08BM (TES) TOP-OFF RADIATION SAFETY ANALYSIS

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NSLS-II TECHNICAL NOTE BROOKHAVEN NATIONAL LABORATORY	NUMBER: **NSLSII-TOS-RPT-007**
AUTHORS: M. Benmerrouche, R. Fliller and Y. Li	DATE: 08/04/2016
08BM (TES) 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 potentially high dose rates on the FOE walls. The radiological consequences of this fault condition specifically for 08BM (Tender Energies Spectroscopy [TES] and Imaging) are analyzed and discussed in this report. For this beamline, many FE components lie along the short straight (SS) centerline while remaining FE components, ratchet wall collimators, and FOE components are vertically offset. 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 08BM (TES) FE components is presented in Figure 1 and the layout of the FOE components is presented in Figure 2.

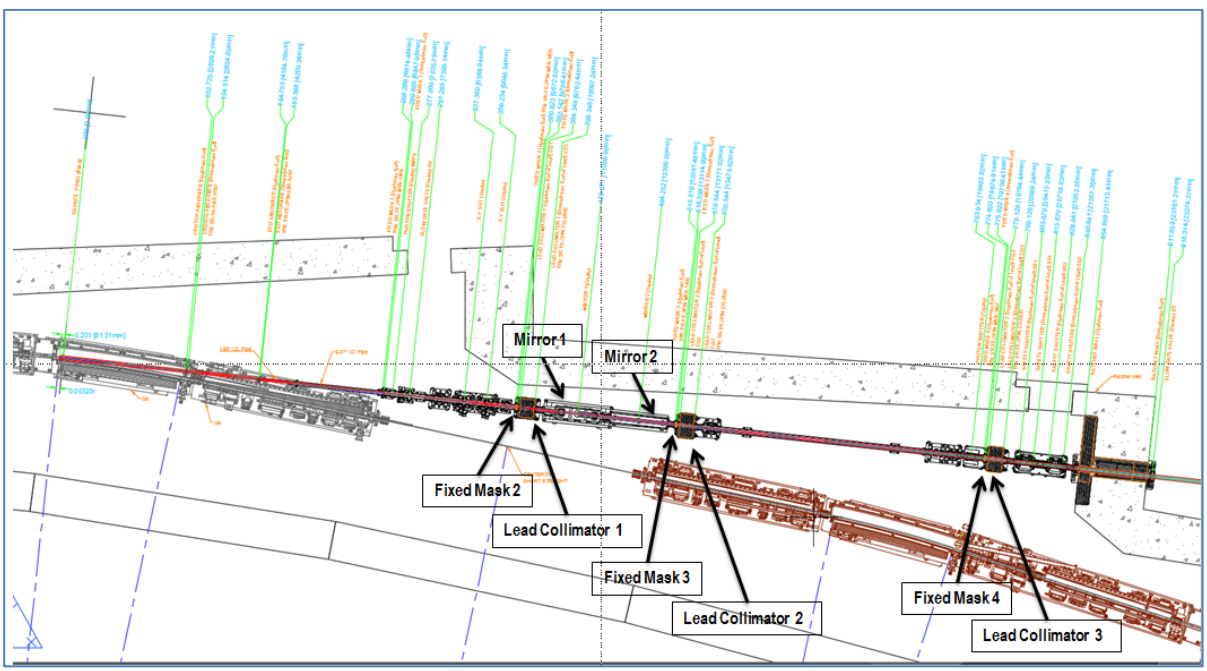

Figure 1: Layout of 08BM (TES) FE showing major components consisting of Masks, Collimators, Mirrors, Safety Shutters, and Ratchet Wall Collimator.

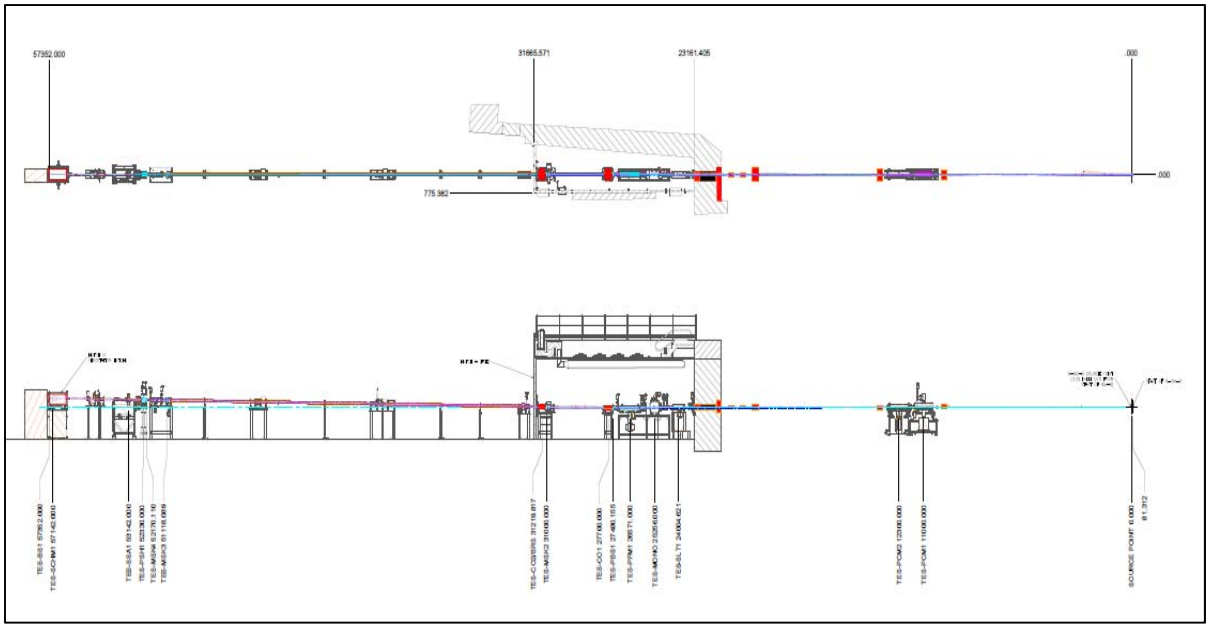

Figure 2: Layout of 08BM (TES) Beamline

Based on the ray tracing analysis it has been determined that the injected electrons will not travel beyond the lead collimator 2 (LCO2) in the FE and will be completely stopped at LCO2. FLUKA simulations were performed with a pencil beam traveling from fixed mask 1 (FM1) to the safe end point at LC02.

The extreme ray tracing analysis for 08BM (TES) 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 08BM (TES) 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 Radiological Scatter Targets

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. The 08BM (TES) beamline has 2 mirrors in the front end (FE) which reflect the synchyroton beam downward as illustrated in Figure 3(a). The apertures of the front end components downstream of Mirror 2 which consist of Fixed mask 3 (FM3), lead collimator 2 (LCO2), fixed mask 4 (FM4), lead collimator 3 (LCO3) and ratchet wall collimator (RCO) are shifted vertically by 25 mm downward with respect to the short straight centerline to allow the pink beam to exit the front end and into the FOE. Figure 3(b) shows that primary electrons will be stopped by LCO2. For the top off radiological analysis we assumed all primary targets that could intercept the electron beam as it exits the exit absorber and travels along the front end to the end safe point. Therefore, the primary scatter targets considered for the top-off analysis are FM1, FM2, Mirror 1, and FM3. The beam impact at FM1 and FM2 is assumed to be 5 mm from the downstream aperture of the fixed mask. For the mirror 1, the beam was assumed to hit the upstream face of the mirror and at its center. For FM3 the beam impact is determined by the 2 vertical extreme rays.

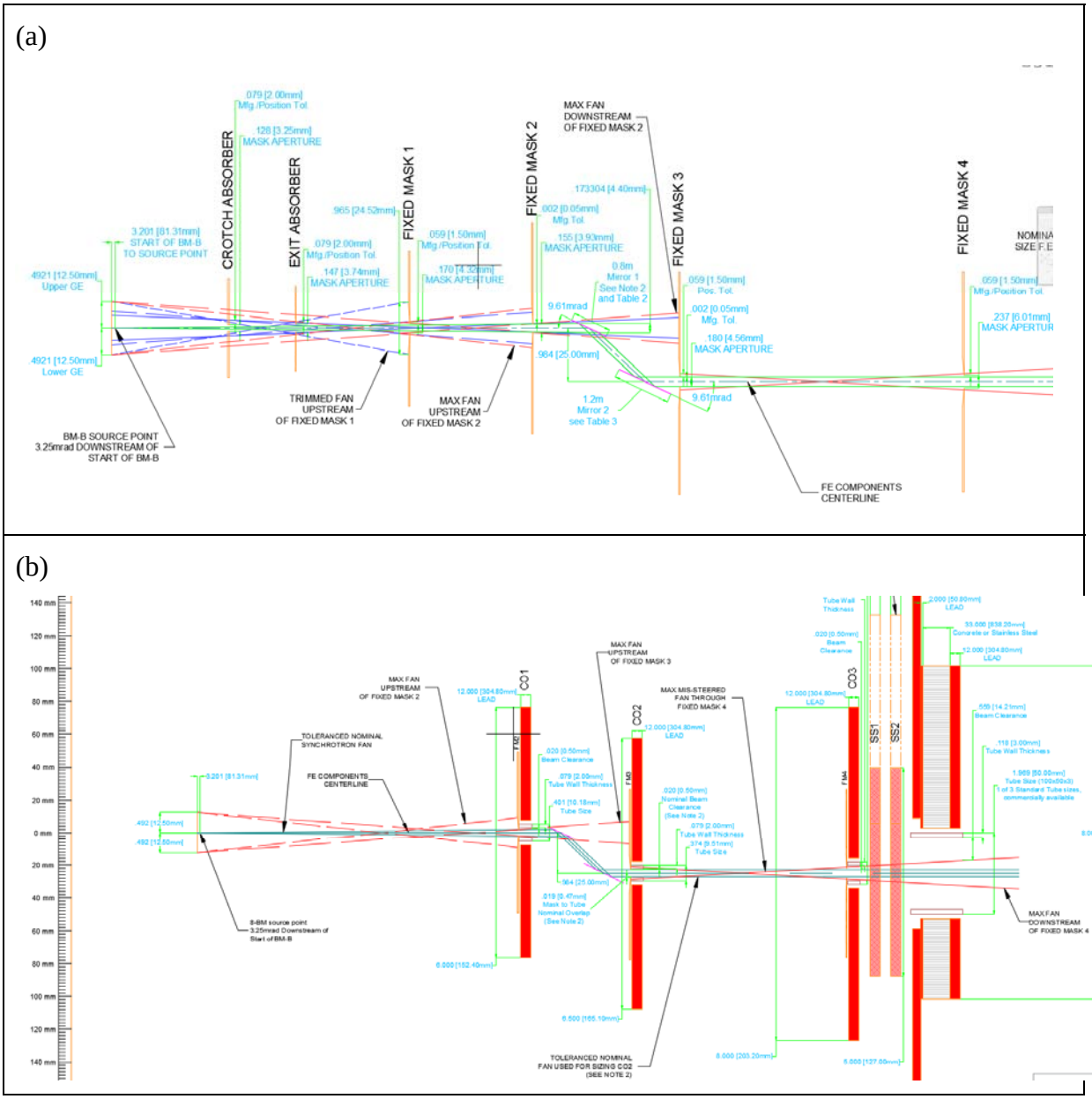

Figure 3. 08BM-TES front end vertical ray tracings for (a) synchroton beam and (b) bremmstrahlung.

3. Description of the FLUKA Model

The plan and elevation views of the FLUKA geometry used for the Top-Off simulations of the 8BM (TES) 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 and output files are kept in the Radiation Physics Folder.

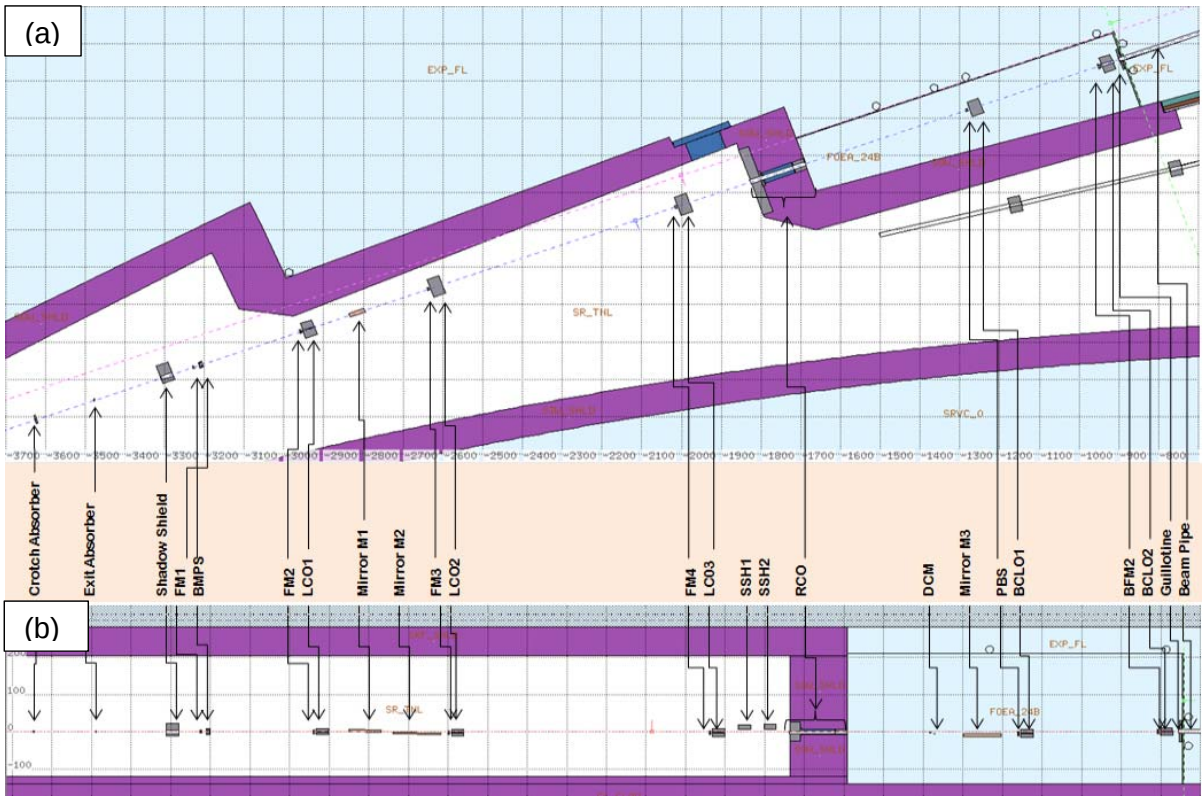

Figure 4: (a) Plan (y=0) and **(b)** elvation views of the FLUKA geometry used in Top-Off simulation of the 08BM (TES) Beamline.

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 extreme ray tracing analysis described in section 2, the beam is assumed to start just upstream of the FM1 aperture and travels down the front end toward 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 collimators LCO2, LCO3 and RCO. The aperture dimensions for 8BM (TES) are compared to those for XFP in Table 1 noting that XFP has no LCO3. The parameters for 17BM-XFP are extracted from 17BM (XFP) Top-Off Radiation Safety Analysis (PS-C-ASD-TOS-RPT-004, May 19, 2016).

Table 1. LCO2, LCO3, and RCO apertures.

	08BM-TES	**17BM-XFP**
LCO2 Dimensions X (mm)	43.94	36.42
LCO2 Dimesnions Y (mm)	14.51	33.60
LCO3 Dimensions X (mm)	62.76	--
LCO3 Dimesnions Y (mm)	18.43	--
RCO Dimensions X (mm)	106.00	106.38
RCO Dimensions Y (mm)	56.00	57.84
Vertical Offsets (mm) LCO2/LCO3/RCO	25.0/25.0/25.0	62.34/--/87.29

The dimensions of the 08BM (TES) LC02 vertical apertures are smaller than those for 17BM-XFP but the dimensions of the RCO are comparable. The 08BM-TES simulations

were undertaken to evaluate the implications of the apertures of LCO2, LCO3, and RCO on the dose rates outside the FOE walls and roof.

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

1. Injected beam starting at the inboard side of the downstream aperture of FM1.
2. Injected beam starting at the outboard side of the downstream aperture of FM1
3. Injected beam starting at the inboard side of the downstream aperture of FM2
4. Injected beam starting at the outboard side of the downstream aperture of FM2
5. Injected beam starting at the center of Mirror 1.
6. Injected beam starting at the upstream face of Mirror 1
7. Injected beam starting at the position of the top extreme ray on the front face of FM3
8. Injected beam starting at the position of the bottom extreme ray on the front face of FM3

The dose rates on the downstream FOE wall were found to be negligible for cases 7 and 8 mostly due to LCO2 attenuating the shower created in FM3. Results for the first 5 scenarios give slightly elevated dose rates compared to the remaining scenarios but still below 100 mrem/hr on contact with the walls and roof of the FOE.

4.1 Injected beam starting at the inboard side of the downstream aperture of FM1

In this simulation, the injected electron beam was started just upstream of the selected point of contact and impinges 5 mm from the inboard side of the FM1 downstream aperture. The total dose distributions (mrem/h) in the FE and FOE are shown in Figure 5 and the corresponding neutron distributions are given in Figure 6. The total dose rates on the roof, lateral wall and downstream wall of the FOE are below 100 mrem/hr and the neutron dose rates are approximately an order of magnitude smaller.

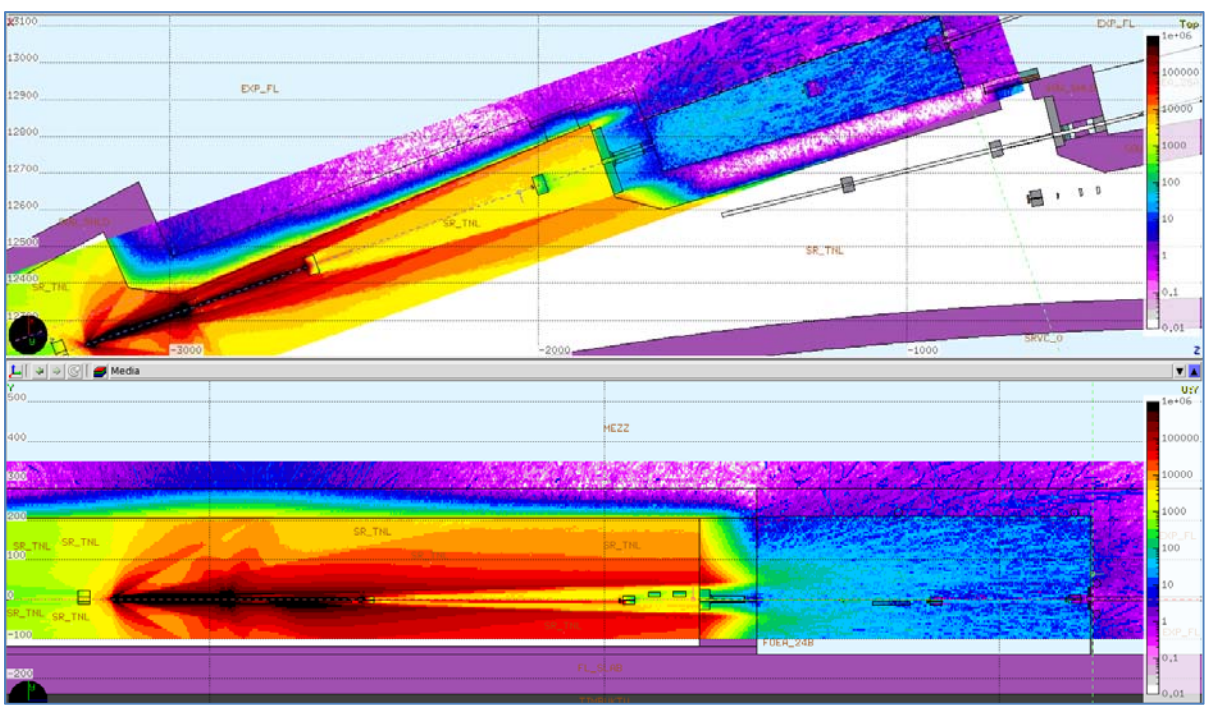

Figure 5: Total dose rate distributions (mrem/h). The Top view at y=0 is shown in the top figure and the elevation view in the bottom figure.

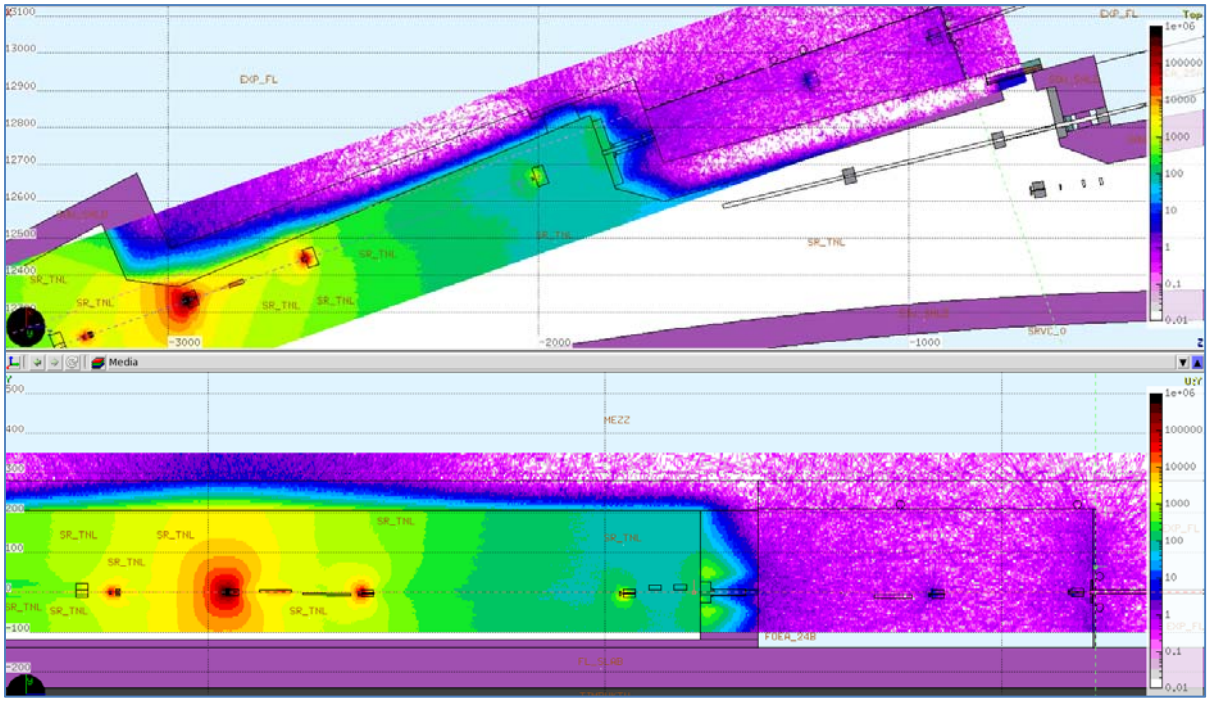

Figure 6: Neutron dose rate distributions (mrem/h). The Top view at y=0 is shown in the top figure and the elevation view in the bottom figure.

4.2 Injected beam starting at the outboard side of the downstream aperture of FM1

In this simulation, the injected electron beam was started just upstream of the selected point of contact and impinges 5 mm from the outboard side of the FM1 downstream aperture. The total dose distributions (mrem/h) in the FE and FOE are shown in Figure 7. These dose rates are similar to those for scenario 1. For both cases the dose rates on the roof and walls of the FOE are below 100 mrem/hr.

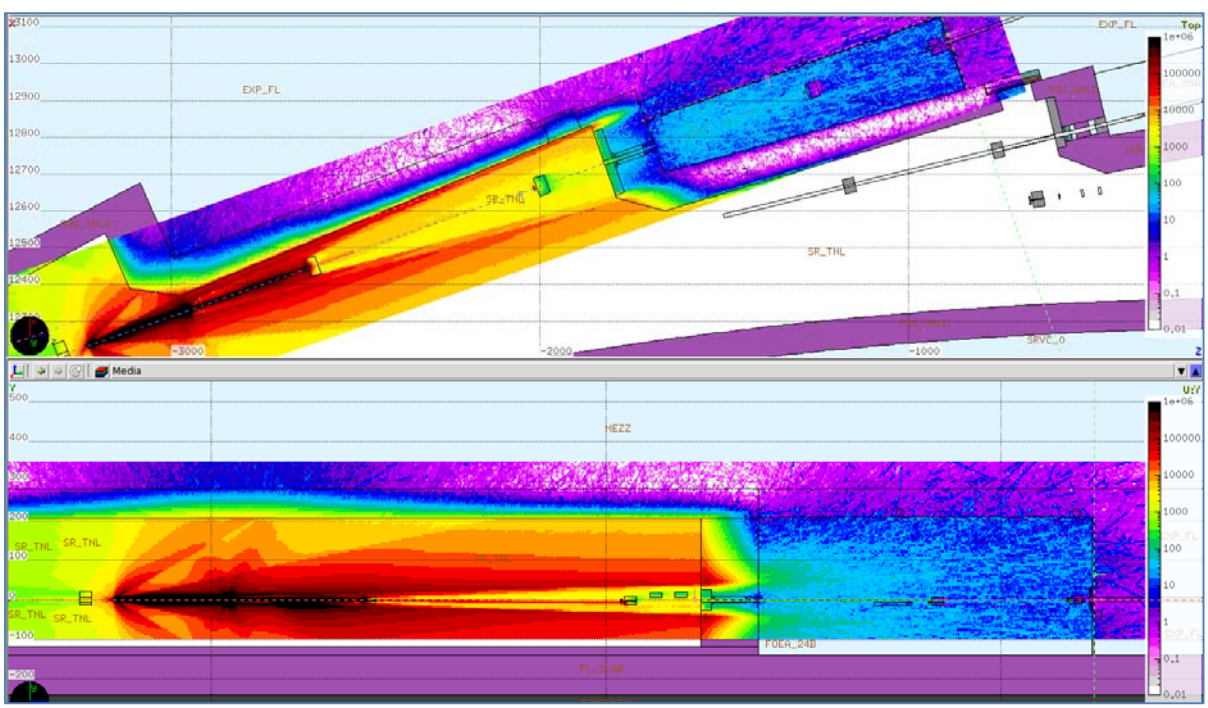

Figure 7: Total dose rate distributions (mrem/h). The Top view at y=0 is shown in the top figure and the elevation view in the bottom figure.

4.3 Injected beam starting at the inboard side of the downstream aperture of FM2

In this simulation, the injected electron beam was started just upstream of the selected point of contact and impinges 5 mm from the inboard side of the FM2 downstream aperture. The total dose distributions (mrem/h) in the FE and FOE are shown in Figure 8 and the corresponding neutron distributions are given in Figure 9. The total dose rates on the roof, lateral wall and downstream wall of the FOE are below 100 mrem/hr and the neutron dose rates are approximately an order of magnitude smaller.

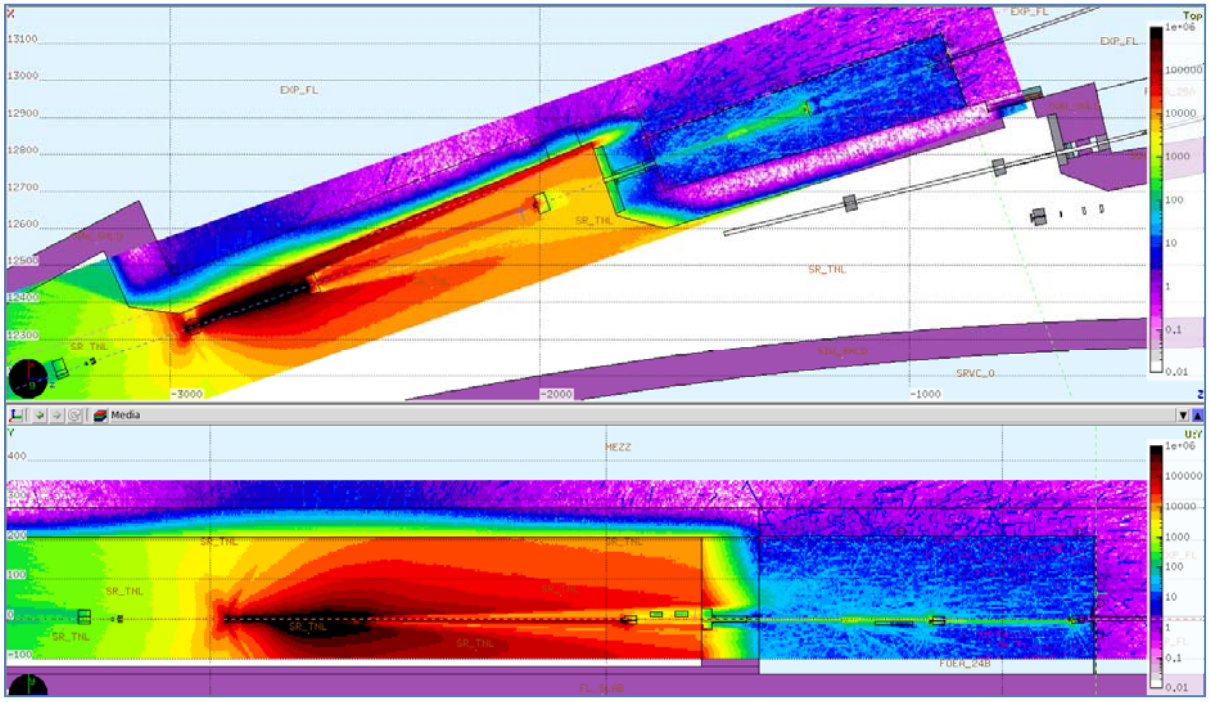

Figure 8: Total dose rate distributions (mrem/h). The elevation view at y=0 is shown in the top figure and the plane view in the bottom figure.

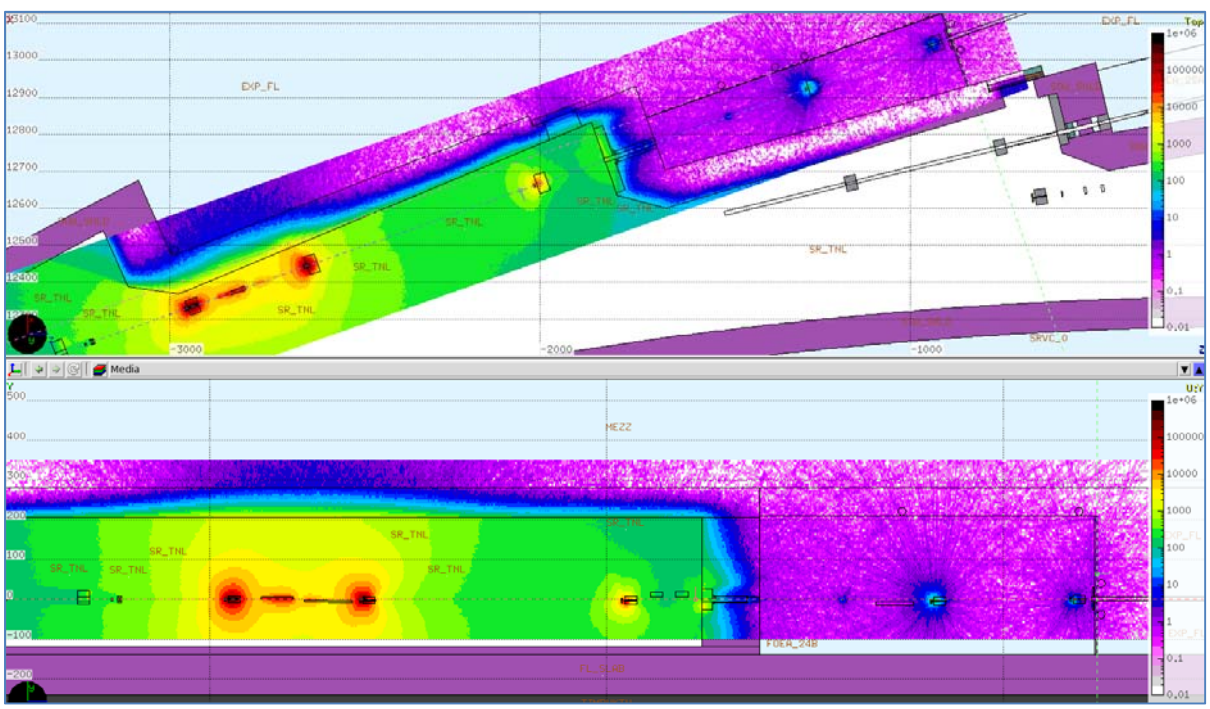

Figure 9: Neutron dose rate distributions (mrem/h). The Top view at y=0 is shown in the top figure and the elevation view in the bottom figure.

4.4 Injected beam starting at the outboard side of the downstream aperture of FM2

In this simulation, the injected electron beam was started just upstream of the selected point of contact and impinges 5 mm from the outboard side of the FM2 downstream aperture. The total dose distributions (mrem/h) in the FE and FOE are shown in Figure 10. These dose rates are similar to those for scenario 3. For both cases the dose rates on the roof and walls of the FOE are below 100 mrem/hr.

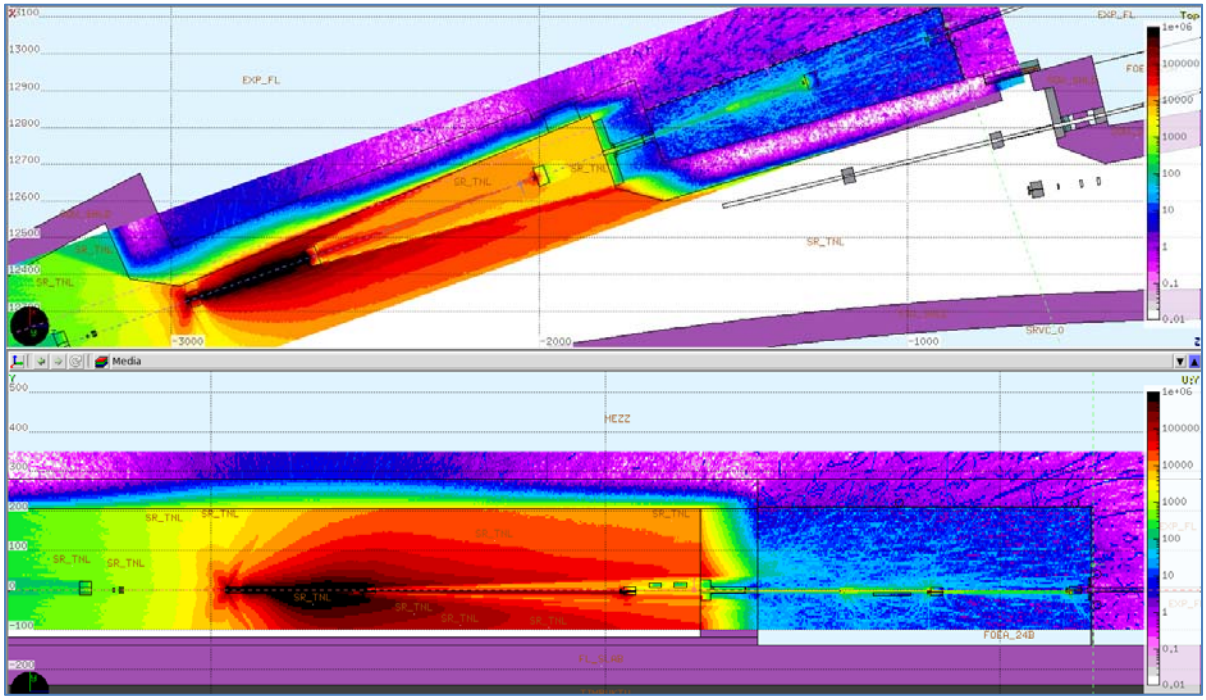

Figure 10: Total dose rate distributions (mrem/h). The elevation view at y=0 is shown in the top figure and the plane view in the bottom figure.

4.5 Injected beam starting at the center of Mirror 1

In this simulation, the injected electron beam was started just upstream of the selected point of contact and impinges at the center of Mirror 1. The total dose distributions (mrem/h) in the FE and FOE are shown in Figure 11 and the corresponding neutron distributions are given in Figure 12. The total dose rates on the roof, lateral wall and downstream wall of the FOE are below 100 mrem/hr and the neutron dose rates are approximately an order of magnitude smaller.

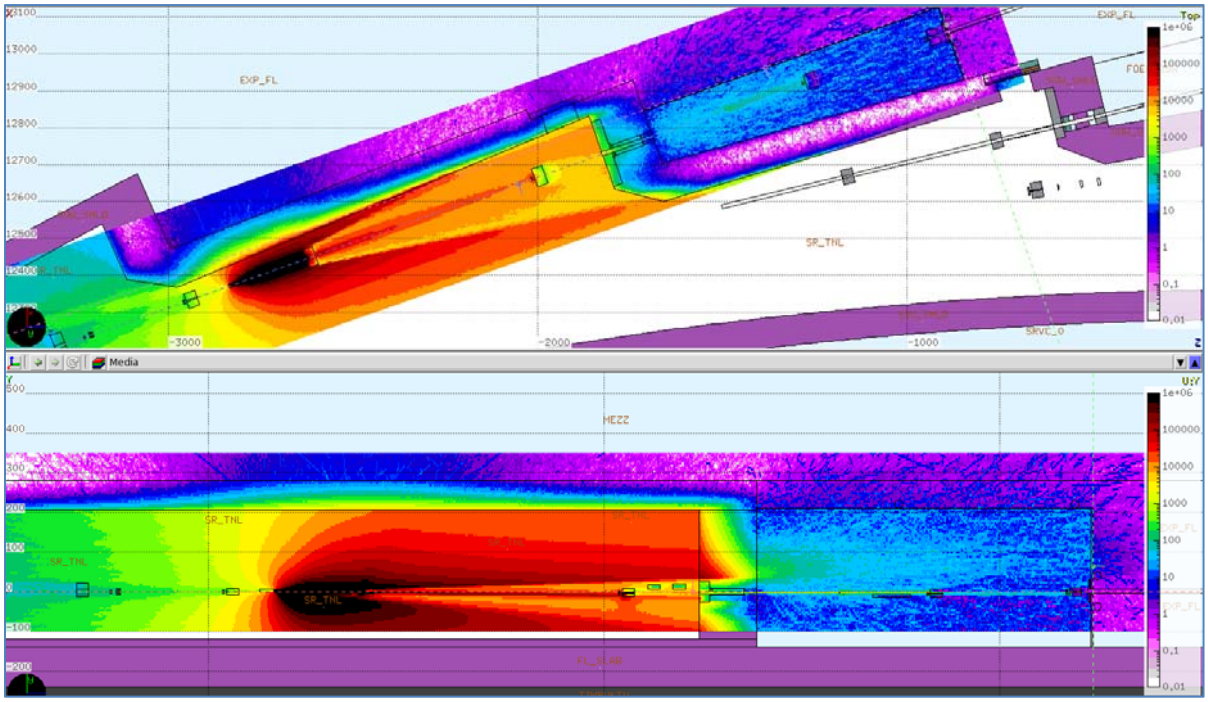

Figure 11: Total dose rate distributions (mrem/h). The elevation view at y=0 is shown in the top figure and the plane view in the bottom figure.

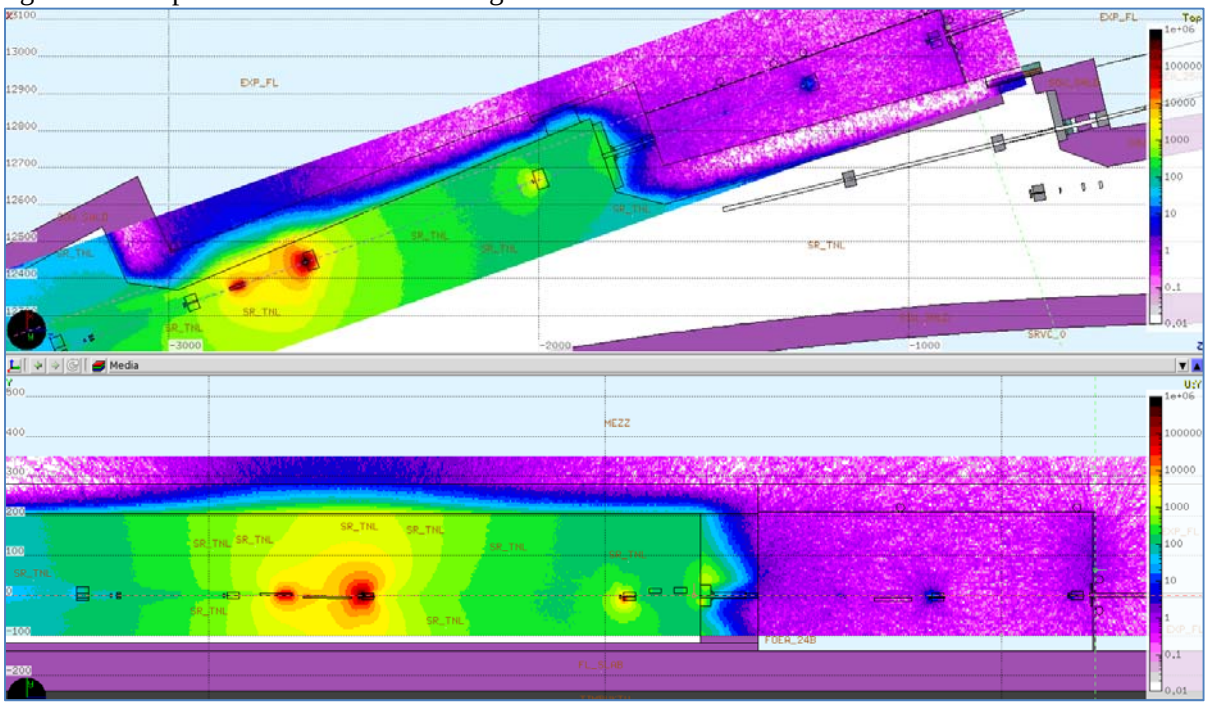

Figure 12: Neutron dose rate distributions (mrem/h). The Top view at y=0 is shown in the top figure and the elevation view in the bottom figure.

4.6 Injected beam starting at the upstream face of Mirror 1

In this simulation, the injected electron beam was started just upstream of the selected point of contact and impinges at the upstream side of Mirror 1. The total dose distributions (mrem/h) in the FE and FOE are shown in Figure 13 and the corresponding neutron distributions are given in Figure 14. The total and neutron dose rates on the roof, lateral wall and downstream wall of the FOE are well 10 mrem/hr.

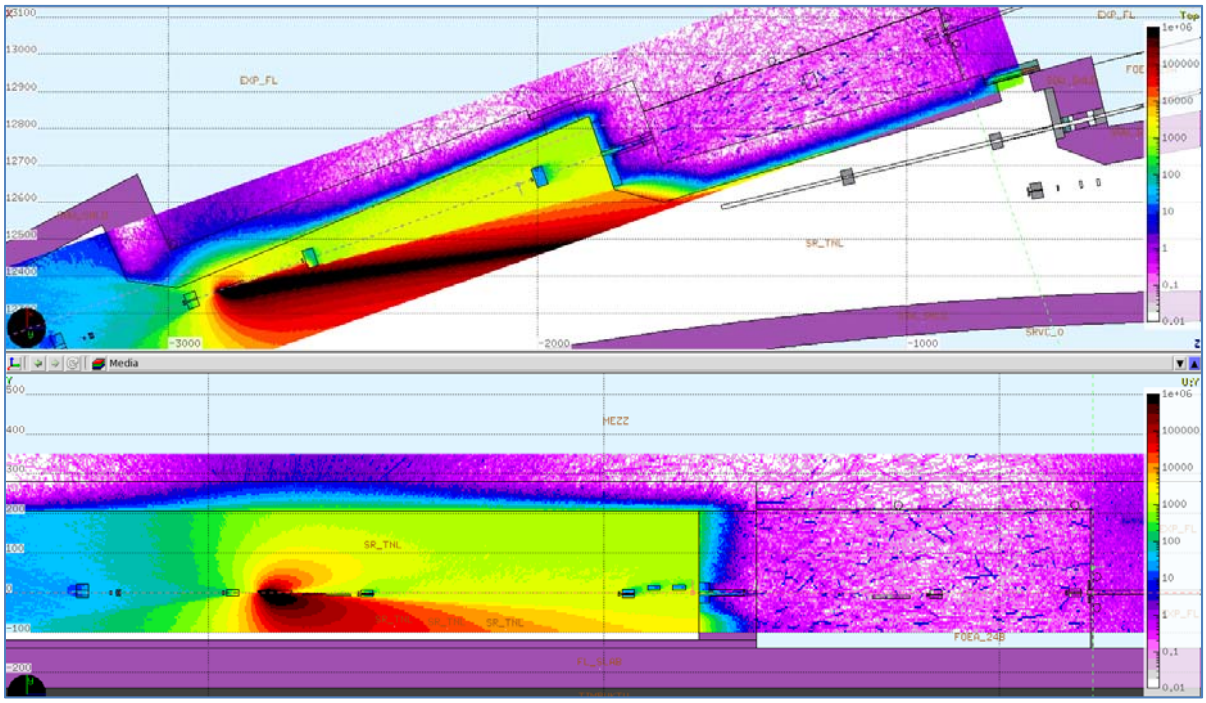

Figure 13: Total dose rate distributions (mrem/h). The elevation view at y=0 is shown in the top figure and the plane view in the bottom figure.

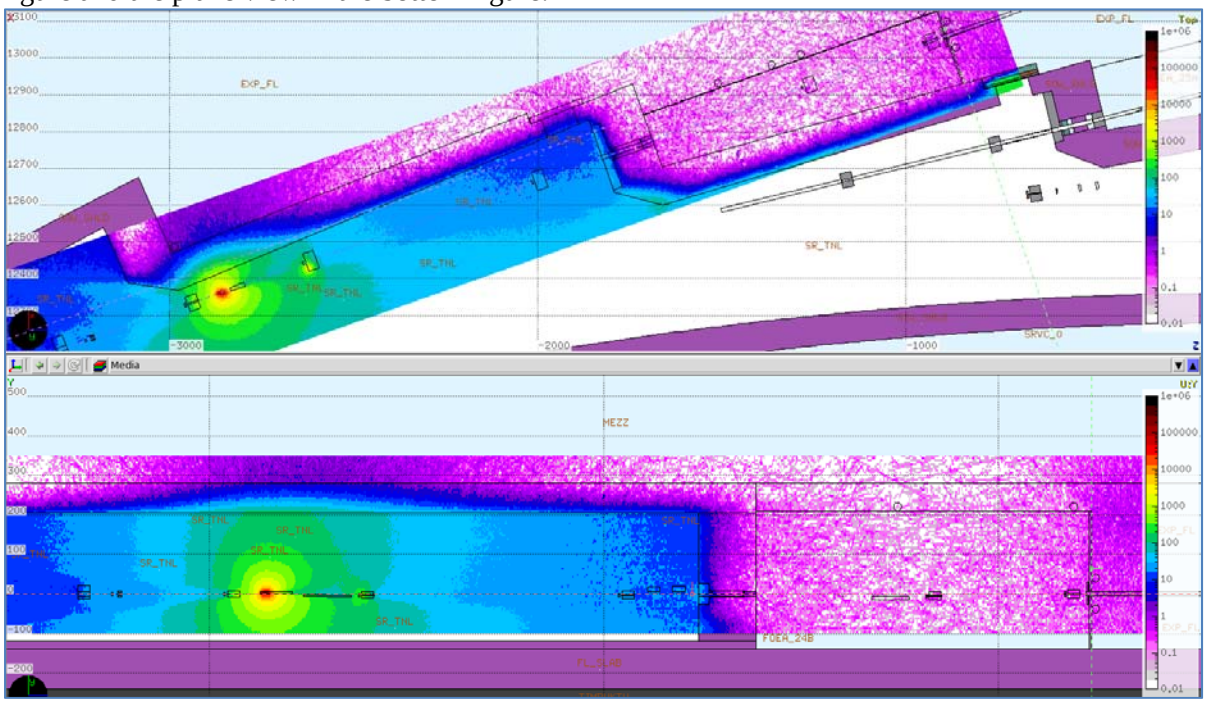

Figure 14: Neutron dose rate distributions (mrem/h). The Top view at y=0 is shown in the top figure and the elevation view in the bottom figure.

4.7 Injected beam starting at the position of the top extreme ray on the front face of FM3

In this simulation, the injected electron beam was started just upstream of the selected point of contact and impinges at the position of the top extreme ray on the front face of FM3 (see figure 3). The total dose distributions (mrem/h) in the FE and FOE are shown in Figure 15 and the corresponding neutron distributions are given in Figure 16. The total and neutron dose rates on the roof, lateral wall and downstream wall of the FOE are well below 1 mrem/hr.

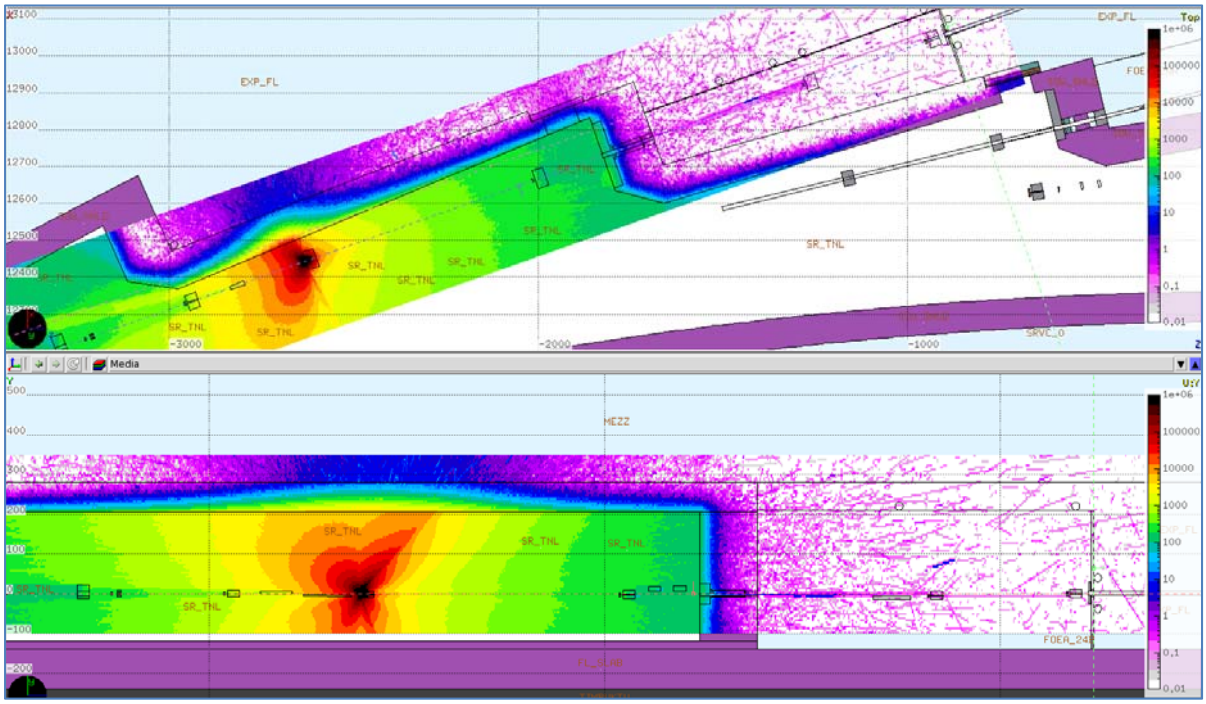

Figure 15: Total dose rate distributions (mrem/h). The elevation view at y=0 is shown in the top figure and the plane view in the bottom figure.

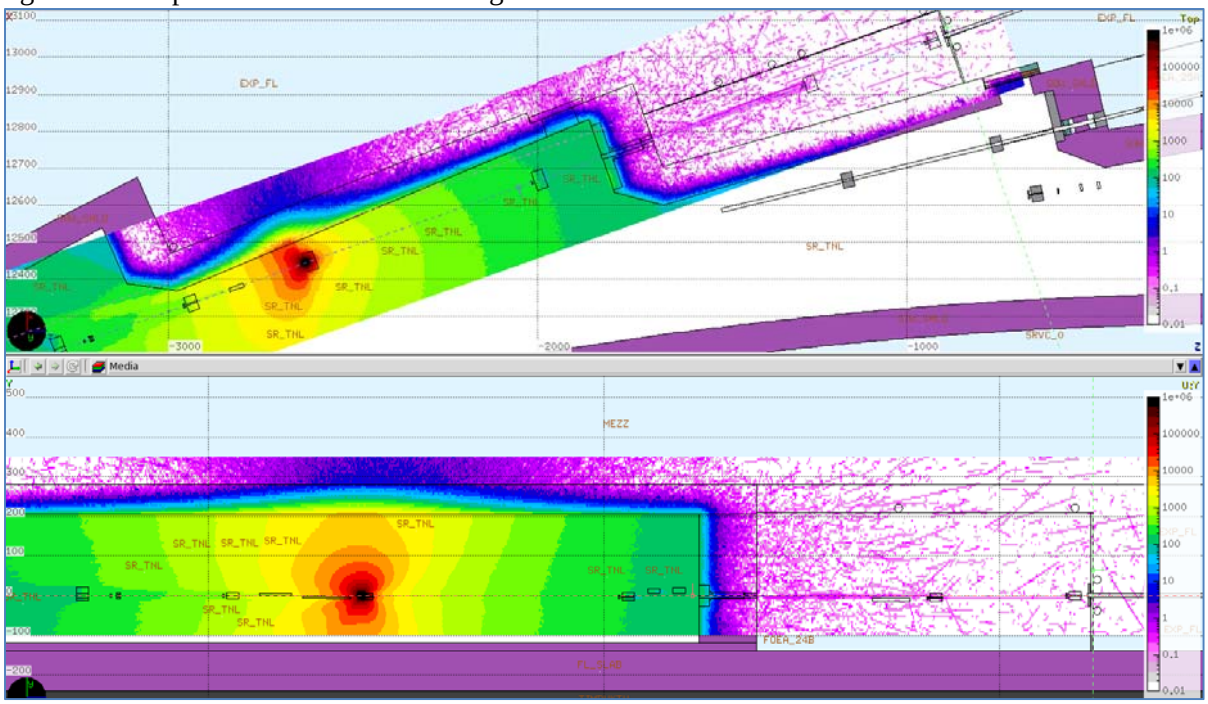

Figure 16: Neutron dose rate distributions (mrem/h). The Top view at y=0 is shown in the top figure and the elevation view in the bottom figure.

4.8 Injected beam starting at the position of the bottom extreme ray on the front face of FM3

In this simulation, the injected electron beam was started just upstream of the selected point of contact and impinges at the position of the bottom extreme ray on the front face of FM3 (see figure 3). The total dose distributions (mrem/h) in the FE and FOE are shown in Figure 17 and the corresponding neutron distributions are given in Figure 18. These dose rates are similar to those for scenario 7. For both cases the dose rates on the roof and walls of the FOE are below 1 mrem/hr.

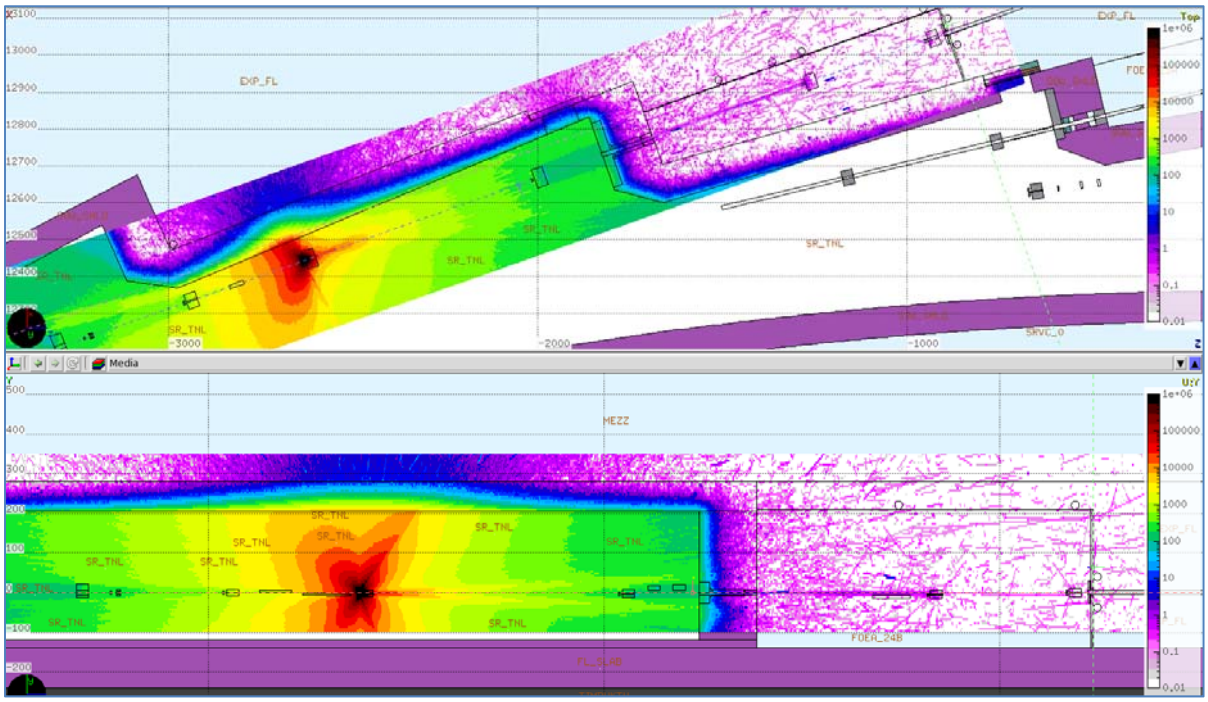

Figure 15: Total dose rate distributions (mrem/h). The elevation view at y=0 is shown in the top figure and the plane view in the bottom figure.

5. Summary and Conclusions

Based on the FLUKA simulations described in sections 4.1 and 4.8 of this note, assuming a fault condition where an injected beam starting at the exit mask and travels along the front end of 08BM-TES. For this fault condition, the ambient dose rates on the walls and roof of the 08BM (TES) FOE are lower than 100 mrem/hr. According to the NSLS-II Shielding policy [3], radiation fields below 100 mrem/hr for such a fault condition do not require any additional engineered controls beyond what TOSS provides. In addition to Lead Collimators and RCO which are 08BM-TES Front End Radiation Safety Components, Fixed Masks 1, 2 and 3 should be kept under configuration control for purposes of top off safety.

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.

6. Acknowledgements:

We would like to thank Paul Northrup and Ed Haas for providing all the beamline geometry information listed in Appendix 1 and for multiple discussions.

Appendix 1

08BM-TES Input provided by Paul Northrop, E. Haas, John Tuozzolo and R. Gambella: updated on June 23, 2016

TES is the only currently planned beamline utilizing a bending magnet as its X-ray source (no 3PW).
The source point is the origin of the co-ordinate system. The Z-axis lies along the beam centerline
The GB direction will be 3.5mrad outboard with respect to the beam centerline. The GB has been considered to be directed along the beam centerline in the simulations.

Table 1.1 Beamline Enclosure: First Optical Enclosure

Shielding Information (dimensions in mm)	Z Position* (m)	Thickness (mm)	Material
8-BM-A SR Ratchet Wall; DS Face (inside FOE)	23.160	1448	Concrete / Lead
OB wall distance from 8-BM (3.25 mrad) photon beam centerline	0.75 m minimum	19.05	Lead
Minimum distance from beam centerline to roof Pb shielding[note 3]	2.076	6.35	Lead
Minimum distance from photon beam Z-axis to SR wall face	0.79 minimum		Concrete
Angle of SR wall from photon beam Z-axis: 4 degrees			
Distance of roof from SS centerline in FOE	211.0-2.5=208.5cm	0.635 cm	
Distance of FOE side wall from beamline (is sidewall parallel to the beamline?	72.0 cm	1.9 cm	
DS End of 8-BM FOE Back wall	31.662	50.8 (reqmt=50)	Lead

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 at FOE DS wall Angle wrt Z axis
	ID=3.834”, OD=4” SS thickness=0.083”=0.211cm	Pipe is not shielded	Y=11mm

NOTE 5: There is a 6.75” diameter hole in the downstream FOE wall.

Table 1.3 Beamline FOE Components for FLUKA Calculations

Front End Component	Z location, m (Distance from Source Point) (US), (DS) or center (C)	Dimensions			Offset (vertical or horizontal) w.r.t beam centerline	Material	Associated Drawings
		Outer dimensions of material (W)x(H)x(L)	Lead CO or Mask DS Aperture	Mask upstream Aperture			
Crotch Absorber	2.609 (US) 2.655 (DS)	215.2 mm 45.4 mm 43.6 mm	22.74mm(W) 7.25 mm(H)		-	GlidCop GlidCop	SR-VA-ABS-1093
Exit Absorber	4.185 (US)	Diameter to edge holes 51.99 mm L = 16.71 mm	16.54 mm(W) 7.74 mm(H)	22.70mm W 13.90 mm H	Aperture centered WRT beamline. Absorber block offset 5.23 mm to outboard side		SR-FE-3PW-ABS-0010
G6 shadow shield	5.975 (U)	20inch (W) 13 inch (H) 12inch (L)	4.25in(W) 4.25in (H)		See f igure	Lead	SR-SHLD-6410.pdf
FE MSK1	6.8156 (US)	Ø72.9 mm 42.1 mm	21.69 mm(W) 7.32 mm(H)	39.02 mm 24.64mm	-	Cu-Cr-Zr	SR-FE-3PW-MSK-1894
FE photon shutter 1	703.58(C)	Cu Cylinder D=100mm L= 34.0mm	Steel shell OD=152mm L=120mm				V-1868651PI-VLV-0027_idw.pdf
FE MSK2	9.674 (US)	Ø96.8 mm L=42.1 mm	24.42 mm(W) 4.03 mm(H)	41.76 mm 21.36 mm	-	Cu-Cr-Zr	SR-FE-3PW-MSK-1895
FE CO1	9.762 (US)	16″ x 6″x 12″	36.52mm(W) 15.18 mm(H)		-	Lead	SR-FE-3PW-CO-0500
M1 Mirror	11.000(C)	100 mm (W) 60 mm (H) 813 mm(L)	N/A		angled downward 6.8-20.0 mrad M1rot=20mrad.	Silicon (Cr & Ni coating)	PD-TES-PCM-1000 (3D model in Vault TES/PCM file
Beam centerline and all beamline components offset: Y= -25 mm							

M2 Mirror	12.300(C)	70 mm (W) 40 mm (H) 1200 mm(L)	N/A		angled upward @ 6.8-20.0 mr Y= -25 mm M2rot=20mrad	Silicon (Cr & Ni coating)	PD-TES-PCM-2000 (3D model in Vault TES/PCM file)
FE MSK3	13.083 (US)	Ø96.8 mm 42.1 mm	36.07 mm 7.66 mm	53.39 mm 8.23 mm	Y = -25 mm	Cu-Cr-Zr	SR-FE-3PW-MSK-1896
FE CO2	13.171 (US)	20″ x 6.5″ 12″	43.94 mm 14.51 mm		Y = -25 mm	Lead	SR-FE-3PW-CO-0550
FE MSK4	19.676 (US)	Ø96.8 mm 42.1 mm	53.97 mm 9.01 mm	71.30 mm 26.34 mm	Y = -25 mm	Cu-Cr-Zr	SR-FE-3PW-MSK-1897
FE CO3	19.764 (US)	20.74″ x 8″ 12″	62.76 mm 18.43 mm		Y = -25 mm	Lead	SR-FE-3PW-CO-0570
Safety Shutter SS1	20.415 (US)	165.10mm(W)123.83 (H) 304.80mm(L)				Lead	SR-FE-SS-4000
Safety Shutter SS2	21.053 (US)	165.10mm(W) 123.83 (H) 304.80mm(L)				Lead	SR-FE-SS-4100
M2 Mirror	12.300(C)	70 mm (W) 40 mm (H) 1200 mm(L)	N/A		angled upward @ 6.8-20.0 mr Y= -25 mm M2rot=20mrad	Silicon (Cr & Ni coating)	PD-TES-PCM-2000 (3D model in Vault TES/PCM file)
Apertures in ratchet wall offset y=-2.5cm. Ratchet wall Collimators, etc centered on source centerline							
Lead in Ratchet wall RC0	21.713 (US)	1841.5 mm(W) 508.0 mm (H) 254 mm (L)	115.7 mm(W) 67.7 (H) mm		Y = -25 mm	Lead	SR-FE-RCO-5000
Lead block RC1	21.967 (US)	406.40mm(W) 203.20mm(H) 50.80mm(L)	115.7 mm(W) 67.7 (H) mm		Y = -25 mm	Lead	SR-FE-RCO-5000
Concrete block	22.053 (US)	292.1 mm (W) 142.75 mm (H) 784.22 mm (L)	115.7 mm(W) 67.7 mm (H)		Y = -25 mm	concrete	SR-FE-RCO-5180
Lead block RCO	22.856 (US)	292.1mm (W) 139.7 mm (H) 304.8 mm (L)	106mm (W) 56 mm (H)		Y = -25 mm	Lead	SR-FE-RCO-5180

Table 1.4 Beamline FOE Components for FLUKA Calculations

First Optical Enclosure Component	Z location, m (Distance from Source Point) (US), (DS) or center (C)	Dimensions		Offset (vertical or horizontal) w.r.t 8-BM 3.25 mrad beam	Material	Associated Drawings
		Outer dimensions of material (W)x(H)x(L)	Lead CO or Mask Aperture, mm [note 12](W)x(H) or (C)			
Monochromator Crystal 1	Crystal 1 at 25.256 (C)	Si: 70mm(w) 30mm(L)3mm(H) Cu backing block; 3″ (W)1.5″ (L) 0.5″t	N/A	Y = -25 mm Θ rotation range: 11-80° Crystals not rotated in model	Interchangeable crystals incl Si(111), InSb, Quartz, Beryl	PD-TES-MONO-1000 (3D model in Vault TES/MONO file)
Monochromator Crystal 2	25.356 (C)	Same size as above no Cu		Y = -60 mm		
M3 Mirror	26.571 (C)	100 mm (x) 80 mm (y) 960 mm (z)	N/A	Y = -60 mm M3 angle 7 mrad	Silicon (Cr & Ni coating)	PD-TES-PFM-1000 (3D model in Vault TES/PFM file)
BL MSK1 / Pink Beam Stop	27.457 (US)	Ø 115.3 mm L= 42.1 mm	60.06 mm (x) 11.74 mm (y)	Y = -48 mm Whole block has an offset	Cu-Cr-Zr	PD-TES-MSK-1100 (Similar to SR-FE-3PW-MSK-1896)
BL CO1*	27.547 (US) 27.851 (DS)	16.5″ (x) 8″ (y) 12″ (z)	72.83 (x) 24.38 (y)	Y = -47 mm Whole block has an offset	Lead	PD-TES-CO-0100
BL MSK2	30.979 (US)	Ø 115.3 mm L= 42.1 mm	52.86 mm (x) 18.41 mm (y)	Y = +3 mm Whole block has an offset	304 SS	PD-TES-MSK-1200
BL CO2*	31.066 (US) 31.371 (DS)	16.5″ (x) 8″ (y) 12″ (z)	63.80 (x) 34.66 (y)	Y = +3mm (U) Rotated 14mrad	Lead	PD-TES-CO-0200
Guillotine	31.539 m	22.25inch (W) 22.25inch (H) 50.8 mm (L)	4 inches (diameter)	Y = + 11 mm	lead	
6.75″ diameter hole in DS FOE wall.						

Table 1.5 Transport Line components outside the FOE

Transport Line Component	Z location, m (Distance from Source Point) (U), (D) or center (C)	Dimensions		Offset (vertical or horizontal) w.r.t 8-BM 3.25 mrad beam	Material	Associated Drawings
		Outer dimensions of material (W)x(H)x(L)	Lead CO or Mask Aperture, mm [note 12] (W)x(H) or (C)			
BL MSK3	51.275 (C)	152mm OD L=17.5 mm	50 mm ID (C)	Y = +286 mm	304 SSt	PD-TES-MSK-1300
Photon Shutter	52.33 (C)	125 mm (W) 150 mm (H) 38 mm (L)	40 mm × 25 mm	Y = +301 mm	Tungsten	PD-COM-PSH-1000
BL MSK4	52.190 (C)	17.5 mm	25 mm I.D.	Y = +303 mm	304 SSt	PD-TES-MSK-1400
Be Window	56.304 (C)	Ø 8 mm L=12 microns	Be window (mounted in 2.75”CF x 0.40” t SSt)	Y = +356 mm	Be	PD-TES-WIN-1000
Hutch Box	56.4 (US)	37.5” long 19” high 18.25” wide	N/A	Hutch box is centered on beam	1.06 mm Pb	PD-TES-HU-1400
Beamstop	57.352 (US)	Two panes of 4” (x) 6” (y) 2.1 mm (z)	N/A	Hutch box is perpendicular to beam	Leaded Glass	PD-TES-HU-1400

*Note: Beamline Bremsstrahlung collimators have 2 mm wall SS rectangular vacuum chambers with *nominal* inside dimensions:
CO1: 65.47 mm Horiz x 15.38 Vert (maximum)
CO2: 56.44 mm Horiz x 25.66 Vert (maximum)