17BM (XFP) TOP-OFF RADIATION SAFETY ANALYSIS

APPROVALS

6/6/2016

X Ray Fliller

Ray Fliller
Coordination Group for Top Off Safety Leader
Signed by: Fliller, Raymond

6/6/2016

X Ferdinand Willeke

Ferdinand Willeke
Accelerator Division Director
Signed by: Willeke, Ferdinand

6/16/2016

X

Paul Zschack
Photon Science Division Director
Signed by: Zschack, Paul

6/15/2016

X

Steve Moss
Authorization Basis Manager
Signed by: Moss, Steven H

6/6/2016

X

Robert Lee
ESH Manager
Signed by: Lee, Robert J

6/14/2016

X

Jennifer Bohon
XFP Lead Beamline Scientist
Signed by: Bohon, Jennifer

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AUTHORS: M. Benmerrouche, R. Fliller and Y. Li	DATE: 05/19/2016
17BM (XFP) Top-Off Radiation Safety Analysis	

1. Introduction

The purpose of this technical note is to analyze the top off safety of the 17BM-XFP beamline, which was not covered by the Top-Off design report issued in 2014 [1]. The 17BM-XFP beamline has a mirror in the front end (FE) which will deflect the synchrotron beam vertically and pass through the vertically offset ratchet wall collimator (RCO) aperture. This report can be used as a basis to approve the Top-Off Operation of the 17BM-XFP beamline, provided that the recommendations identified in section 5 of this report have been implemented properly. The Top-Off operation of new beamlines and the approval process shall be in accordance with procedure PS-C-ASD-PRC-183 [2].

The primary radiological safety concern for the top-off injection, with the FE safety shutters open, is the scenario where injected electrons could be conveyed down to the beamline through the FE due to erroneous combination of lattice magnetic field settings and beam energy. With the ratchet wall collimator aperture vertically offset by approximately 8.7 cm from the electron beam orbit, the electrons are unlikely to escape the 17BM-XFP FE to reach the first optical enclosure (FOE). For 17BM-XFP the worst scenario will be for the electrons to propagate down the FE and interact with the FE components. Backward particle tracking analysis was performed and has determined that the injected electrons will not travel beyond Fixed Mask 2 (FM2) located just upstream of the lead collimator 1 (LCO1). More specifically, FLUKA simulations were performed with a pencil beam of electrons striking FM2 inboard and outboard at 5mm from the downstream aperture edge. The radiological consequences of this fault condition are analyzed and discussed in this report. The goal of the simulations documented here was to estimate the radiation dose levels generated outside of the FOE during this top-off fault condition, thus evaluating the efficacy of the FE radiation safety components and FOE shielding.

The top-off backward particle tracking analysis for 17BM-XFP 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 a conclusion are presented in Section 5.

2. Top-Off Particle Tracking Analysis

Figures 1 and 2 show the particle tracking simulations for 17BM-XFP, which takes into account the Top-Off Safety System (TOSS) interlock specifications [1]. The two apertures shown in the figures at positions ~4.5 m and ~8 m from the source point represent the apertures through the Exit Absorber and Fixed Mask 2, respectively.

Since there are mirrors deflecting x-ray beam vertically, no electron beam can reach the FOE. This simulation shows that injected electron cannot even go beyond FM2, which will be used as an input into the FLUKA simulation, discussed in Sections 3 and 4.

Based on the backward particle tracking simulation [1], the electron beam will have at least a 5 mm distance away from the FM2 aperture edge for 17BM-XFP beamline (i.e. electron beam cannot go through the FM2 aperture and intercept downstream FE components, such as White Beam Mirror, FM3 or FM4).

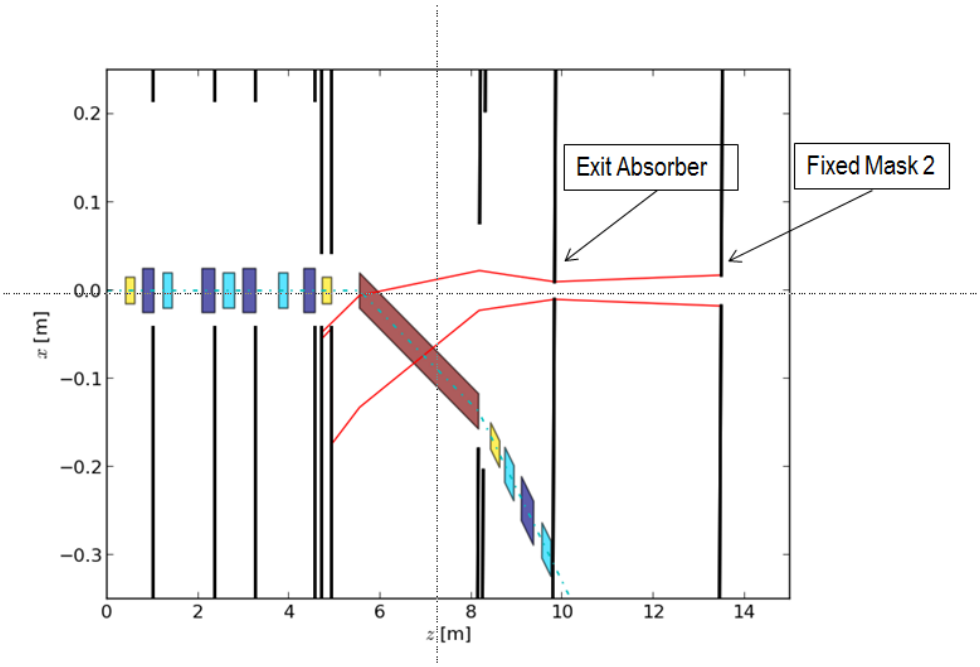

Figure 1: On momentum envelope of backward particle tracking trajectories for the 17BM-XFP beamline assuming 5 mm from aperture of FM2 with 2 mm tolerance included

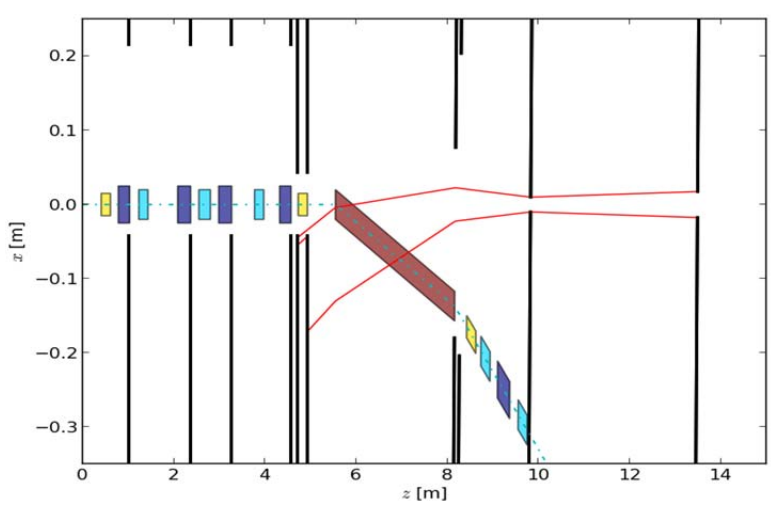

Figure 2: Off (+3%) momentum envelope of backward particle tracking trajectories for the 17BM-XFP beamline assuming 5 mm from aperture of FM2 with 2 mm tolerance included

3. Description of the FLUKA Model

The layout of the 17BM-XFP beamline front end is presented in Figure 3. The beamline component location and dimensions were extracted from the FE Ray Trace [3] [SR-FE-3PW-7001]. The ray trace drawings list the major components along the beamline and provide the position of each component. The positions, dimensions and materials of the main components considered in the FLUKA geometry are included in Appendix 1.

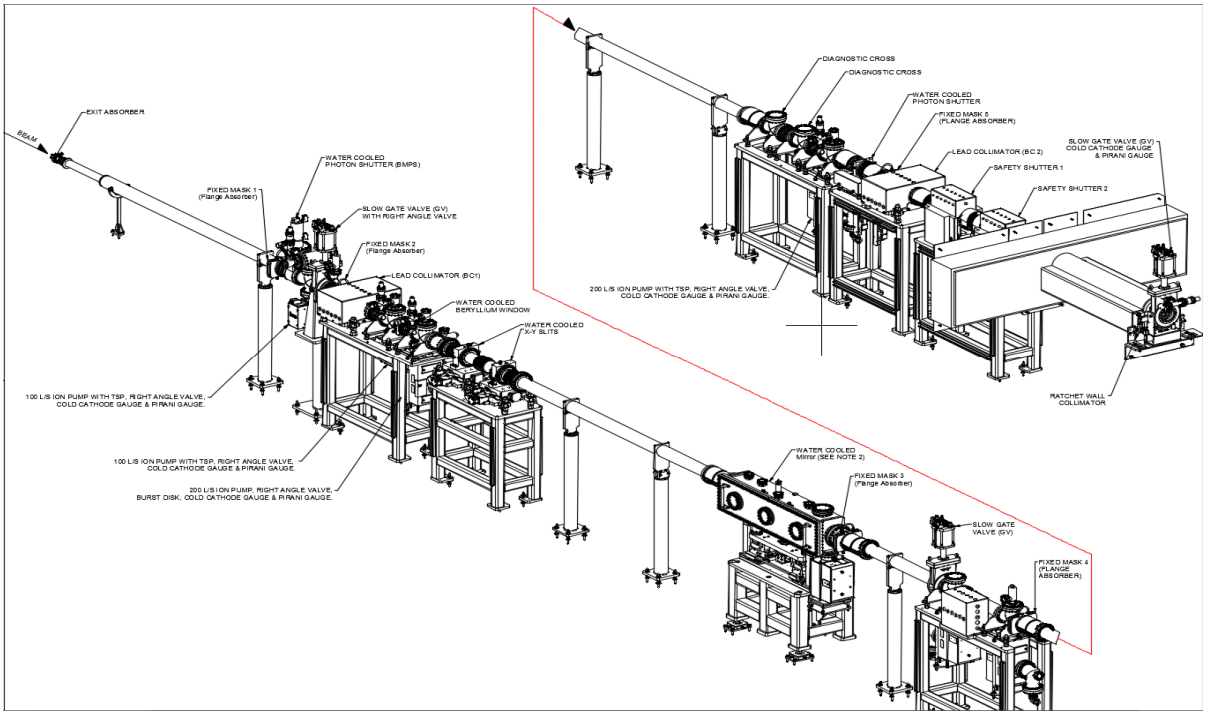

Figure 3: Layout of 17BM-XFP FE showing major components consisting of Masks, Mirror, Collimators, Safety Shutters, and Ratchet Wall Collimator

The 17BM-XFP FLUKA model includes the relevant FE components, surrounding storage ring shielding, and the FOE walls and roof. The FOE outboard lateral panel is made of 18 mm Pb, roof 4 mm Pb and downstream FOE wall 50 mm Pb (~1000 cm from the ratchet wall). A copper target is placed inside of the FOE at approximately 100 cm from the downstream end of the ratchet wall and is inclined 15 degrees with respect to the beam.

The FLUKA model (Top and Elevation views) of the 17BM-XFP beamline is shown in Figure 4 with all components that were incorporated in the FLUKA model. All components are placed symmetrically with respect to the beam centerline in the transverse direction. For the FLUKA model, the Z axis represents the beam centerline, the X axis the horizontal axis normal to the beam direction, the Y axis is the vertical axis and the beam travels from left to right.

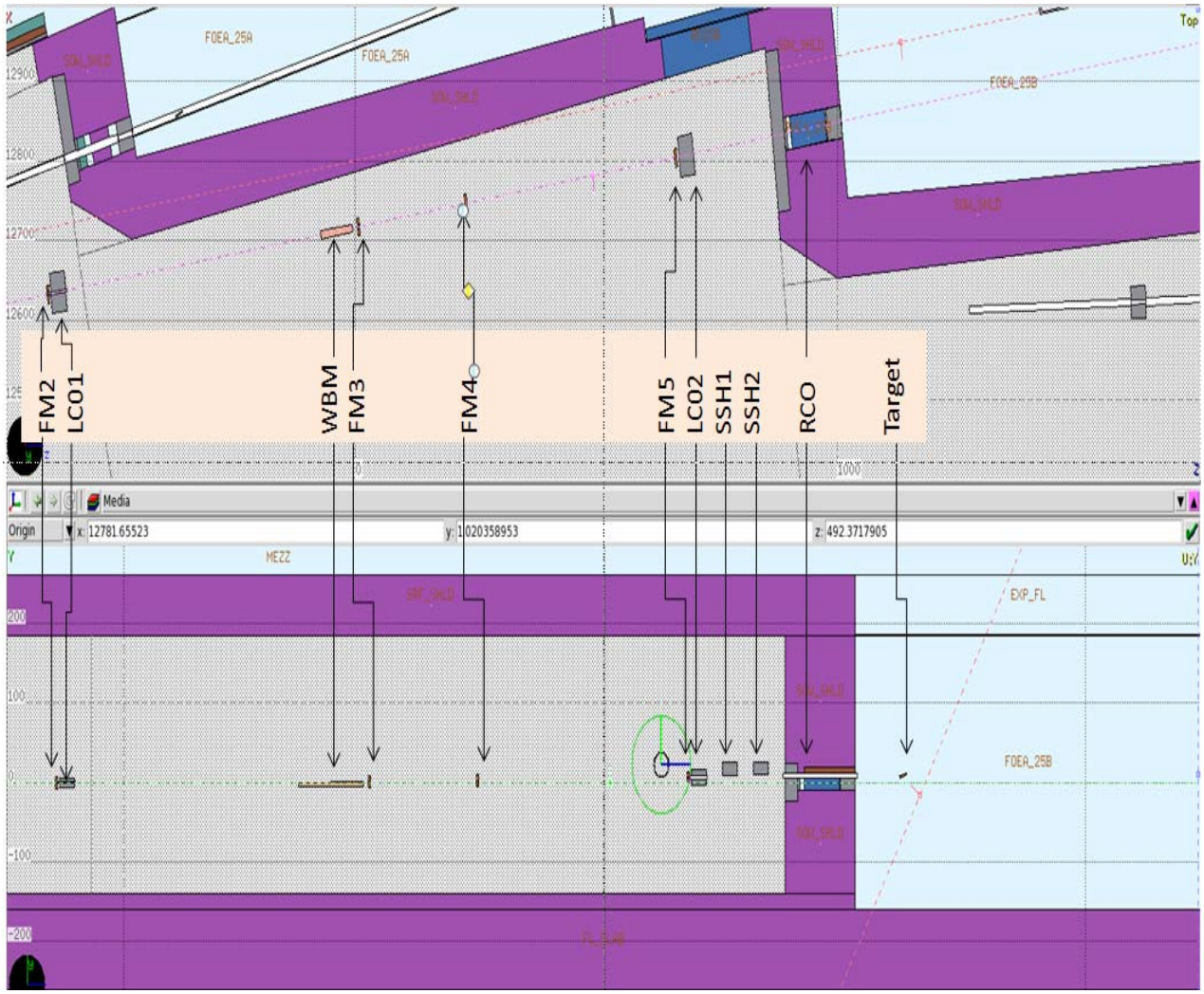

Figure 4: Plan and elevation view of the FLUKA geometry used in Top-Off simulation of the 17BM-XFP beamline

The apertures of Lead Collimator 2 (LCO2) and Ratchet Wall Collimator (RCO) for 17BM-XFP beamline are shifted vertically to allow the upward reflected synchrotron beam to exit the FE and into the FOE. Table 1 lists the aperture sizes of LCO2 and RCO, and corresponding vertical offset with respect to the electron beam orbit. For comparison, the 05ID-SRX beamline RCO aperture is 78.44 mm (x) and 21.80 mm (y) while the LCO2 aperture for the 05ID-SRX beamline is 79.2 mm (x) and 28.4 mm (y). Figure 5 shows some details of the LCO2, RCO, the FE Safety Shutters (in the open position) and the scatter target to mimic a typical beamline component.

Table 1: LCO2 and RCO Aperture Dimensions for 17BM-XFP Beamline [4]

	Dimensions X (mm)	Dimensions Y (mm)	Vertical offset Y (mm)
LCO2 aperture	**36.42**	**33.60**	**62.34**
RCO aperture	**106.38**	**57.84**	**87.29**

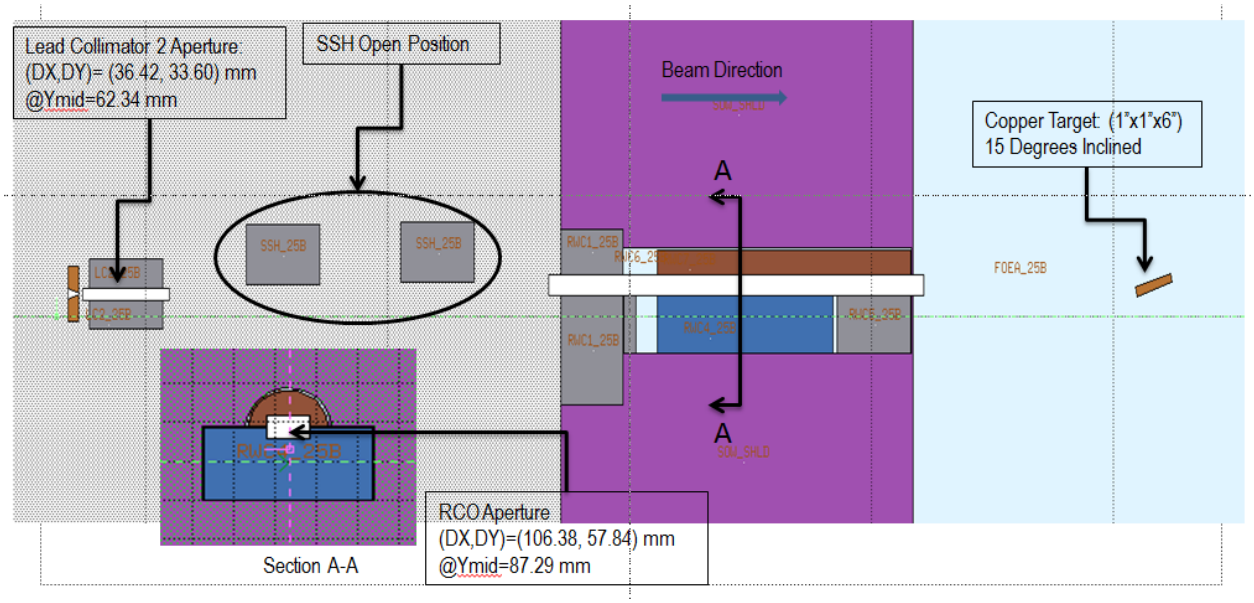

Figure 5: Main components for 17BM-XFP near the ratchet wall collimator including lead collimator 2, redundant safety shutters, and an inclined copper target inside the FOE

The proposed lead bremsstrahlung stop (BRS) (20" × 20" × 8") that was incorporated into the FLUKA simulations is discussed in Sections 3 and 4, and is required to mitigate the elevated dose rates on the FOE downstream wall (see Section 4). The position and size of the BRS needed to intercept the high radiation fan are provided in Figure 6. The relative vertical offset of the BRS with respect to the RCO aperture centerline is 5 cm.

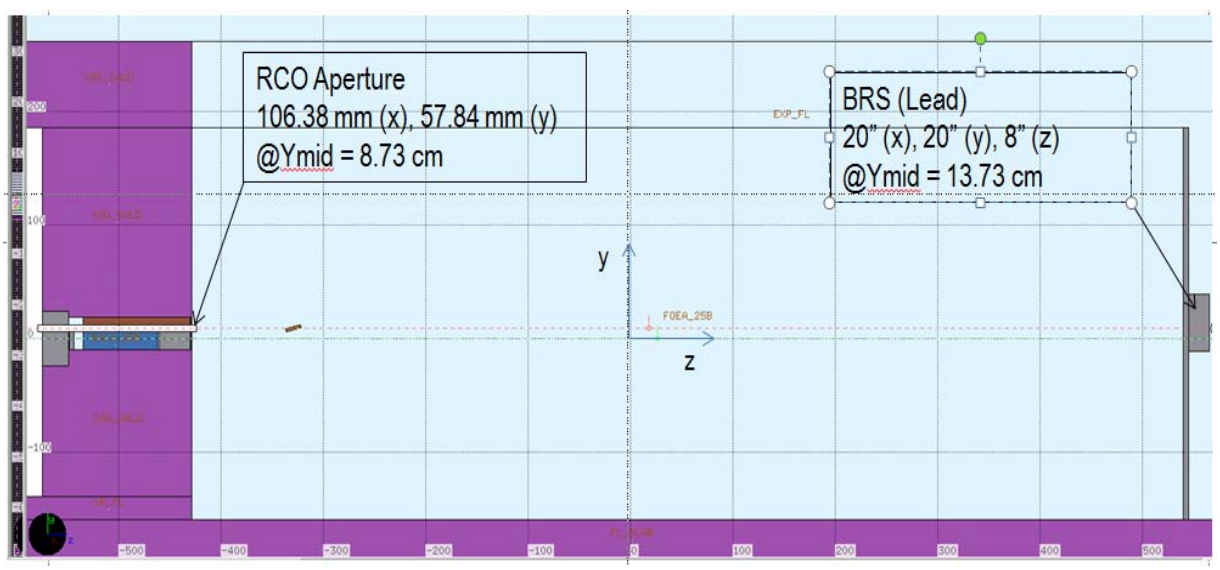

Figure 6: Position and dimension of the BRS used in the simulation. The center of the BRS is at 5 cm above the RCO centerline.

4. Results for Top-Off FLUKA Simulations

In all FLUKA simulation, a pencil beam of 3 GeV energy 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 downstream aperture edge of FM2). The following two scenarios have been considered in the FLUKA simulation analysis and for which radiation dose results are reported in this note:

1. Injected beam lost at 5 mm from the inboard side of the downstream aperture of FM2
2. Injected beam lost at 5 mm from the outboard side of the downstream aperture of FM2

4.1 Injected electron beam incident 5 mm from the inboard side of the downstream aperture of FM2

Figure 7 shows the FM2 and LCO1 and corresponding apertures. The FM2 aperture is tapered in both the vertical and horizontal planes. In this simulation, the injected electron beam (shown in green in Figure 7) was started just upstream of the selected point of contact and impinges on the inboard tapered plane 5mm from the neck of the aperture.

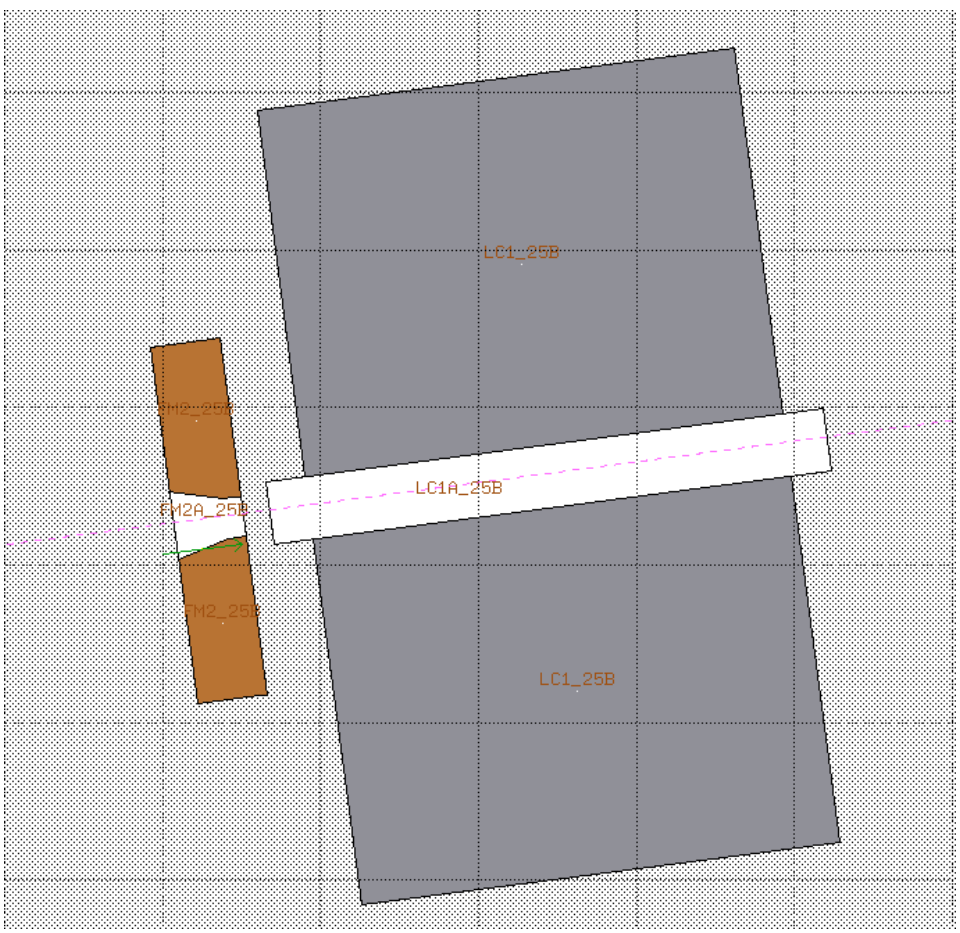

Figure 7: Injected electron beam incident (green arrow) 5 mm from the inboard side of the downstream aperture of FM2

The total dose distributions in mrem/h (on contact) on the lateral and the downstream wall of the FOE are shown in Figures 8, 9, and 10. To understand the contribution of the various FE components on the dose distribution it is useful to look at the top and elevation views of the dose distribution in the FOE (Figures 8, 9, and 10). When the injected electron hits the copper FM2 it is scattered largely in the forward direction. The radiation that passes through FM2 and the collimator LCO1 impinges on the white beam mirror, FM3 and FM4, which become scattering targets. The dose rates on the lateral wall and bump-out wall are below 100 mrem/hr as can be seen from Figure 9 and therefore no additional controls are required, as per the Photon Sciences Shielding Policy [5].

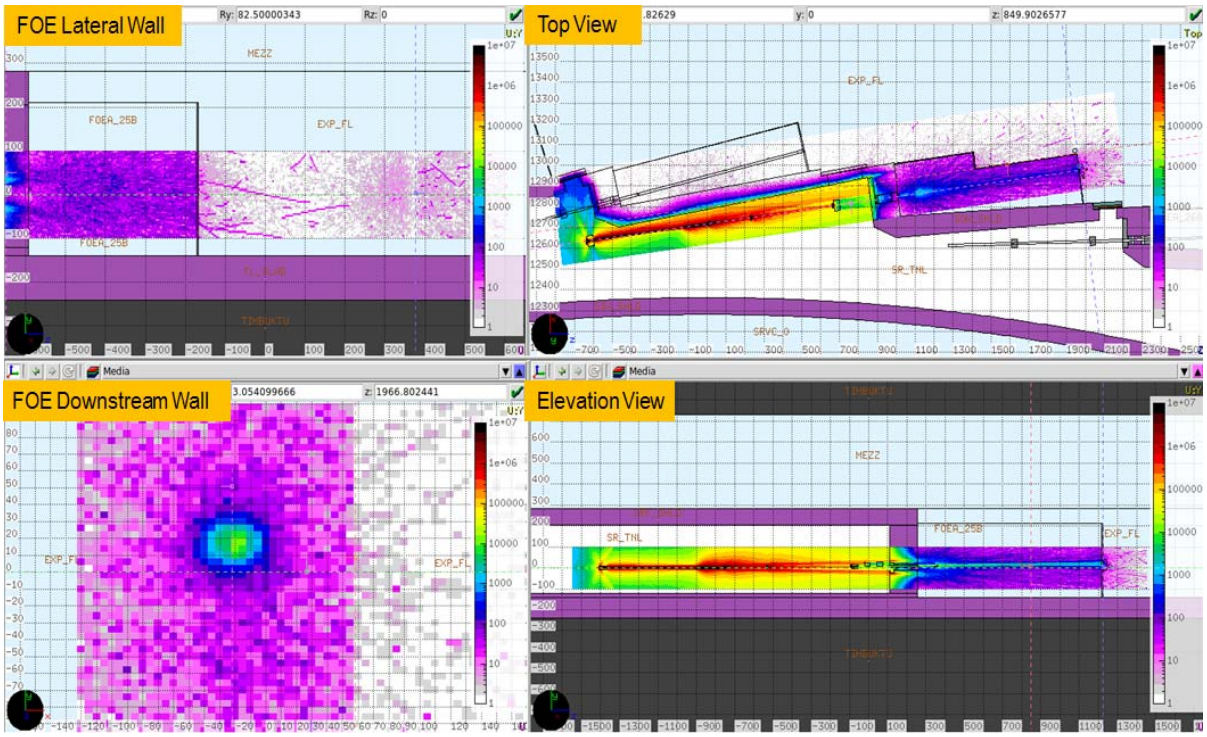

Figure 8: Total dose rate distributions in mrem/h (on contact) with the lateral wall (top left) and downstream wall of the FOE (bottom left). The Top view (Top right) is at y=0 cm and the elevation view (bottom right) is at electron beam centerline.

Clearly the total dose rates on the downstream wall of the FOE exceeds the 2000 mrem/hr threshold for a small area of approximately 50x50 cm^2. Aproposed BRS, with the position and size as illustrated in Figure 6, is required to reduce the dose rates to below 100 mrem/hr and therefore avoid any additional controls as per the NSLS-II Shielding policy [5]. To attenuate radiation levels behind the downstream wall of the FOE to levels below 100 mrem/hr, the bremsstrahlung stop shall be thick enough, large enough to cover an area of approximately 50x50 cm^2 and properly positioned to intercept the high radiation fan shown in Figures 8 and 9. Figure 10 shows the attenuation effect of the BRS positioned outside the downstream wall of the FOE. It illustrates that the BRS reduces the dose rates on the downstream wall of the FOE to levels less than 100 mrem/hr.

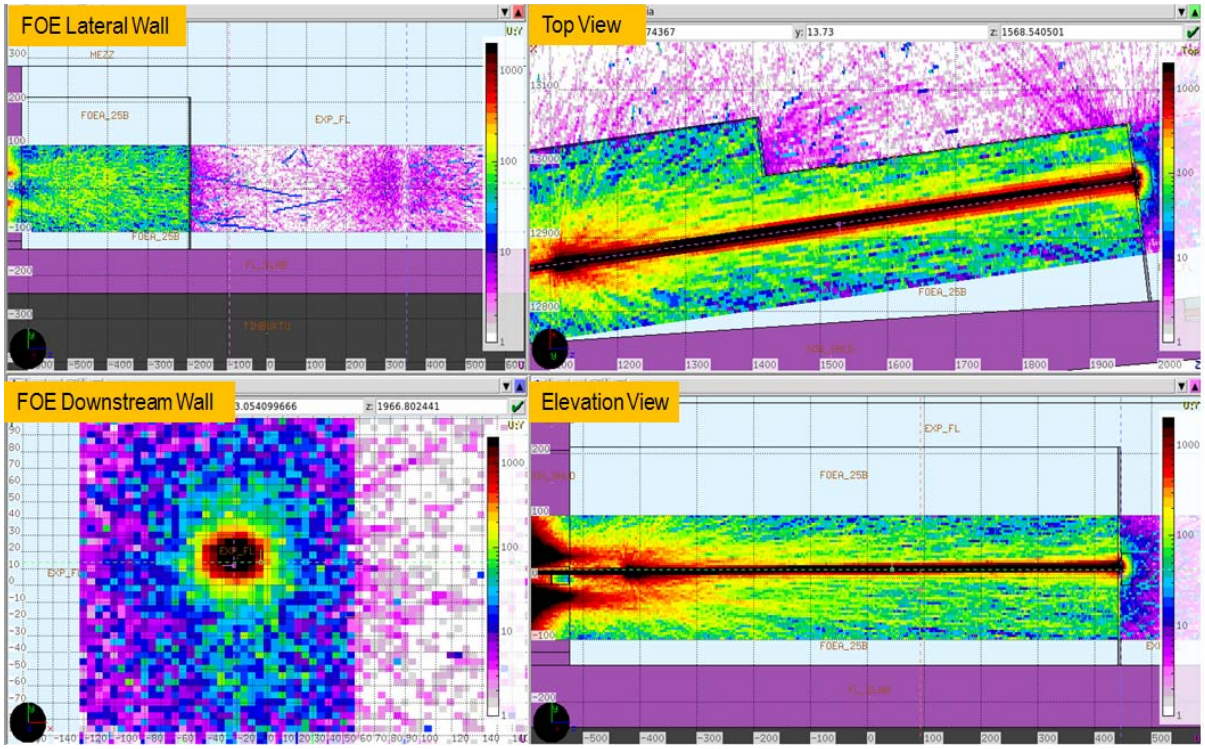

Figure 9: Same as Figure 8 with the maximum dose rate set to 2000 mrem/hr to visually identify areas where a 2000 mrem/hr dose rates are exceeded. The Top View is at y = 13.73 cm.

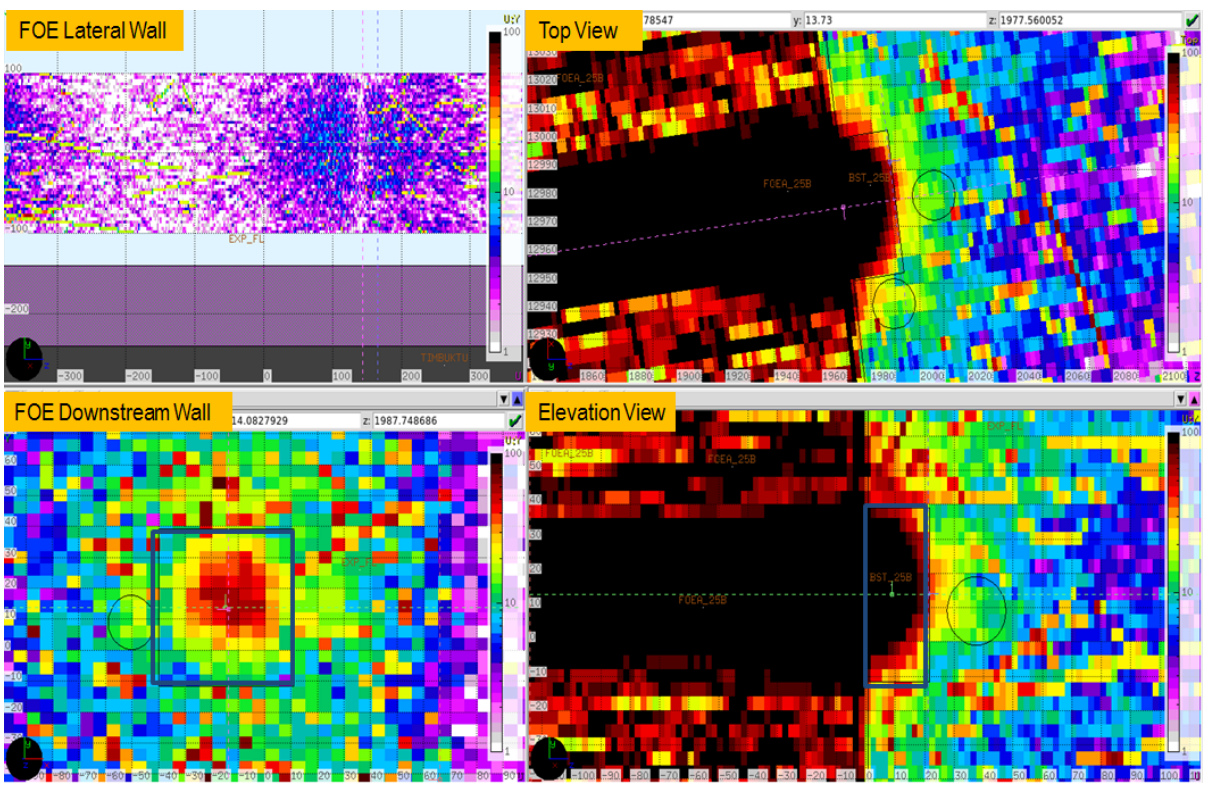

Figure 10: Same as Figure 8 with the maximum dose rate set to 100 mrem/hr to visually identify areas where a 100 mrem/hr dose rates are exceeded. The top view is at y = 13.73 cm. As seen from the Top, Elevation and FOE downstream wall, the BRS (outlined in blue rectangle) located behind the FOE downstream wall should attenuate radiation to levels to below 100 mrem/hr.

4.2 Injected electron beam incident 5 mm from the outboard side of the downstream aperture of FM2

In this simulation, the injected electron beam (shown in green in Figure 11) was started just upstream of the selected point of contact and impinges on the outboard tapered plane 5mm from the neck of the aperture. Figures 12 and 13 show the dose rates profiles for the injected beam striking the outboard side of FM2 downstream aperture and the results are similar to the case where the beam strikes the inboard side of FM2 downstream aperture. In particular, the BRS as illustrated in Figure 6, is required to reduce dose rates on the downstream wall of the FOE to below 100 mrem/hr. Dose rates on lateral wall, bump-out wall and the roof are below 100 mrem/hr. Figure 14 shows the neutron dose rates and are much lower than the photon dose rates.

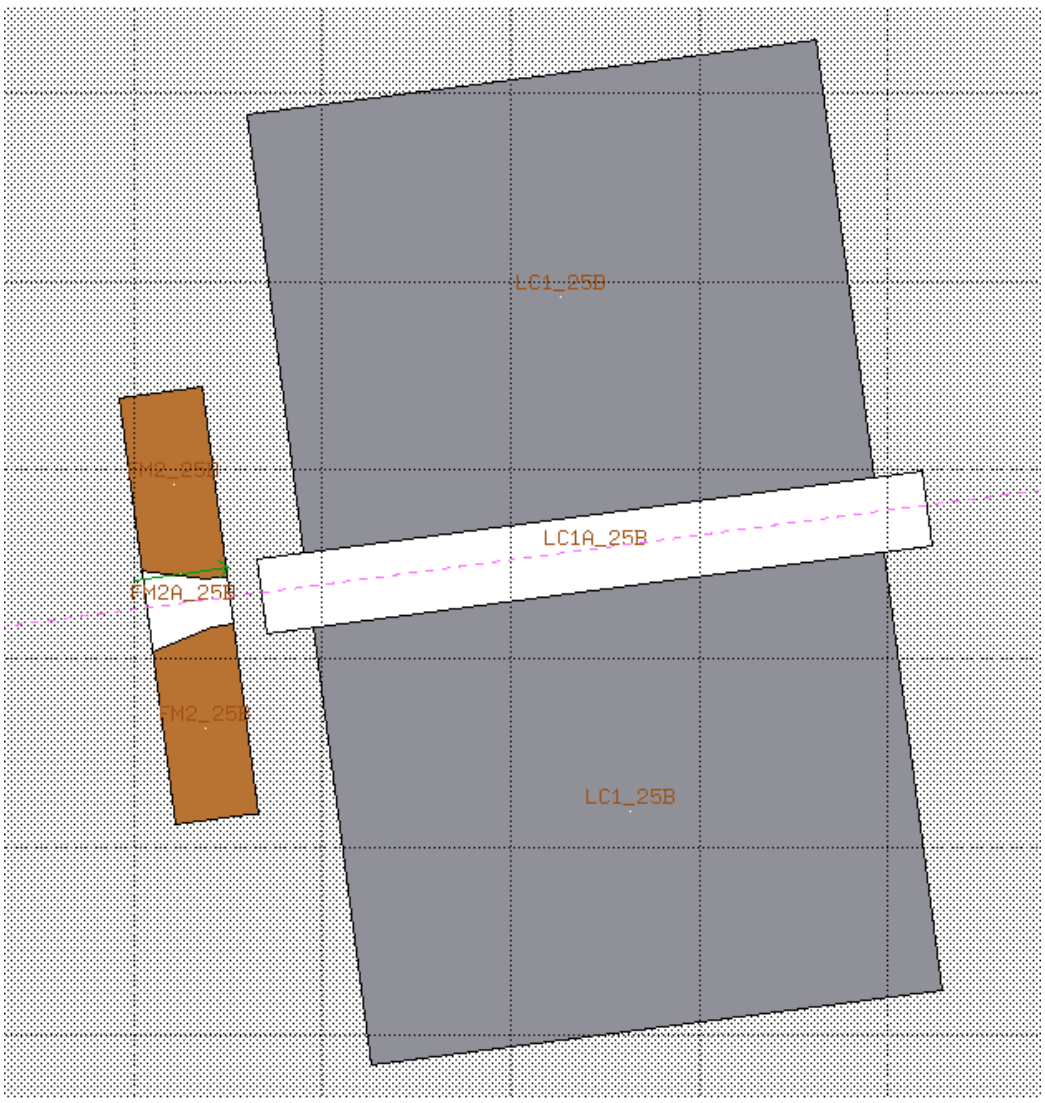

Figure 11: Injected beam striking the front face of the FM2 at 5 mm from the outboard edge of downstream FM2 aperture

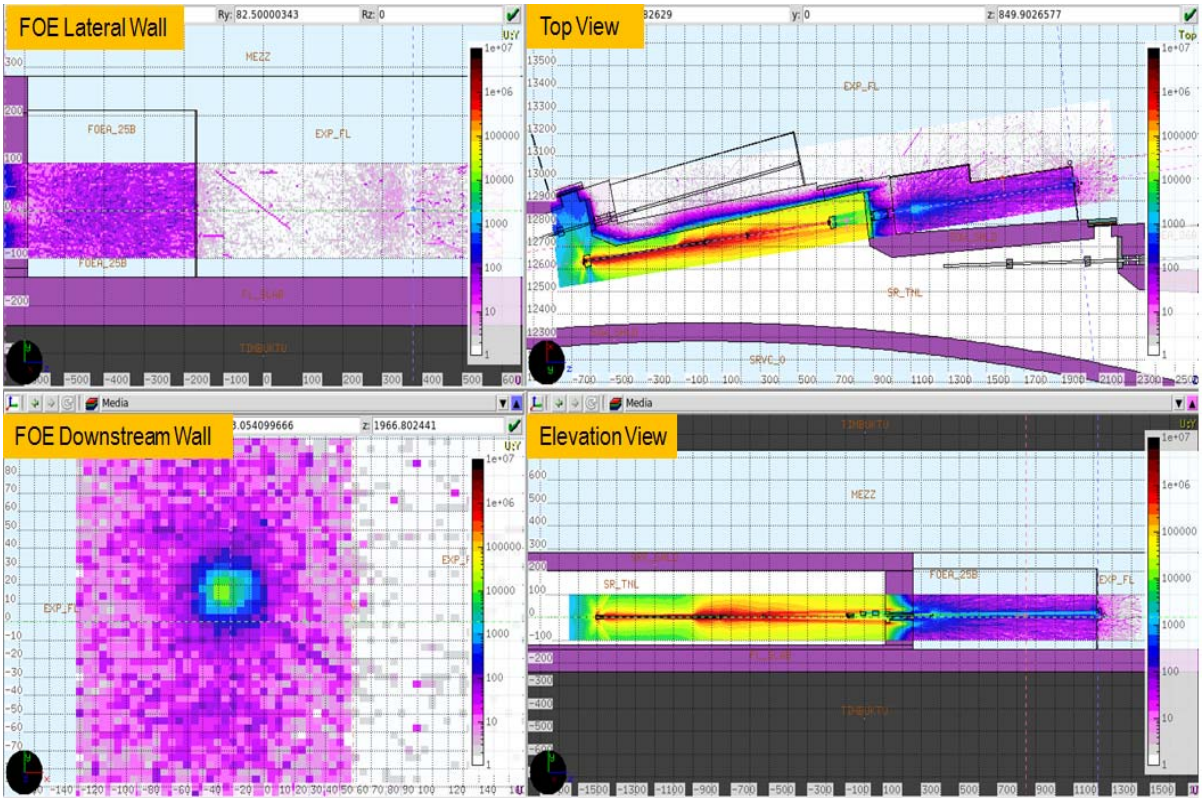

Figure 12: Same as Figure 8 but with injected beam striking the outboard side of the FM2

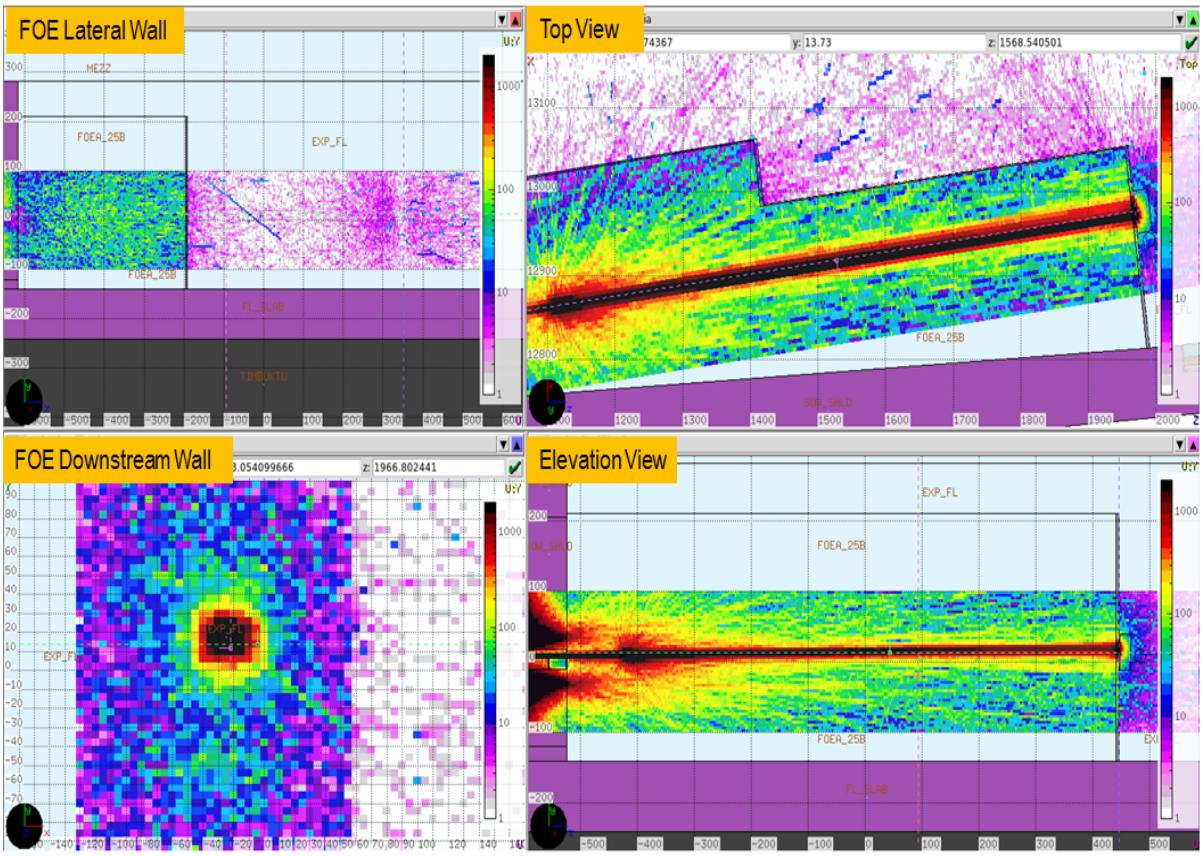

Figure 13: Same as Figure 9 but with injected beam striking the outboard side of the FM2

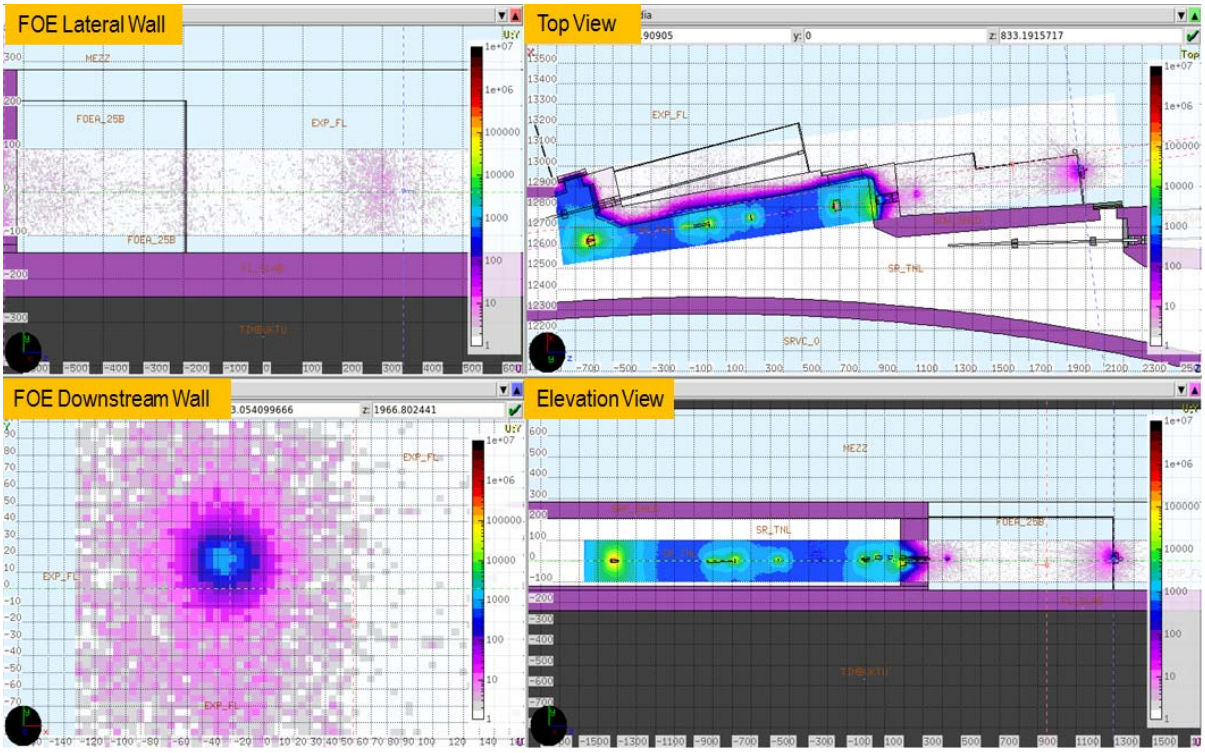

Figure 14: Same as Figure 12 but showing only the dose rates due to neutrons.

The above simulations have also been repeated (i) with a short (1 inch cube) copper target to mimic slits and located in the FOE at approximately 50 cm from the ratchet wall and (ii) with no target in the FOE. The results are consistent with the ones described above and a BRS with the same dmensions and position as given above is required to keep the total dose rates below 100 mrem/hr.

5. Summary and Conclusions

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 17BM-XFP FE has shown that the safe endpoint for the injected electron beam is the FM2, located just upstream from the lead collimator 1. To ensure this safe point the following apertures are credited with horizontal alignment tolerances:

- Fixed Mask 2 : ± 2mm
- Exit Absorber: ± 5 mm
- Storage Ring Chamber S4: ± 5mm
- Blank Off flange on chamber S4

Based on the FLUKA simulations described in this note, assuming an injected beam striking FM2 5 mm from the edge of downstream aperture, the ambient dose rates on the downstream wall of the 17BM-XFP FOE exceed the 100 mrem/hr within an area (approximately 50cm x 50cm in size) on the downstream wall of the 17BM-XFP FOE. Ambient Dose rates on the lateral wall were found below 100 mrem/hr. Therefore, the following additional shielding is required for Top-Off safety of this beamline:

- Lead bremsstrahlung stop (BRS) located on the downstream wall of the FOE with 20 inch x 20 inch in area and 8 inch in thickness. The center of this stop is located at an elevation of 5 cm above the centerline of the ratchet wall collimator (RCO) downstream aperture. The BRS should be centered 137.3 mm above the 1400 mm nominal electron beam centerline corresponding to 1537.3 mm above the experimental floor and the relative elevation between RCO aperture and BRS must be maintained. The position and minimum required size of the BRS is further shown in Figure 6.

The BRS should have allowed positions tolerances as follows:

- X = ± 1 mm
- Y = ± 1 mm
- Z = +0 mm / -25 mm
- Distance from the 3PW center to the upstream face of the BRS is at 34645 mm

Gap between the lead and rear downstream wall of FOE should not exceed 5mm. The 20” ×20” area of the lead must be centered 50 mm above the centerline of the downstream side of the RCO tube.

This should reduce the dose rate on the downstream wall of the FOE to below 100 mrem/hr.

These credited apertures and additional shielding are required with the existing TOSS interlocks to ensure top off safety for 17BM-XFP beamline.

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] XFP, Cell 17-BM, Front End Ray Tracing, SR-FE-3PW-7001, Rev. B (Oct 2015).

[4] Email “XFP lead apertures” from J. Tuozzolo to M. Benmerrouche (December 17, 2015).

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

Appendix 1

Table 1.1 17BM-XFP Beamline Enclosures

The FLUKA geometry for the storage shielding is based on the architectural drawing 42509a-fp01-RING.dwg

Wall	Position	Thickness	Material
D/S End of 17-BM-A Ratchet Wall	2489.2 cm		
D/S End of FOE (17-BM-A) Downstream Wall	3464.0 cm	5.0 cm	Lead
D/S End of FOE Bump-out (17-BM-A) Downstream Wall	2914.3 cm	5.0 cm	Lead
Distance of FOE Sidewall from SC	80.6 cm	1.8 cm	Lead
Distance of FOE Bump-out Sidewall from SC	159.9 cm	1.8 cm	Lead
Distance of FOE Roof from SC	210.6 cm	0.4 cm	Lead
Distance of FOE Floor from SC	140.0 cm		
Length of FOE	974.8 cm		

SC: Straight Centerline

Co-ordinate system

The z axis or beam centerline lies along the Front End centerline. The positions (z co-ordinates) of the various beamline components are defined with respect to the center of 3PW source. For 17BM-XFP the front end 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 1.2 17BM-XFP Beamline Components

Components	Z = Distance from 3PW Center U,D or C	Dimensions (specify units)		Vertical (y)/ Horizontal (x) Offset & Rotation w.r.t CENTERLINE	Material used in FLUKA	Associated Drawings
		Outer dimensions (W)x(H)x(L)	Aperture (W)x(H) or (R)			
Fixed mask 2 (FM2)	827.7 cm (U)	22.86 cm (x) 15.24 cm (y) 4.45 cm (z)	US: 4.29cm (x) 2.14cm (y) DS: 2.50cm (x) 0.34cm (y)		Copper	SR-FE-3PW-MSK-1872

Components	Z = Distance from 3PW Center U,D or C	Dimensions (specify units)		Vertical (y)/ Horizontal (x) Offset & Rotation w.r.t CENTERLINE	Material used in FLUKA	Associated Drawings
		Outer dimensions (W)x(H)x(L)	Aperture (W)x(H) or (R)			
Lead Collimator 1 (LCO1)	836.6 cm (U)	50.80 cm (x) 12.70 cm (y) 30.48 cm (z)	4.04cm (x) 1.70cm(y)		Lead	SR-FE-3PW-CO-0700
White Beam Mirror (WBM)	1400.0 cm (C)	10.16 cm (x) 5.08 cm (y) 134.00 cm (z)		4.2 mrad	Silicon	PD-XFP-PFM-1000
Fixed mask 3 (FM3)	1477.3 cm (U)	22.86 cm (x) 15.24 cm (y) 4.45 cm (z)	US: 5.38cm (x) 2.80cm (y) DS: 4.25cm (x) 1.10cm (y)	Y=+0.85cm	Copper	SR-FE-3PW-MSK-1873
Fixed mask 4 (FM4)	1702.2 cm (U)	22.86 cm (x) 15.24 cm (y) 4.45 cm (z)	US: 5.38cm (x)2.80cm (y) DS: 3.65cm (x)1.08cm (y)	Y=+2.71cm	Copper	SR-FE-3PW-MSK-1874
Fixed mask 5 (FM5)	2140.9 cm (U)	22.86 cm (x) 15.24 cm (y) 4.45 cm (z)	US: 3.78cm (x)2.77cm (y) DS: 2.05cm (x)1.05cm (y)	Y=+6.35cm	Copper	SR-FE-3PW-MSK-1875
Lead Collimator 2 (LCO2)	2149.9 cm (U)	51.82 cm (x) 19.05 cm (y) 30.48 cm (z)	3.64cm (x) 3.36cm (y)	Y=+6.24cm	Lead	SR-FE-3PW-CO-0600
Safety Shutter 1	2214.6 cm (U)	17.78 cm (x) 16.51 cm (y) 30.48 cm (z)		Y=+17.24cm (open)	Lead	SR-FE-3PW-SS-4000
Safety Shutter 2	2278.5 cm (U)	17.78 cm (x) 16.51 cm (y) 30.48 cm (z)		Y=+17.24cm (open)	Lead	SR-FE-3PW-SS-4001

Components	Z = Distance from 3PW Center U,D or C	Dimensions (specify units)		Vertical (y)/ Horizontal (x) Offset & Rotation w.r.t CENTERLINE	Material used in FLUKA	Associated Drawings
		Outer dimensions (W)x(H)x(L)	Aperture (W)x(H) or (R)			
Ratchet Wall Collimator (RCO)	2344.5 cm (U)	See FE Ray Tracing, SR-FE-3PW-7001	See FE Ray Tracing, SR-FE-3PW-7001	Aperture at Y=+8.73 cm See FE Ray Tracing, SR-FE-3PW-7001	Lead, Concrete Steel	SR-FE-3PW-RCO-7000
Bremsstrahlung Stop (BRS) Behind downstream wall of FOE	3464.5 cm (U)	Minimum Requirement 50.80 cm(x) 50.80 cm(y) 20.32 cm(z)		Y=+13.73 cm	Lead	Proposed