NSLS II TECHNICAL NOTE BROOKHAVEN NATIONAL LABORATORY	NUMBER **227**
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08BM-TES Beamline Radiation Shielding Analysis	

1. Introduction

Beamlines are required to shield against two primary sources of radiation, the primary gas bremsstrahlung (GB) and the synchrotron beam, as well as the secondary radiation resulting from the scattering of these two primary beams by the beamline components and/or air. The shielding requirements for the First Optical Enclosure (FOE) are dominated by the scattering of the primary bremsstrahlung and not the synchrotron beam. Guidelines for the NSLS-II Beamline Radiation Shielding Design are also provided in reference 1**.** These guidelines were used to determine the thickness of the FOE walls as well as dimensions of the supplementary shielding required to reduce the dose on the downstream FOE wall. The shielding recommended for the lateral and roof panels is generally sufficient for most white beam component configurations. However, the recommended as-built shielding for the downstream FOE wall may not be sufficient to protect against secondary gas bremsstrahlung (SGB).

The NSLS-II BEAMLINE RADIATION SHIELDING POLICY has been stated as follows in reference 1: 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 Photon Science 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/h (based on occupancy of 2000 hours/year) or less than 1 rem in a year.

For a fault event, the dose 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 radiation controlled area, it is hoped that in the future, it can be declared a non-radiation controlled area. As such, beamlines should be shielded such that in the event of a fault, the total dose, integrated over the duration of the fault, is < 20 mrem.

The radiation shielding analysis for the Tender Energy x-ray absorption Spectroscopy (TES) beamline (08BM-TES) is documented in this technical note. The goal of the simulations documented here was to estimate the radiation dose levels generated inside and outside the FOE during normal operations and some fault conditions, thus evaluating the efficiency of FOE and the as-designed SGB shielding.

The layout of the 08BM-TES beamline is presented in figure 1. These drawings were extracted from the Beamline Ray Trace Layout [PD-TES-RAYT-0001]. The beam travels from right to left in the Ray Trace drawings.

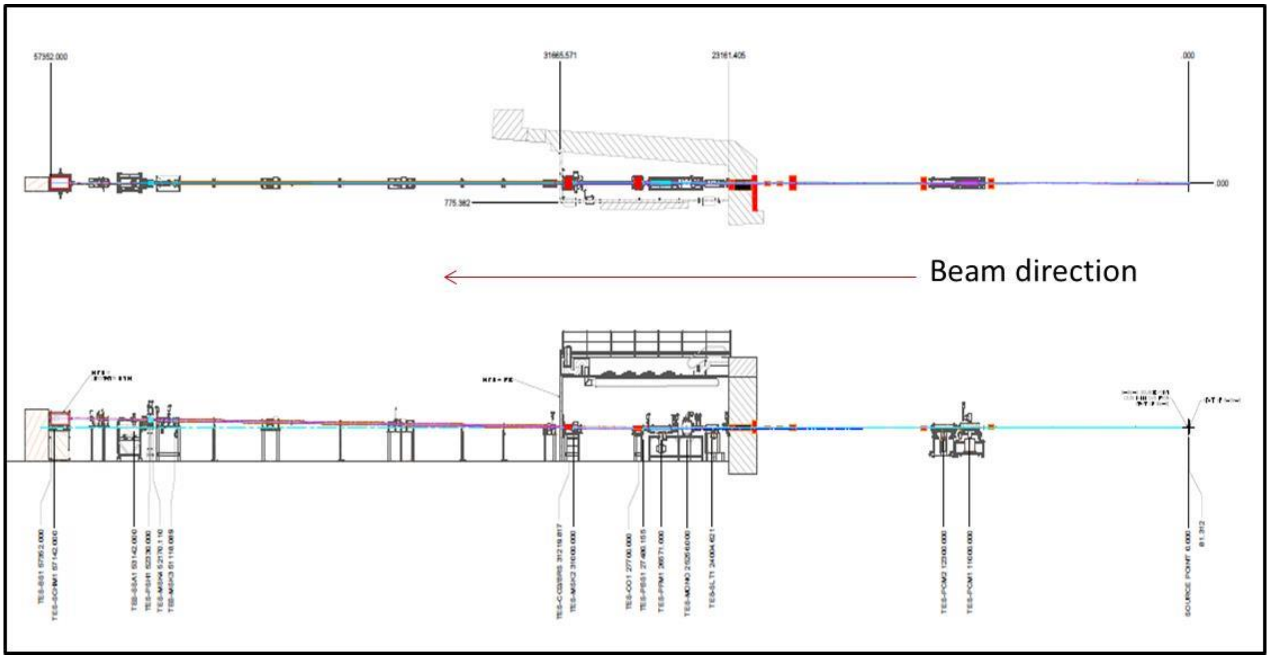

Figure 1: Layout of 08BM-TES showing the major beamline components in the FE and the FOE

The NSLS-II primary gas bremsstrahlung (GB) source parameters are listed in Table 1.

Table 1: NSLS-II primary bremsstrahlung source parameters

Electron energy	3 GeV
Stored current	500 mA
Length of short straight section	6.6 m
Pressure in straight section	1 ntorr

The beam is normalized at 7.2μW incident power, for the short (6.6m) straight. This value corresponds to the estimated bremsstrahlung power generated by a 500mA electron beam of 3GeV, assuming that the vacuum in the straight sections is better than 10^{-9}Torr. The bremsstrahlung source file is kept in the NSLS-II Radiation Physics folder.

The Fluka model is described in section 2. The positions, dimensions and materials of the main components are included in Appendix 1. . A prototype FLUKA input and output files are kept in the NSLS-II Radiation Physics folder.

The simulations performed to confirm the adequacy of the radiation safety components are presented in Table 2. The position of the GB source is given with respect to the short straight centerline. The results of the GB simulations are presented in section 3.

Table 2: List of Fluka simulations

#	Simulation	Position of GB source
1(a)	GB incident on fixed mask 1 (FM1) inboard (5mm from edge of DS aperture)	x=-1.5845, y=0.0, z=-1490.74
1(b)	GB incident on FM1 outboard (5mm from edge of DS aperture)	x=+1.5845, y=0.0, z=-1490.74
2(a)	GB incident on FM2 inboard (5mm from edge of DS aperture)	x=-1.721, y=0.0, z=-1204.90
2(b)	GB incident on FM2 outboard (5mm from edge of DS aperture)	x=+1.721, y=0.0, z=-1204.90
3(a)	GB incident near center of Mirror M1	x=0.0, y=0.0, z=-1072.30
3(b)	GB incident near upstream front face of M1	x=0.0, y=1.0, z=-1112.95
4(a)	GB incident on front face of FM3 – top extreme rays (see Ray Tracings)	x=0.0, y=+0.7, z=-864.00
4(b)	GB incident on front face of FM3 – bottom extreme rays (see Ray Tracings)	x=0.0, y=-0.7, z=-864.00
5	GB incident on center of the Bend Magnet Photon Shutter (BMPS) in the closed position	x=0.0, y=0.0, z=-1473.72

The results of the synchrotron radiation simulations are presented in section 4.

A summary of all simulation results is presented in Section 5. The results of the GB simulations are summarized in table 5. This table lists the maximum dose rate (in mrem/h) on the roof, sidewall and the downstream FOE wall for each simulation.

All shielding simulations should be validated by comparisons with measurements of the dose rates near the walls of the FOE, the beam transport pipe and the end station enclosure during commissioning.

2. Description of the FLUKA model

At NSLS-II the First Optical Enclosure (FOE) shielding requirements are dominated by the scattering of the primary gas bremsstrahlung and not the synchrotron beam.
The white beam components disperse the primary bremsstrahlung without significant energy loss; thereby greatly increasing the angular range of very high-energy bremsstrahlung photons. It is necessary to intercept this secondary bremsstrahlung before it hits the downstream FOE wall. The design of the TES beamline includes additional shielding in order to reduce the dose on the downstream wall.

As recommended by reference 1 Appendix A we use the "custom GB generator based on an analytic representation of the source's energy spectrum which was scaled in intensity in accordance with the experimental estimates of total GB power. This custom source assumes a 1/E energy spectrum dependency, with a maximum energy of 3GeV, and generates internally the corresponding probability density function from analytical descriptions". The beam is normalized at 7.2μW incident power, for the short straight (6.6m). This value corresponds to the estimated bremsstrahlung power generated by a 500mA electron beam of 3GeV, assuming that the vacuum in the straight sections is better than 10^{-9}Torr.

The 08BM-TES Fluka model includes the FOE roof, sidewall, the downstream wall as well as the ratchet wall and long wall of the storage ring (SR). The FOE outboard lateral panel is made of 18 mm Pb (72.0 cm distance from beam), roof 6 mm Pb (~ 208 cm above beam) and downstream FOE wall 50 mm Pb (~850 cm from the ratchet wall).

The FLUKA model of the 08BM-TES beamline components in the FE and the FOE are shown in Figure 2. For the Fluka models the Z axis represents the beam centerline, the X axis the horizontal axis normal to the beam direction and the Y axis is the vertical axis. For the Ray Trace drawings the zero of the co-ordinate system is the center of the short straight. However, for the Fluka input files the downstream end of the ratchet wall is set as the zero of the Z axis. The beam travels from right to left in the Ray Trace drawings. For the Fluka model the beam travels from left to right.

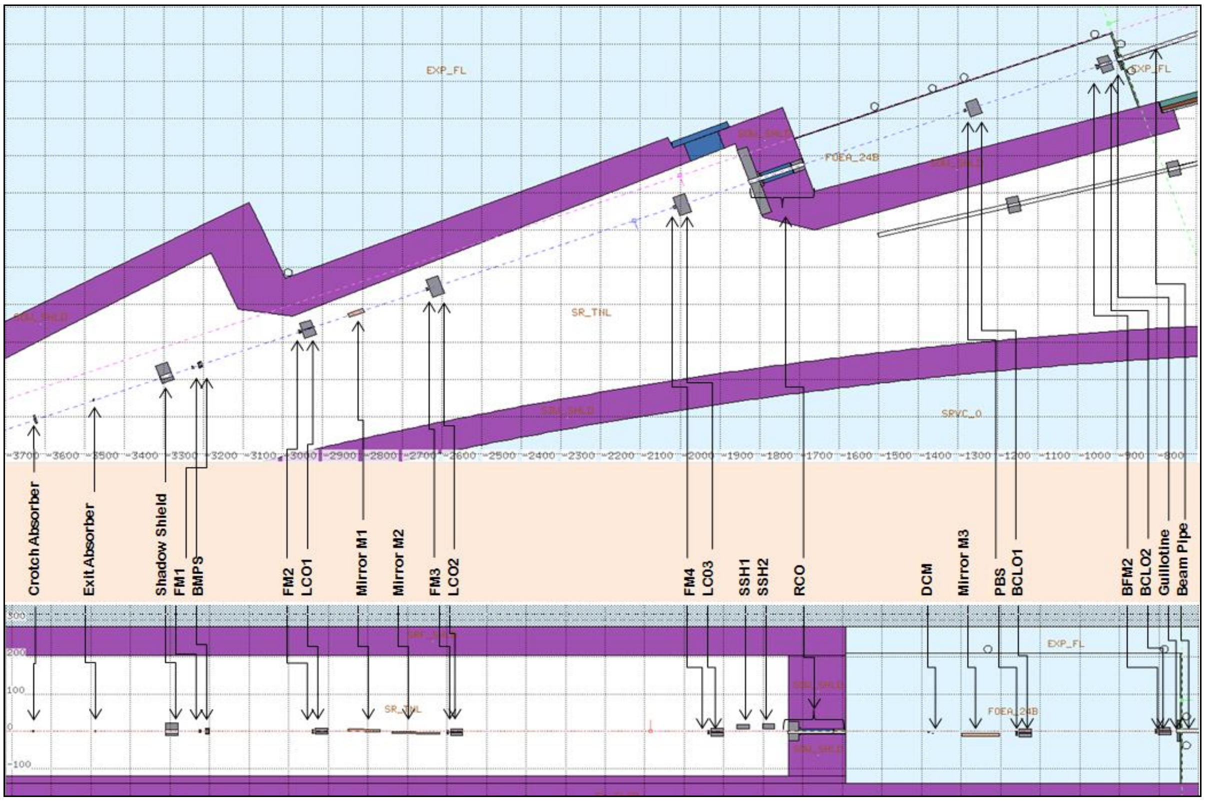

Figure 2: FLUKA geometry of the beamline components in the FE and FOE.

The positions, dimensions, materials and drawings of the main components are included in Appendix 1. The bremsstrahlung source file and sample Fluka input files are stored on the Radiation Physics server.

3. Results for primary gas Bremsstrahlung (GB) simulations

The simulations performed to confirm the adequacy of the radiation safety components are presented in Table 2. A summary of the simulation results is presented in Section 5.

3.1(a) GB incident on fixed mask 1 (FM1) inboard (5mm from edge of DS aperture)

In this simulation the GB was started just upstream of the selected point of contact at x=-1.5845, y=0.0, z=-1490.74 and impinges on the inboard tapered plane 5mm from the neck of the downstream aperture of FM1. The total dose distributions (mrem/h) in the FOE are shown in Figure 3 and the corresponding neutron distributions are given in Figure 4.

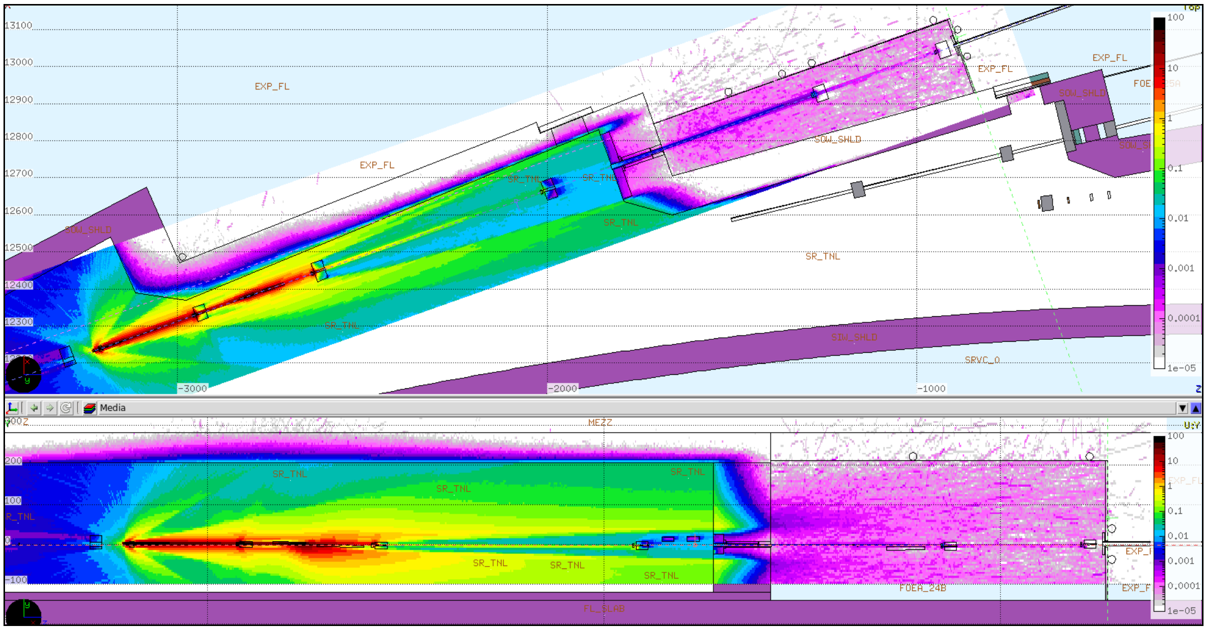

Figure 3: **The total dose rate distribution (mrem/h) in the vertical (bottom plot) beam plane. The horizontal view (top plot) is at y=-2.5cm showing the leakage through the ratchet wall collimator.**

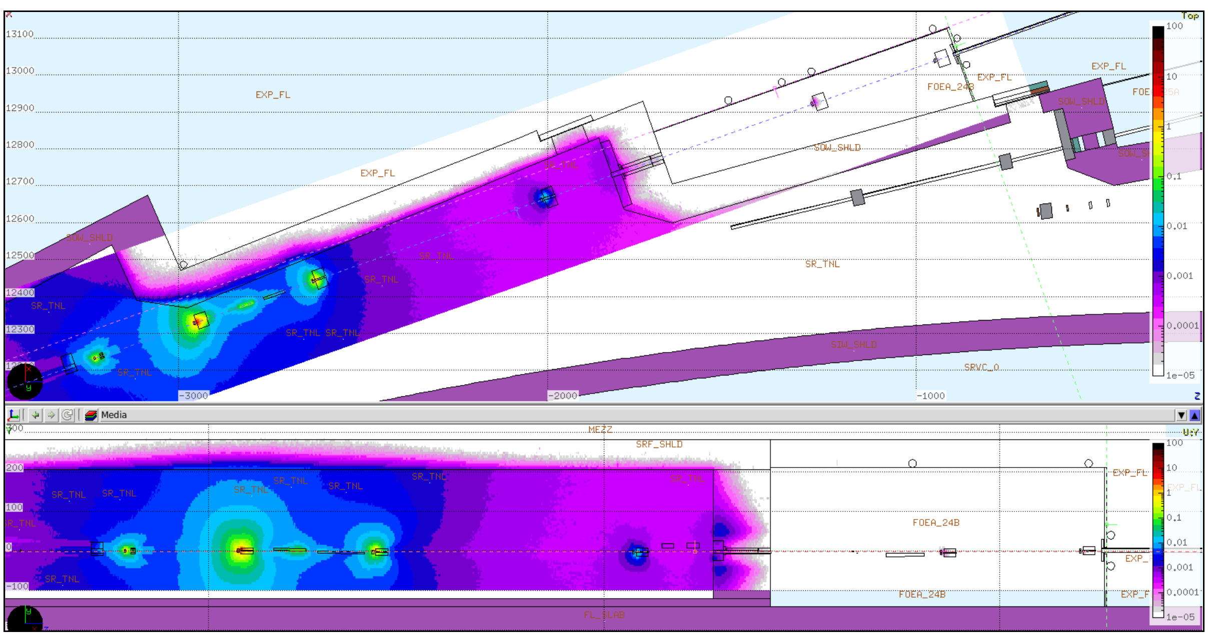

Figure 4: **The neutron dose rate distribution (mrem/h) in the horizontal at y = -2.5 cm (top plot) and vertical (bottom plot) beam plane.**

The total dose rates on the roof, lateral wall and downstream wall of the FOE are well below 0.01 mrem/hr. The radiation that leaks through the aperture of the RCO is completely stopped by the collimators in the FOE.

3.1(b) GB incident on FM1 outboard (5mm from edge of DS aperture)

In this simulation the GB was started just upstream of the selected point of contact at x=+1.5845, y=0.0, z=-1490.74 and impinges on the outboard tapered plane 5mm from the neck of the downstream aperture of FM1. The total dose distributions (mrem/h) in the FOE are shown in Figure 5 and the corresponding neutron distributions are given in Figure 6. These dose rates are similar to those for scenario 3.1(a). For both cases the dose rates on the roof and walls of the FOE are well below 0.01 mrem/hr.

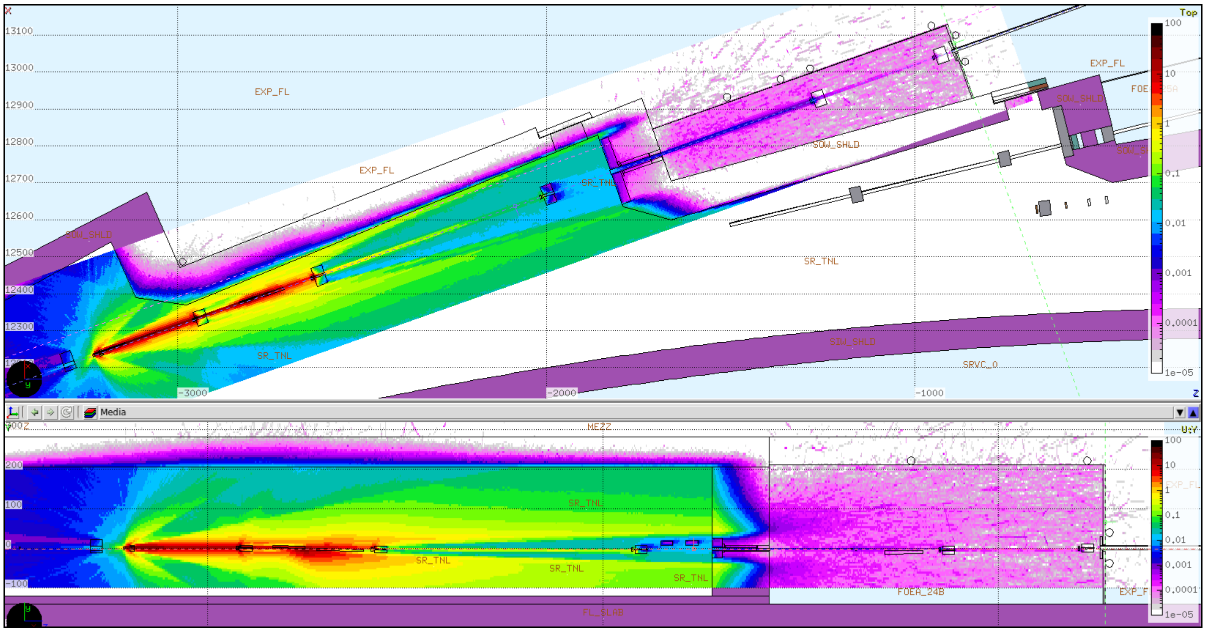

Figure 5: **The total dose rate distribution (mrem/h) in the vertical (bottom plot) beam plane. The horizontal view (top plot) is at y=-2.5cm showing the leakage through the ratchet wall collimator.**

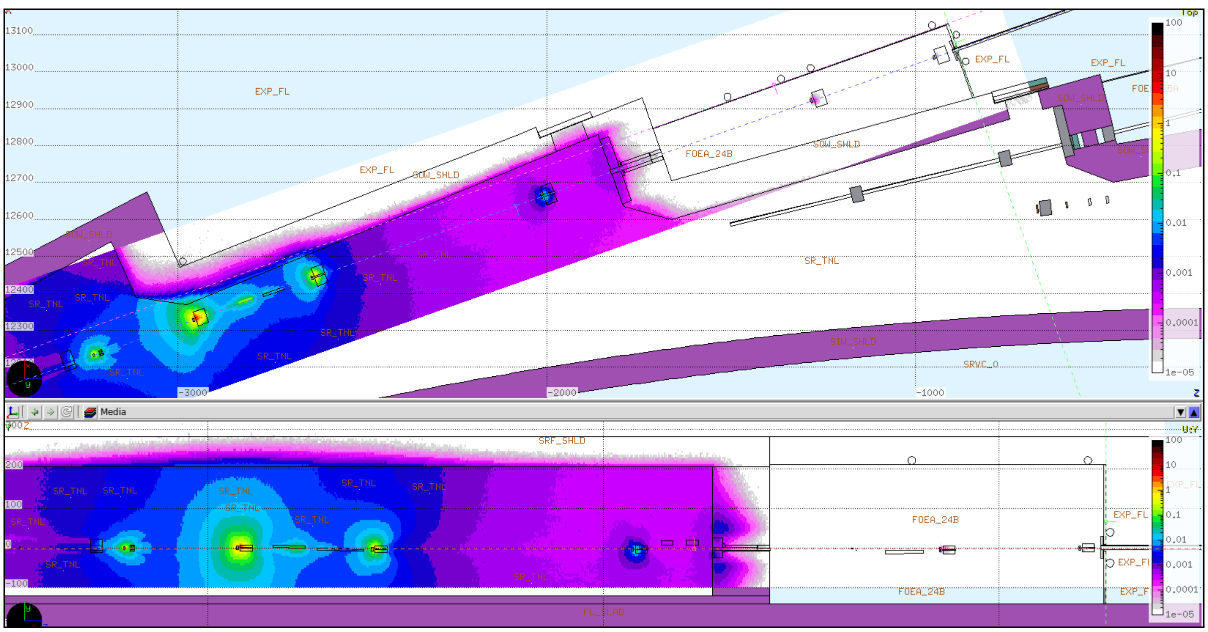

Figure 6: **The neutron dose rate distribution (mrem/h) in the horizontal at y = -2.5 cm (top plot) and vertical (bottom plot) beam plane.**

3.2(a) GB incident on FM2 inboard (5mm from edge of DS aperture)

In this simulation the GB was started just upstream of the selected point of contact at x=-1.721, y=0.0, z=-1204.90 and impinges on the inboard tapered plane 5mm from the neck of the downstream aperture of FM2. The total dose distributions (mrem/h) in the FOE are shown in Figure 7 and the corresponding neutron distributions are given in Figure 8. The total dose rates on the roof, lateral wall and downstream wall of the FOE are well below 0.01 mrem/hr. The radiation that leaks through the aperture of the RCO is completely stopped by the collimators in the FOE.

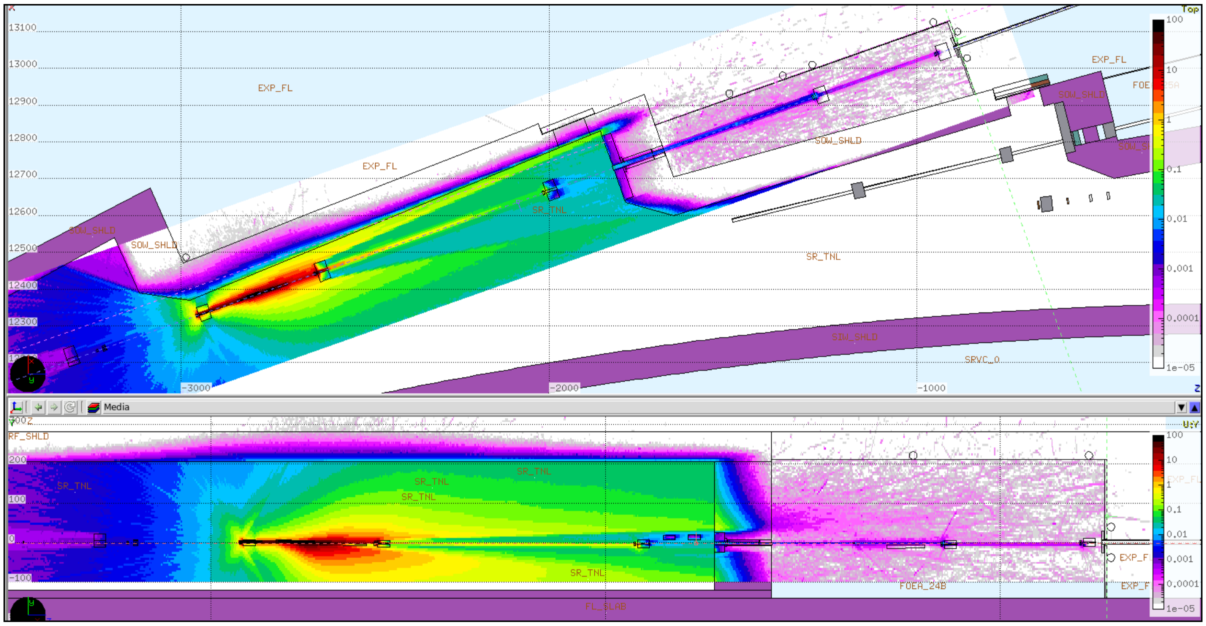

Figure 7: **The total dose rate distribution (mrem/h) in the vertical (bottom plot) beam plane. The horizontal view (top plot) is at y=-2.5cm showing the leakage through the ratchet wall collimator.**

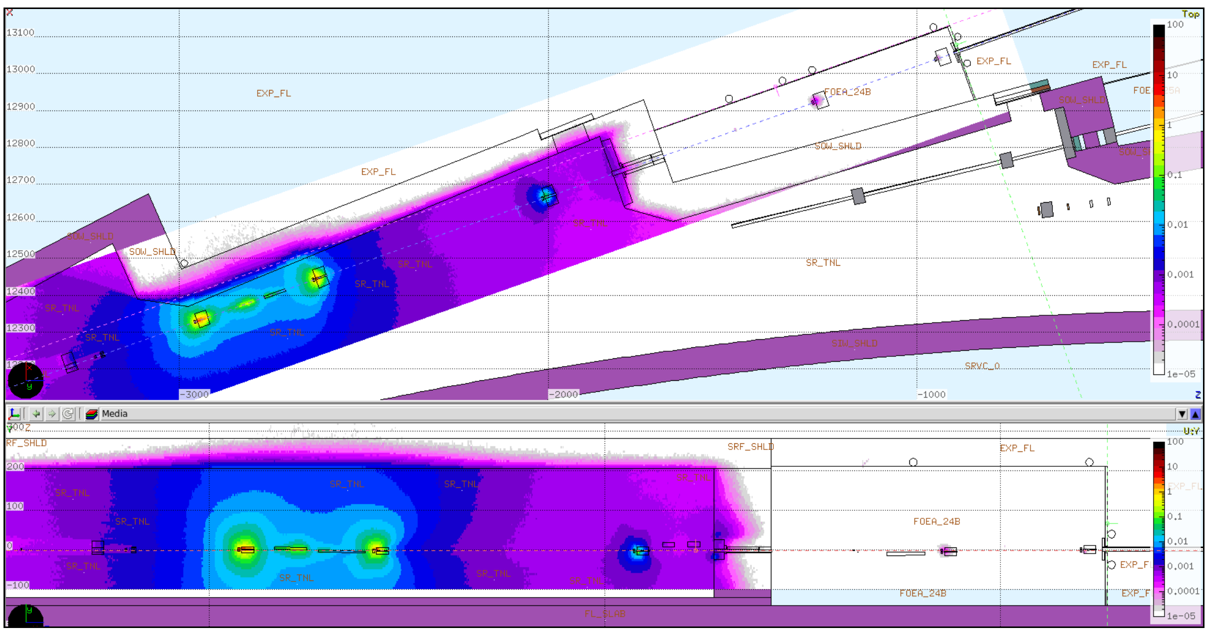

Figure 8: **The neutron dose rate distribution (mrem/h) in the horizontal at y = -2.5 cm (top plot) and vertical (bottom plot) beam plane.**

3.2(b) GB incident on FM2 outboard (5mm from edge of DS aperture)

In this simulation the GB was started just upstream of the selected point of contact at x=+1.721, y=0.0, z=-1204.90 and impinges on the outboard tapered plane 5mm from the neck of the downstream aperture of FM2. The total dose distributions (mrem/h) in the FOE are shown in Figure 9 and the corresponding neutron distributions are given in Figure 10. These dose rates are similar to those for scenario 3.2(a). For both cases the dose rates on the roof and walls of the FOE are well below 0.01 mrem/hr.

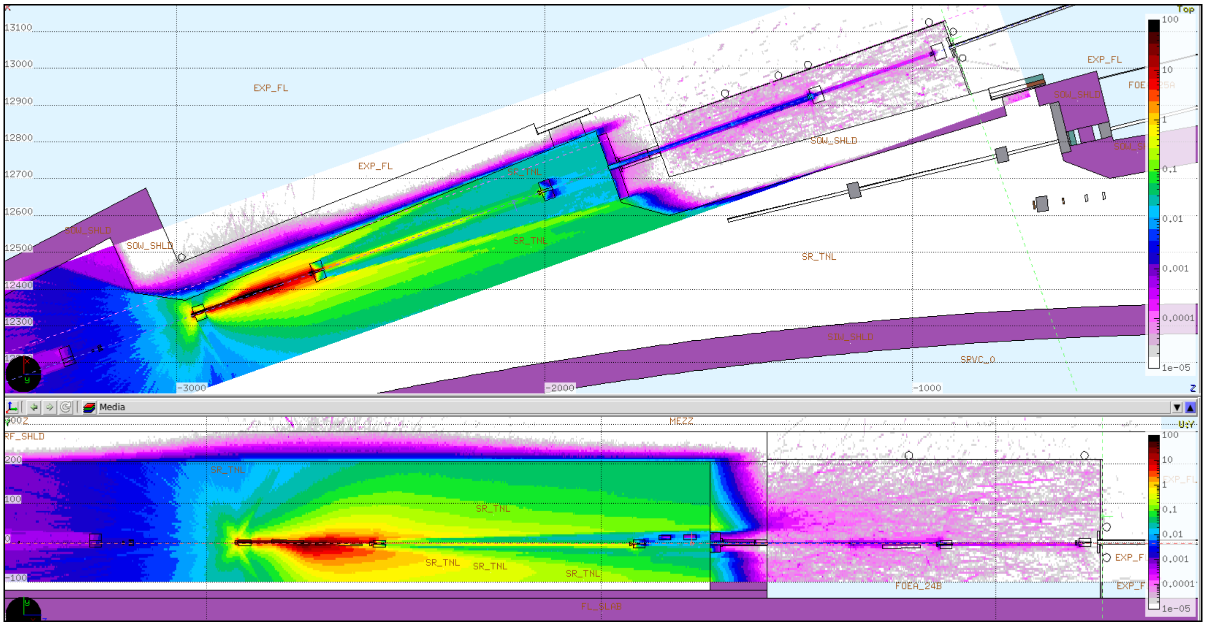

Figure 9: **The total dose rate distribution (mrem/h) in the vertical (bottom plot) beam plane. The horizontal view (top plot) is at y=-2.5cm showing the leakage through the ratchet wall collimator.**

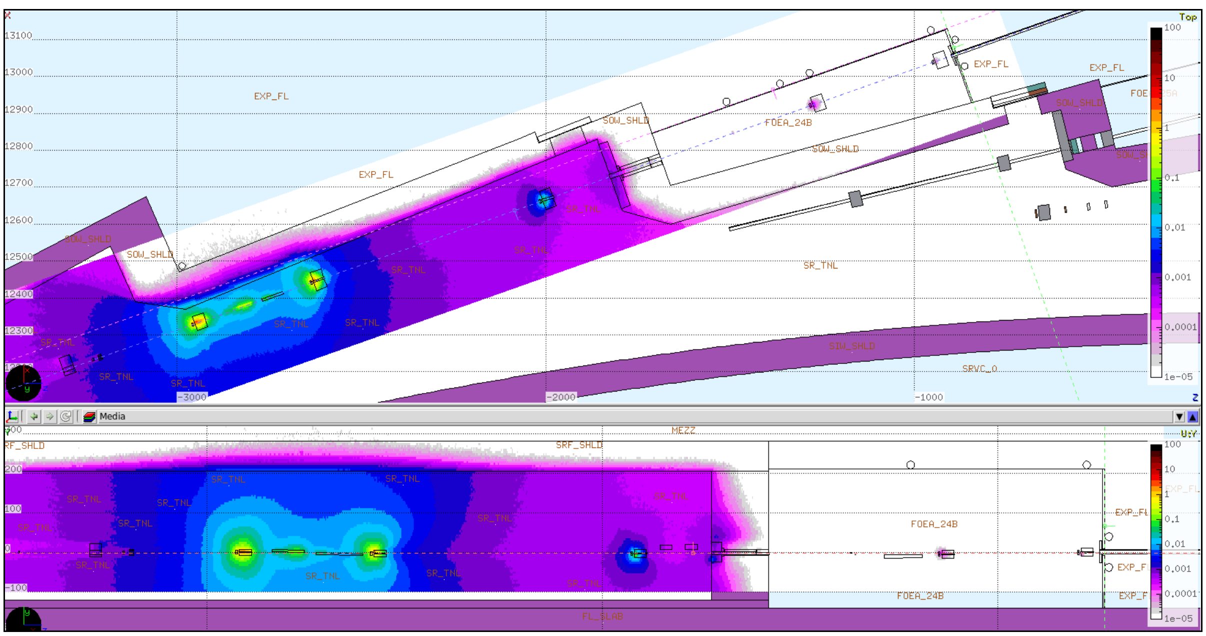

Figure 10: **The neutron dose rate distribution (mrem/h) in the horizontal at y = -2.5 cm (top plot) and vertical (bottom plot) beam plane.**

3.3(a) GB incident near center of Mirror M1

In this simulation the GB was started just upstream of the selected point of contact at x=0.0, y=0.0, z=-1072.30 and impinges near the center of the mirror 1. The total dose distributions (mrem/h) in the 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 well below 0.01 mrem/hr. The radiation that leaks through the aperture of the RCO is completely stopped by the collimators in the FOE.

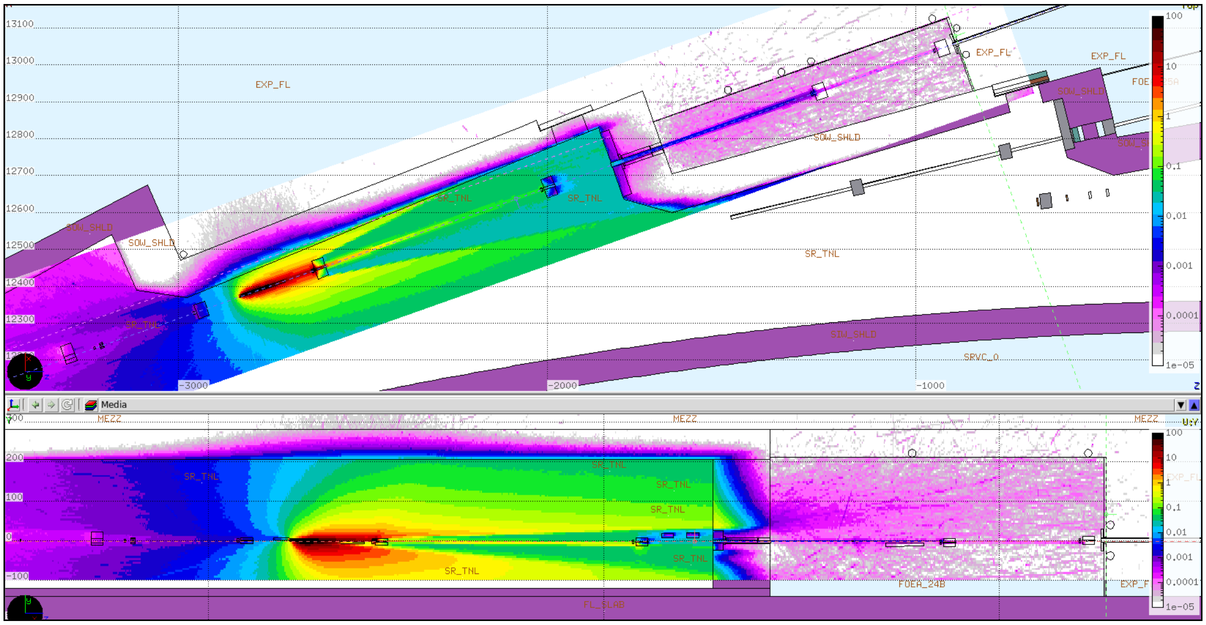

Figure 11: **The total dose rate distribution (mrem/h) in the vertical (bottom plot) beam plane. The horizontal view (top plot) is at y=-2.5cm showing the leakage through the ratchet wall collimator.**

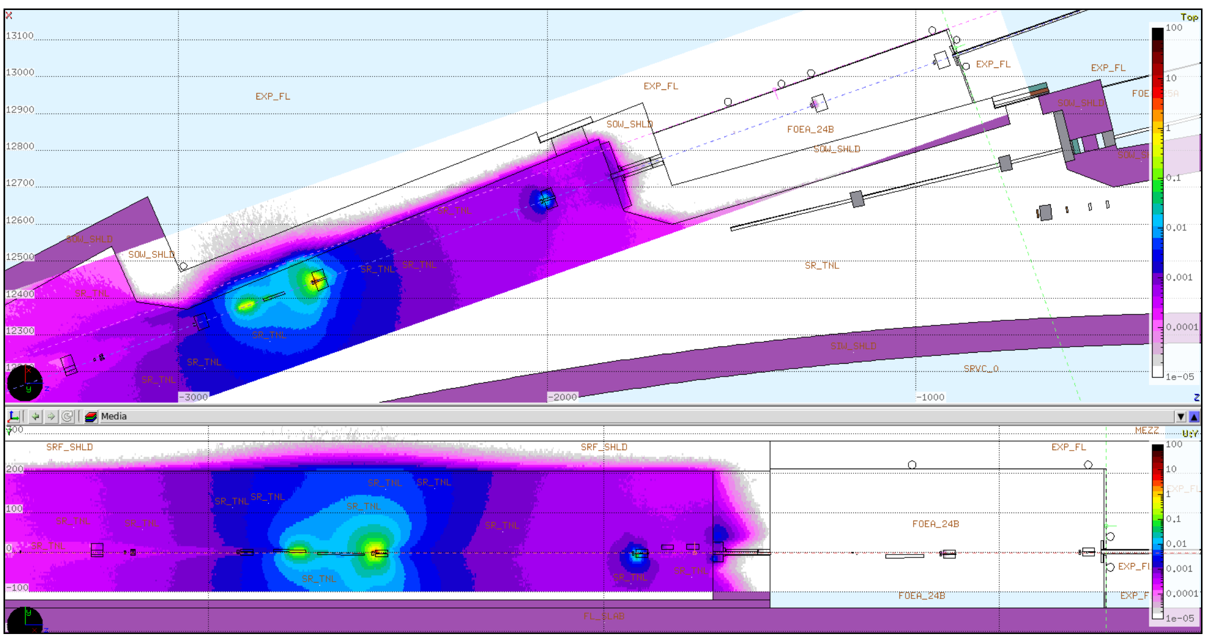

Figure 12: **The neutron dose rate distribution (mrem/h) in the horizontal at y = -2.5 cm (top plot) and vertical (bottom plot) beam plane.**

3.3(b) GB incident near upstream front face of Mirror M1

In this simulation the GB was started just upstream of the selected point of contact at x=0.0, y=1.0, z=-1112.95 and impinges near the upstream face of mirror 1. The total dose distributions (mrem/h) in the FOE are shown in Figure 13 and the corresponding neutron distributions are given in Figure 14. The total dose rates on the roof, lateral wall and downstream wall of the FOE are well below 0.01 mrem/hr. The radiation that leaks through the aperture of the RCO is completely stopped by the collimators in the FOE.

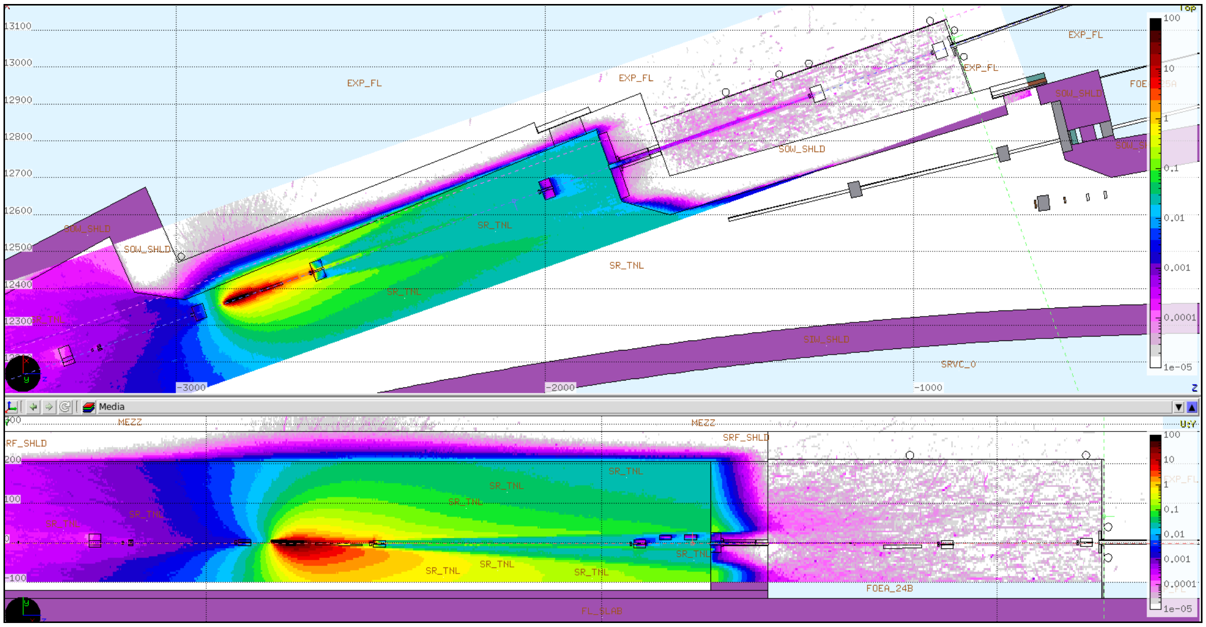

Figure 13: **The total dose rate distribution (mrem/h) in the vertical (bottom plot) beam plane. The horizontal view (top plot) is at y=-2.5cm showing the leakage through the ratchet wall collimator.**

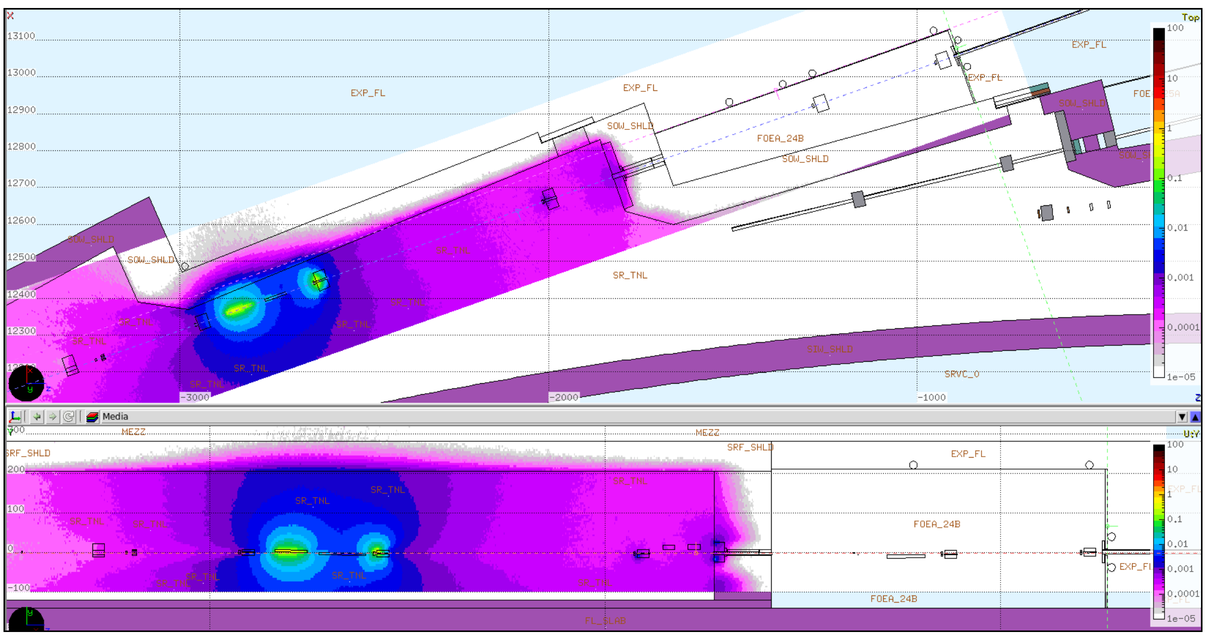

Figure 14: **The neutron dose rate distribution (mrem/h) in the horizontal at y = -2.5 cm (top plot) and vertical (bottom plot) beam plane.**

3.4(a) GB incident on front face of FM3 – top extreme rays

In this simulation the GB was started just upstream of the selected point of contact at x=0.0, y=+0.7, z=-864.00 and impinges at the position of the top extreme ray on the front face of FM3. The total dose distributions (mrem/h) in the FOE are shown in Figure 15 and the corresponding neutron distributions are given in Figure 16. The total dose rates on the roof, lateral wall and downstream wall of the FOE are well below 0.01 mrem/hr. The amount of radiation that leaks through the aperture of the RCO is negligible because the front end lead collimator 2 that is just downstream of FM3 is effective in stopping the electromagnetic shower.

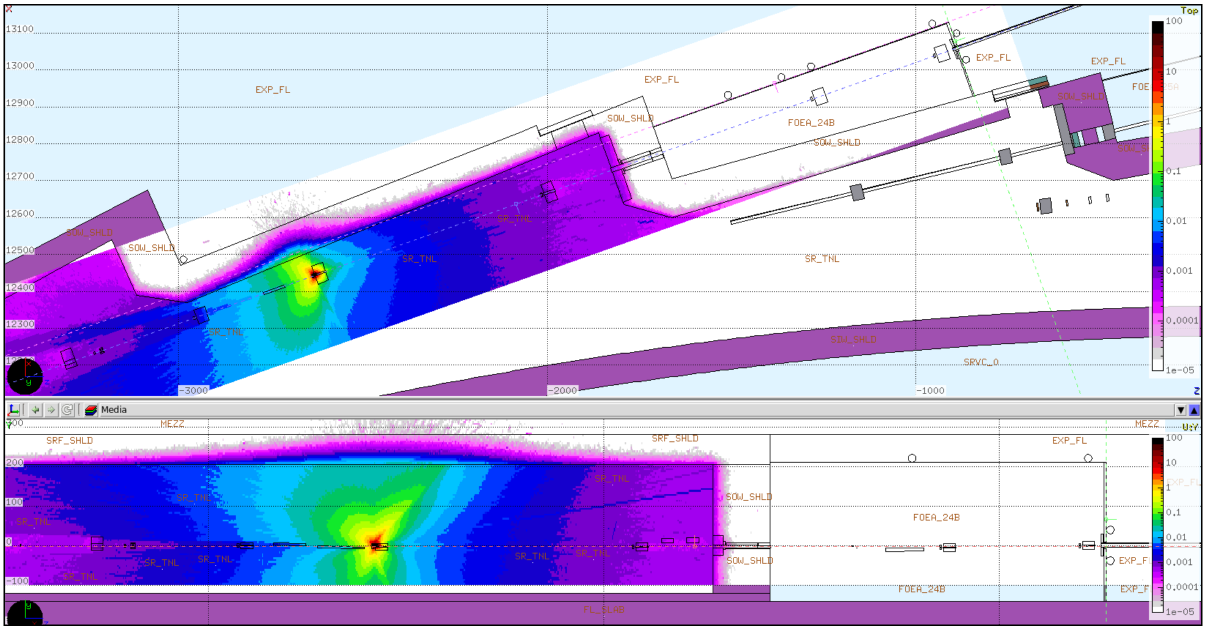

Figure 15: **The total dose rate distribution (mrem/h) in the vertical (bottom plot) beam plane. The horizontal view (top plot) is at y=-2.5cm showing no leakage through the ratchet wall collimator.**

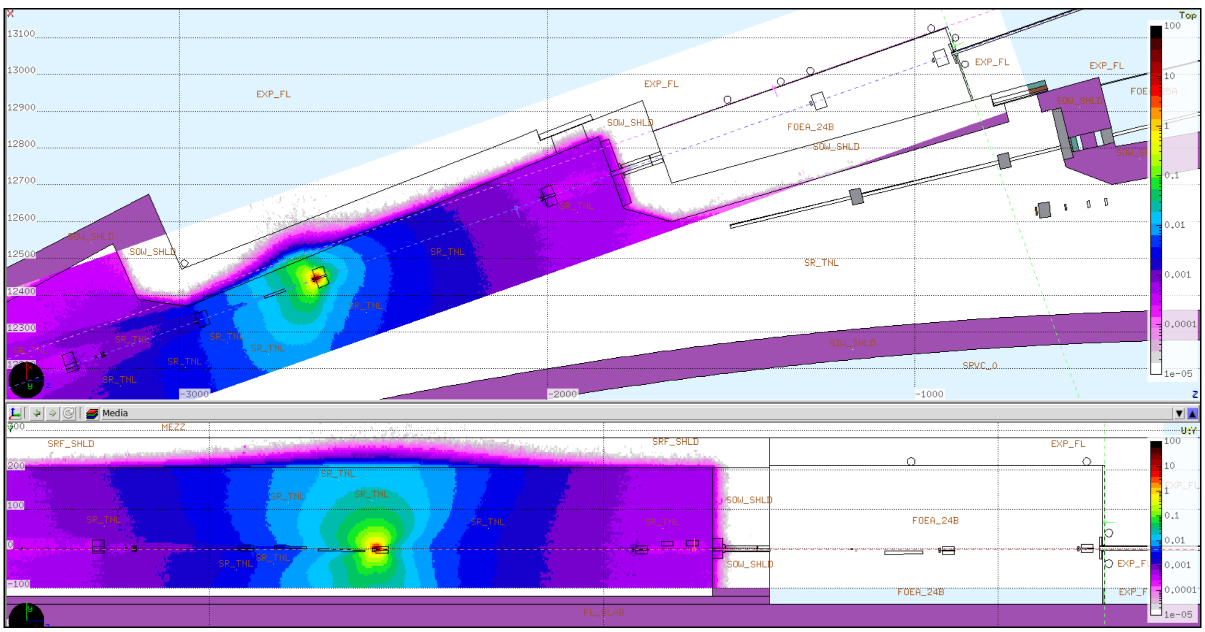

Figure 16: **The neutron dose rate distribution (mrem/h) in the horizontal at y = -2.5 cm (top plot) and vertical (bottom plot) beam plane.**

3.4(b) GB incident on front face of FM3 – bottom extreme rays

In this simulation the GB was started just upstream of the selected point of contact at x=0.0, y=-0.7, z=-864.00 and impinges at the position of the bottom extreme ray on the front face of FM3. The total dose distributions (mrem/h) in the 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 3.4 (a). For both cases the dose rates on the roof and walls of the FOE are well below 0.01 mrem/hr.

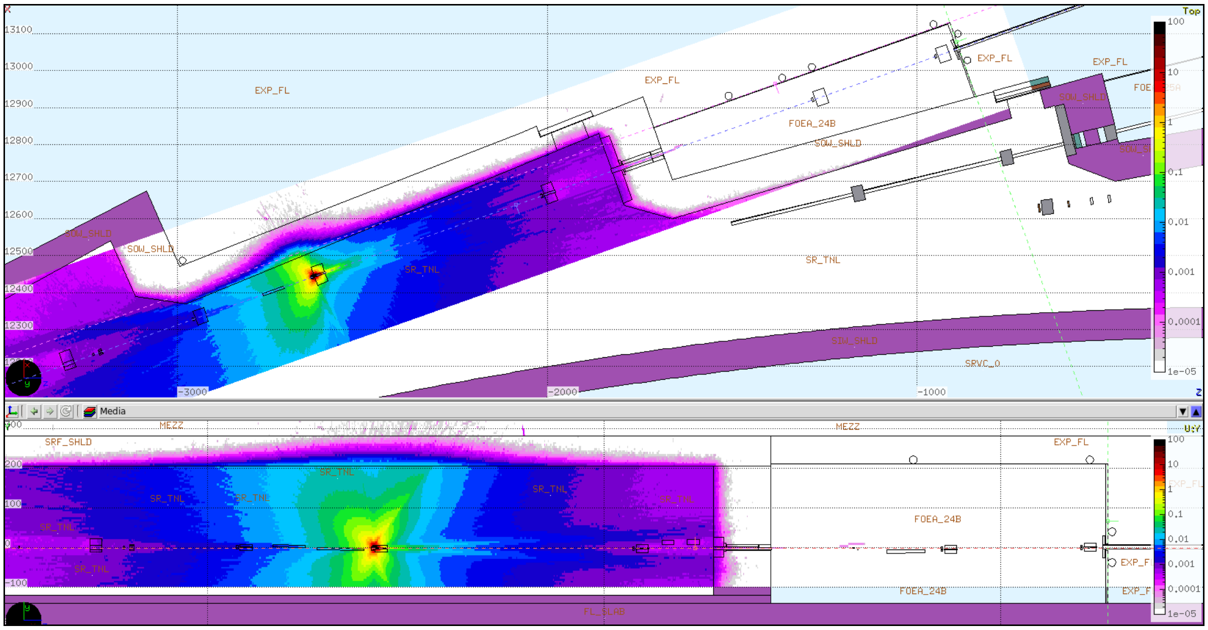

Figure 17: **The total dose rate distribution (mrem/h) in the vertical (bottom plot) beam plane. The horizontal view (top plot) is at y=-2.5cm showing the leakage through the ratchet wall collimator.**

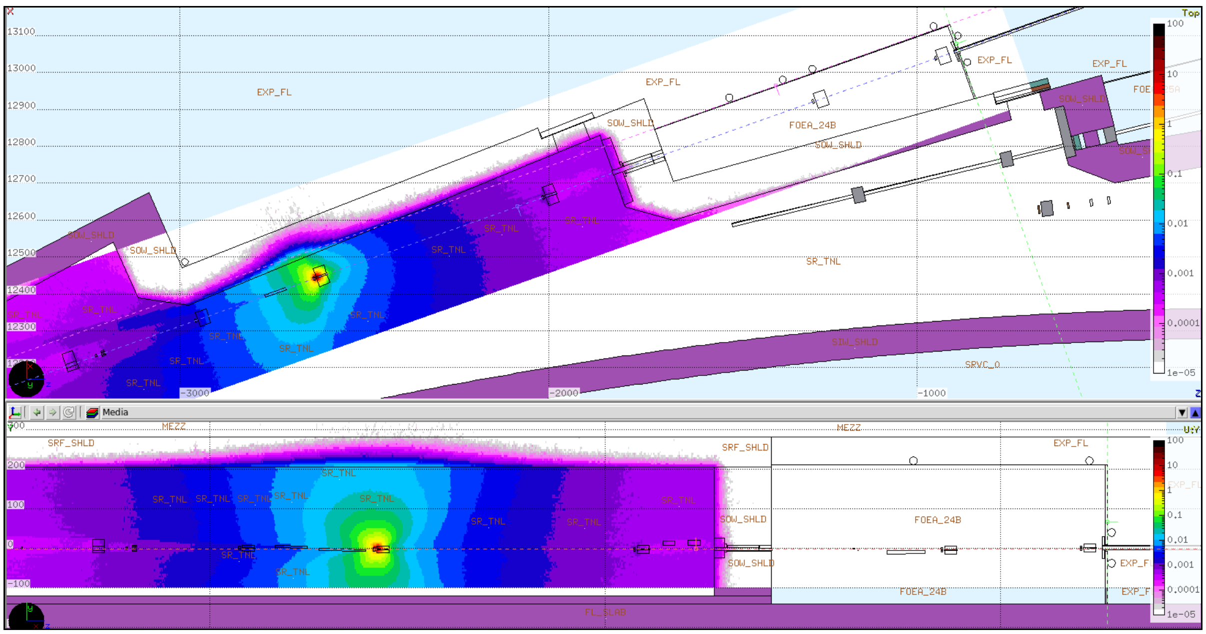

Figure 18: **The neutron dose rate distribution (mrem/h) in the horizontal at y = -2.5 cm (top plot) and vertical (bottom plot) beam plane.**

3.5 GB incident on center of the Bend Magnet Photon Shutter in the closed position

In this simulation the GB was started just upstream of the selected point of contact at x=0.0, y=0.0, z=-1473.72 and impinges at the center of the closed bend magnet photon shuter (BMPS). The total dose distributions (mrem/h) in the FOE are shown in Figure 19 and the corresponding neutron distributions are given in Figure 20. The total dose rates on the roof, lateral wall and downstream wall of the FOE are well below 0.01 mrem/hr. The amount of radiation that leaks through the aperture of the RCO is negligible because the front end lead collimators that are downstream of BMPS are effective in attenuating the forward electromagnetic shower.

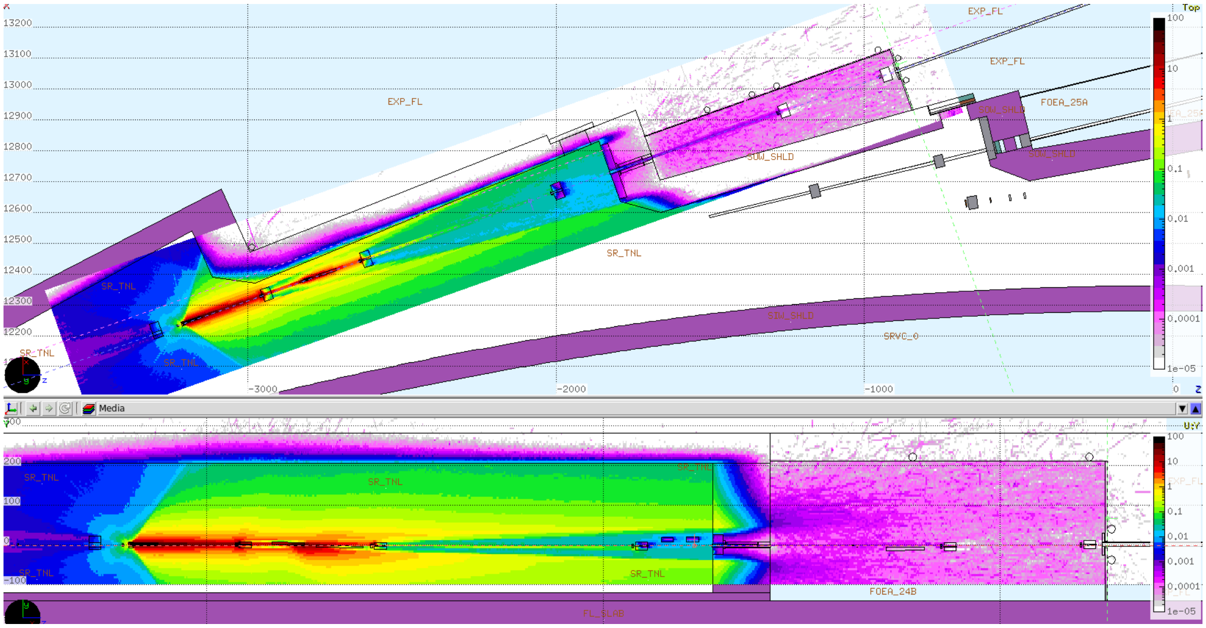

Figure 19: **The total dose rate distribution (mrem/h) in the vertical (bottom plot) beam plane. The horizontal view (top plot) is at y=-2.5cm showing the leakage through the ratchet wall collimator.**

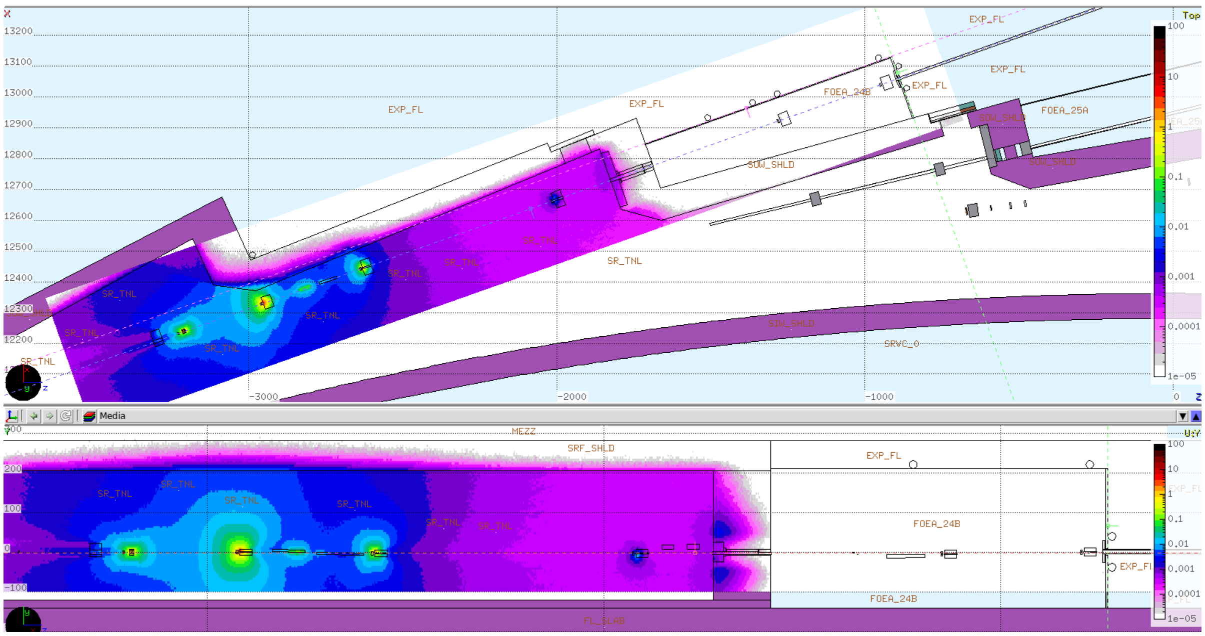

Figure 20: **The neutron dose rate distribution (mrem/h) in the horizontal at y = -2.5 cm (top plot) and vertical (bottom plot) beam plane.**

4. Synchrotron Radiation Calculation

The 08BM-TES beamline is a bending magnet source and its parameters are extracted from reference 1 and reproduced in Table 3. The NSLS-II stored electron beam parameters of 3 GeV and 500 mA (See Table 1) have been used to calculate the critical energy (column 6) and the total integrated power (column 7).

Table 3: Source parameters used for 08BM (TES) synchrotron radiation calculations

Source	Max. source opening	No. Of periods	Max. B_{eff} (T)	Period (mm)	E_c (keV)	STAC8 Total power (kW) @500 mA
BM	10.0 mrad-H	1	0.4	--	2.4	0.345

The analytic code STAC8 [3] was used to calculate the ambient dose equivalent rates in the occupied areas outside beamline enclosures and transport pipes. The build-up factor in shield was included in the calculation. However, the effect of SR polarization was not considered leading to the same shielding requirements for the lateral wall and roof provided the distance from the scatter target to dose point is the same. The shielding calculations for the transport beam pipe and ESE assume that bremsstrahlung has been completely stopped in the FOE.

4.1 First Optics Enclosure (FOE)

For maximum scattered radiation the scattering target is assumed to be a silicon disk of 10 cm radius and 2 cm thick tilted at 0.155 degree with the respect to the incident beam [4]. The position of the scatter target is assumed to be located at 08BM-TES MONO approximately 640 cm from the FOE downstream wall, 72 cm from the lateral wall and 210 cm from the roof. For the pink beam to enter the FOE it requires the synchrotron beam from the bend magnet to be doubly reflected from mirror M1 and M2. For 1 mm of lead the ambient dose rates are negligible. Therefore the existing shielding thicknesses of the FOE walls and roof as given in Appendix 1 are more than adequate to meet the shielding design goal of 0.05 mrem/h.

4.2 Transport pipe and ESE (08-BM-B)

The monochromatic beam that exit the FOE is reflected by mirror M3 in the FOE and therefore the photon flux is much reduced for higher energy photons. STAC8 was used to estimate the worse -case scenario of a normal incident monochromatic beam on 1 mm of iron. The ambient dose rates are 4.96E-07 mrem/hr. The transport pipe of 08BM-TES is made of 2.11 mm of stainless steel which is more than adequate to shield against the monochromatic beam. The ESE (08-BM-B) is made of few mm of lead which is more than adequate to shield against the monochromatic beam.

5. Summary and Conclusions

At NSLS-II the white beam or First Optical Enclosure (FOE) shielding requirements are dominated by the scattering of the primary bremsstrahlung and not the synchrotron beam. For the simulations the GB beam is normalized at 7.2µW incident power. This value corresponds to the estimated bremsstrahlung power generated by a 500mA electron beam of 3GeV, assuming that the vacuum in the 6.6 m short straight sections is better than 10^{-9}Torr.

Beamline components that intercept the primary GB beam were selected as scattering targets in the simulations based on the Ray Trace Drawings. A summary of the simulation results is presented in table 4.

Table 4. Maximum total dose rates (mrem/hr) on the roof, lateral wall, and the downstream wall of 08BM-TES FOE

#	Simulation	**Maximum dose (mrem/hr)**		
		Roof	Lateral Wall	Downstream wall
1(a)	GB incident on fixed mask 1 (FM1) inboard (5mm from edge of DS aperture)	< 0.05	< 0.05	< 0.05
1(b)	GB incident on FM1 outboard (5mm from edge of DS aperture)	< 0.05	< 0.05	< 0.05
2(a)	GB incident on FM2 inboard (5mm from edge of DS aperture)	< 0.05	< 0.05	< 0.05
2(b)	GB incident on FM2 outboard (5mm from edge of DS aperture)	< 0.05	< 0.05	< 0.05
3(a)	GB incident near center of Mirror M1	< 0.05	< 0.05	< 0.05
3(b)	GB incident near upstream front face of M1	< 0.05	< 0.05	< 0.05
4(a)	GB incident on front face of FM3 – top extreme rays	< 0.05	< 0.05	< 0.05
4(b)	GB incident on front face of FM3 – bottom extreme rays	< 0.05	< 0.05	< 0.05
5	GB incident on center of the Bend Magnet Photon Shutter (BMPS) in the closed position	< 0.05	< 0.05	< 0.05

Based on the STAC8 calculation, the dose rates outside the FOE, ESE, and beam transport pipe are much less than 0.05 mrem/hr.

All shielding simulations should be validated by comparisons with measurements of the dose rates near the walls of the FOE, the beam transport pipe and the end station enclosure during commissioning.

6. References

[1] LT-C-ESH-STD-001, Guidelines for the NSLS-II Beamline Radiation Shielding Design, November 7, 2014.
[2] Email from P. Northrup to M. Benmerrouche (June 01, 2016) and private communication.
[3] Y. Asano, “A study on radiation shielding and safety analysis for a synchrotron radiation beamline,” JAERI-Research-2001-006, March 2001.

[4] Attenuation of Scattered Monochromatic Synchrotron Radiation in Iron and Lead", Z. Xia and W.-K. Lee, NSLS-II TN145 (09/16/2014).

7. Acknowledgements

We would like to thank Paul Northrop, E. Haas, John Tuozzolo and R. Gambella for providing all the beamline geometry information listed in Appendix 1. We would like to thank Paul Northrop 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 FE Components for FLUKA Calculations

Front End Component	Z location, m (Distance from Source Point) (US),	Dimensions			Offset (vertical or horizontal) w.r.t beam centerline	Material	Associated
		Outer dimensions of	Lead CO or Mask DS	Mask upstream			

	(DS) or center (C)	material (W)x(H)x(L)	Aperture	Aperture			Drawings
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	36.07 mm	53.39 mm	Y = -25 mm	Cu-Cr-Zr	SR-FE-3PW-MSK-

		mm	7.66 mm	8.23 mm			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	

NOTE: 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)