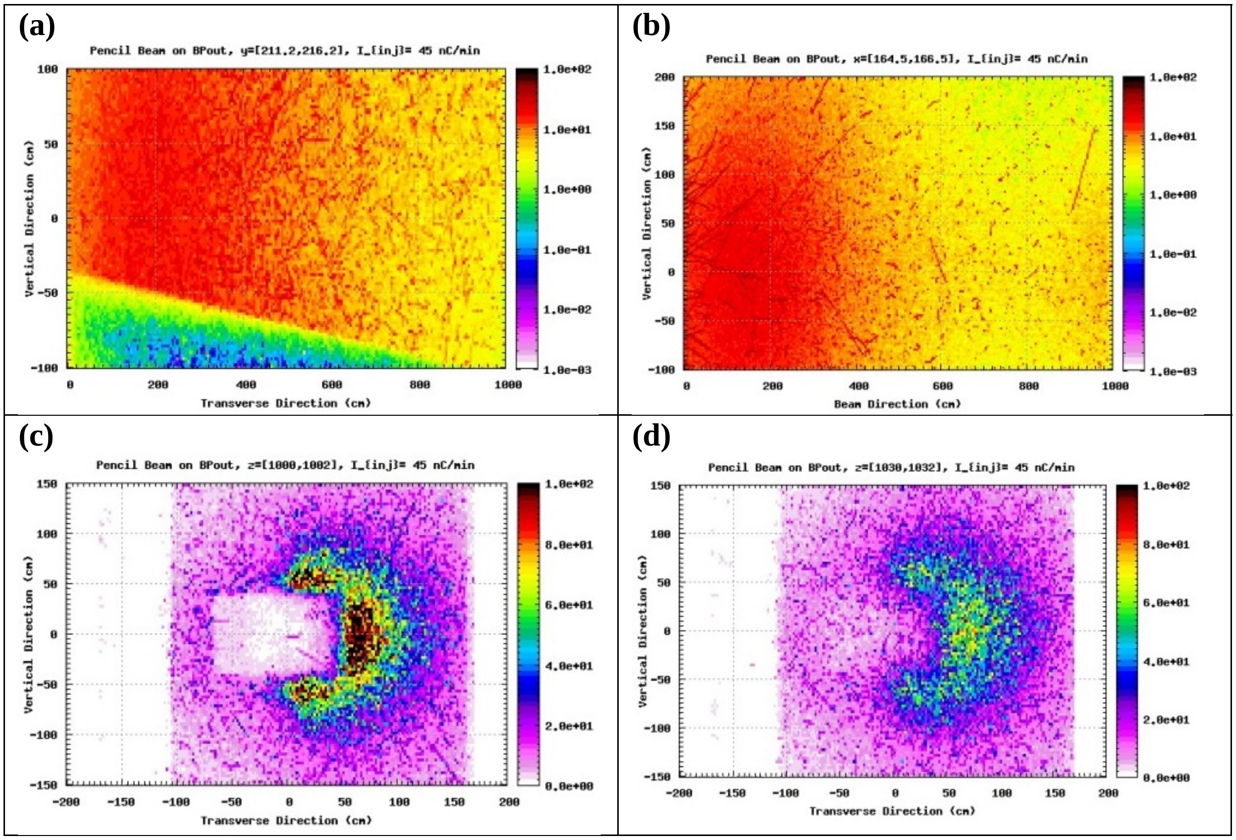

Figure 10: Total dose rate distributions (mrem/h) (a) on the roof, (b) on the sidewall, (c) on contact with the downstream FOE wall and (d) 30cm downstream of the FOE wall.

The dose rates on the roof [Figure 10(a)] and the sidewall [Figure 10(b)] were again well below 100 mrem/h. The dose rate on contact with the downstream FOE wall is still somewhat higher than 100 mrem/h, but goes down to ~70 mrem/h at 30cm downstream of the wall.

5. Summary and Conclusions

Based on the FLUKA simulations described in sections 4.3 and 4.4 of this note, assuming an injected beam striking the inside surface of the beampipe 40 cm upstream of the collimator LC2 the ambient dose rates on the downstream wall of the 21-ID (ESM) FOE are slightly higher than 100 mrem/hr on contact but less than 100 mrem/hr 30cm downstream of the FOE wall. The dose rate on the roof and the sidewall were well below 100 mrem/h.

According to the NSLS-II Shielding policy [3] "Radiation fields <100 mrem/hr can be mitigated via administrative controls only when the use of ARMs is not practical. Abnormal operating conditions creating radiation levels >2000 mrem/hr, require a second independent system to mitigate their resulting radiological impacts."

The ESM FE has an ARM installed on the wall outside the sliding door. There is an additional ARM installed on the side wall of the FOE near the hutch door [see Figure 2(b)]. If there is a Top-Off accident where injected electrons could be conveyed down the beamline to collimator LC2, the radiation plume produced in the FE will leak through the corner of the sliding door and be detected immediately by the ARM, thereby shutting off the beam. Even the second ARM on the sidewall will detect dose rates as high as tens of mrem/h. These ARMs will ensure that the electron beam is turned off and that the beamline personel and users are not exposed to dose rate higher than those allowed by the NSLS-II shielding policy [3].

6. References

[1] Top-Off Safety Analysis and Requirement of Hazard Mitigation for NSLS-II Facility, PS-RASD-RPT-DRV-001, 2014.

[2] PS-C-ASD-PRC-183, Approval of New and Modified NSLS-II Beamline Front Ends for Top Off Safety, Jan 14, 2015.

[3] Photon Sciences Shielding Policy, PS-C-ASD-POL-005, March 26, 2014.

7. Acknowledgements:

We would like to thank Y. Zhu, S. Pjerov, John Tuozzolo and Chris Amundsen for providing all the beamline geometry information listed in Appendix 1. We would like to thank E. Vescovo and Y.Zhu for multiple discussions.

Appendix 1
21-ID (ESM) Beamline
Input provided by Yi Zhu, John Tuozzolo and Chris Amundsen

Co-ordinate system

For non-canted beamlines the z axis lies along the long or short straight centerline. The positions (z co-ordinates) of the various components are defined with respect to the center of the straight. The SS centerline was used as the z or beamline axis for the FLUKA models. Y is the vertical axis and x the horizontal axis orthogonal to the y and z axes.

Table 1.1 Beamline Enclosures

Wall	Position	Thickness	Material
D/S End of 21-ID-A Ratchet Wall Collimator	25474.0 mm		
D/S End of FOE (21-ID-A) Backwall	35468.2 mm	50 mm	Lead
Distance of FOE Sidewall from SS CENTERLINE	1627.3 mm	18 mm	Lead
Distance of FOE Roof from SS CENTERLINE	2102 mm	10 mm	Lead
Distance of FOE Floor from SS CENTERLINE	1400 mm	-	

Table 1.2 Beamline Transport Pipe

Transport Pipes extending beyond FOE back wall	ID= OD= inches Material: Stainless Steel	Shielding Thickness 0.0mm Shielding Material: Lead	Point of exit Angle wrt Z axis
	ID=3.834”, OD=4” SS thickness=0.083”=0.211cm	Pipe is not shielded	2.5° (inboard)

Table 1.3 ESM Beamline Components and SGB shields. Specify U (upstream), D (downstream) or C (center) of component

Components	Z = Distance from SS centerline U,D or C	Dimensions (specify units)		Offset/ Rotation wrt Straight Centerline	Material	Associated Drawings
		Outer dimensions (W)x(H)x(L)	Aperture (W)x(H) or (R)			
White Beam mask (New)	26667.23 mm (US flange) Cu Block 26667.23+17.45+ 19.05	85 mm X 85 mm 174.63 mm(L)	11.46 mm(Radius)(U) 5.25 mm(Radius)(D) Z1=150.23 Z2=174.65	-	Glidcop AL-15	PD-ESM-BL-MSK-1001
Brem collimator	26969.1 mm(U)	152.4 mm(W)X 152.4 mm(H)X 304.8 mm(L)	21.8 mm(W) 21.8 mm(H)	-	Lead	PD-ESM-BRS-1000
M1 Entrance mask	29288.8 mm(U)	See drawings (a)L=80.0 mm $R_{effective}$ = 44 mm (b)L=8.0 mm $R_{effective}$ = 30 mm	Changed R(D)from 16 to 13.0mm (a)36 mm(Radius)(U) 6.5 mm(Radius)(D) (b) 6.5 mm(Radius)	-	Glidcop	PD-ESM-BL-MIR-1020
White beam Mirror	29790 mm(C)	70 mm(W) 60 mm(H) 605 mm(L)	Rotates beam 2.5 degree wrt Z axis	Rotate 1.25 degree wrt Y axis	Silicon	PD-ESM-BL-MIR-0010
White beam stop	30157.7 mm surface center	Length 70 mm OD: 77 mm $R_{effective}$ = 35 mm	-	X: 3.2 mm Rotated -70 deg	copper	PD-ESM-BL-MIR-1007
M1 Exit mask	30214.6 mm(U)	125 mm(W) 80 mm(H) 19 mm(L)	Changed x=y from 16 to 13.5mm 13.5 mm(W) 13.5 mm(H)	Rotated 2.5 deg X:-18.5 mm(U)	OFHC	PD-ESM-BL-MIR-1008
Pink Beam mask PBM #1 PBMs identical	30677.6 mm(U)	See drawings 47.1 mm (Radius) 27 mm(L)	34.6 mm(Diameter)(U) 12.5 mm(Radius)(D) Z2=27.0-4.4=22.6 mm	X:-38.8 mm(U)	Glidcop AL-15	PD-ESM-MSK-1100
Except for aperture size PBM #2	31029.6 mm(U)	See drawings 47.1 mm (Radius) 27 mm(L)	40.6 mm(Radius)(U) 7.25 mm (Radius)(D) Z2=22.6 mm	X:-54.1 mm(U)	Glidcop AL-15	PD-ESM-MSK-1025

Shielding wall SGB1	31105.9 mm(U)	609.6 mm(W)X 609.6 mm(H)X 101.6 mm(L)	38.84 mm(W) 24.8 mm(H)	X:-57.5 mm(U)	Lead	PD-ESM-BRS-1050
Brem Stop	31207.5 mm(U)	279.4 mm(W) 127 mm(H) 203.2 mm(L)	38.84 mm(W) 24.8 mm(H)	X:-61.9mm(U)	Lead	PD-ESM-BRS-1050
Pink Beam mask #3	33216.1 mm(U)	See drawings 47.1 mm (Radius) 27 mm(L)	41.1 mm(diameter)(U) 7.5 mm (Radius)(D) Z2=22.6 mm	X:-149.6mm(U)	Glidcop AL-15	PD-ESM-MSK-1050
Photon Shutter Simplified model	34932.6 mm (C)	12.5 cm (W) 15 cm (H) **3.8cm (L)**	40 mm × 25 mm Centered wrt block	X:-224.5mm(U)	Tungsten	PD-COM-PSH-1000 (unreleased)
Pink Beam mask PBM #4	35087.3 mm(U)	See drawings 47.1 mm (Radius) 27 mm(L)	41.6 mm(Diameter)(U) 7.75 mm(Radius)(D) Z2=22.6 mm	X:-231.3mm(U)	Glidcop AL-15	PD-ESM-MSK-1075
Guillotine	35317.2 mm(U)	**84 cm W** **80 cm** H 10 cm (L)	External diameter of pipe = 4 inch	centered on beamline not SS centerline X:-24.22cm	Lead	

Table 1.4 Beamline Components outside the FOE

Components	Z = Distance from SS centerline U,D or C	Dimensions (specify units)		Offset/ Rotation wrt Straight Centerline	Material	Associated Drawings
		Outer dimensions (W)x(H)x(L)	Aperture (W)x(H) or (R)			
Plane grating monochromator (PGM) housing	**40654.2 mm(C)**	OD=1100.0 mm ID=1084.0 mm Height 700.0 mm		SS Cylinder -30 <Y< 40 cm **X:-474.3 mm**	SS	PD-ESM-PGM-1000
PGM Entrance mask	**- 555.2 mm(U) Along**	(a)95mm(W)58mm(H) 5mm (L)	(a)20 mm(W)20 mm(H)		OFHC	PD-ESM-PGM-1001

2 blocks	**reflected beam from M1**	(b)95mm(W)100(H) 12mm(L)	(b)20 mm(W)20 mm(H)			
PGM Exit mask 2 blocks	**+545.2mm(U) Along reflected beam from M1**	(a)95mm(W) 102mm(H)12mm (L) (b)60mm(W)58mm(H) 5mm (L)	16 mm (W)46 mm(H)	Y: +40 mm	OFHC	PD-ESM-PGM-1002
Secondary Brem stop #1	Exit mask posn +0.5+1.2+1.7cm	See drawings 40 mm(L)	See drawings	Y:+40 mm	Tungsten	PD-ESM-PGM-1002
Secondary Brem stop #2	Exit mask posn +1.7+1.7+4.0cm	See drawings 10 mm(L)	See drawings	Y: +40 mm	Tungsten	PD-ESM-PGM-1002
PGM mirror is not in center of the tank	**-207 mm(C) Along reflected beam from M1**	60mm(W)X70mm(H)X 585 mm(L)	-	Top surface at y=0 in rotated 3.1 d wrt x axis	Silicon	PD-ESM-BL-MIR-0020
Monochromator Grating	**+125.5mm(C) Along reflected beam from M1**	40 mm(W)40 mm(H) 165 mm(L);	-	Y: +40 mm	Silicon	PD-ESM-BL-GRTG-0001 PD-ESM-BL-GRTG-0002
Pipe connector at PGM exit mask	Pipe thickness 5mm Flange thickness 22mm					
Pipe connector at PGM entrance mask	Pipe thickness 5mm Flange thickness 22mm					

Table 1.5 Front End and Beamline Components for FLUKA Calculations

Front End Components	Z location(m) (Distancefrom SS center) (U),(D)or (C)	Dimensions		Offset From SS centerline	Material	Associated Drawings
		Outer dimensions (W),(H),(L)	Apertures, mm (W)x(H) or (R)			
Lead collimator LC01	19356.18 mm (U)	406.41mm (W) 101.60mm (H) 304.80 (L)	32.19mm (W) 28.09mm (H)	0	Lead	SR-FE-CO-3120

Photon Shutter PSH	21505.97 mm (U)	107.95mm (W) 82.55mm(H) 254.00(L)	63.63mm (W) 18.67mm (H)	0	Glidcop Al-15	SR-FE-PSH-3004
Lead collimator LC02	22285.03 mm (U)	457.20mm (W) 127.00mm (H) 304.80mm (L)	53.79mm (W) 41.08mm (H)	0	Lead	SE-FE-CO-3100
Safety Shutter SS1	22865.31 mm (U)	165.10mm(W) 123.83mm(H) 304.80mm(L)			Lead	SR-FE-SS-4000
Safety Shutter SS2	23439.80 mm (U)	165.10mm(W) 123.83mm(H) 304.80mm(L)			Lead	SR-FE-SS-4100
Lead in Ratchet wall RC_26A-1	24020.41mm (U)	1397.0mm (W) 508.00mm(H) 254.00mm	82.20mm(W) 44.10mm(H)	0	Lead	SR-FE-RCO-0500
Lead block RC_26A-2	24274.58 mm (U)	406.40mm(W) 203.20mm(H) 50.80mm(L)	82.20mm(W) 44.10mm(H)	0	Lead	SR-FE-RCO-0500
Poly Block RC_26A-3	24325.21mm (U)	406.40mm(W) 203.20mm(H) 152.40mm(L)	82.20mm(W) 44.10mm(H)	0	HDPE	SR-FE-RCO-0500
Air gap RC_26A-4		6.93 cm (L)		0	Air	SR-FE-RCO-3110
Concrete block RC_26A-5	24546.88 mm (U)	317.50mm (W) 139.70mm (H) 387.35mm (L)	82.20mm (W) 44.10mm (H)	0	Concrete	SR-FE-RCO-3110
Air gap RC_26A-6		23.49 (L)		0	Air	SR-FE-RCO-3110
Lead block RCO RC_26A-7	25169.19mm (U) 2547.4 cm (D)	278.64mm (W) 158.75mm (H) 304.80mm(L)	40.14mm (W) 36.19mm (H)	0	Lead	SR-FE-RCO-3110

Total thickness of ratchet wall= 2547.4-2402.04=145.36 cm