NSLS II TECHNICAL NOTE BROOKHAVEN NATIONAL LABORATORY	NUMBER **255**
AUTHOR: M. Benmerrouche	DATE **07/17/2017**
06BM BMM Beamline Radiation Shielding Analysis - Revised	

1. Introduction

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

In this report the recommended shielding is based on calculations to achieve dose rates less than 0.05 mrem/h in continuously occupied areas and less than 0.5 mrem/h on contact with the downstream wall of the First Optical Enclosure (FOE) [2] during normal operations

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 sources by the beamline components and/or air. The shielding requirements for the 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) and additional shielding is usually necessary.

The radiation shielding analysis for the Beamline for Materials Measurement (BMM) is documented in this Technical Note. The goal of the simulations documented here was to estimate the radiation dose levels generated inside and outside of the FOE during normal operations and some fault conditions, thus evaluating the effectiveness of the as-designed shielding.

The layout of the 06BM-BMM beamline is presented in Figure 1. These drawings were extracted from the Beamline Ray Trace Layout [PD-BMM-RAYT-0001]. The ray trace drawings include the major components in the beamline and provide their positions. Beam is shown traveling from right to left. For shielding analysis, this information in addition to the geometries and materials of the components and shielding are collected into an input document, included herein as Appendix 1.

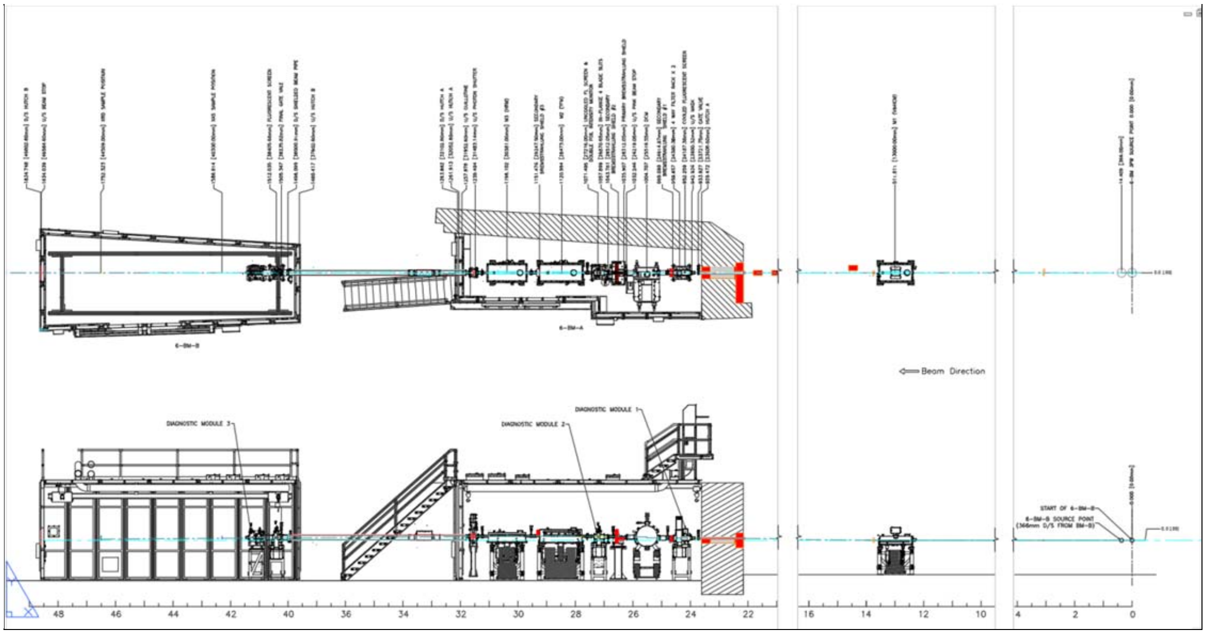


Figure 1: Layout of 06BM-BMM showing the location of the 3PW source, mirror M1 in the FE, major beamline components, the FOE (06BM-A) and End Station Enclosure (06BM-B).

The remainder of this document is organized as follows:

- Section 2: Describes the model generated for FLUKA analysis of primary GB and SGB in 06BM-BMM FE and FOE, using NSLS-II source parameters, and all 06BM-BMM shielding and beamline components as described in the rays tracings and component design drawings.
- Section 3: Presents the FLUKA simulation results. The analysis finds that bremsstrahlung radiation is mostly stopped by shielding at or before the 06BM-BMM FOE downstream wall.
- Section 4: Describes analysis of the synchrotron radiation, considering pink beam from the M1 mirror up to the pink beam stop (PBS) located in the FOE, and monochromatic beam through the transport pipe to the end station enclosure 06BM-B.
- Section 5: Summary and Conclusions
- Section 6: References
- Section 7: Acknowledgments

2. Description of the FLUKA Model

At NSLS-II the FOE shielding requirements are dominated by the scattering of the primary GB 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 06BM-BMM beamline includes additional shielding in order to reduce the dose on the downstream wall and around the transport pipe.

As described in Appendix A of Reference 1 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 NSLS-II primary 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 BM straight section	6.6 m
Pressure in straight section	1 ntorr

The beam is normalized at 7.2 μW incident power for the short straight (6.6 m). This value corresponds to the estimated bremsstrahlung power generated by a 500 mA, 3 GeV electron beam, 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.

Based on 06BM-BMM ray tracings primary GB will interact with some of the components per the descriptions in Appendix 1. The areas of the components intercepted by the primary GB are shown in each subsection of Section 3, which describes the results of the primary GB striking each component. Only areas intercepted by the primary GB, per the ray tracing, were sampled for analysis. The simulations performed to confirm the adequacy of the FOE shielding and radiation safety components are presented in Table 2. Components referenced in Table 2 are described in more detail in Appendix 1.

Table 2: List of FLUKA Simulations

Case # / Report Section	Simulation	GB Beam Position (x, y, z) in cm
1 / 3.1	**M1c**: GB incident near center of Mirror M1	(0.0 , 0.0 , -971.08)
2 / 3.2	**FM3**: GB incident on Fixed Mask 3	(0.0 , 3.49 , -322.66)
3 / 3.3	**FM**: GB incident on Fixed Mask in FOE	(0.0 , 5.91 , 178.45)
4 / 3.4	**BS1**: GB incident on the Secondary Bremsstrahlung Shield 1	(0.0 , 5.91 , 244.91)
5 / 3.5	**DCM**: GB incident on DCM	(0.0 , 6.37 , 331.38)
6 / 3.6	**PBS**: GB incident on DCM	(0.0 , 6.59 , 405.33)

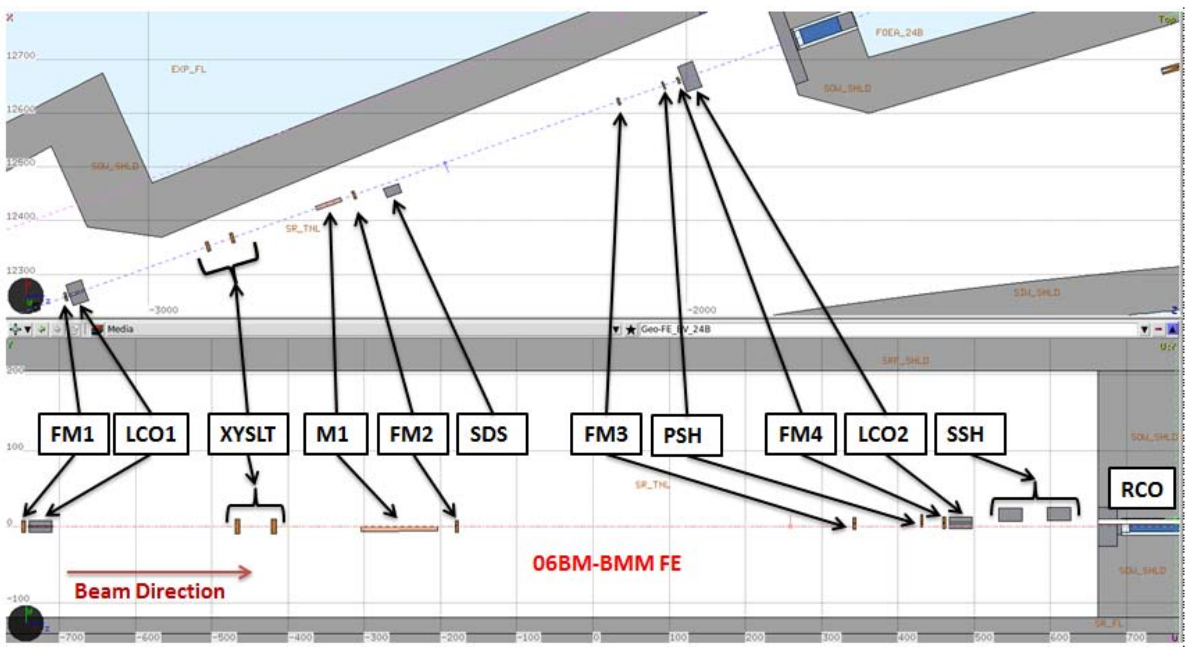
During the final survey of the beamline components the dimensions of the SBS2 and corresponding apertures were found different from what used in the simulations. The top (above Y=0 centerline) and bottom (below Y=0 centerline) of the SBS2 lead changed from {379.00, 96.50} mm to {393.63, 69.99} mm. The SBS2 lead aperture size changed from $\{a_h, a_v\}$ ={64.00, 29.50} mm to {61.45, 31.03} mm and its vertical offset moved up by 0.76 mm.

The PBS downstream aperture has also slightly changed from $\{a_h , a_v\}$ ={50.80, 20.80} mm to {46.25, 21.43} mm and its vertical offset moved down by 2.02 mm. As a result of these changes, cases 3, 4, 5, and 6 should be the most likely affected by these changes and were rerun and analyzed with the corresponding figures updated. It was found that the originally estimated dose on the FOE walls and roof did not change substantially in response to these changes.

The 06BM-BMM FLUKA model includes the FOE roof, lateral wall, 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 (97.14 cm from short straight centerline and becomes 152.74 cm for the bump-out wall), roof 4 mm Pb (210 cm above short straight centerline) and downstream FOE wall 50 mm Pb (~849 cm from the ratchet wall). See Appendix 1 for more details.

The FLUKA model of the 06BM-BMM 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. In FLUKA model the beam travels from left to right. The positions, dimensions, materials and reference to drawings of the main components are given in Appendix 1.

(a)



(b)

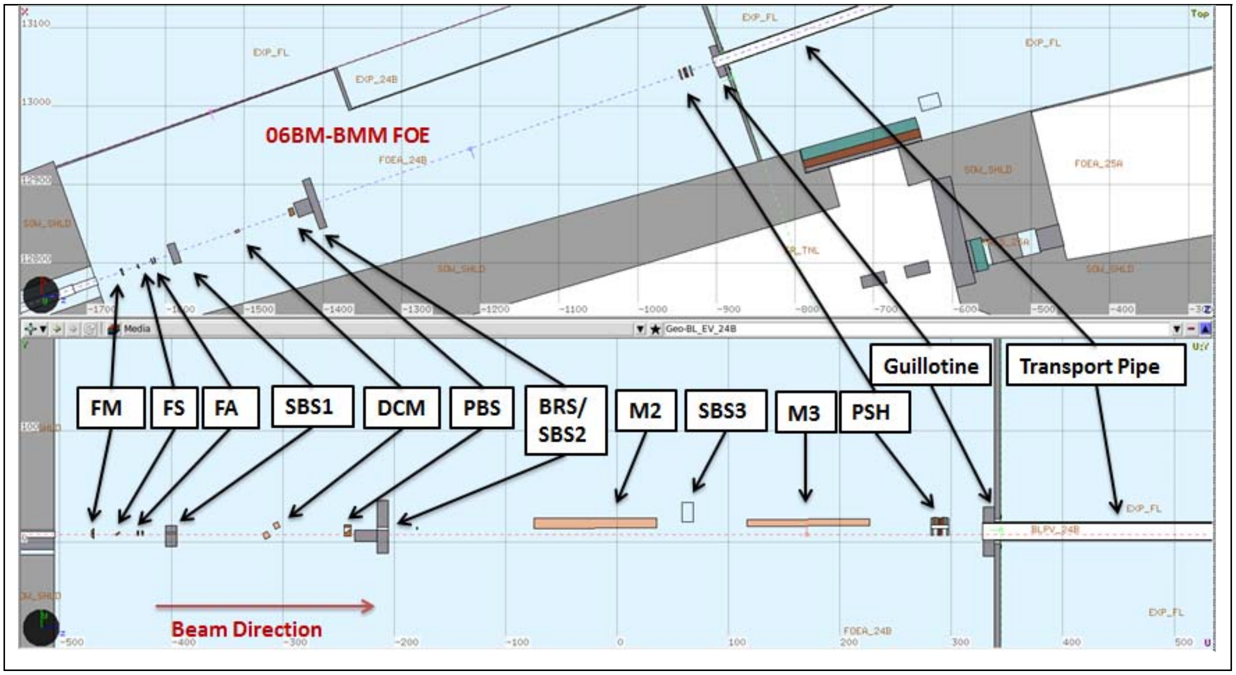


Figure 2: FLUKA Model used in Top-Off simulation of the 06BM-BMM Beamline (a) Front End and (b) beamline

ACRONYMS:

3PW	Three Pole Wiggler
ALARA	As Low As Reasonably Achievable
BM	Bend Magnet
BMM	Beamline for Material Measurement
DCM	Double Crystal Monochromator
DOE	Department of Energy
ESE	End Station Enclosure
FE	Front End
FM	Fixed Mask
FOE	First Optical Enclosure
GB	Gas Bremsstrahlung
GeV	Giga Electron Volts
KeV	Kilo Electron Volts
LCO	Lead Collimator
M	Mirror
NSLS-II	National Synchrotron Light Source II
PBS	Pink Beam Stop
PSH	Photon Shutter
RCO	Ratchet Wall Collimator

SBS	Secondary Bremsstrahlung Shield
SGB	Secondary Gas Bremsstrahlung
SR	Synchrotron Radiation
TLD	Thermoluminescent Dosimeter

3. Results for Primary GB Simulations

The shielding requirement for the FOE is dominated by the scattering of the primary Gas Bremsstrahlung radiation originating from the storage ring's electron beam interacting with residual gas in the storage ring. The paths of this radiation are determined by ray tracing of the GB through and around the FE and beamline components. The analysis approach was to place the GB beam at various locations within the area of the component intercepted by the primary. The simulations performed to confirm the adequacy of the radiation safety components are presented in Table 2. All simulations include the two secondary bremsstrahlung shields SBS1 (upstream of the DCM) and SBS2 (downstream of the DCM). SBS3 was found not required to keep the dose rates below 0.05 mrem/h and therefore was not included in the simulations. Section 5 includes a summary of the simulations results.

3.1 M1c

In this simulation the GB was started just upstream of the selected point of contact at x=0.0 cm, y=0 cm, z=-971.08 cm and impinges near the center of Mirror 1. The total dose distributions (mrem/h) in the FE and FOE are shown in Figure 3 and the corresponding neutron distributions are given in Figure 4. 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 RCO is negligible because the LCO2 that is just downstream of FM4 is effective in attenuating the forward directed electromagnetic shower.

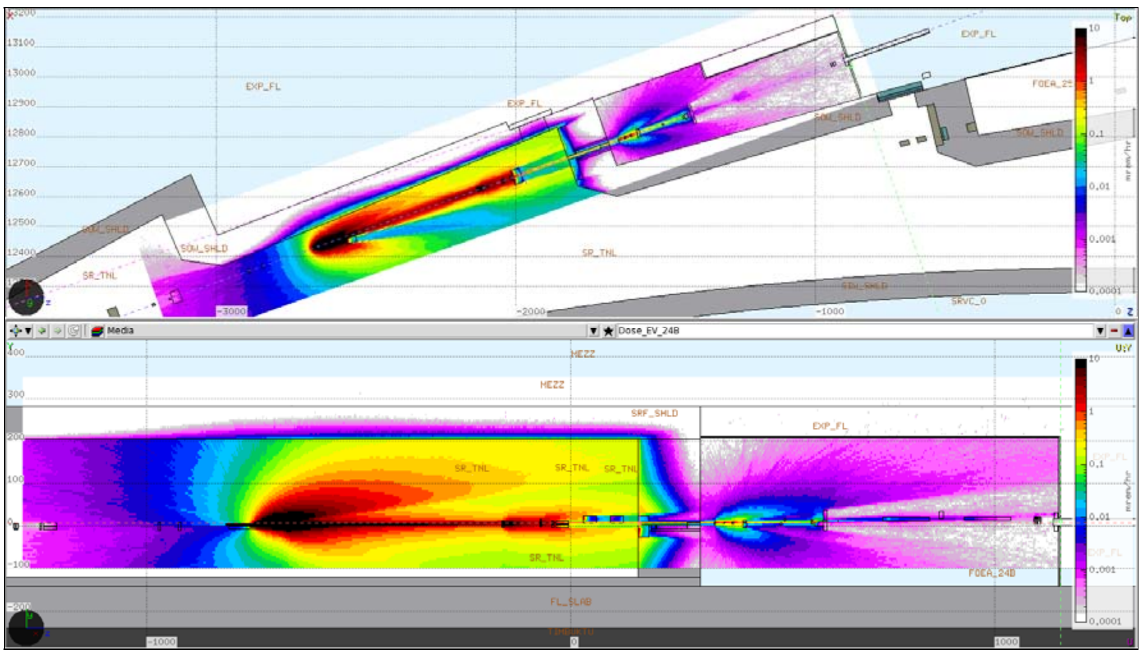


Figure 3: The total dose rate distribution (mrem/h) in the horizontal at y = 6.68 cm (top plot) and vertical (bottom plot) beam plane

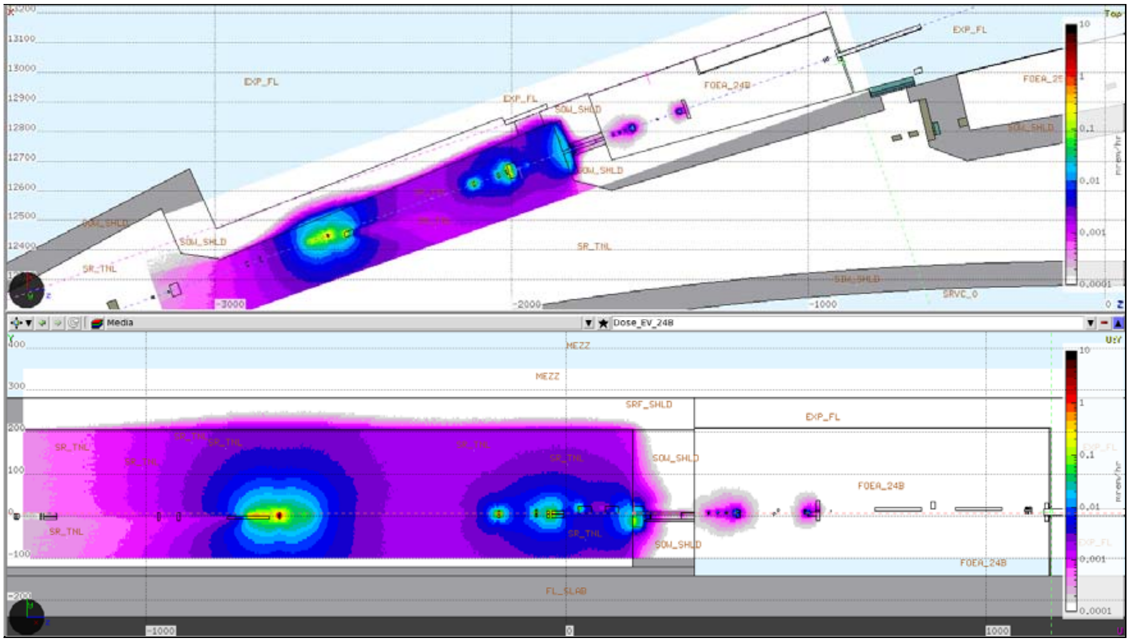


Figure 4: The neutron dose rate distribution (mrem/h) in the horizontal at y = 6.68 cm (top plot) and vertical (bottom plot) beam plane

3.2 FM3

In this simulation the GB was started just upstream of the selected point of contact at x=0 cm, y=3.49 cm, z=-322.66 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 5 and the corresponding neutron distributions are given in Figure 6. The amount of radiation that leaks through the aperture of the RCO is significantly attenuated by the SBS1 and SBS2 in the FOE. The total dose rates on the roof, lateral wall and downstream wall of the FOE are well below 0.01 mrem/hr.

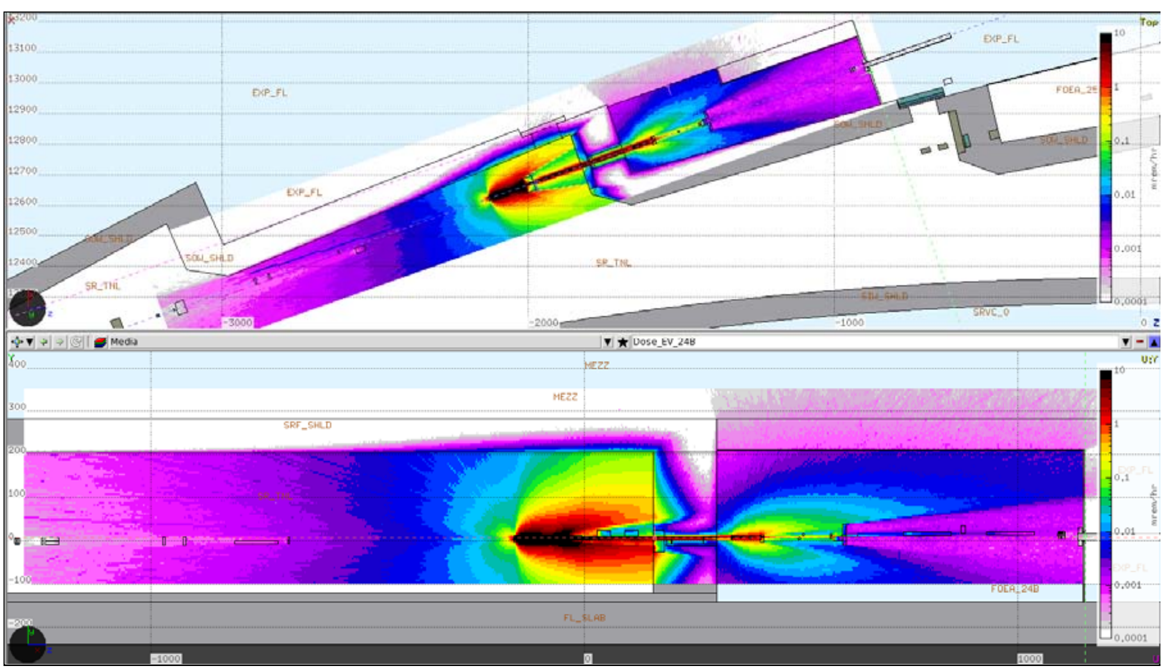


Figure 5: The total dose rate distribution (mrem/h). The vertical view is shown in the bottom plot. The horizontal view (top plot) is at y=6.68 cm (RCO centerline) showing the leakage through the ratchet wall collimator.

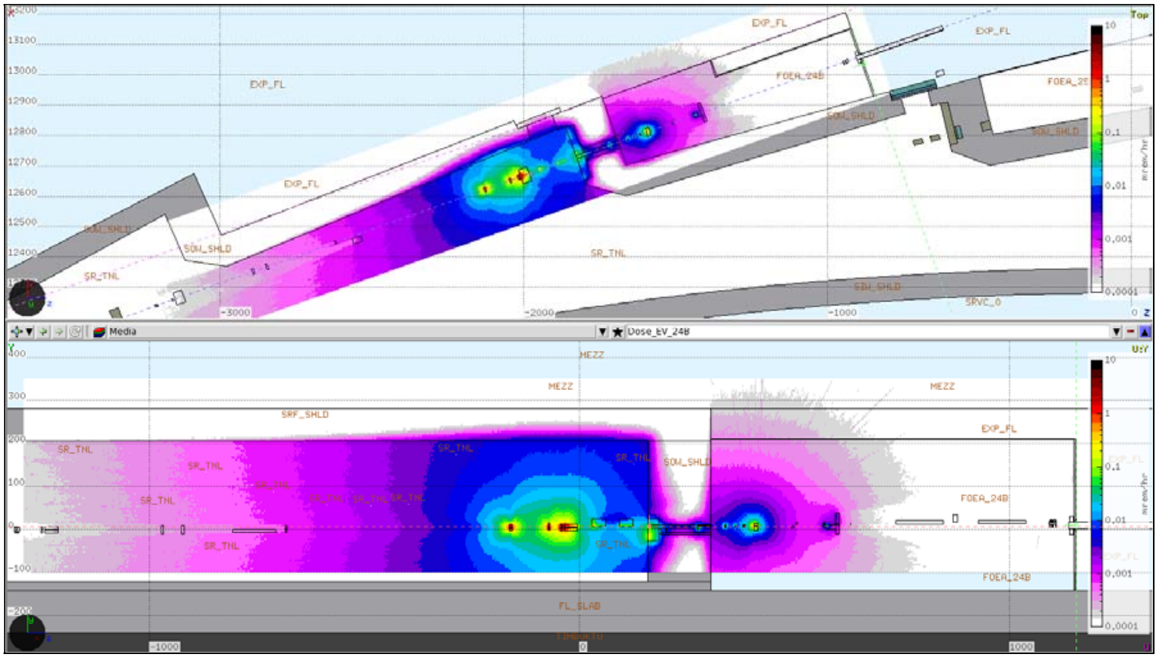


Figure 6: The neutron dose rate distribution (mrem/h) in the horizontal at y = 6.68 cm (top plot) and vertical (bottom plot) beam plane

3.3 FM

In this simulation the GB point of impact is based on maximum bremsstrahlung fan downstream from the RCO as defined in the FE vertical ray tracings. In this case GB was started just upstream of the selected point of contact at x=0 cm, y=5.91 cm, z=178.45 and impinges at the position of the top extreme ray on the front face of fixed mask in the FOE. The total dose distributions (mrem/h) in the FOE are shown in Figure 7 and the corresponding neutron distributions are given in Figure 8, which clearly shows that SBS1 is very effective in attenuating the forward electromagnetic shower and the amount of radiation that leaks through its aperture is stopped by SBS2.

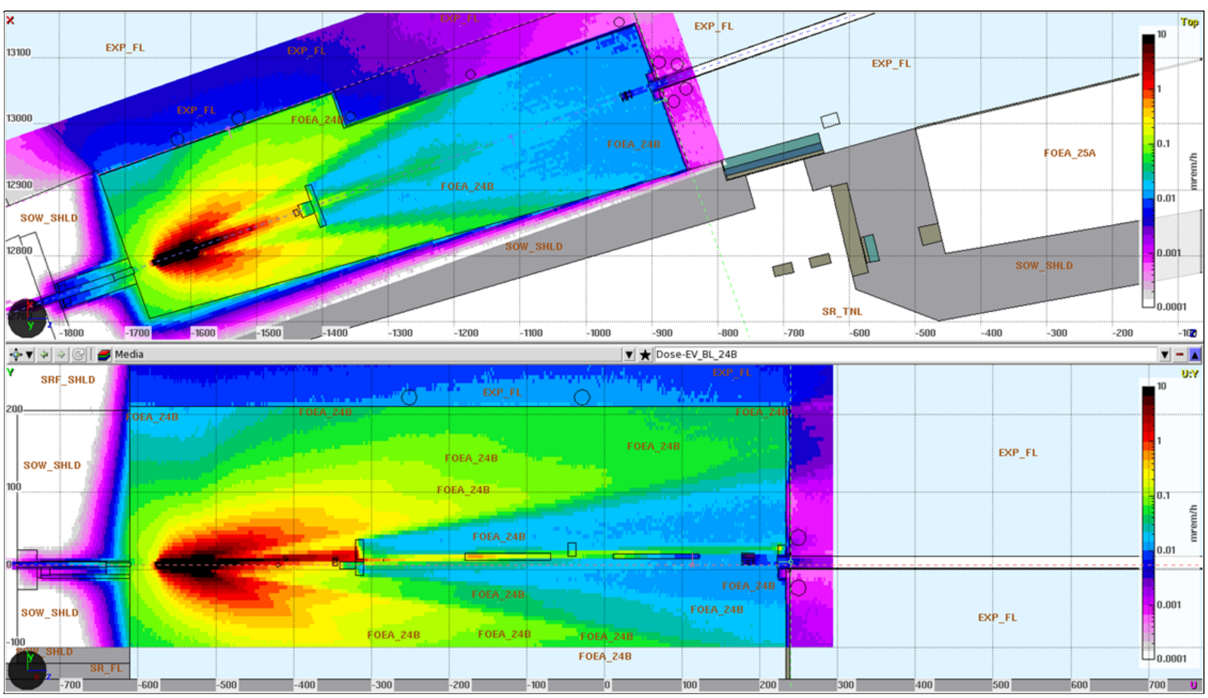


Figure 7: Total dose rate distributions (mrem/h). The Top view at y=6.68 cm (centerline of the RCO) is shown in the top figure and the elevation view shown in the bottom figure.

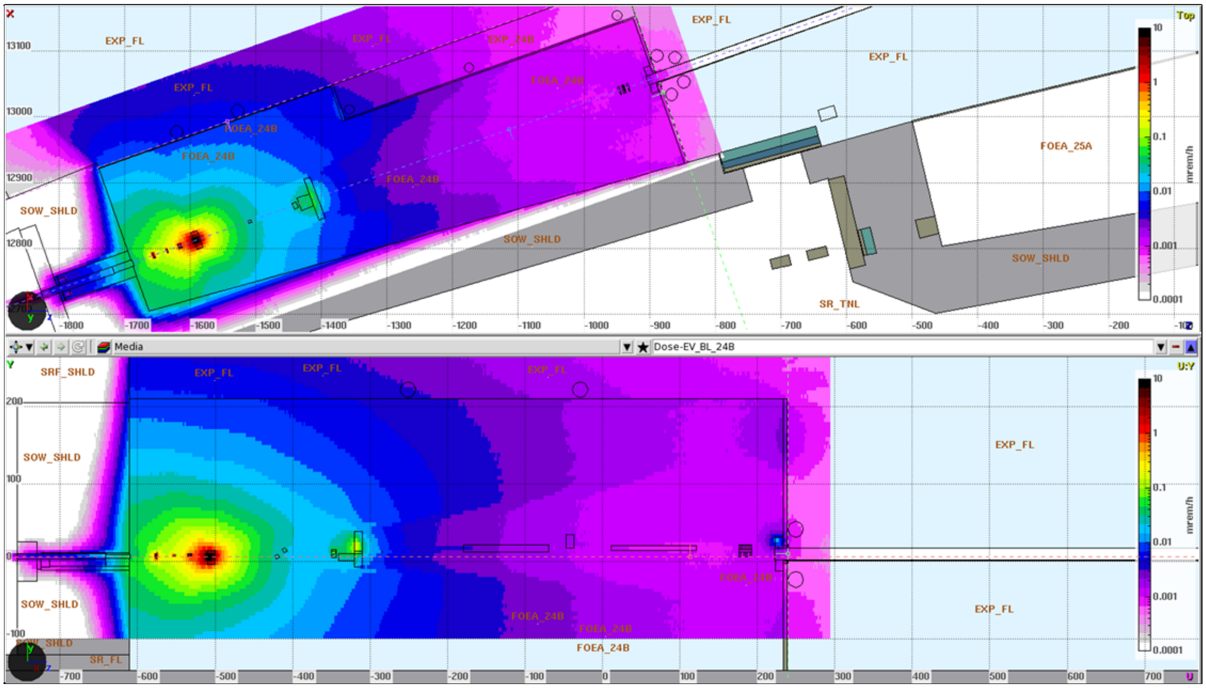


Figure 8: Neutron dose rate distributions (mrem/h). The Top view at y=6.68 cm (center of the RCO) is shown in the top figure and the elevation view shown in the bottom figure.

Unlike the previous 2 cases, total dose rates are slightly above 0.01 mrem/hr on the roof [Figure 9(a)], the downstream wall [Figure 9(b)] and the lateral wall [Figure 9(c) and (d)] but still below 0.05 mrem/h.

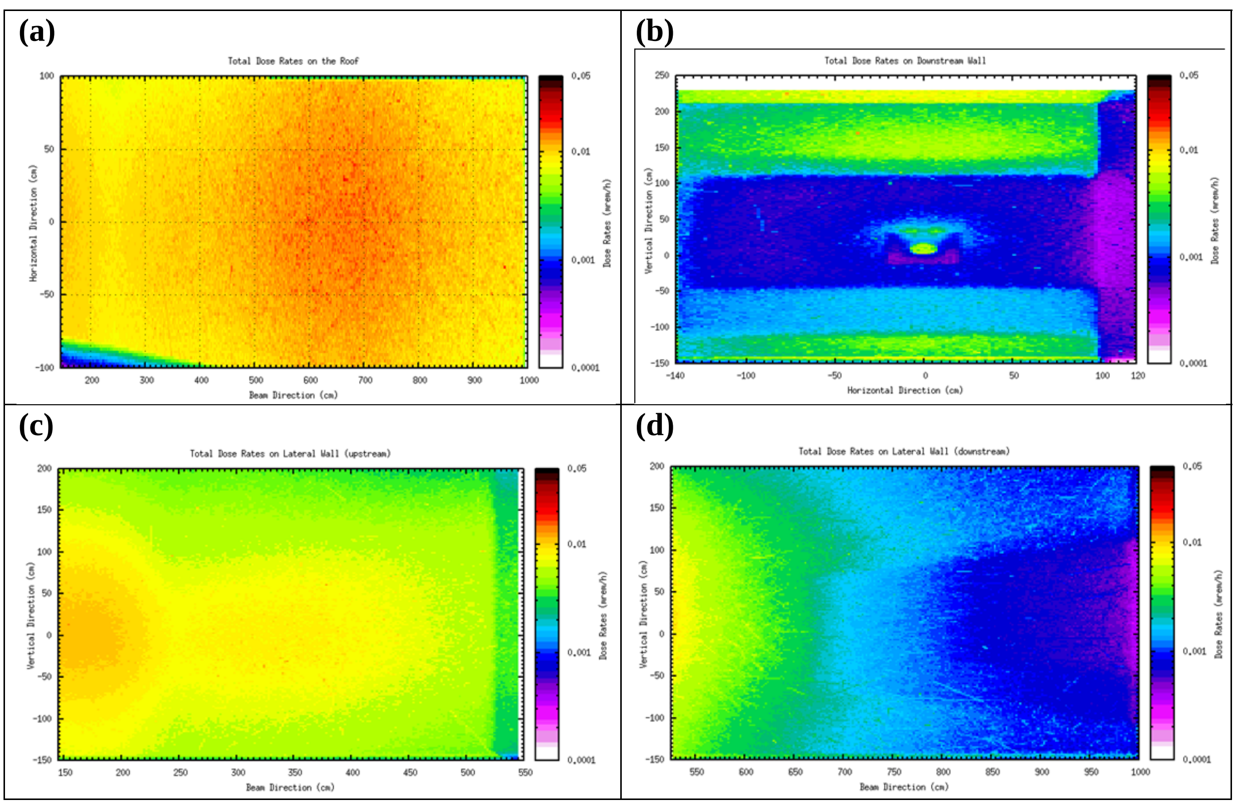


Figure 9: Total dose rate distributions (mrem/h) (a) on the roof, (b) on contact with the downstream FOE wall, (c) on the upstream lateral wall (bump-out wall), and (d) on the downstream on lateral wall.

3.5 SB1

In this simulation the GB was started just upstream of the selected point of contact at x=0 cm, y=5.91 cm, z=244.91 cm and impinges at the position of the top extreme ray on the front face of the SBS1. The total dose distributions (mrem/h) in the FOE are shown in Figure 10 and the corresponding neutron distributions are given in Figure 11.

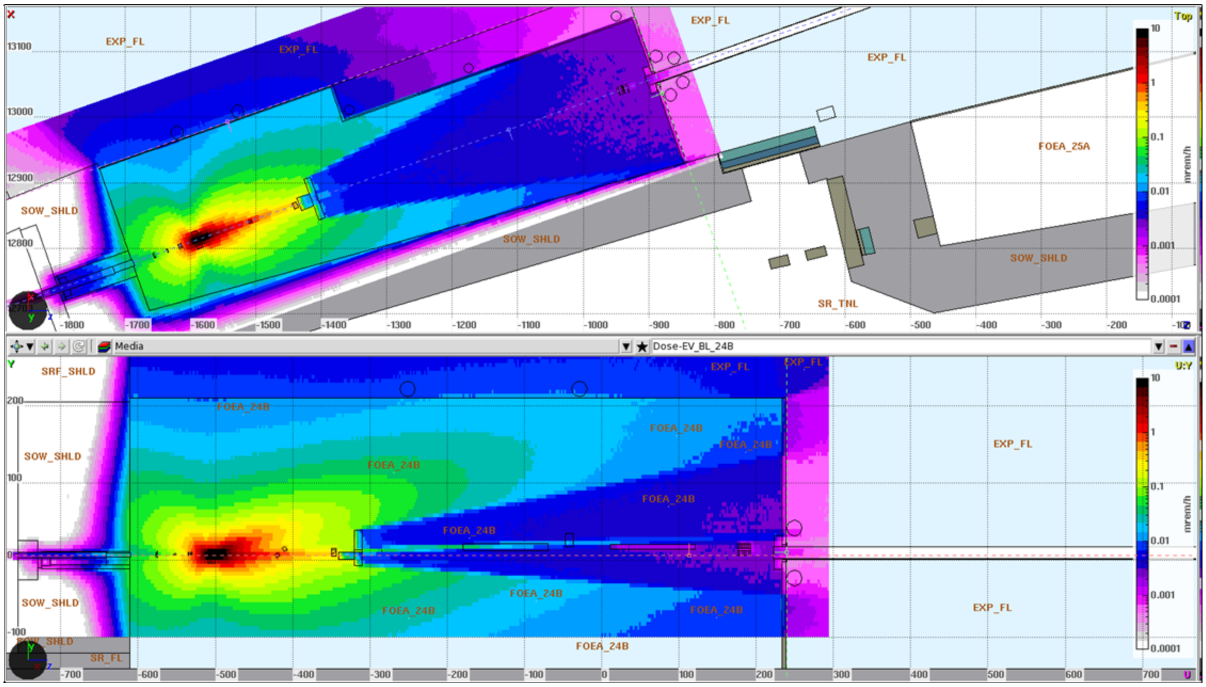


Figure 10: Total dose rate distributions (mrem/h). The Top view at y=6.68 cm (centerline of the RCO) is shown in the top figure and the elevation view shown in the bottom figure.

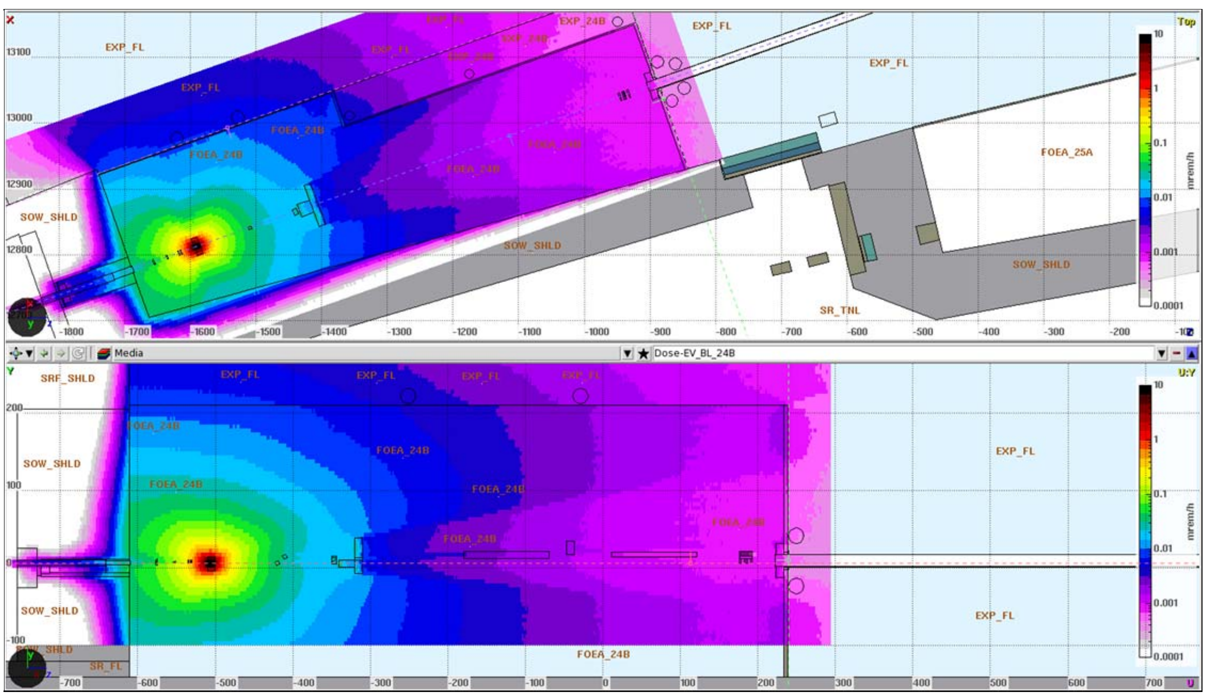


Figure 11: Neutron dose rate distributions (mrem/h). The Top view at y=6.68 cm (center of the RCO) is shown in the top figure and the elevation view shown in the bottom figure.

The total dose rates are similar to case 3.4 and are highest on the roof and lateral wall. The dose rates on contact with the roof [Figure 12(a)], the downstream wall [Figure 12(b)] and the lateral wall [Figure 12(c) and (d)] are below 0.05 mrem/h. The SBS2 is very effective in attenuating the forward electromagnetic shower generated in SBS1 and its shadow can be seen in Figure 12(b). The amount of radiation that leaks through the apertures of SBS2 is negligible.

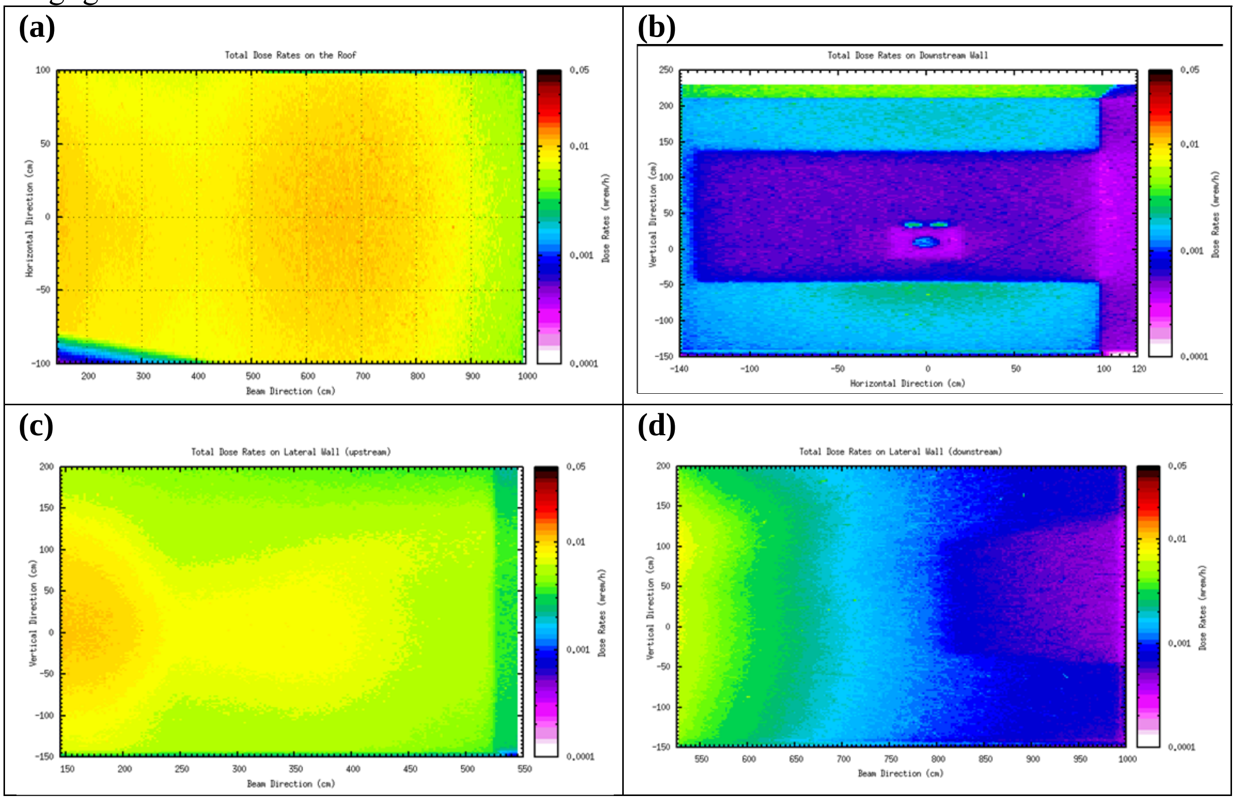


Figure 12: Total dose rate distributions (mrem/h) (a) on the roof, (b) on contact with the downstream FOE wall, (c) on the upstream lateral wall (bump-out wall), and (d) on the downstream on lateral wall.

3.5 DCM

The GB source was placed just upstream of the front face of the crystal 1 of the DCM at position x=0 cm, y=6.37 cm, and z=331.38 cm. The total dose distributions (mrem/h) in the FOE are shown in Figure 13 and the corresponding neutron distributions are given in Figure 14. It clearly shows that SBS2 is very effective in attenuating the forward electromagnetic shower and the amount of radiation that leaks through its aperture misses the guillotine but still small enough to result in total dose rates lower than 0.05 mrem/h as it can be seen from Figure 15(b). The total dose rates are highest on the roof and downstream wall. The dose rates on contact with the roof [Figure 15(a)], the downstream wall [Figure 15(b)] and the lateral wall [Figure 15(c) and (d)] are below 0.05 mrem/h.

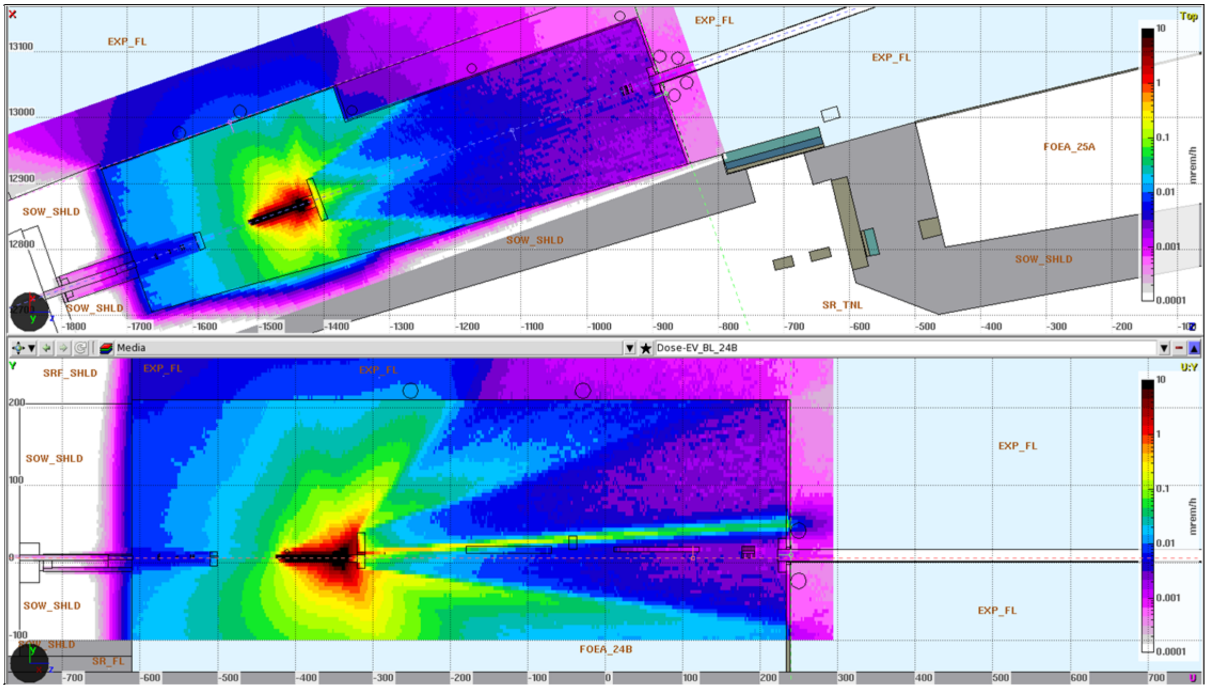


Figure 13: Total dose rate distributions (mrem/h). The Top view at y=6.68 cm (centerline of the RCO) is shown in the top figure and the elevation view shown in the bottom figure.

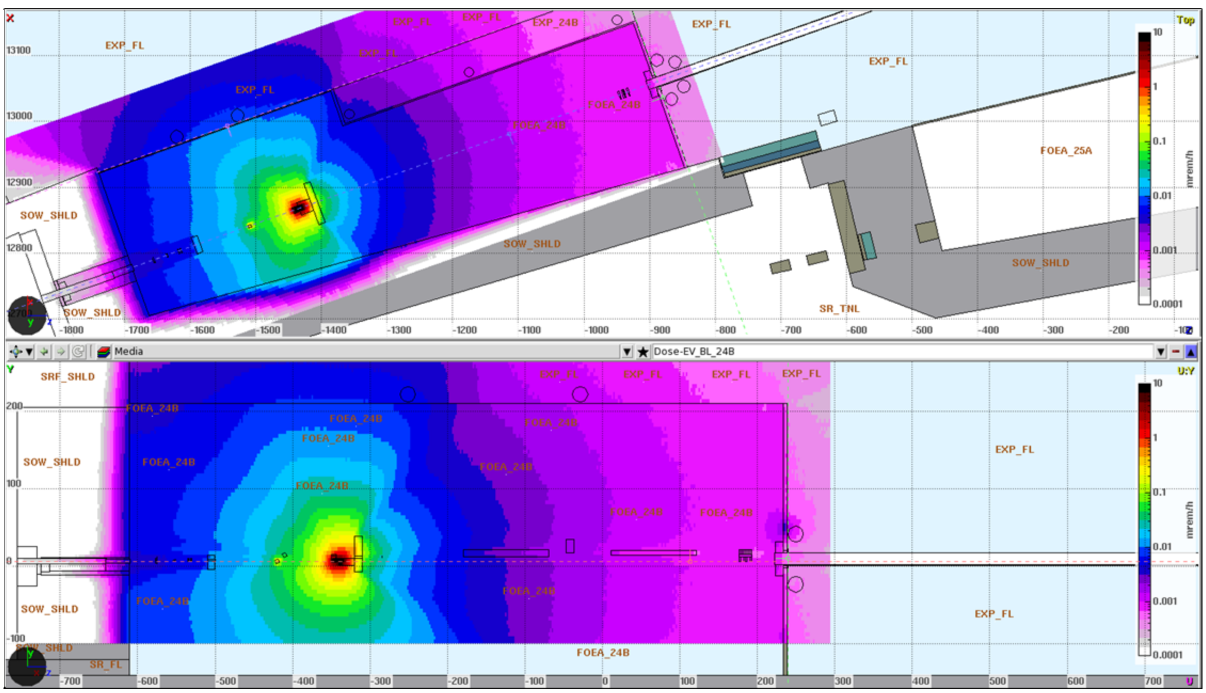


Figure 14: Neutron dose rate distributions (mrem/h). The Top view at y=6.68 cm (center of the RCO) is shown in the top figure and the elevation view shown in the bottom figure.

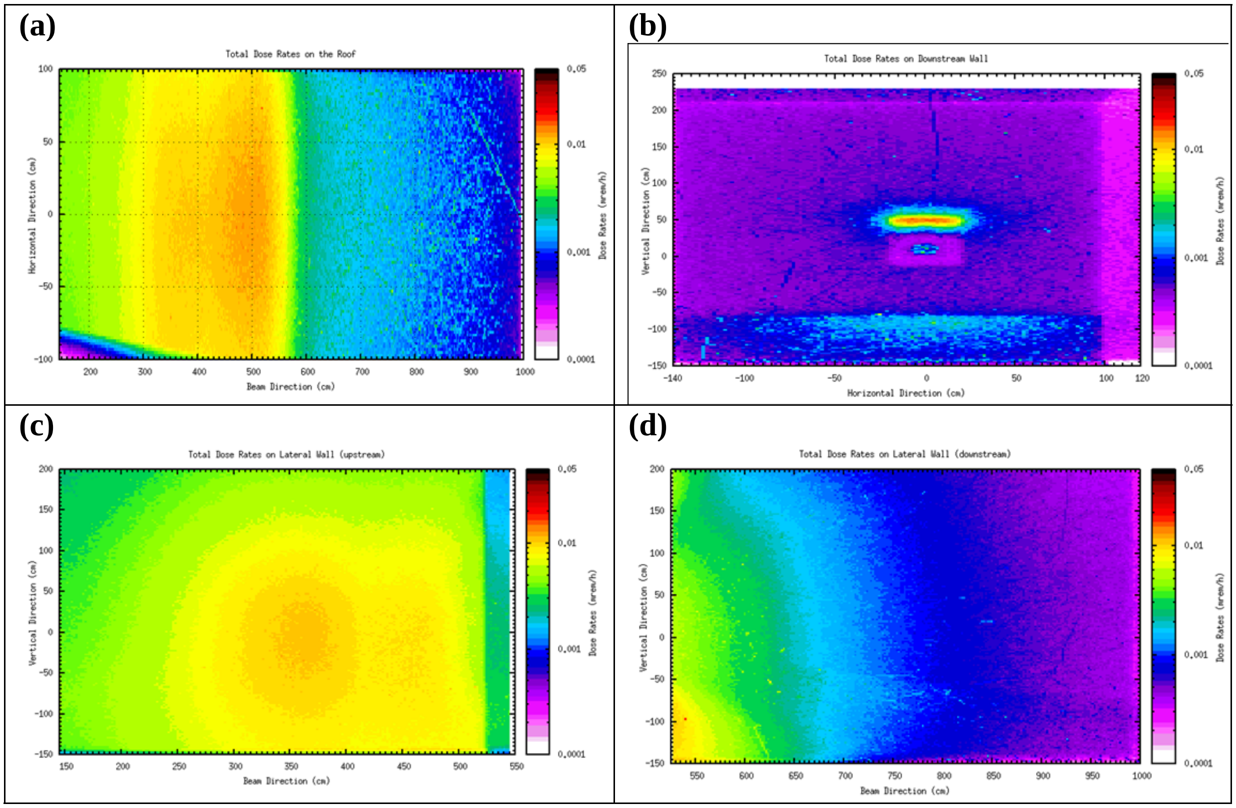


Figure 15: Total dose rate distributions (mrem/h) (a) on the roof, (b) on contact with the downstream FOE wall, (c) on the upstream lateral wall (bump-out wall), and (d) on the downstream on lateral wall.

3.6 PBS

In this simulation the GB was started just upstream of the selected point of contact at x=0 cm, y=6.59 cm, z=405.33 cm and incident just upstream face of the PBS. The total dose distributions (mrem/h) in the FOE are shown in Figure 16 and the corresponding neutron distributions are given in Figure 17. It clearly shows that SBS2 is very effective in completely stopping the forward electromagnetic shower and the neutron distribution which is generated mostly in SBS2 due to its lead content (high z material) is very similar to previous case 3.5. There is no leakage of radiation due to the proximity of the PBS to SBS2 as it can be seen from Figure 16 and 18(b).

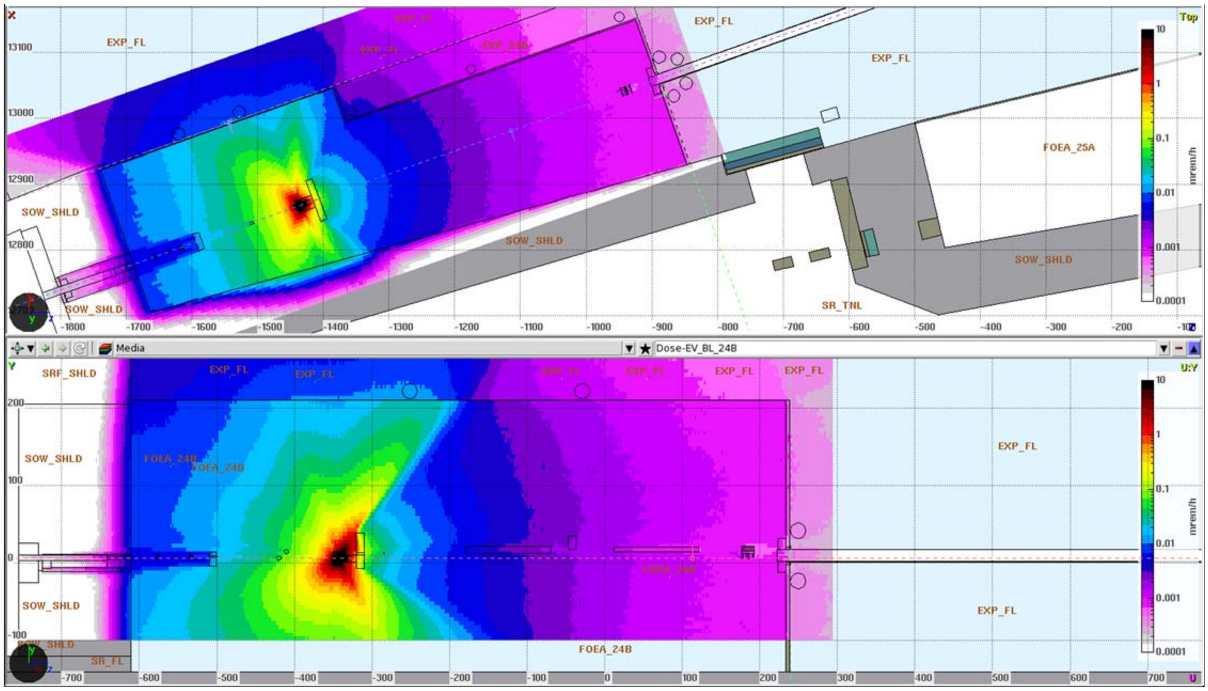


Figure 16: Total dose rate distributions (mrem/h). The Top view at y=6.68 cm (centerline of the RCO) is shown in the top figure and the elevation view shown in the bottom figure.

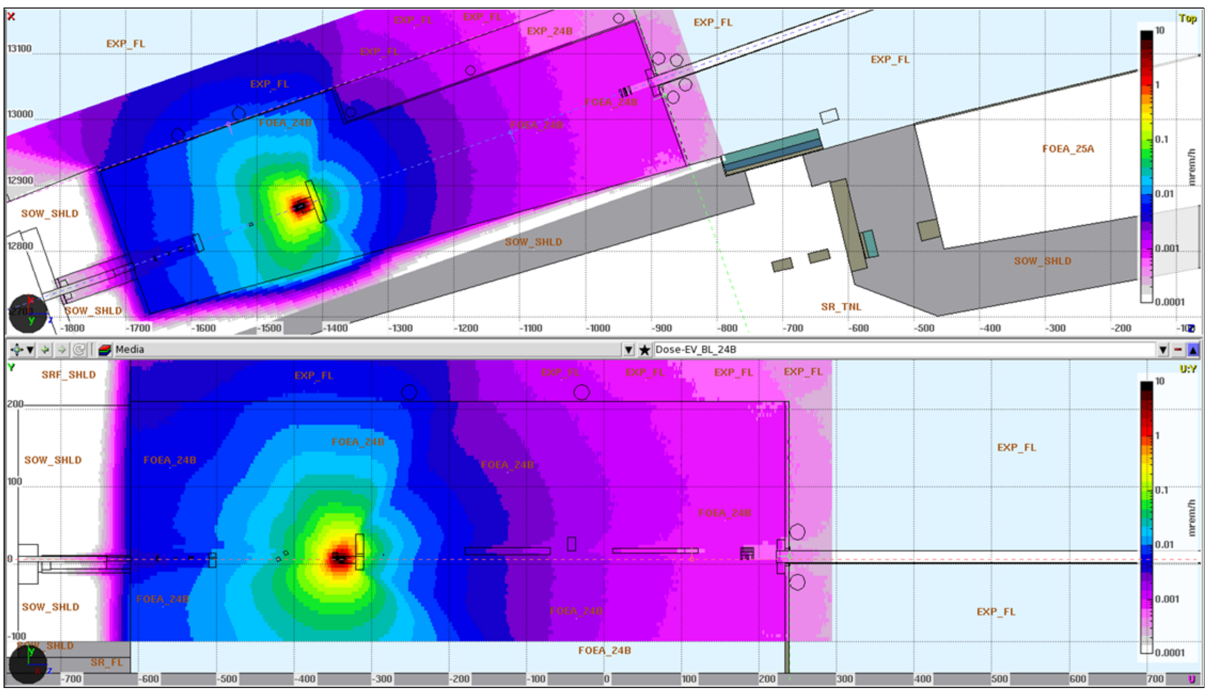


Figure 17: Neutron dose rate distributions (mrem/h). The Top view at y=6.68 cm (center of the RCO) is shown in the top figure and the elevation view shown in the bottom figure.

The total dose rates are highest on the roof and lateral wall similar to case 3.5 but unlike case 3.5 there is no radiation leakage on the downstream wall. The dose rates on contact with the roof [Figure 18(a)], the downstream wall [Figure 18(b)] and the lateral wall [Figure 18(c) and (d)] are below 0.05 mrem/h.

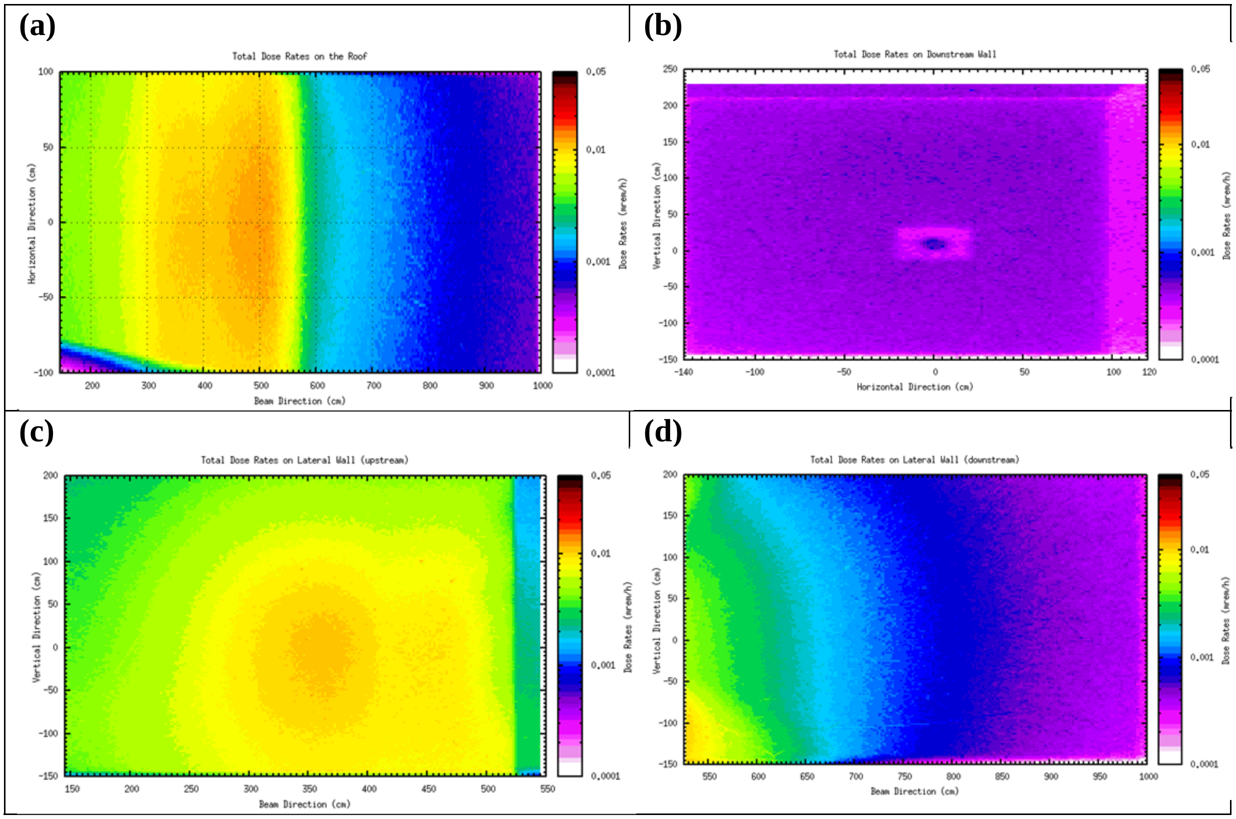


Figure 18: Total dose rate distributions (mrem/h) (a) on the roof, (b) on contact with the downstream FOE wall, (c) on the upstream lateral wall (bump-out wall), and (d) on the downstream on lateral wall.

4. Synchrotron Radiation Calculation

The 06BM-BMM beamline is a three pole wiggler (3PW) source and its parameters are extracted from references [1, 3] and reproduced in Table 3. It has a focusing mirror in the FE, which will deflect the synchrotron beam vertically and pass through the vertically offset RCO aperture. Therefore, the synchrotron beam entering the FOE is a mirror reflected pink beam. For simplicity, the FOE analysis below is based on a white beam, which is very conservative. The horizontal opening angle for the 06BM-BMM source fan entering the FOE is provided in column 2. 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 06BM-BMM Synchrotron Calculations

Source	Max. source opening	No. Of periods	Max. B_{eff} (T)	Length (m)	E_c (keV)	STAC 8 Total Power (kW) @ 500mA
3PW	3.0 mrad-H	1	1.2	0.25	6.7	0.28

The analytic code STAC8 [4] was used to calculate the ambient dose equivalent rates in the occupied areas outside the FOE, monochromatic beam transport pipe and end-station enclosure 06BM-B. The build-up factor in shielding 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 pipe and the ESE assume that the primary bremsstrahlung has been completely stopped in the FOE. Targets for maximum scattered radiation were considered in the STAC8 calculations. These cases considered are described in Section 4.1and 4.2.

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 grazing angle of 0.155 degree with the respect to the incident beam [5]. The position of the scatter target is assumed to be located at the 06BM-BMM DCM approximately 658 cm from the FOE downstream wall, 152 cm from the lateral wall and 210 cm from the roof. The minimum required shielding for the SR source (no credit has been given to the secondary bremsstrahlung shielding or guillotine) and the corresponding ambient dose rates are given in Table 4. The results show that the shielding thicknesses required for the GB will largely shield for the scattered synchrotron radiation. 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.

Table 4: SR Shielding Design Requirements for 02ID-SIX FOE

	Distance (cm)	Minimum Required Shielding	Max Ambient Dose Rate (mrem/h)
Lateral wall	152	4 mm Pb	0.026
Roof	210	4 mm Pb	0.014
Downstream Wall (> 1^{o})	658	6 mm Pb	0.035

4.2 Transport Pipe and ESE (11-BM-B)

The lead thickness of the 06BM-BMM monochromatic beam transport pipe is 5 mm which exceed the minimum shielding requirement of 2 mm specified in Reference [1]. Figure 19 shows the vertical synchrotron ray tracings which illustrates that under certain Mirror M2 and M3 configurations, the monochromatic beam shown in purple trace could potentially strike the lead shielded transport pipe.

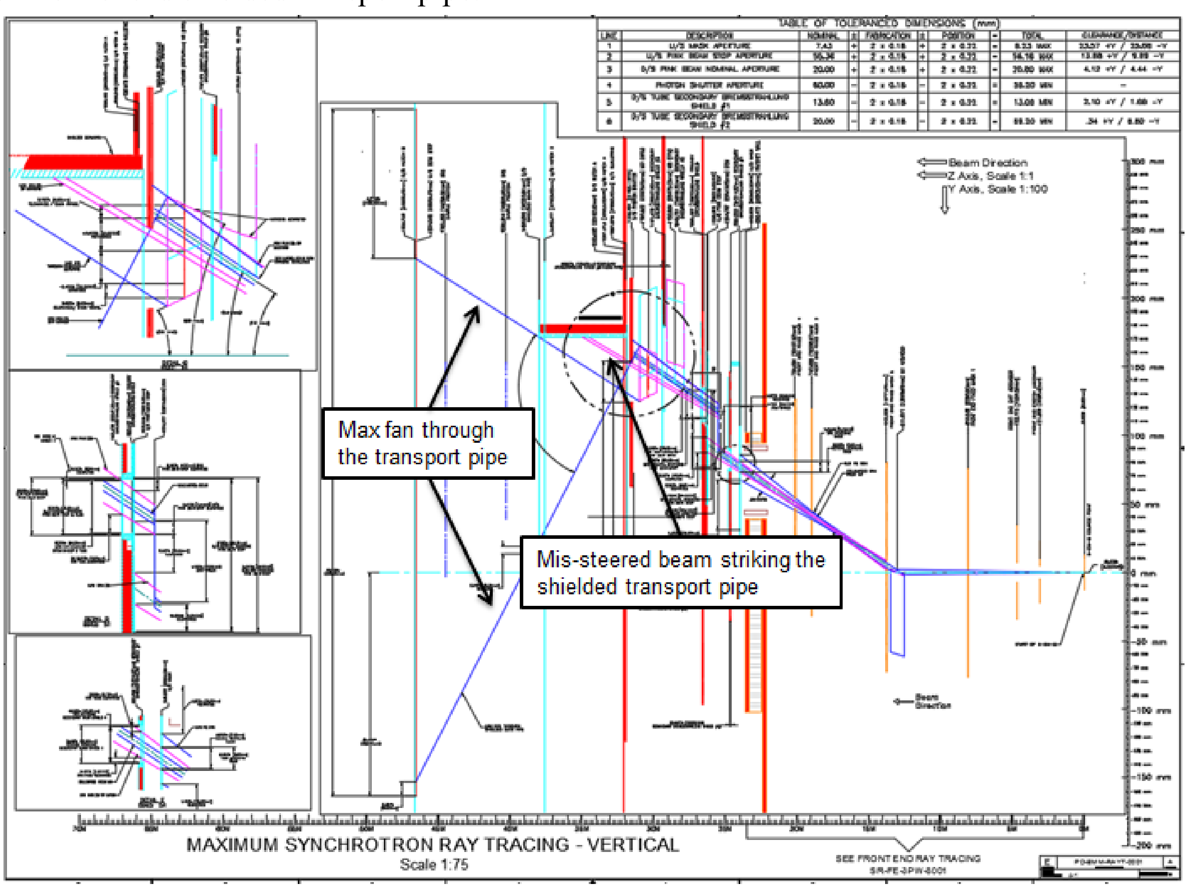


Figure 19: Synchrotron vertical ray tracings showing mis-steered monochromatic beam striking the shielded transport pipe

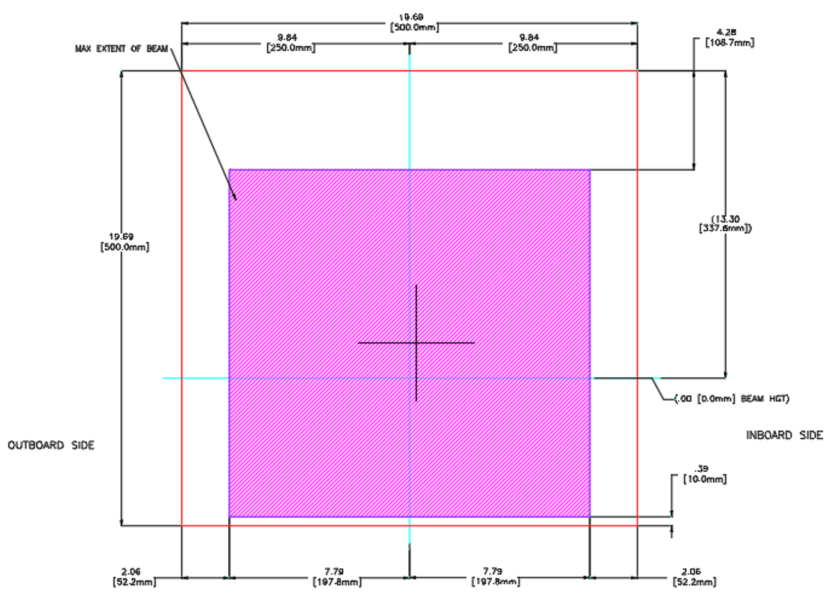
We assumed a pink beam from Rh coated M1 mirror with a lowest incident angle of 3.5 mrad needed for the reflected beam to enter the FOE and incident on the first crystal of the DCM. Assuming five higher harmonic reflections (111, 333, 444, 555, and 777) of the fundamental mode of 22 keV with corresponding bandwidths [5], the dose rate is calculated directly on contact with the lead shielded transport pipe by the "NICK" card in STAC8. The calculated ambient dose rate is 9.4E-05 mrem/h for this abnormal mis-steering event and is well below the design criteria of 0.05 mrem/h.

The ESE dimensions are given in appendix 1 (Table 1.3). The STAC8 calculation was carried out with the same silicon scatter target used for the FOE analysis. The location of target is assumed to be at the sample positions for XAS located at 40300 mm from the 3PW source and for XRD located at 44509 mm from 3PW source. For the beam to enter ESE, the DCM and Mirrors M2 and/or M3 inside the FOE must be inserted to direct the beam into the beam transport pipe and toward the ESE. For this calculation, we ignore the reflections from M2 and M3, which is very conservative. The dose rates on the walls and roof are given in Table 5. For the downstream wall we give the dose rates for the XAS and XRD sample locations and no credit was given to the beam stop. In all cases the ambient dose rates are well below the design criteria of 0.05 mrem/h.

Table 5: SR Shielding Design Requirements for ESE (06BM-B Enclosure)

	Distance (cm)	Installed Shielding	Ambient Dose rate (mrem/h)
Lateral wall	96	3 mm Fe	3.6E-05
Roof	210	2 mm Fe	1.7E-05
Downstream Wall (> 1^{o})	630/209	6 mm Fe	2.4E-05/2.2E-04

In the absence of any targets in the ESE, the maximum synchrotron fan through the shielded transport pipe, as shown in Figures 19 and 20, is completely stopped by the 12 mm (50 cm x 50 cm) lead beam stop on the downstream wall of the ESE.



DETAIL A–A BEAM STOP
SCALE: 1:2

Figure 20: Illustrates that the maximum synchrotron fan is within the area of the monochromatic beam stop shown as red square

5. Summary and Conclusions

At NSLS-II, the white beam or 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 7.2 μW incident power. This value corresponds to the estimated bremsstrahlung power generated by a 500 mA electron beam of 3 GeV, assuming that the vacuum in the 6.6 m long 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 5.

Table 5: Maximum Total Dose Rates (mrem/h) on the Roof, Lateral Wall, and the Downstream Wall of the FOE

Case # / Report Section	Simulation	Roof	Lateral Wall	D/S Wall
1 / 3.1	**M1c**	< 0.05	< 0.05	< 0.05
2 / 3.2	**FM3**	< 0.05	< 0.05	< 0.05
3 / 3.3	**FM**	< 0.05	< 0.05	< 0.05
4 / 3.4	**SB1**	< 0.05	< 0.05	< 0.05
5 / 3.5	**DCM**	< 0.05	< 0.05	< 0.05
6 / 3.6	**PBS**	< 0.05	< 0.05	< 0.05

Based on the STAC8 calculation, the dose rates outside of the FOE, beam transport pipe and the ESE are much less than 0.05 mrem/h and are consistent with the NSLS-II Shielding Policy for normal operating conditions, as well as fault events.

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 ESE during commissioning.

6. References

[1] *Guidelines for the NSLS-II Beamline Radiation Shielding Design* LT-C-ESH-STD-001, November 7, 2014.

[2] *NSLS-II Issue and Decision Paper: ALARA Analysis for Installations of Secondary Bremsstrahlung Shields in the First Optics Enclosure*, R. Lee, PS-C-ESH-STD-005, (06/01/2016).

[3] NSLS-II document PS-C-XFD-RSI-SST-BMM-001 (Version 1, 02/27/2015).

[4] Y. Asano, "*A study on radiation shielding and safety analysis for a synchrotron radiation beamline*," JAERI-Research-2001-006, March 2001. Y. Asano and N. Sasamoto, "*Development of Shielding Design Code for Synchrotron Radiation Beamline*," Radia. Phys. Chem. 44 (1994) 133.

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

7. Acknowledgements

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Appendix 1

06BM-BMM Input provided by Mark Breitfeller and John Fabijanic: updated on March 21, 2017.

The source point is the origin of the co-ordinate system. The FE 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. The following convention is used to specify distance of the component from the 3PW source: U: upstream, D: downstream, and C: center of component.

Table 1.1: Beamline First Optical Enclosure (FOE)

Wall	Position	Thickness	Material
D/S End of 6-BM-A Ratchet Wall	2360.86 cm		
D/S End of FOE (6-BM-A) Backwall	3210.03 cm	5.0 cm	Lead
Distance of Sidewall from straight CENTERLINE	97.14 cm (inside)	1.8 cm	Lead
Distance of Roof from straight CENTERLINE	210.00 cm	0.4 cm	Lead
D/S End of FOE bump-out (6-BM-A) Backwall	2735.88 cm	5.0 cm	Lead
Distance of bump-out Sidewall from straight CENTERLINE	152.74 cm (inside)	1.8 cm	Lead

Table 1.2: Beamline Transport Pipe

Transport Pipe between FOE & experimental enclosure	ID= 14.98 cm OD=15.60 cm Material: Stainless Steel	Shielding Thickness = 0.5 cm Shielding Material: Lead Beampipe is 9.69 cm (y) above center line

Table 1.3: Beamline End Station Enclosure (ESE)

Wall	Position	Thickness	Material
U/S End of 6-BM-B Wall	3760.26 cm	0.3 cm	Steel
D/S End of 6-BM-B Backwall	4660.26 cm	0.6 cm	Steel
Distance of inboard Sidewall from straight CENTERLINE	U/S 96.24 cm / DS149.66 cm	0.3 cm	Steel
Distance of outboard Sidewall from straight CENTERLINE	U/S 171.25 cm / DS 196.68	0.3 cm	Steel
Distance of Roof from straight CENTERLINE	210.00 cm	0.2 cm	Steel
D/S Wall beam stop location (49.5cm x 49.5cm)	4658.46 cm (U/S)	1.2 cm	Lead

Table 1.4: Beamline FOE Components for FLUKA Calculations

Shielding	Z location (Distance from S.S. center) (US), (DS) or center	Dimensions (specify units)		Offset (vertical or horizontal) Straight CENTERLINE	Material	Associated Drawings
		Outer dimensions (W)x(H)x(L)	Aperture (W)x(H) or (R) (MAX includes mfr & positional tolerance)			
Crotch Absorber	305.8 cm (US)	26.44cm (x) 4.24 cm [body] 1.40 cm(y) [tip] 4.445 cm (z)	2.547cm (x) 1.392cm (y)	-0.347cm (x)	Glidcop AL-15	SR-VA-ABS-1098
Exit Absorber	463.2 cm (US)	6.93cm (x) 6.93cm (y) 1.91cm (z)	1.80cm (x) MAX 1.80cm (y) MAX Aperture .85 cm (x) offset from body ctr	0	Cu-Cr-Zr	SR-FE-3PW-ABS-0011
FM1	809.1 cm (DS)	22.86cm (x) 15.24cm (y) 4.445cm(z)	DS & US (No Taper) 1.628cm (x) MAX 0.253cm (y) MAX	0	Cu-Cr-Zr	SR-FE-3PW-MSK-1911
LCO1	813.6 cm (US)	41.25 cm (x) MIN 15.0 cm (y) MIN 30.0 cm (z) MIN	Lead Aperture 3.323cm (x) MAX 2.140cm (y) MAX	0	Lead	SR-FE-3PW-CO-0900
Be Window	887.0 cm (C)	15.24cm (x) 15.24cm (y) 2.54cm (z)	3.86cm (x) MAX 0.70cm (y) MAX	0	Glidcop with Beryllium foil in aperture	SR-FE-3PW-WIN-0200
X-Y Slit 1	1087.1 cm (C)	18.42cm (x) 19.37cm (y) 6.03cm (z)	Max opening (30mm H x 10 mm V) Minimum opening (-10 mm overlap)	0	Cu-Cr-Zr	SR-FE-3PW-SLT-2011
X-Y Slit 2	1135.0 cm (C)	18.42cm (x) 19.37cm (y) 6.03cm (z)	Max opening (30mm H x 10 mm V) Minimum opening (-10 mm overlap)	0	Cu-Cr-Zr	SR-FE-3PW-SLT-2021
Collimating Mirror	1300.0cm(C)				Silicon	PD-BMM-MIR-1001

FM2	1377.2 cm (DS)	22.86cm (x) 15.24cm (y) 4.445cm(z)	DS: 3.222cm (x)MAX DS: 0.759cm (y)MAX Vert angle = 1 deg US: 0.832cm (y)MAX	+.53cm (y)	Cu-Cr-Zr	SR-FE-3PW-MSK-1912
Inboard Shadow Shield	1430.1 cm (US)	17.5cm (x) MIN 30.0cm (y) MIN 30.0cm (z) MIN	No aperture	X = -7.62cm (outboard face)	Lead	SR-FE-3PW-8015
FM3	1898.9 cm (DS)	22.86cm (x) 15.24cm (y) 4.445cm(z)	DS: 4.271cm (x)MAX DS: 1.018cm (y)MAX Vert angle = 1 deg US: 1.092cm (y)MAX	+4.19 cm (y)	Cu-Cr-Zr	SR-FE-3PW-MSK-1914
Photon Shutter	1985.1 cm (C)	15.24cm (x) 15.88cm (y) 3.175cm (z)	DS & US (No Taper) 5.334cm (x) 1.524cm (y) (aperture offset to part C/L, y = -2.50 cm)	Y=4.79 cm to SR Beam Ht when open	Cu-Cr-Zr	SR-FE-3PW-PSH-0111
FM4	2016.8 cm (DS)	22.86cm (x) 15.24cm (y) 4.445cm(z)	DS: 4.502cm (x)MAX DS: 1.064cm (y)MAX Vert angle = 1 deg US: 1.138cm (y)MAX	+5.02cm (y)	Cu-Cr-Zr	SR-FE-3PW-MSK-1913
LCO2	2021.3 cm (US)	50.0cm (x) MIN 15.0cm (y) MIN 30.0cm (z) MIN	Lead Aperture 5.792cm (x) MAX 2.673cm (y) MAX	+5.02cm (y)	Lead	SR-FE-3PW-CO-0950
Safety Shutter1	2086.1 cm (US)	17.5cm (x) MIN 17.5cm (y) MIN 30.0cm (z) MIN	Tube Aperture 9.4 cm (x) 3.4 cm (y)	Y=+5.47cm when open	Lead	SR-FE-3PW-SS-4000
Safety Shutter2	2150.0 cm (US)	17.5cm (x) MIN 17.5cm (y) MIN 30.0cm (z) MIN	Tube Aperture 9.4 cm (x) 3.4 cm (y)	Y=+5.92cm when open	Lead	SR-FE-3PW-SS-4100
Lead in Ratchet wall RC0	2216.1cm (US)	180.0 cm (x) MIN 50.0 cm (y) MIN 25.0 cm (z) MIN	Lead Aperture 11.6 cm (x) MAX 6.8 cm (y) MAX	+6.68cm (y) Tube centerline	Lead	SR-FE-3PW-RCO-8000
Lead block RC1	2241.1cm (US)	40.0 cm (x) MIN 20.0 cm (y) MIN 5.0 cm (z) MIN	Lead Aperture 11.6 cm (x) MAX 6.8 cm (y) MAX	+6.68cm (y) Tube centerline	Lead	SR-FE-3PW-RCO-8000
RCO Concrete Block & Ratchet Wall Material	2329.0cm (DS) RCO Block	28.9 cm (x) MIN 12.5 cm (y) MIN 72.0 cm (z) MIN	Concrete Aperture 11.6 cm (x) MAX 6.8 cm (y) MAX	+6.68cm (y) Tube centerline	Lead, concrete & HDPE	SR-FE-3PW-RCO-8180 & SR-FE-3PW-RCO-8000

RCO Lead Brick	2360.8cm (DS)	28.9 cm (x) MIN 12.5 cm (y) MIN 30.0 cm (z) MIN	Lead Aperture 10.4 cm (x) MAX 5.5 cm (y) MAX	+6.68cm (y) Tube centerline	Lead, concrete & HDPE	SR-FE-3PW-RCO-8180

Table 1.5: Beamline FOE Components

Components	Z location (Distance from 3PW center) (U), (D) or center	Dimensions (specify units)		Offset (vertical or horizontal) w.r.t Straight CENTERLINE	Material	Associated Drawings
		Outer dimensions (W)x(H)x(L)	Aperture (W)x(H) or (R) (MAX includes mfr & positional tolerance)			
Mask	2395.03 cm (U/S)	9.0 cm & 1.8 cm/ 0.6 cm (z)	3.80 cm (x) MAX 0.82 cm (y) MAX	7.67 cm (V) above centerline	Copper	N/A
Fluorescence screen	2418.74 cm (C)	5.0 cm (x) 4.0 cm (y) 1.4 cm(z) Rotated 45 degrees around horizontal axis	N/A	7.8 cm (V) above centerline	Copper	AFM0085 Rev. 2
Filter Assembly 1	2436.80 cm (C)	7.0 cm (x) 12.4 cm (y) 1.1 cm (z)	N/A	11.85 cm (V) above centerline	Copper with 3.5 cm wide x 0.85 cm high apertures for thin filters	AAM0071 Rev. 1
Filter Assembly 2	2440.5 cm (C)	7.0 cm (x) 12.4 cm (y) 1.1 cm (z)	N/A	11.85 cm (V) above centerline	Copper with 3.5 cm wide x 0.85 cm high apertures for thin filters	AAM0071 Rev. 1
Secondary Brems. shield #1	2461.49 cm (US)	26.35 cm (x) 18.20 cm (y)	7.45 cm (x) MAX 1.80 cm (y) MAX	8.11 cm (V) Aperture is also	Lead	PD-BMM-RAYT-0001

		10 cm (z)		8.11 cm (V) from center line		
DCM 1st crystal (MONO)	2551.96 cm (C)	3.5 cm (x) 5.0 cm (y) 4.5 cm (z) Can be rotated by max. angle of 70 degrees	N/A	Top Surface of crystal is 8.7 cm (V) from center line	Silicon	AHD6340 rev. 1
DCM 2nd crystal (MONO)	2561.26 cm (C)	3.5 cm (x) 6.0 cm (y) 2.0 cm (z) Can be rotated by max. angle of 70 degrees	N/A	Bottom surface of crystal is 11.7 cm (V) above center line	Silicon	AHD6340 rev. 1
Pink Beam stop	2621.91 cm (US)	11.2 cm (x) 11.2 cm (y) 5.85 cm(z)	H (DS) 4.625 cm (x) MAX V (DS) 2.143 cm (y) MAX H (US) 8.08 cm (x) MAX V (US) 5.62 cm (y) MAX	Center 12.0475 cm (V) above centerline	Cu-Cr-Zr	PD-BMM-RAYT-0001
Primary Brems. shield	2631.21 cm (US)	19.7 cm (x) 10.0 cm (y) 20.0 cm (z)	N/A	Bottom is 0.97 cm above centerline	Lead	PD-BMM-RAYT-0001
Secondary Brems. shield #2	2651.21 cm (US)	66.10 cm (x) 46.36 cm (y) 10.00 cm (z)	6.15 cm (x) MAX 3.10 cm (y) MAX	Lead is 16.18 cm above centerline Aperture is 12.35 cm (V) above centerline	Lead	PD-BMM-RAYT-0001
Inflange 4-blade slits	2687.06 cm (C)	2.5 cm (x) 2.5 cm (y) 0.28 cm (z)	N/A	12.48 cm above centerline	Copper	
Mirror 2	2847.30 cm (C)	3.0 cm (x) 9.0 cm (y) 110.0 cm (z) (rotated@ 3.5 mrad max)	N/A	Center of mirror 2 is 17.02 cm above centerline	Silicon	

Secondary Brems. shield #3 ALL simulations were performed without Brems. shield #3	2924.75 cm (US)	25.8 cm (x) 17.36 cm (y) 10 cm (z)	N/A	Bottom is 18.04 cm above centerline	Lead	PD-BMM-RAYT-0001
Mirror 3	3038.1 cm (C)	6.5 cm (x) 6.0 cm (y) 110 cm (z) (rotated@ 3.5 mrad max)	N/A	center of mirror3 is 17.5 cm above centerline	Silicon	
Shutter (PSH)	3148.3 cm (US)	12.5 cm (x) 15 cm (y) 3.8 cm (z)	6.0 cm (x) 3.0 cm (y)	13.87 cm above centerline	Tungsten	PD-COM-PSH-1000
Guillotine	3195.16 cm (US)	41 cm (x) 44 cm (y) 10 cm (z)	152.4 mm (6”) diameter	guillotine and aperture 9.69 cm above centerline	Lead	6-BM-A Guillotine
Hutch wall opening & collar square for 6-BM-A hutch	3205.16 cm (US)	Collar dimensions 44 cm (x) 44 cm (y) 1 cm (z)	22.3 cm diameter wall 15.24 cm diameter lead	9.69 cm (y) above centerline	Lead	Hutch wall and shielded pipe collar