NSLS-II TECHNICAL NOTE BROOKHAVEN NATIONAL LABORATORY	NUMBER **278**
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28ID1 - PDF Beamline Radiation Shielding Analysis	

1. Introduction

The high flux hard x-ray damping wiggler (DW100) located in cell 28-ID provides a synchrotron source for the X-ray Powder Diffraction (XPD) beamline and the Pair Distribution Function (PDF) beamline. The primary purpose of these beamlines is the quantitative characterization of the atomic structure of complex materials; not just carefully prepared ideal systems, but materials as they are actually used. The primary focus of the PDF beamline is high throughput, in-situ, and/or time resolved PDF studies of complex materials in different sample environments and in their real-life applications. The PDF user science program includes, but is not limited to, strongly correlated materials, thin films, batteries and fuel cells, catalysts, and energy related novel nanomaterials. The PDF beamline uses a side bounce monochromator (SBM), which accepts the straight-through white beam after the first crystal of the Double Laue Monochromator (DLM) and horizontally deflects the selected energies at a fixed angle of 5.8°. Figure 1 shows the layout of the 28-ID PDF/XPD beamlines.

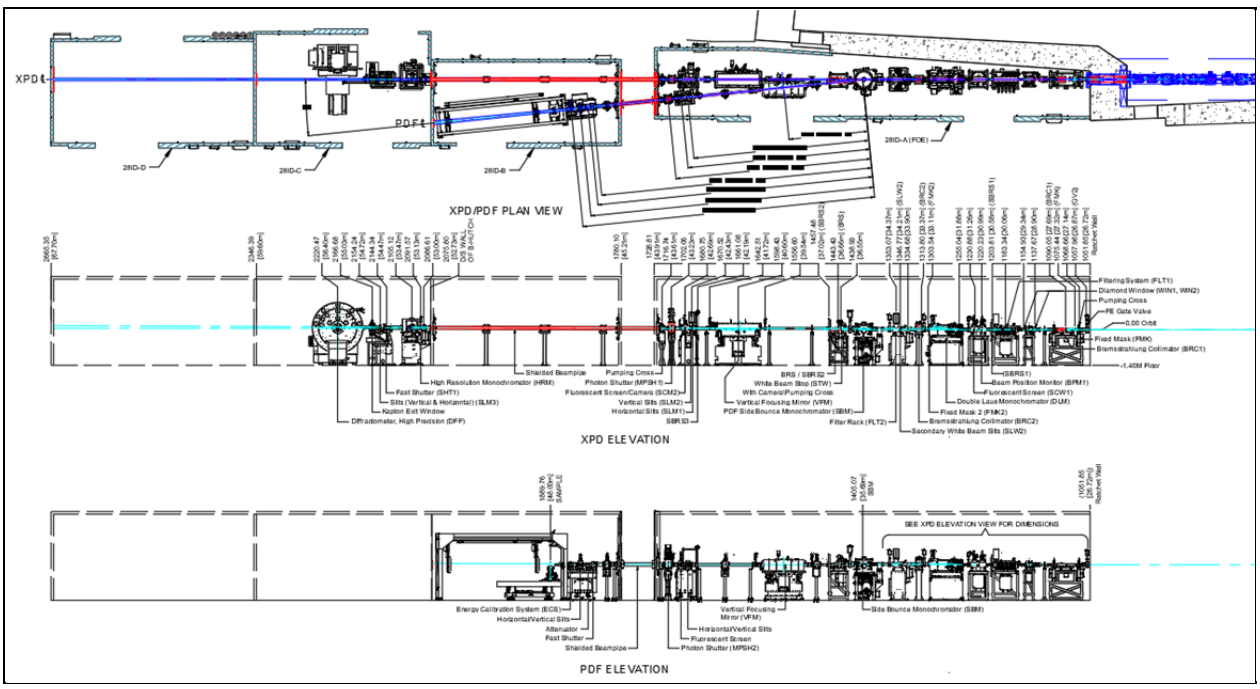


Figure 1: The plan and elevation view layout of 28-ID PDF/XPD Beamlines.

The FOE is made of lead with a 5 cm thick downstream wall, 1.9 cm thick lateral wall and 1.0 cm thick roof. The downstream wall has two lead guillotines, 5 cm thick and 40.64 cm x 55.88 cm in the horizontal and vertical directions. The beam transport pipe for the PDF beamline has

12.0 mm lead wrapped around the stainless steel pipe connecting the 28-ID-A (FOE) and PDF 28-ID-B enclosure. The 28-ID-B enclosure is also made of lead, with 4 mm thick upstream, downstream and lateral walls and a 3 mm thick roof. The white beam is centered along the horizontal (X) axis. It is monochromatized by the DLM crystals giving XPD monochromatic beam that is shifted by 5 cm in the +Y direction. The transmitted beam through the DLM is further monochromatized by the SBM crystal giving PDF monochromatic beam that is deflected horizontally by 5.8 degrees outboard. The resulting monochromatic beams exit the FOE through the lead shielded transport pipes and into the 28-ID-B enclosure. The XPD transport pipe continues into the 28-ID-C enclosure.

The NSLS-II Beamline Radiation Shielding Guidelines [1] state the following: 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/hr (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 at 30 cm from the lateral wall and roof of the FOE and less than 0.5 mrem/h on contact with the downstream wall of the FOE [2] during normal operations.

This report consists of two parts, one dealing with the gas bremsstrahlung (GB) as the source and the other dealing with the scattering of the synchrotron radiation (SR). Both of these cases are constant sources of radiation and the dose rates that are present represent the normal operating conditions. The radiation shielding analysis for the XPD transport pipe, 28-ID-C and 28-ID-D enclosures has been carried out in reference [3]. The radiation shielding analysis for 28-ID-A, the PDF Transport pipe and 28-ID-B enclosure is described in this report. Section 2 describes the FLUKA Monte Carlo radiation transport calculations for the GB as the source and section 3 deals with the synchrotron radiation as the source of radiation.

2. FLUKA Monte Carlo Radiation Transport Simulations

The radiation background in and around the 28-ID-A (FOE) enclosure due to the GB produced in the long straight section of the 28-ID PDF/XPD beamlines, is modeled with the FLUKA Monte Carlo code. The source of GB is the long straight section in the storage ring where the primary electron beam interacts with the residual gas molecules in the vacuum chamber. The GB

spectrum extends up to the primary electron energy of 3 GeV and is a constant source of radiation. When the front end safety shutters and photon shutter are open, it enters the FOE and interacts with the beamline components inside the FOE producing an electromagnetic cascade that results in a radiation environment outside of the FOE.

2.1. FLUKA Model

For the radiation transport simulation, the important radiation safety components are modeled in the geometry as shown in Figures 2. The coordinate system is consistent with the one used in NSLS-II with the +Z axis as the beam direction, +Y axis as the vertical direction and +X pointing outboard. The FOE and the components inside it are based on the information in Appendix A. The radiation safety components are the two fixed masks (FMK1 and FMK2) approximated as copper in this analysis, two bremsstrahlung collimators (BRC1 and BRC2) made of lead and tungsten respectively, three scattered bremsstrahlung shields (SBRS1, SBRS2, SBRS3) made of lead, a white beam stop (STW) modeled as copper, a primary bremsstrahlung stop (BRS) made of lead, the photon shutters (PSH) for the XPD and PDF branch modeled as layers of copper, tungsten and stainless steel, and the downstream wall guillotine made of lead. The other beamline components that were included in the geometry are: 2 diamond Windows (WIN 1&2), 5 SiC filters (FLT1), a Fluorescent Screen Copper Holder (SCW1), Double Laue Monochromator (DLM) Silicon Crystals, Copper White beam Slits (SLW2), a Side Bounce Monochromator (SBM) Silicon Crystal, and a Vertical Focusing Mirror (Silicon) for the XPD and PDF beamlines.

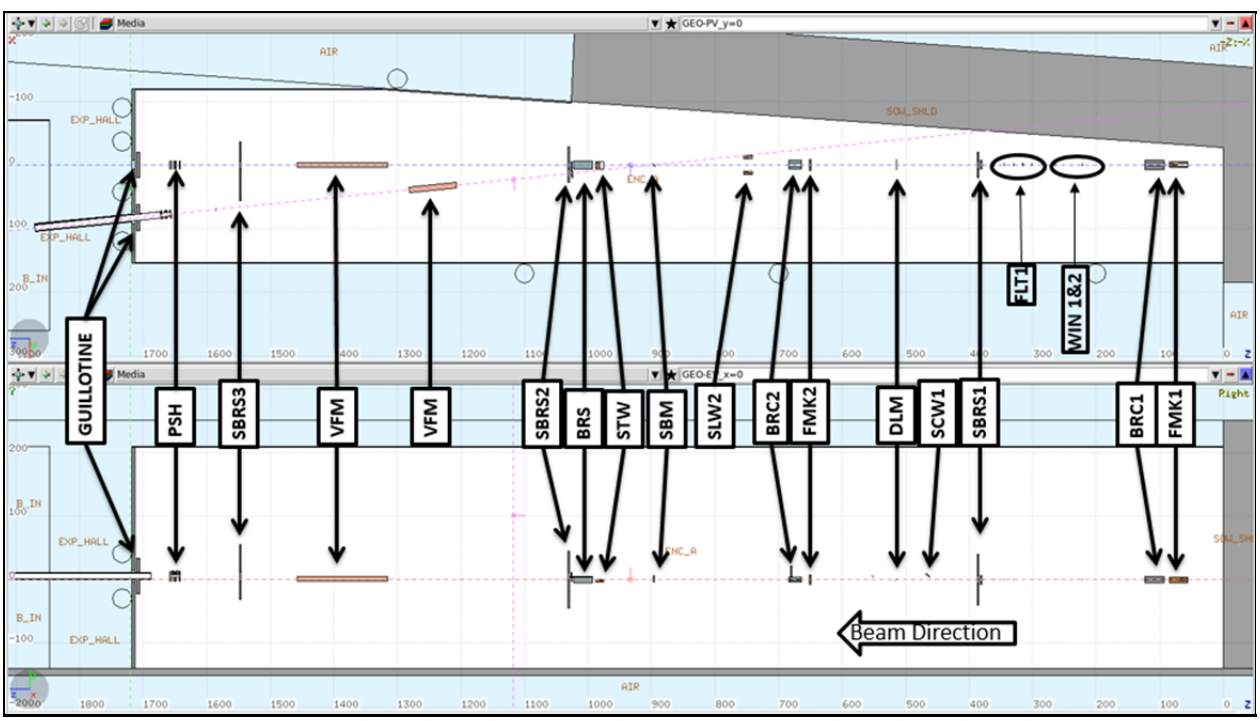


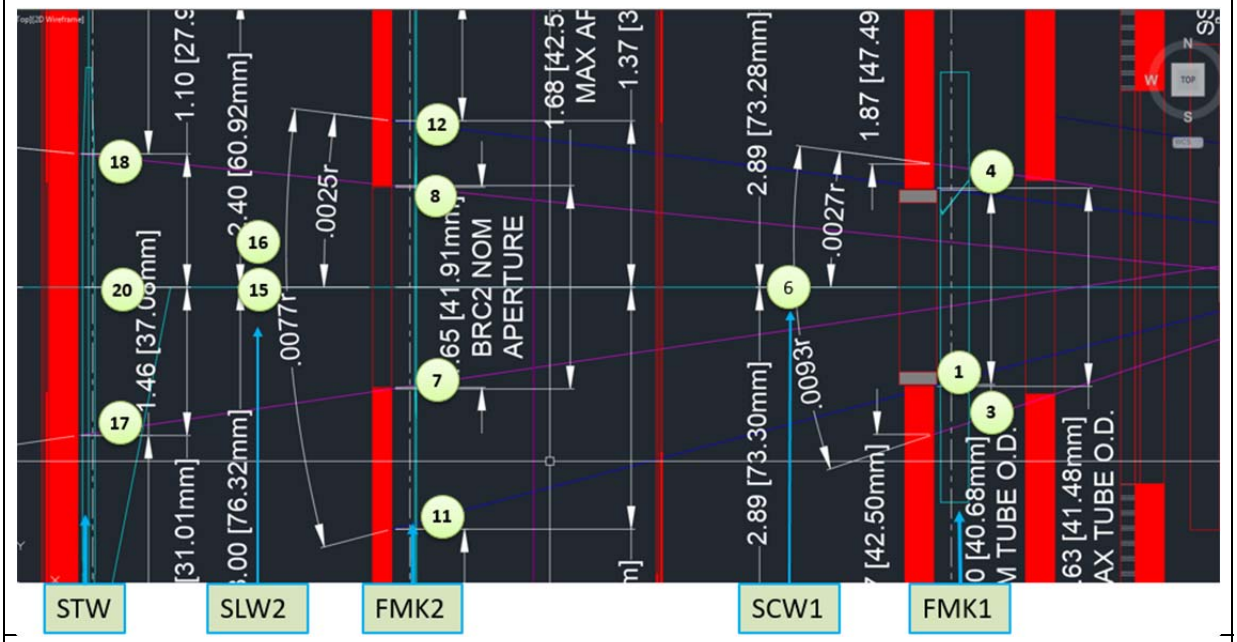
Figure 2: The plan and the elevation view of the 28ID-A (FOE) and the beamlines components modeled for FLUKA simulations.

2.2. Beam Conditions

The source of radiation is the GB spectrum that extends up to 3 GeV is obtained from a source routine, which samples from a 1/E energy spectrum. Twenty one beam loss points are identified from the 28-ID-PDF/XPD beamline ray trace (Figure 3) and are listed here with the X and Y coordinates used in the FLUKA simulations. The full GB power is assumed to be incident on all these locations. The total ambient dose equivalent rates are estimated in a three dimensional mesh by (USRBIN in FLUKA) scoring the fluence and folding them with the fluence to ambient dose equivalent conversion coefficients. All of the results given in these sections are on contact with the shield wall and in units of mrem/h, normalized to 17μW bremsstrahlung power. This is the GB power generated by a 500 mA electron beam of 3 GeV striking the residual air in the 15.5 m long straight section, when the vacuum is 10^{-9} Torr. The following simulations were performed to confirm the adequacy of the beamline enclosure shielding, transport pipes and radiation safety components:

1. On the aperture of FMK1, outboard side (1.76, 0.0) cm
2. On the aperture of FMK1, top side (0.0, 0.38) cm
3. On FMK1, front face outboard side (2.44, 0.0) cm, @ 6.6mrad incidence
4. On FMK1, front face inboard side (-2.32, 0.0) cm @ -2.7mrad incidence
5. On FMK1, front face top side (0.0, 0.88) cm @ 0.1mrad incidence
6. On the SCW1 (Screen Copper Holder) (0.0, 0.0) cm
7. On the aperture of FMK2, outboard side (2.05, 0.0) cm @ 2.96mrad incidence
8. On the aperture of FMK2, inboard side (-2.08, 0.0) cm @ -2.02mrad incidence
9. On the aperture of FMK2, top side (0.0, 0.53) cm @ 0.7mrad incidence
10. On the aperture of FMK2, bottom side (0.0, -0.53) cm @ -0.7mrad incidence
11. On FMK2, front face outboard side (3.6, 0.0) cm, @ 5.26mrad incidence
12. On FMK2, front face inboard side (-2.8, 0.0) cm, @ -2.48mrad incidence
13. On FMK2, front face top side (0.0, 0.94) cm @ 0.9mrad incidence
14. On FMK2, front face bottom side (0.0,- 0.94) cm @ -0.9mrad incidence
15. On SLW2 (White Beam Slits), closed position (-2.0, 0.0) cm
16. On SLW2 (White Beam Slits), open position (-3.0, 0.0) cm
17. On STW (White Beam Stop), outboard side (3.05, 0.0) cm, @ 2.96mrad incidence
18. On STW (White Beam Stop), inboard side (-2.75, 0.0) cm, @ -2.02mrad incidence
19. On STW (White Beam Stop), bottom side (-0.75, 0.0) cm, @ -0.66mrad incidence
20. On STW (White Beam Stop), center (0.0, 0.0) cm, @ normal incidence
21. On BRS, front face top side (0.0, 0.75) cm @ 0.66mrad incidence

(a) Horizontal Bremsstrahlung Ray Tracings



(b) Vertical Bremsstrahlung Ray Tracings

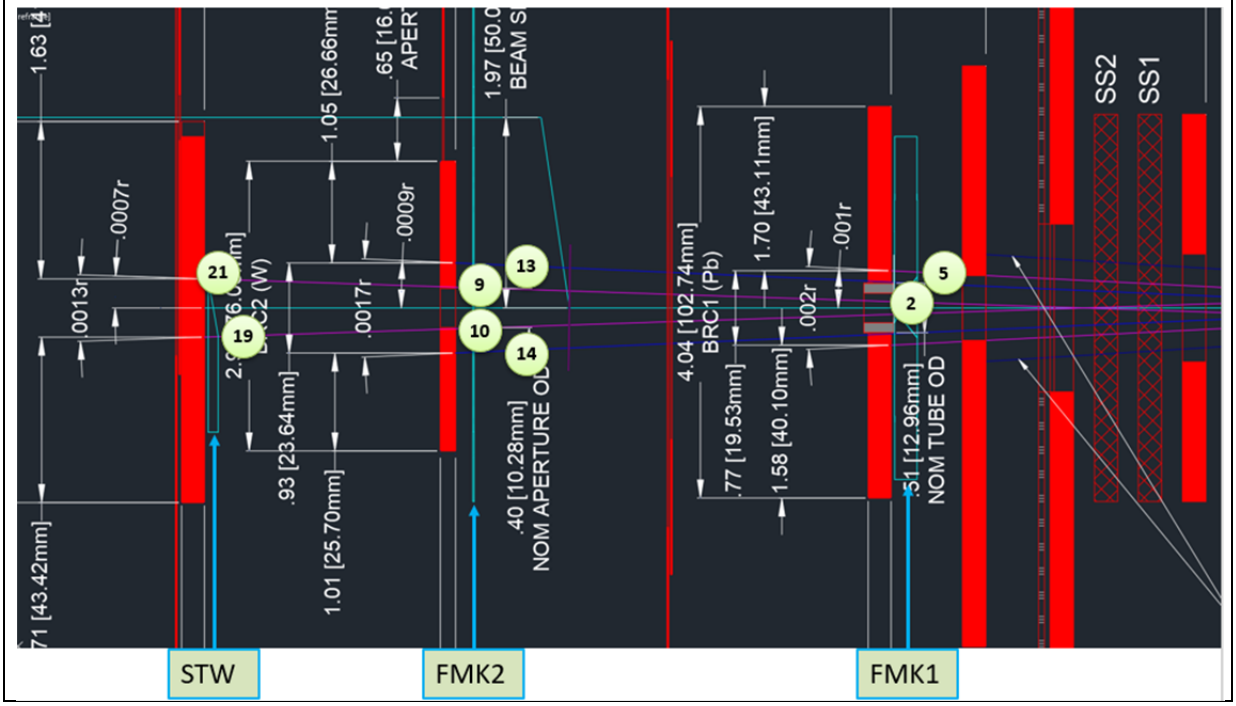


Figure 3: The horizontal (top) and vertical (bottom) Bremsstrahlung ray trace with the beam loss points shown. Beam direction is from right to left.

2.3. Results and Discussions

The GB power is taken as 17 µW, which is generated by 500 mA, 3 GeV electron beam in a 15.5 m long straight section with the vacuum better than 10^{-9} Torr. The total ambient dose equivalent rates (mrem/h) for the 21 loss points described in section 2.2 are shown in the same order in Figures 4a-24a. In these figures, the upper plots show the horizontal view (at y=0) and the lower plots show the vertical views (at x=0). The total ambient dose rates on contact and as applicable 30 cm away from the walls are given in Figures 4b-24b to show the details of the spatial dose rate distributions. Table 1 shows the summary of the results from these figures.

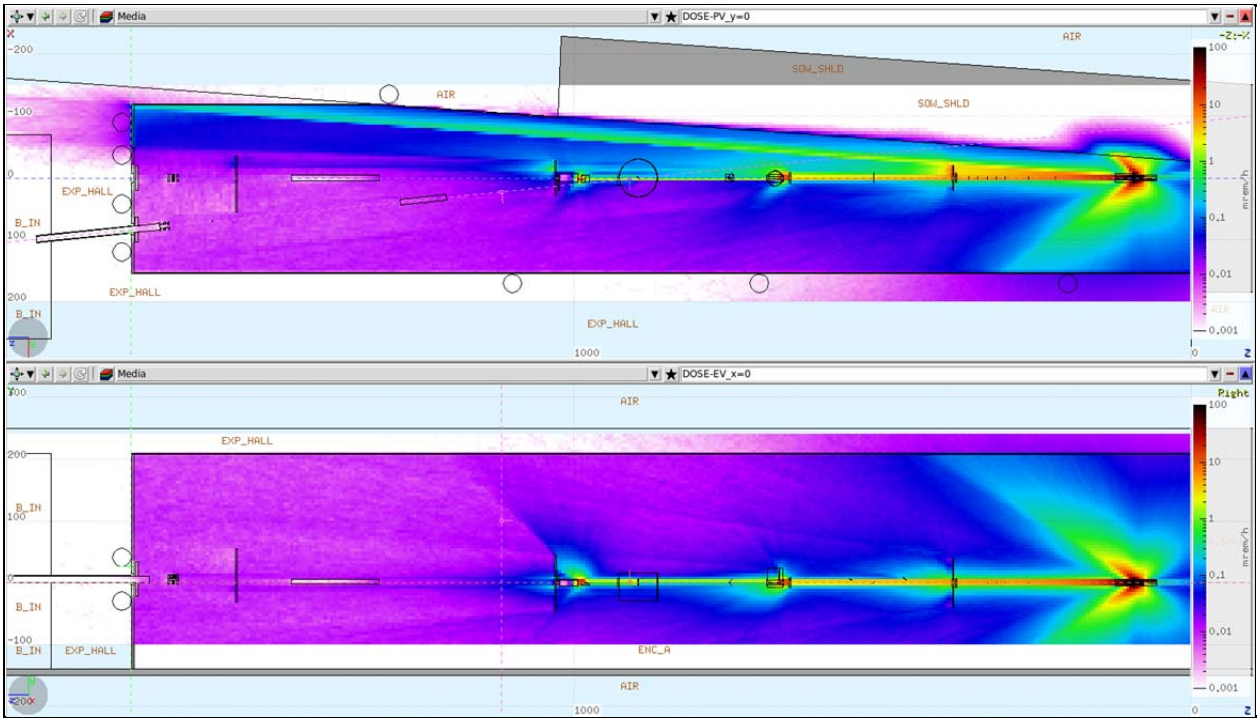


Figure 4a: Total ambient dose equivalent rates in and around the FOE when the GB strikes near the aperture FMK1 on the outboard side (case 1). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

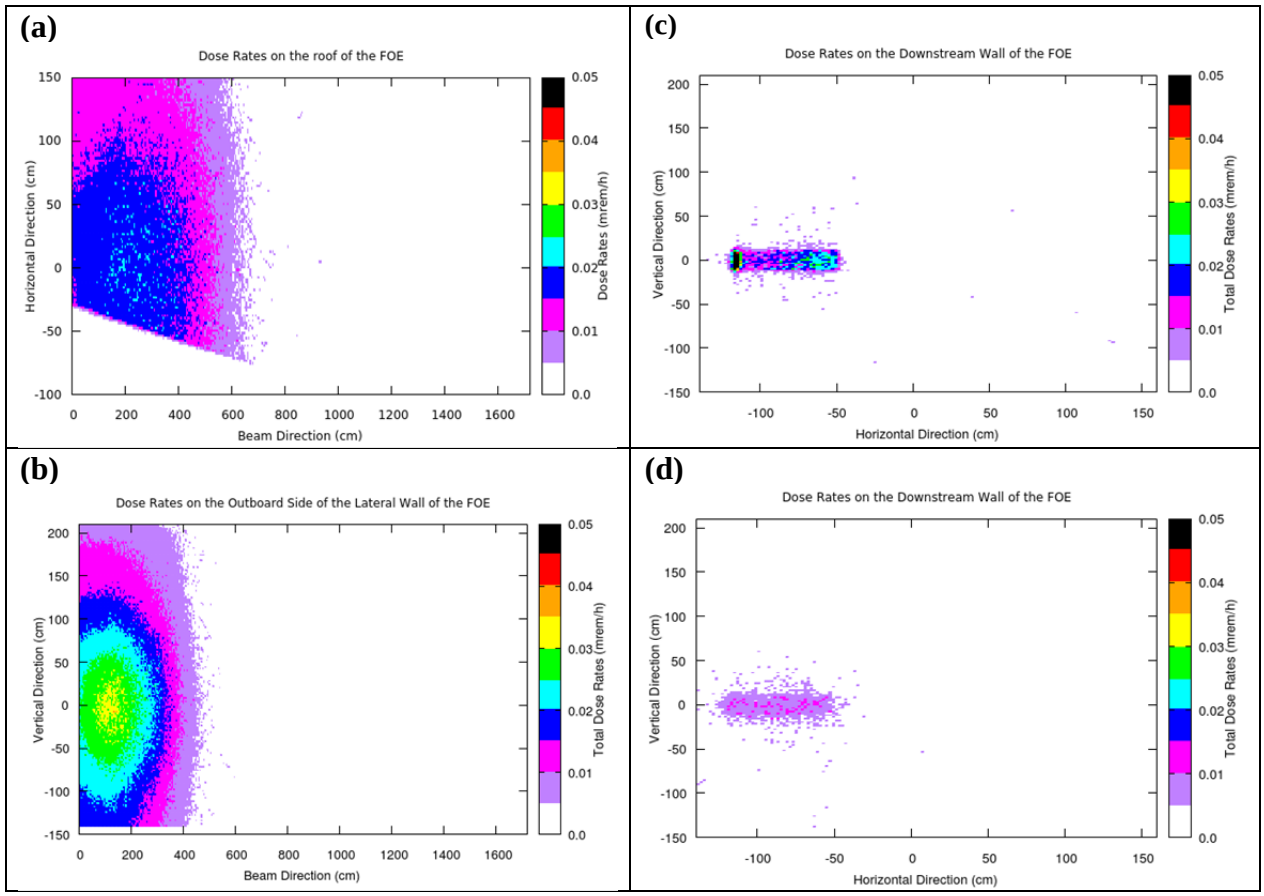


Figure 4b: Total ambient dose rate distributions (mrem/h) on contact with the roof, (a), lateral wall (b), downstream wall (c) and at 30 cm distance from the downstream wall (d) when the beam is incident near the aperture of FMK1 on the outboard side (case 1).

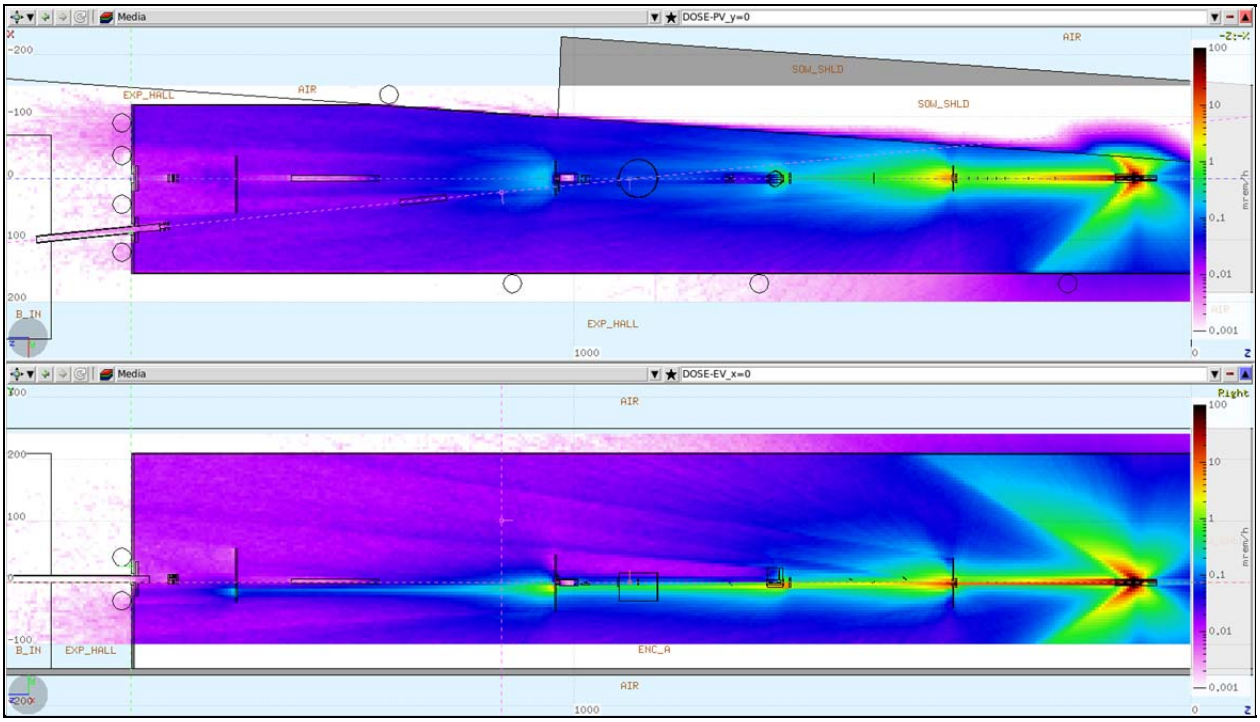


Figure 5a: Total ambient dose equivalent rates in and around the FOE when the GB strikes near the aperture of FMK1 on the top side (case 2). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

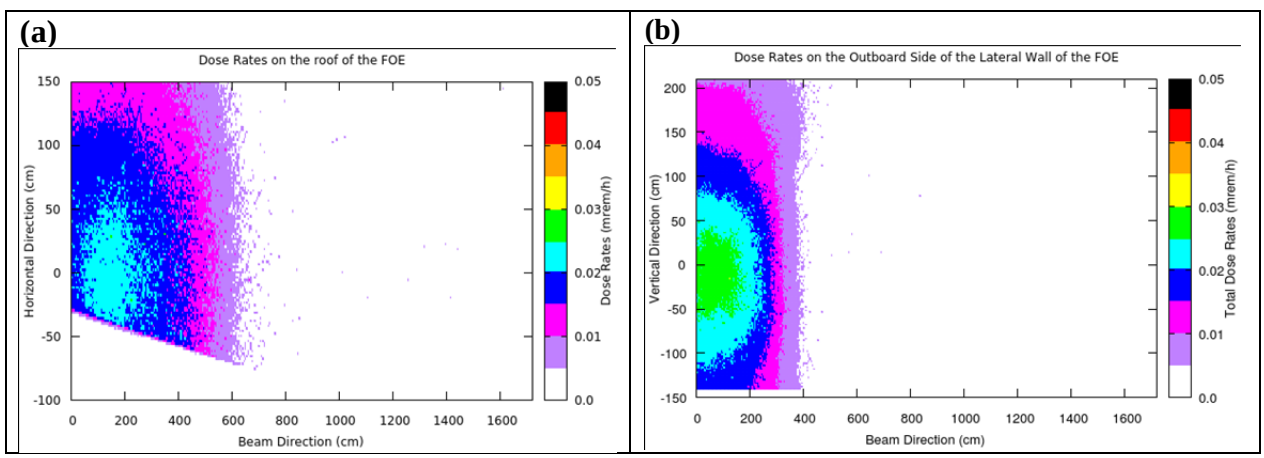


Figure 5b: Total ambient dose rate distributions (mrem/h) on contact with the roof, (a) and lateral wall (b) when the beam is incident near the aperture of FMK1 on the top side (case 2).

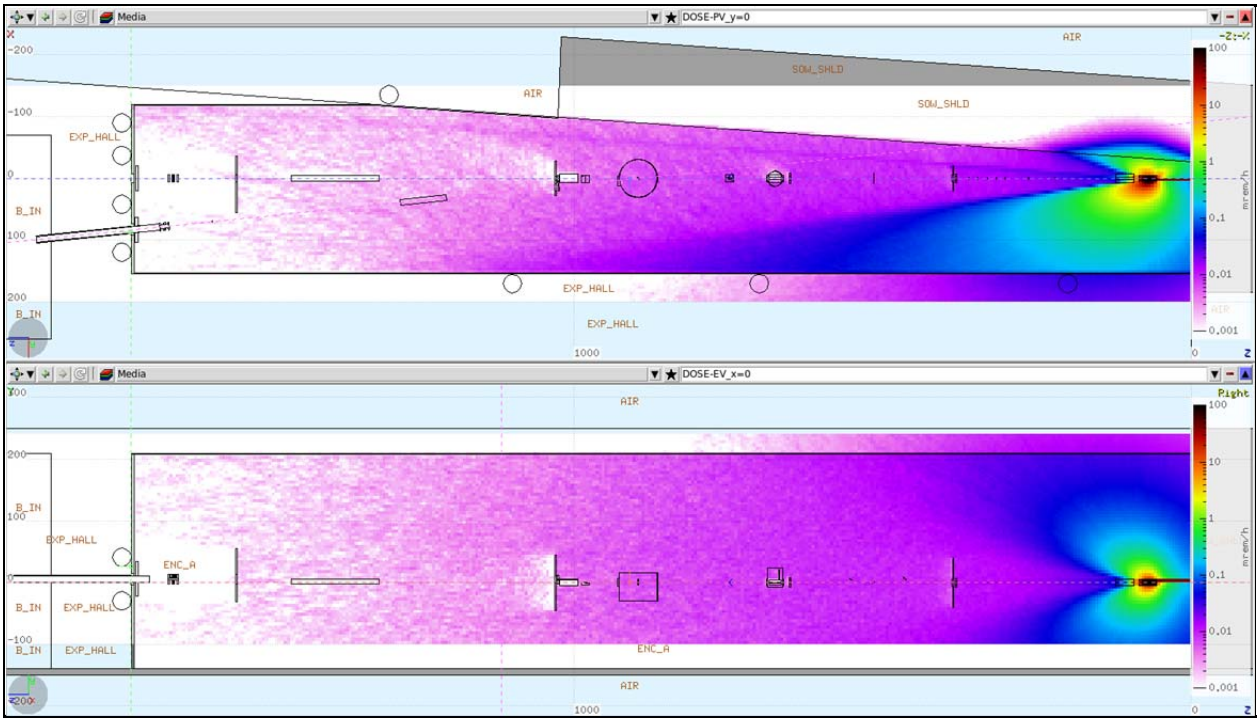


Figure 6a: Total ambient dose equivalent rates in and around the FOE when the GB strikes the outboard side of the front face of FMK1 (case 3). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

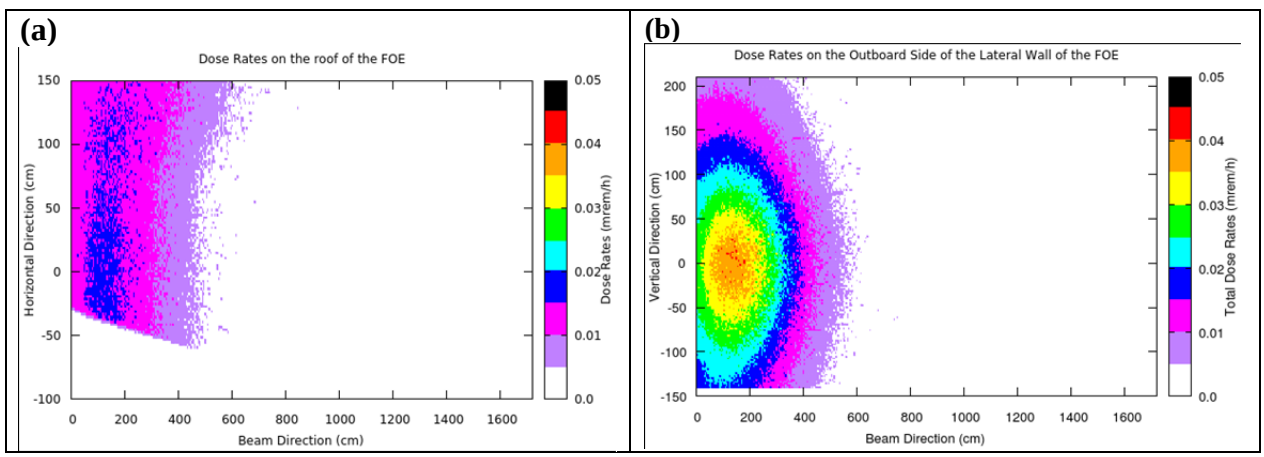


Figure 6b: Total ambient dose rate distributions (mrem/h) on contact with the roof (a) and lateral wall (b) when the beam is incident on the outboard side of the front face of FMK1 (case 3).

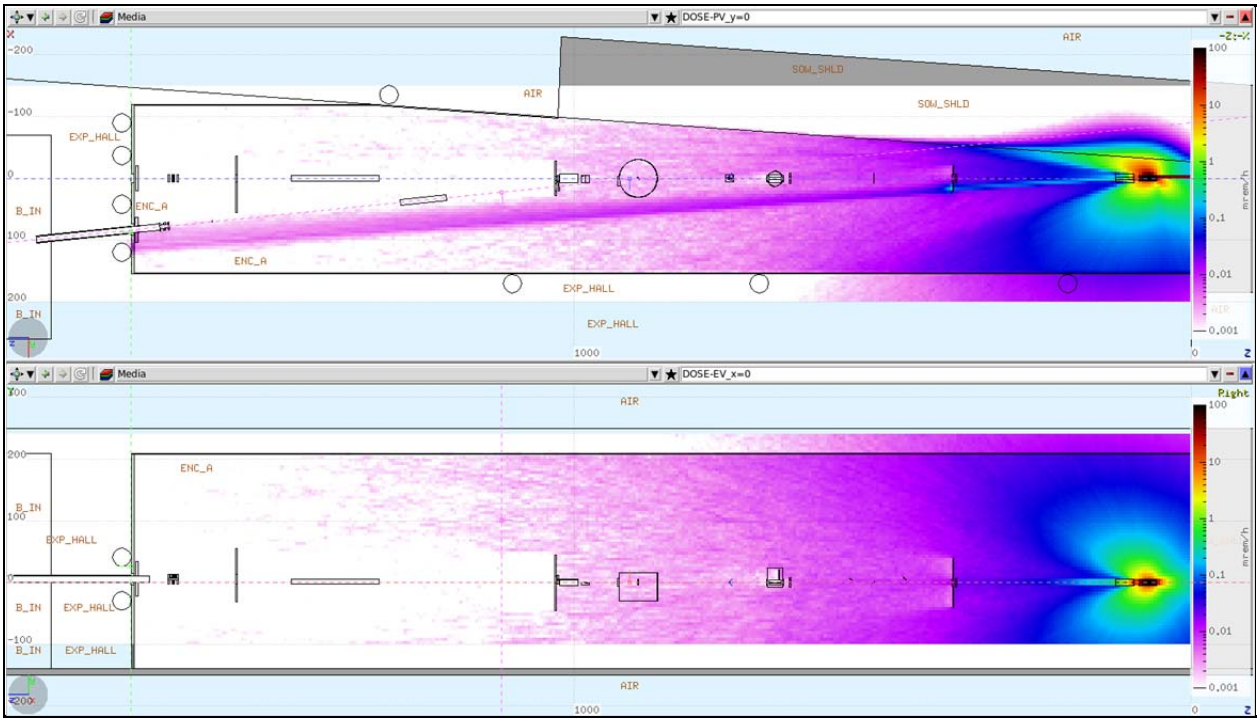


Figure 7a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes the inboard front face of FMK1 (case 4). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

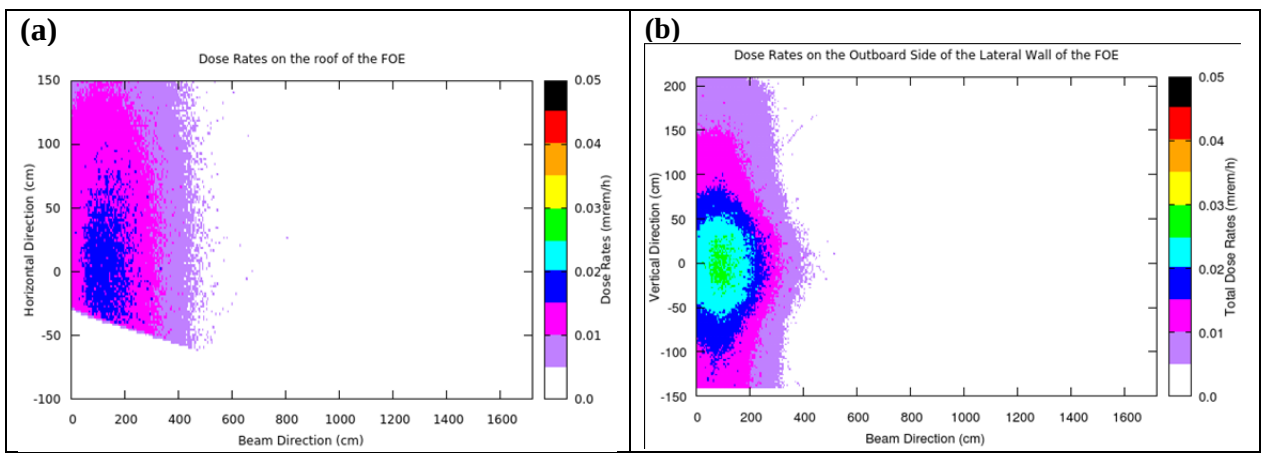


Figure 7b: Total ambient dose rate distributions (mrem/h) on contact with the roof (a) and lateral wall (b) when the beam is incident on the inboard side of the front face of FMK1 (case 4).

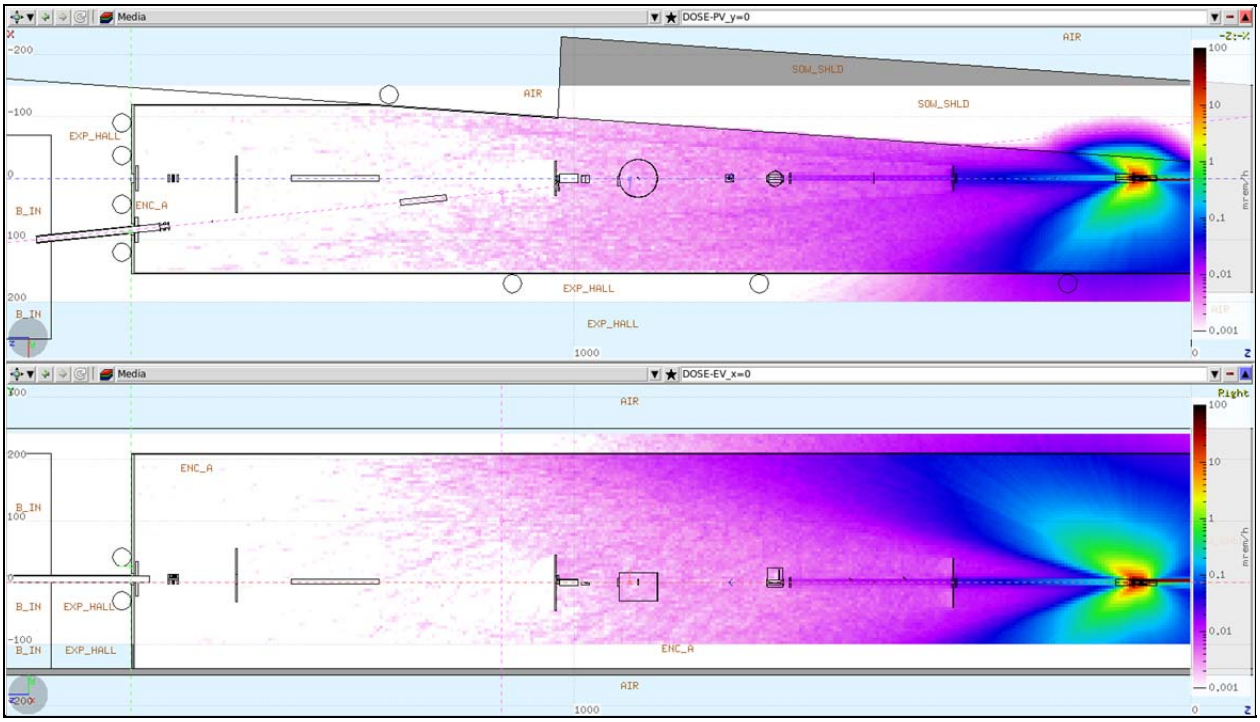


Figure 8a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes the topside of the front face of FMK1 (case 5). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

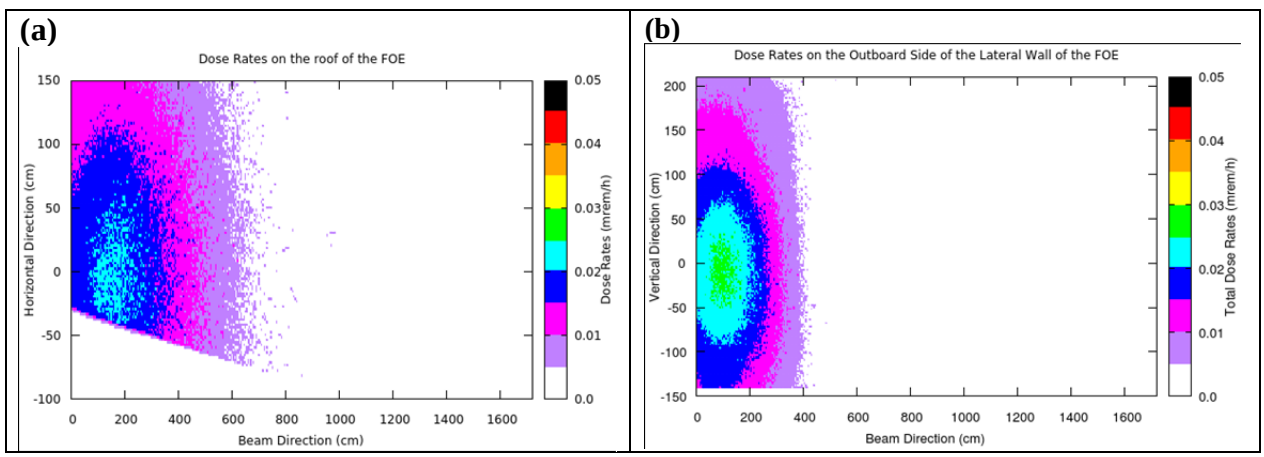


Figure 8b: Total ambient dose rate distributions (mrem/h) on contact with the roof (a) and lateral wall (b) when the beam is incident on the top side of the front face of FMK1 (case 5).

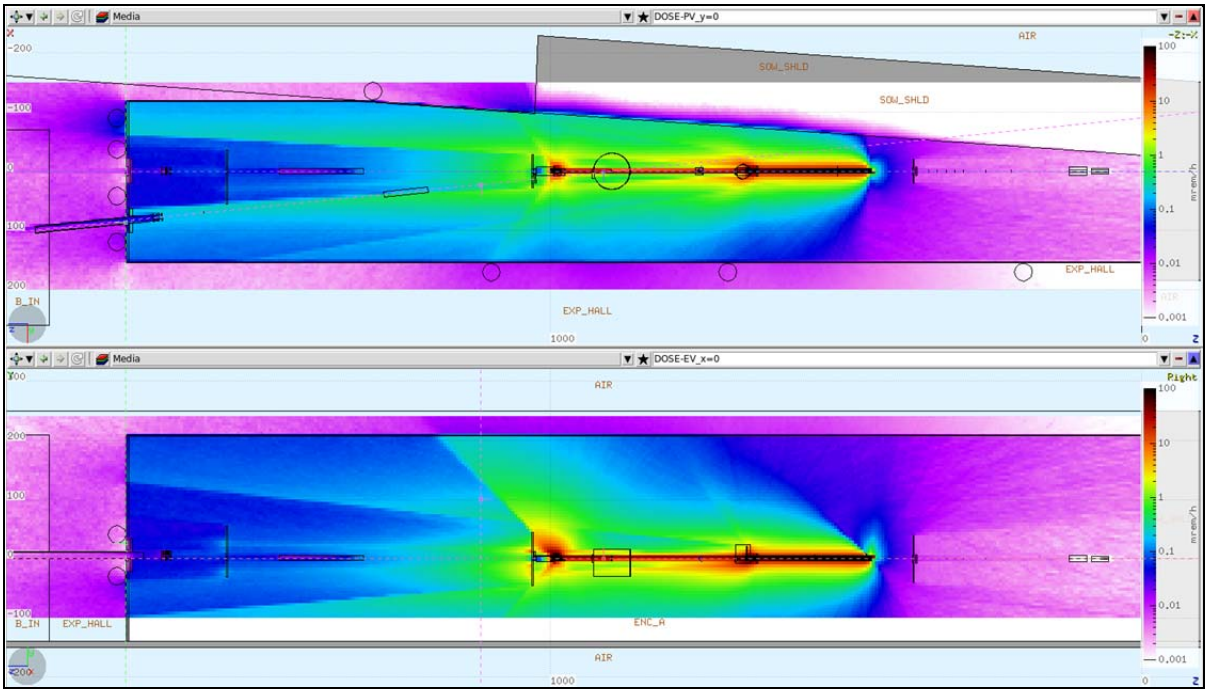


Figure 9a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes the copper holder of fluorescent screen (case 6). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

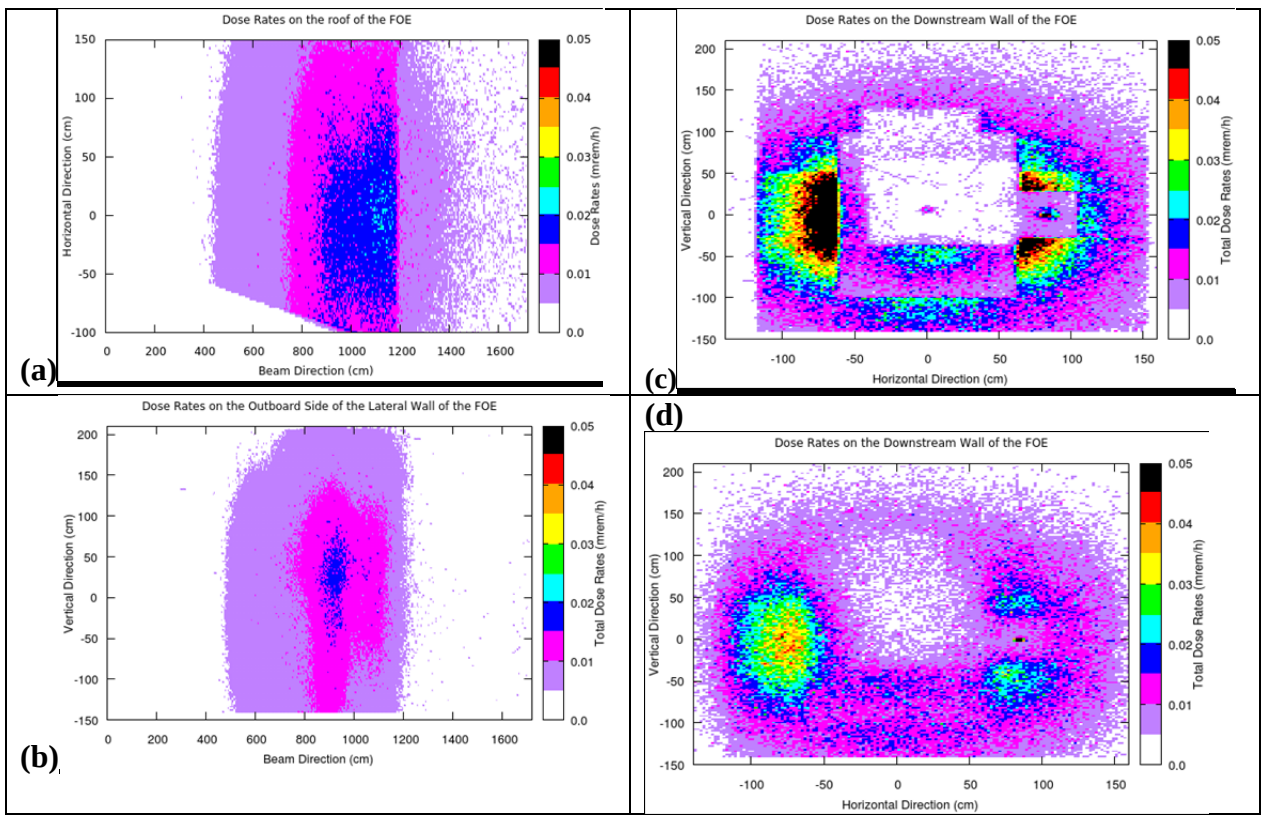


Figure 9b: Total ambient dose rate distributions (mrem/h) on contact with the roof, (a), lateral wall (b), downstream wall (c) and at 30 cm distance from the downstream wall (d) when the beam is incident on the copper holder of the fluorescent screen (case 6).

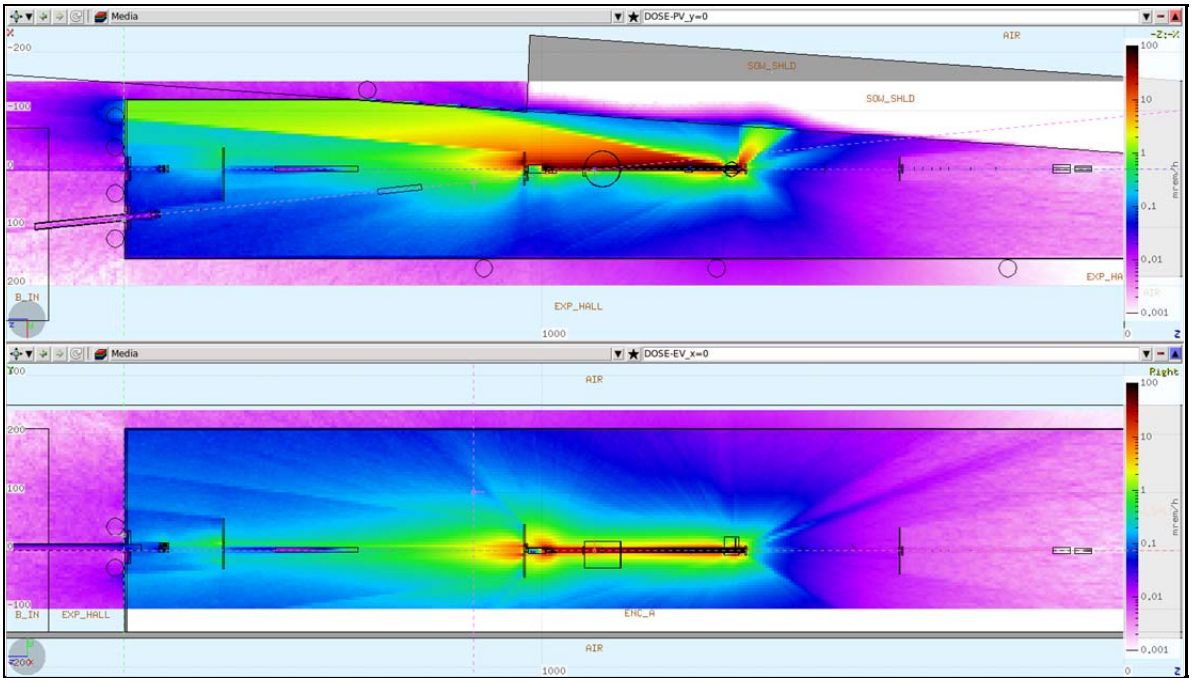


Figure 10a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes near the aperture of FMK2 on the outboard side (case 7). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

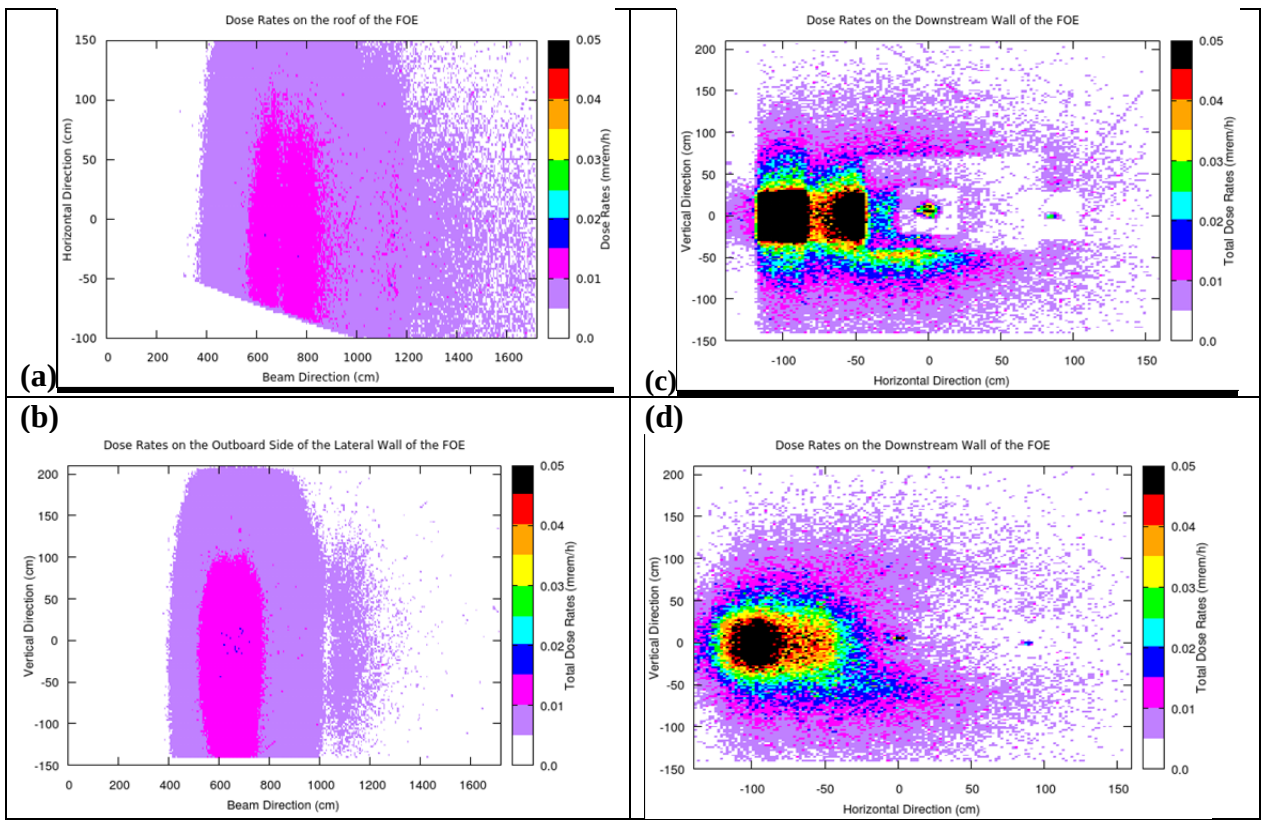


Figure 10b: Total ambient dose rate distributions (mrem/h) on contact with the roof, (a), lateral wall (b), downstream wall (c) and at 30 cm distance from the downstream wall (d) when the beam is incident near the aperture of FMK2 on the outboard side (case 7).

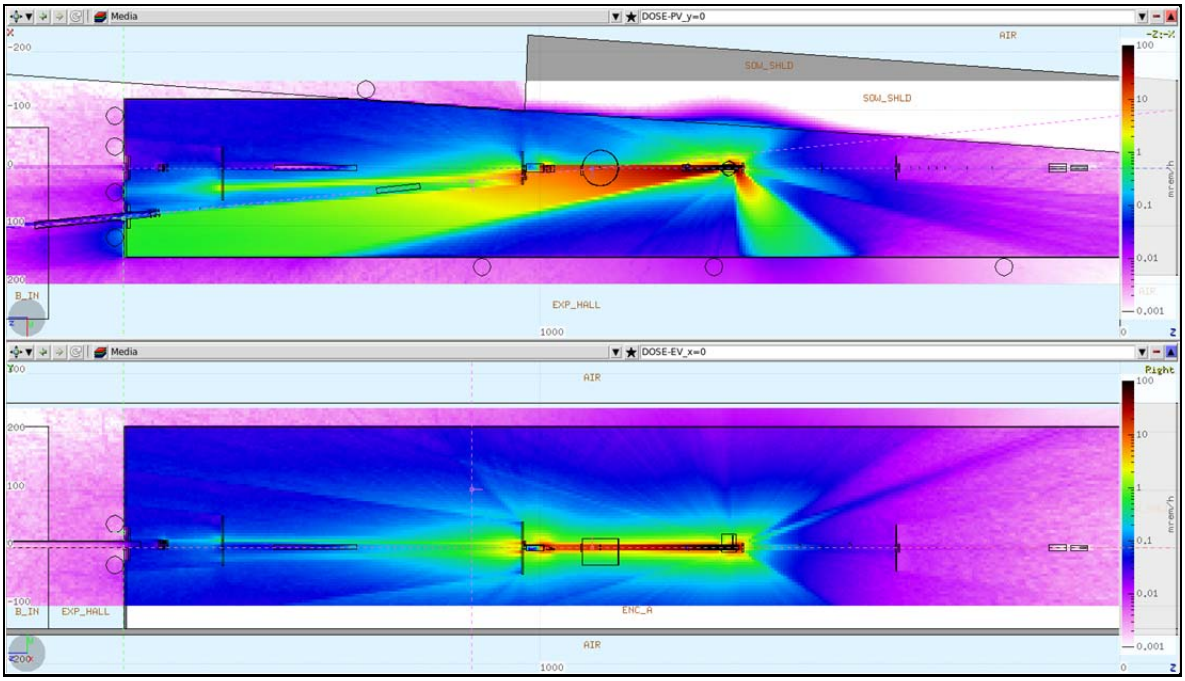


Figure 11a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes near the aperture of FMK2 on the inboard side (case 8). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

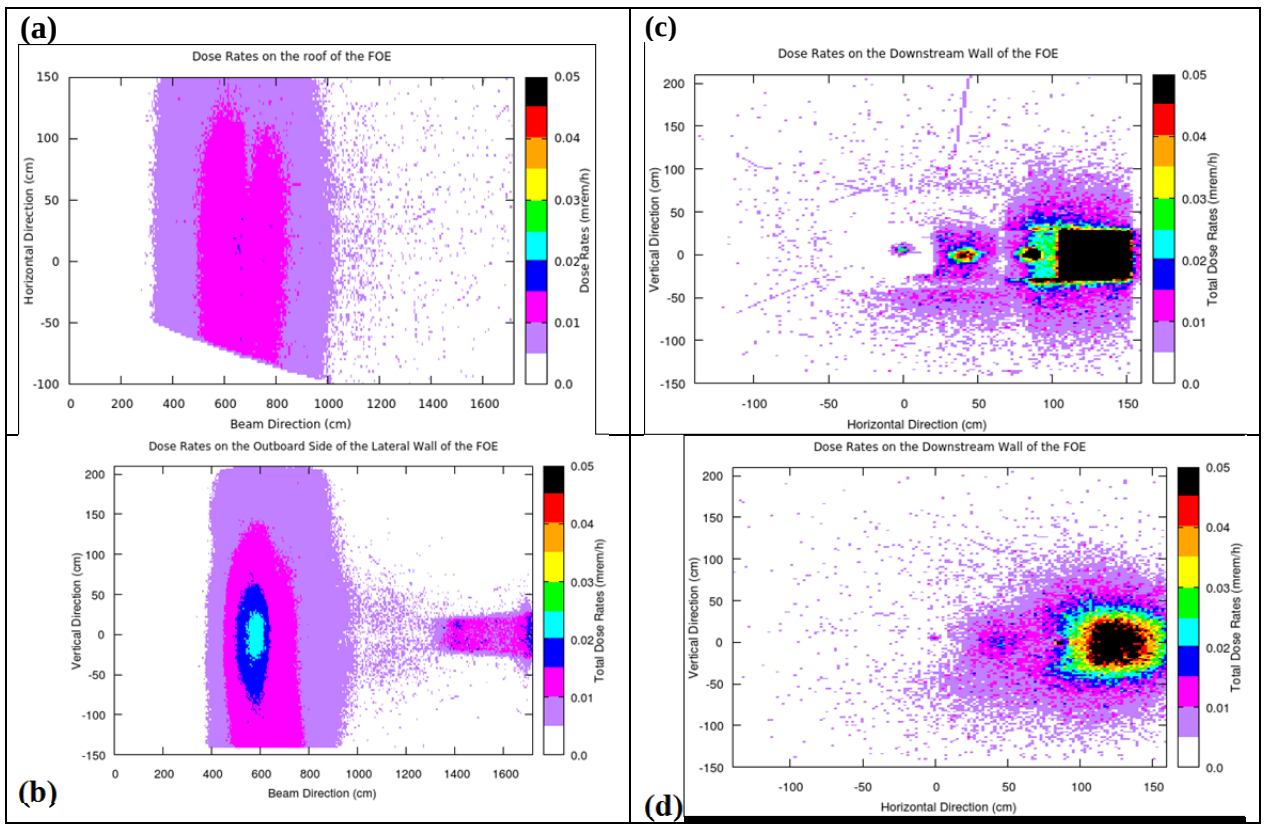


Figure 11b: Total ambient dose rate distributions (mrem/h) on contact with the roof, (a), lateral wall (b), downstream wall (c) and at 30 cm distance from the downstream wall (d) when the beam is incident near the aperture of FMK2 on the inboard side (case 8).

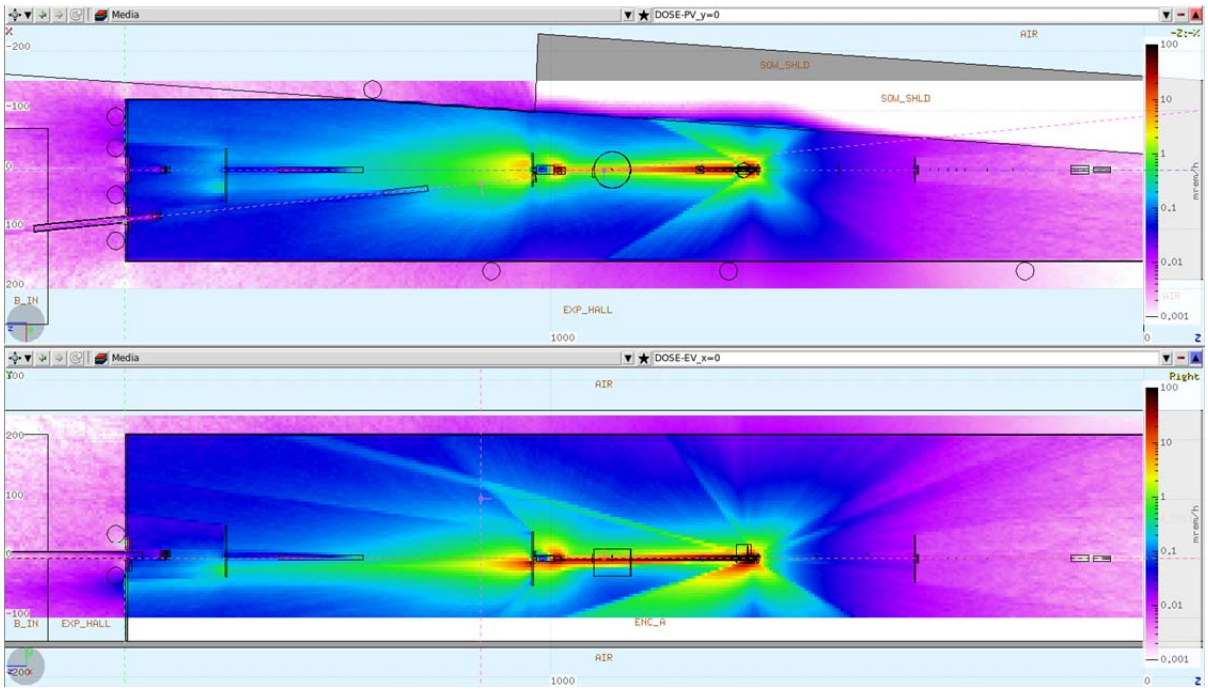


Figure 12a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes near the aperture of FMK2 on the top side (case 9). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

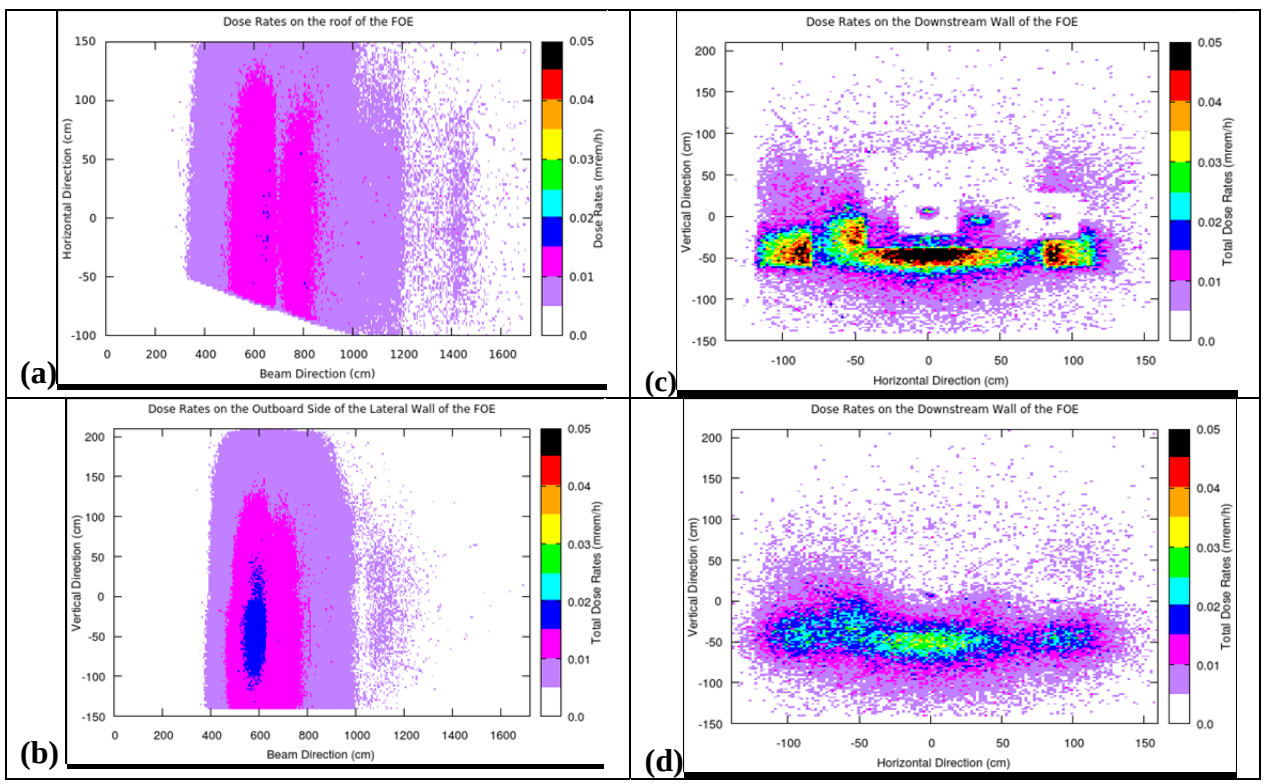


Figure 12b: Total ambient dose rate distributions (mrem/h) on contact with the roof, (a), lateral wall (b), downstream wall (c) and at 30 cm distance from the downstream wall (d) when the beam is incident near the aperture of FMK2 on the top side (case 9).

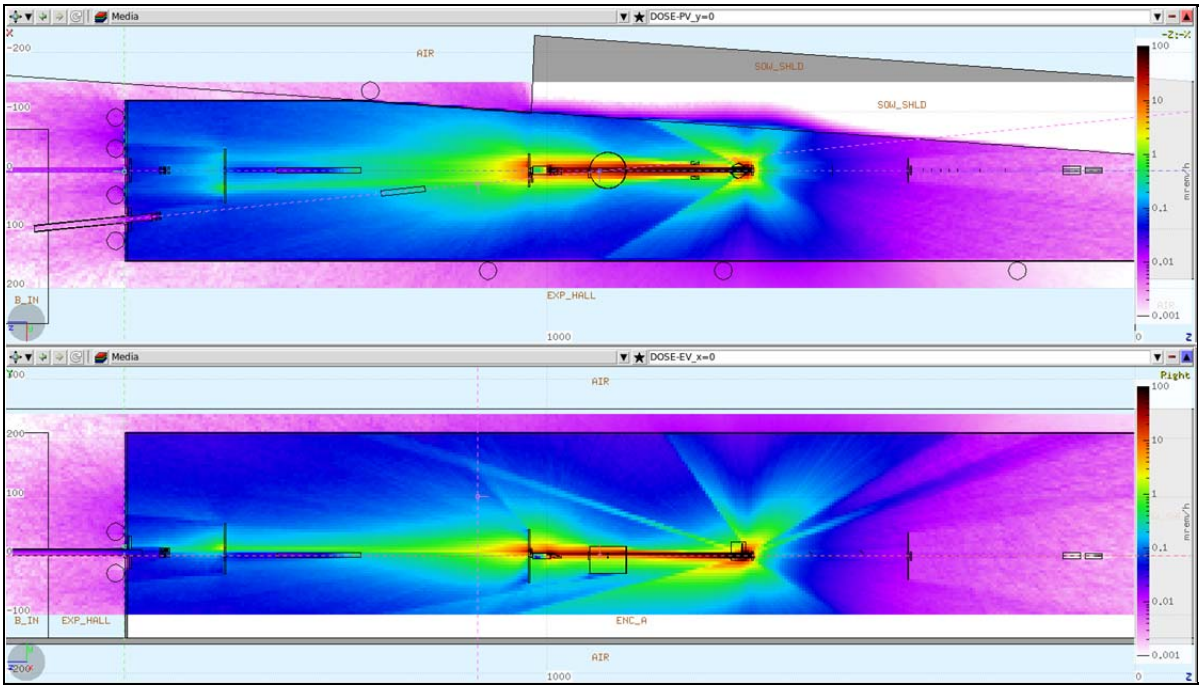


Figure 13a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes near the aperture of FMK2 on the bottom side (case 10). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

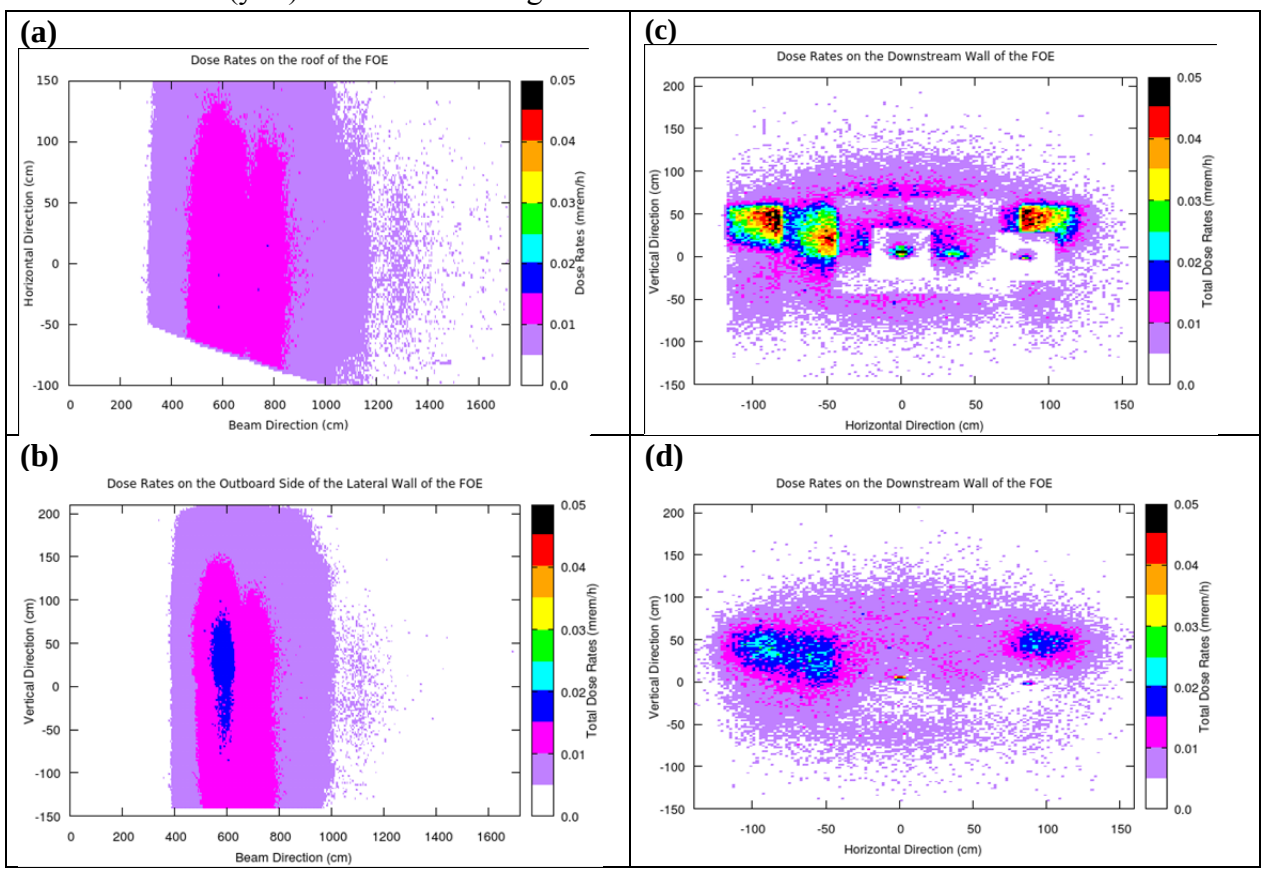


Figure 13b: Total ambient dose rate distributions (mrem/h) on contact with the roof, (a), lateral wall (b), downstream wall (c) and at 30 cm distance from the downstream wall (d) when the beam is incident near the aperture of FMK2 on the bottom side (case 10).

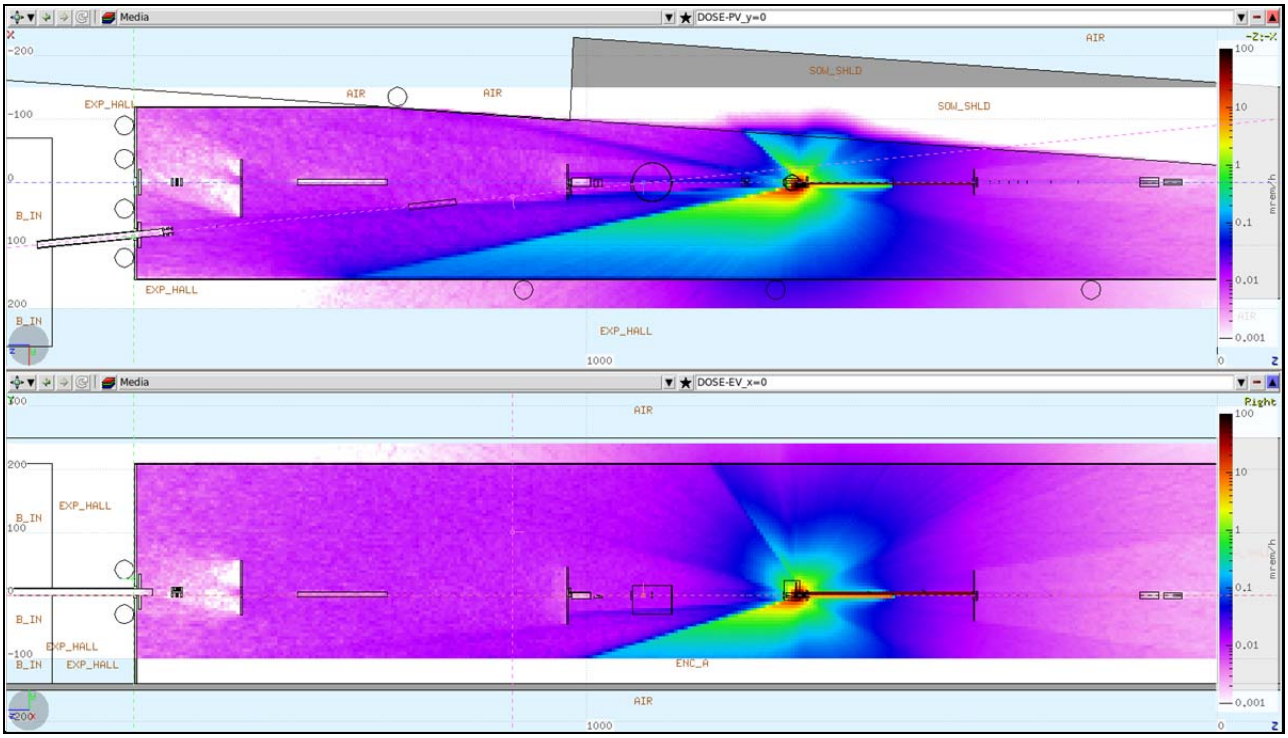


Figure 14a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes the front face outboard side of FMK2 (case 11). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

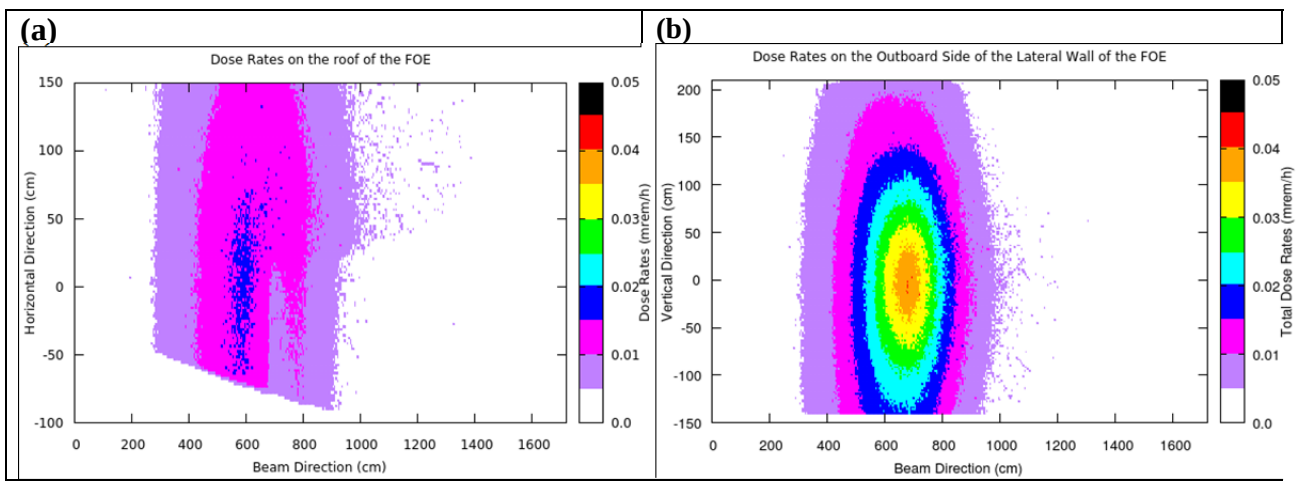


Figure 14b: Total ambient dose rate distributions (mrem/h) on contact with the roof (a) and lateral wall (b) when the beam is incident on the outboard side of the front face of FMK2 (case 11).

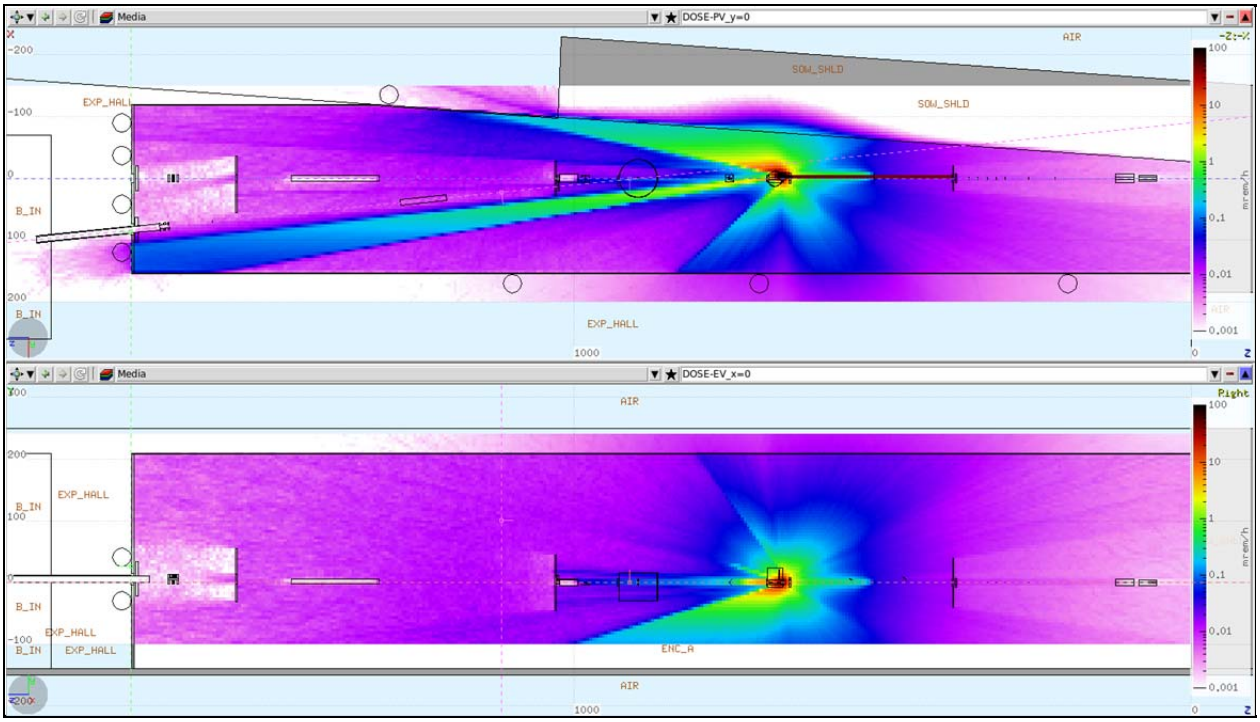


Figure 15a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes the front face inboard side of FMK2 (case 12). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

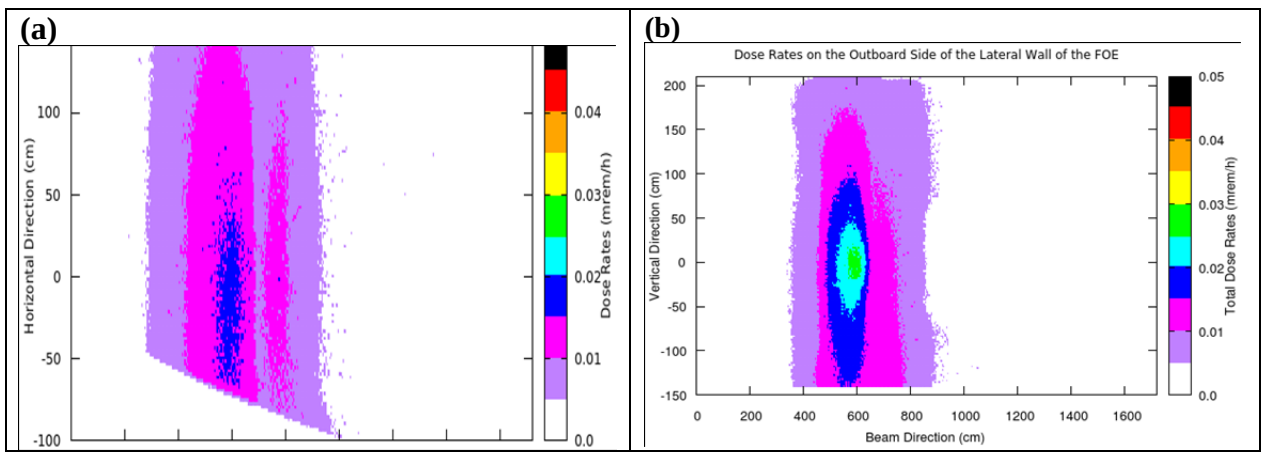


Figure 15b: Total ambient dose rate distributions (mrem/h) on contact with the roof (a) and lateral wall (b) when the beam is incident on the inboard side of the front face of FMK2 (case 12).

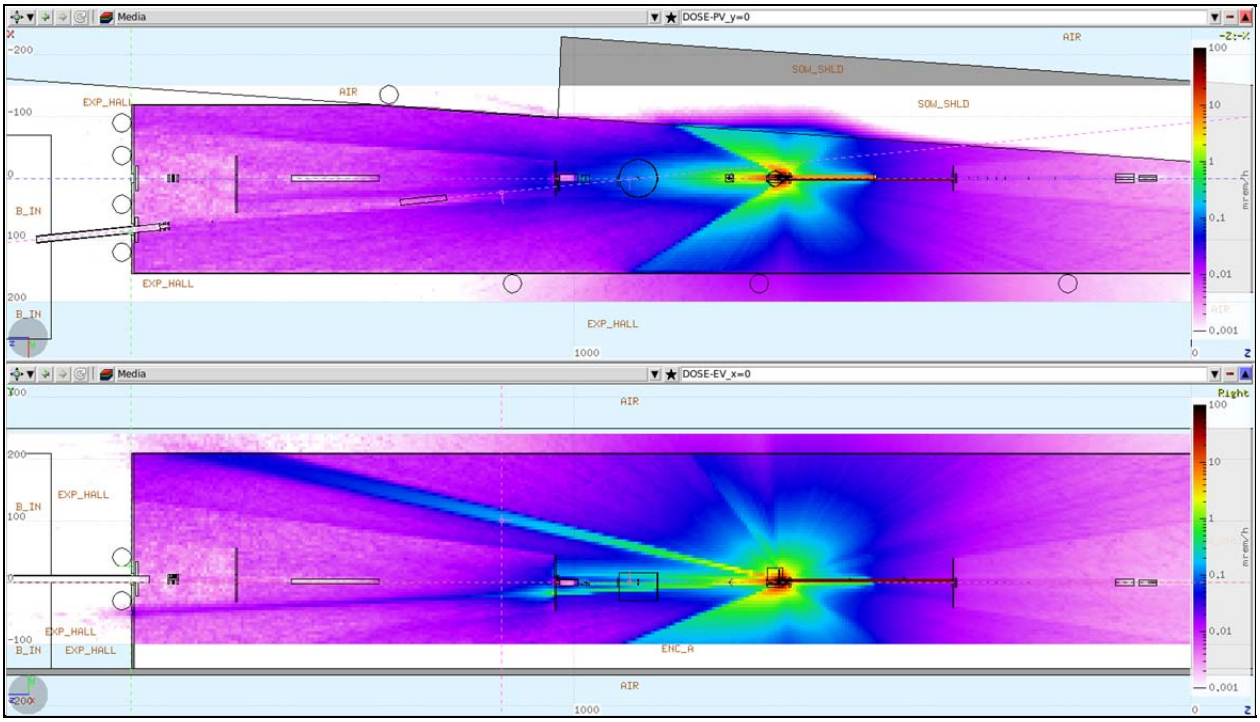


Figure 16a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes the front face top side of FMK2 (case 13). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

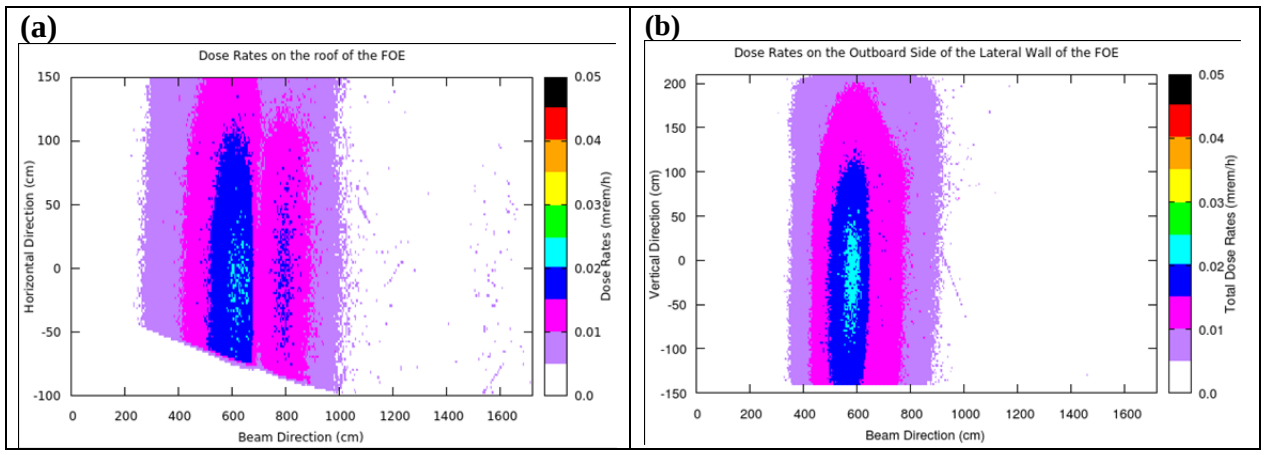


Figure 16b: Total ambient dose rate distributions (mrem/h) on contact with the roof (a) and lateral wall (b) when the beam is incident on the top side of the front face of FMK2 (case 13).

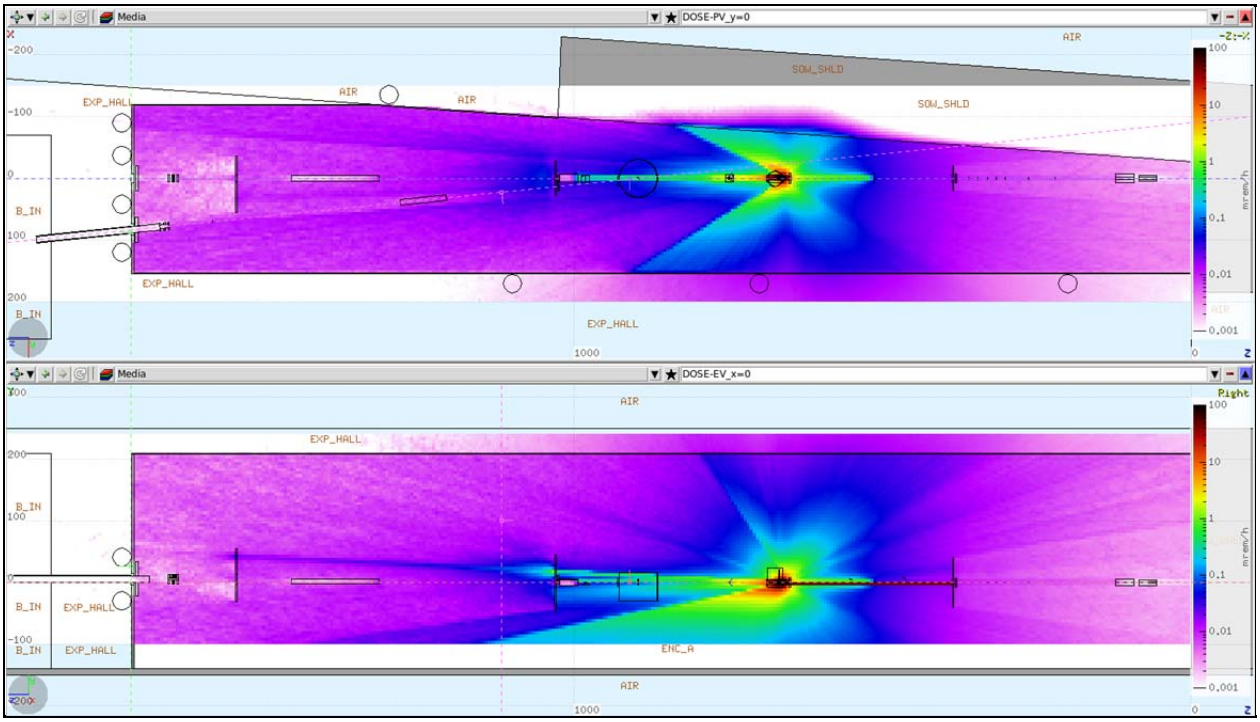


Figure 17a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes the front face bottom side of FMK2 (case 14). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

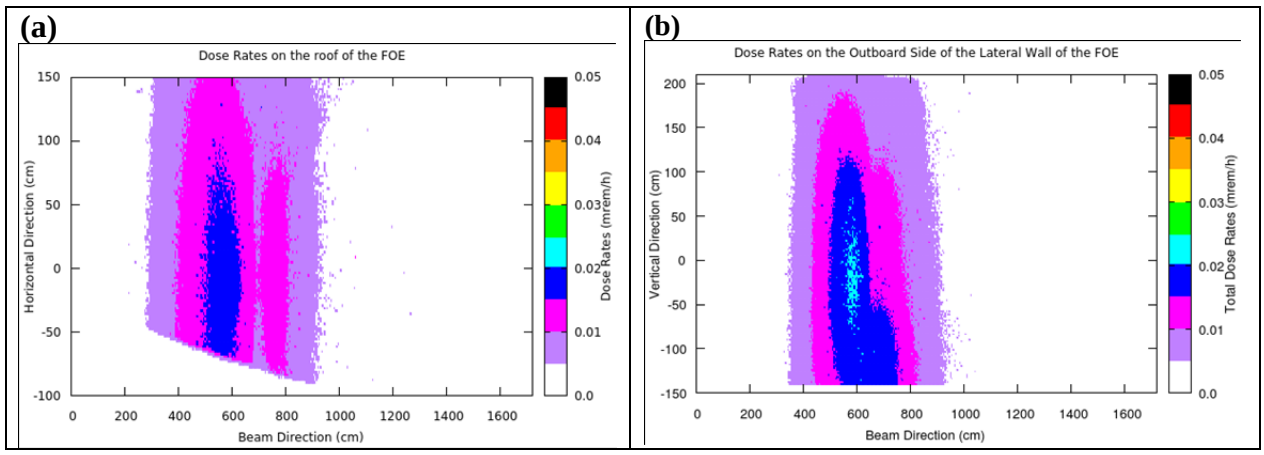


Figure 17b: Total ambient dose rate distributions (mrem/h) on contact with the roof (a) and lateral wall (b) when the beam is incident on the bottom side of the front face of FMK2 (case 14).

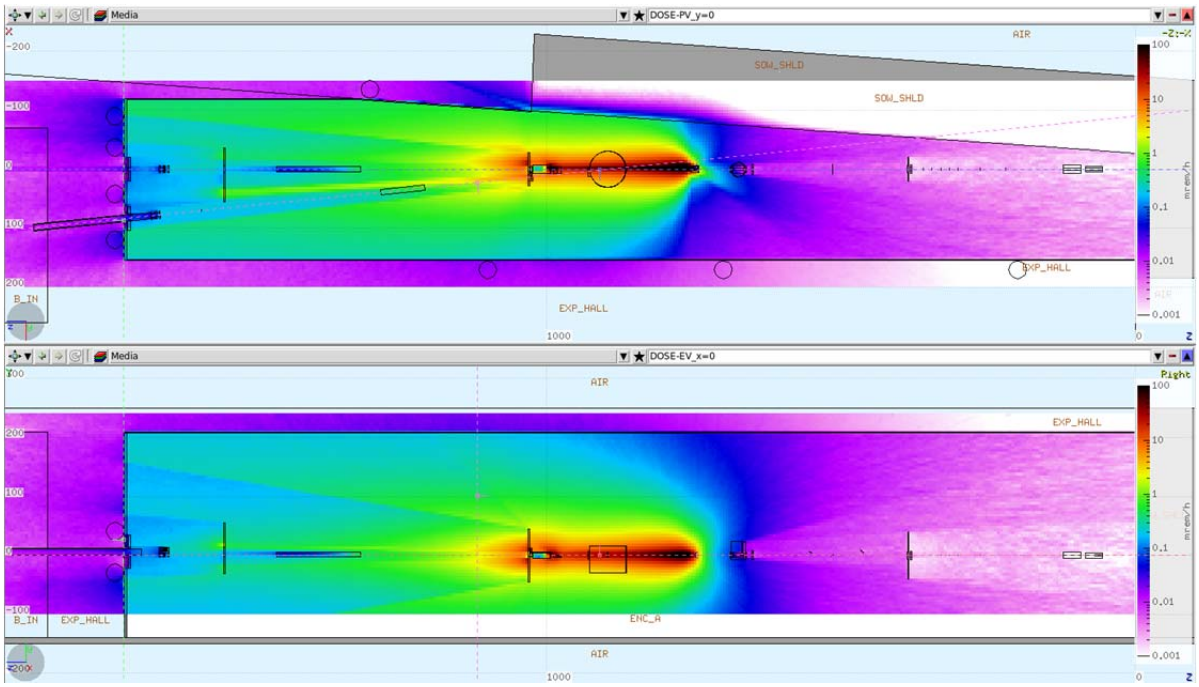


Figure 18a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes the white beam slits in the closed position (case 15). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

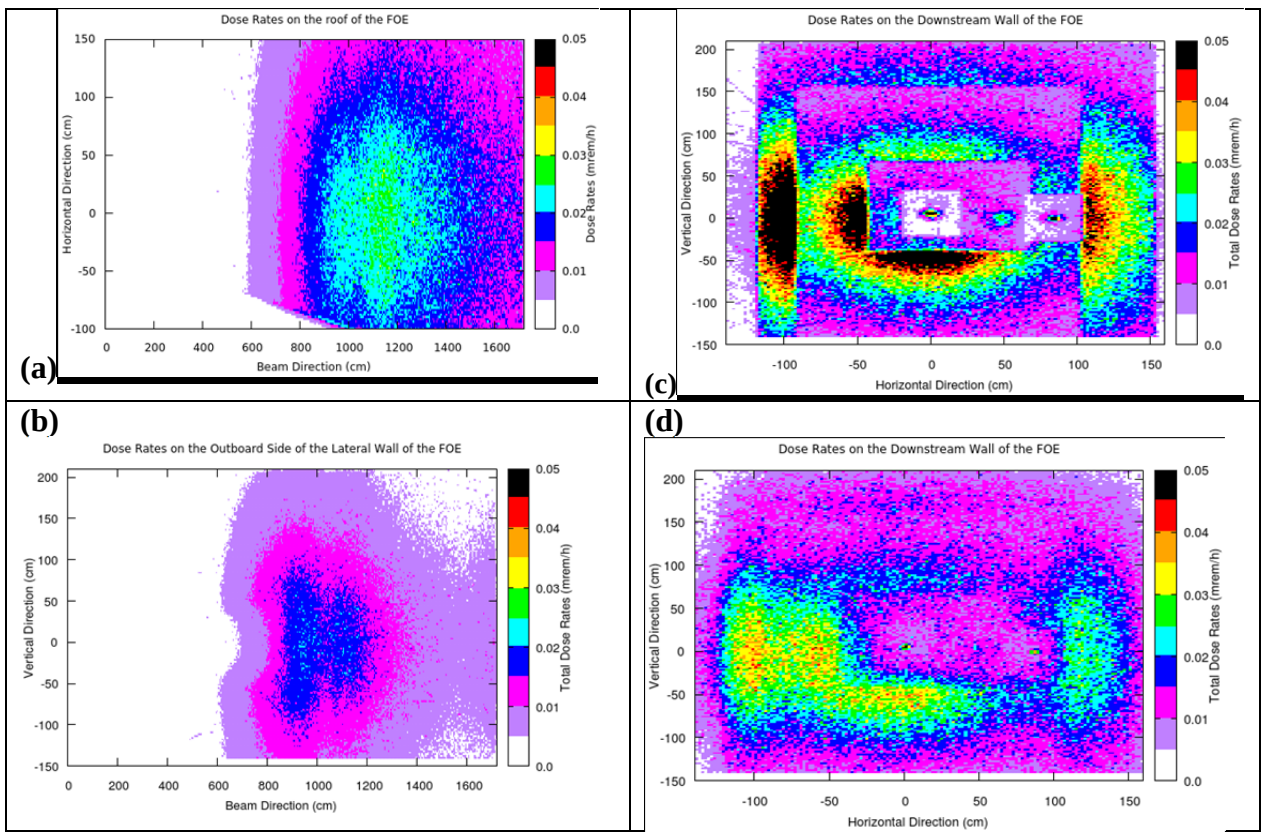


Figure 18b: Total ambient dose rate distributions (mrem/h) on contact with the roof, (a), lateral wall (b), downstream wall (c) and at 30 cm distance from the downstream wall (d) when the beam is incident on the white beam slits in the closed position (case 15).

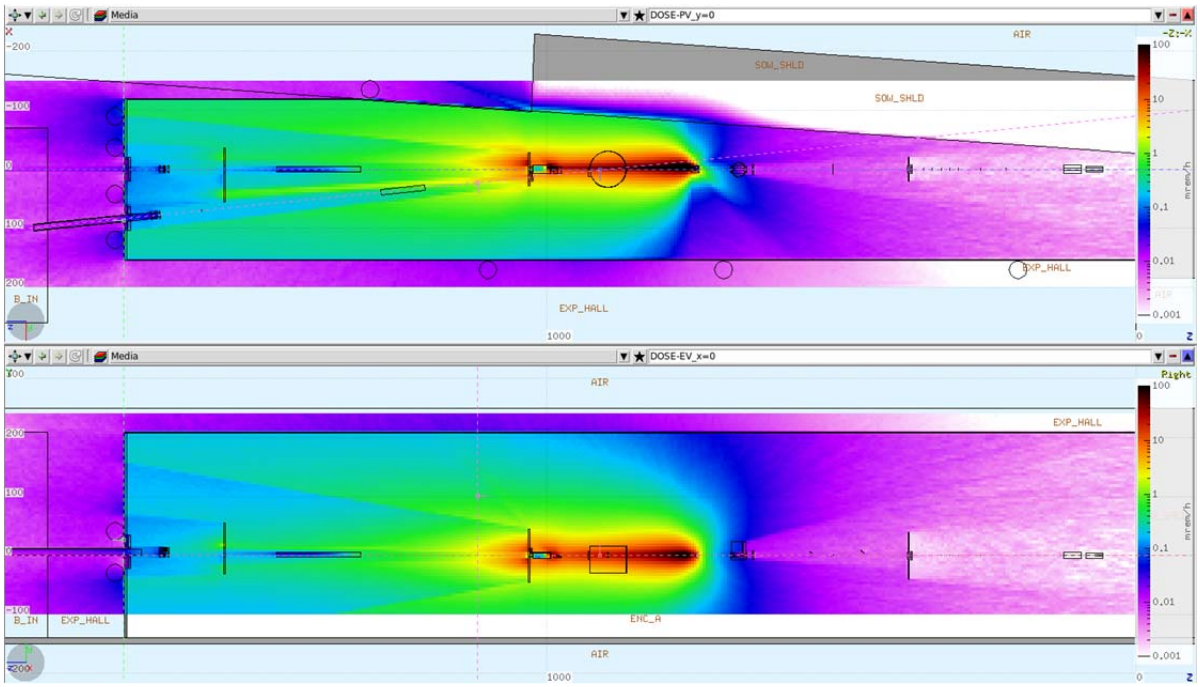


Figure 19a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes the white beam slits in the open position (case 16). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0

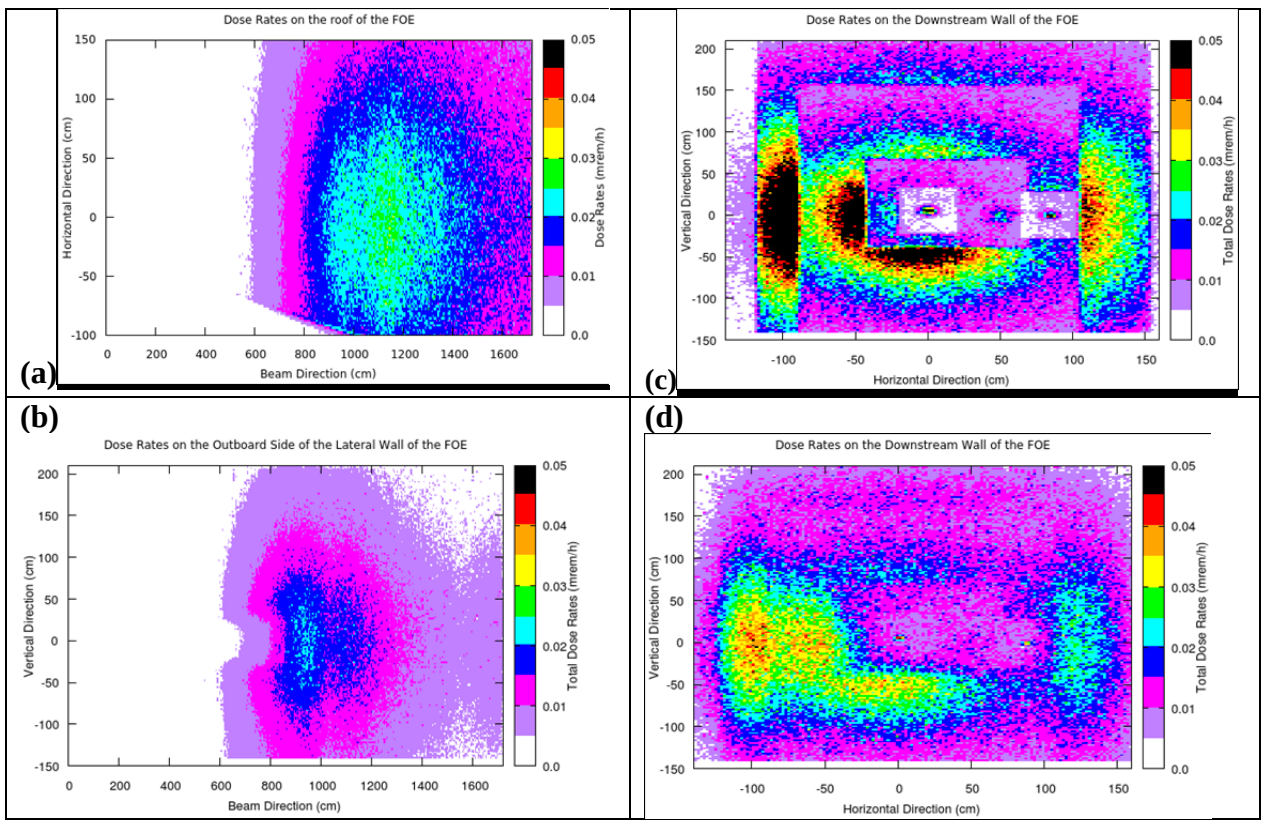


Figure 19b: Total ambient dose rate distributions (mrem/h) on contact with the roof, (a), lateral wall (b), downstream wall (c) and at 30 cm distance from the downstream wall (d) when the beam is incident on the white beam slits in the open position (case 16).

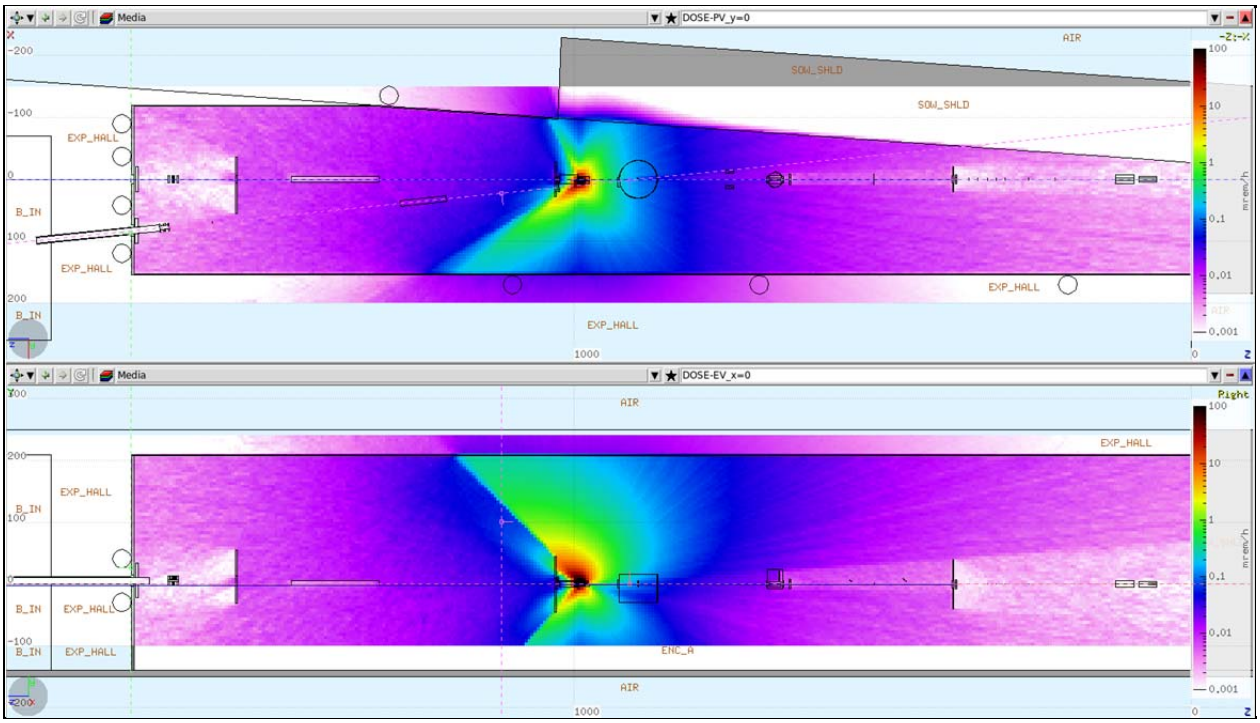


Figure 20a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes the outboard side of the white beam stop (case 17). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

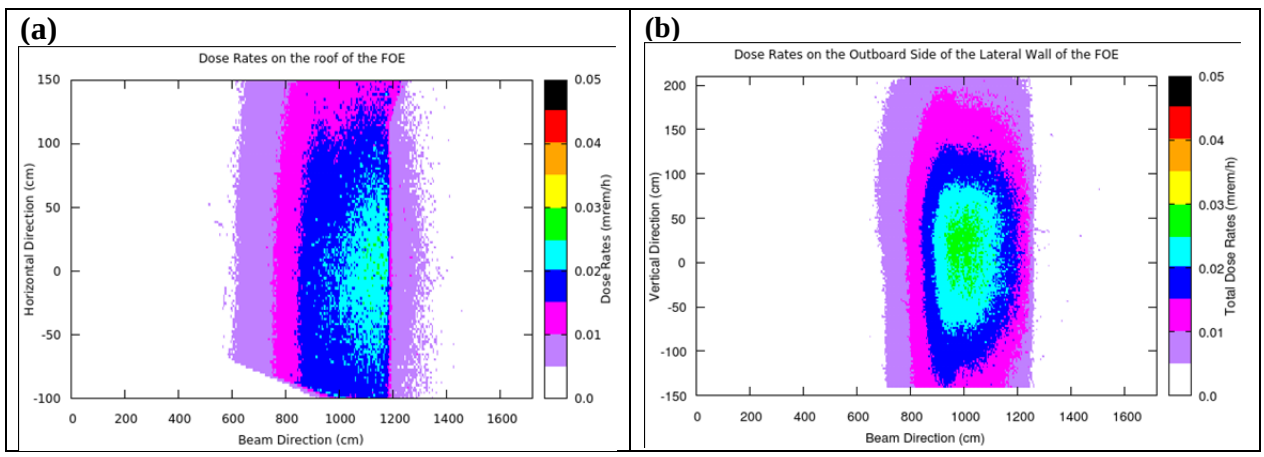


Figure 20b: Total ambient dose rate distributions (mrem/h) on contact with the roof (a) and lateral wall (b) when the beam is incident on the outboard side of the white beam stop (case 17).

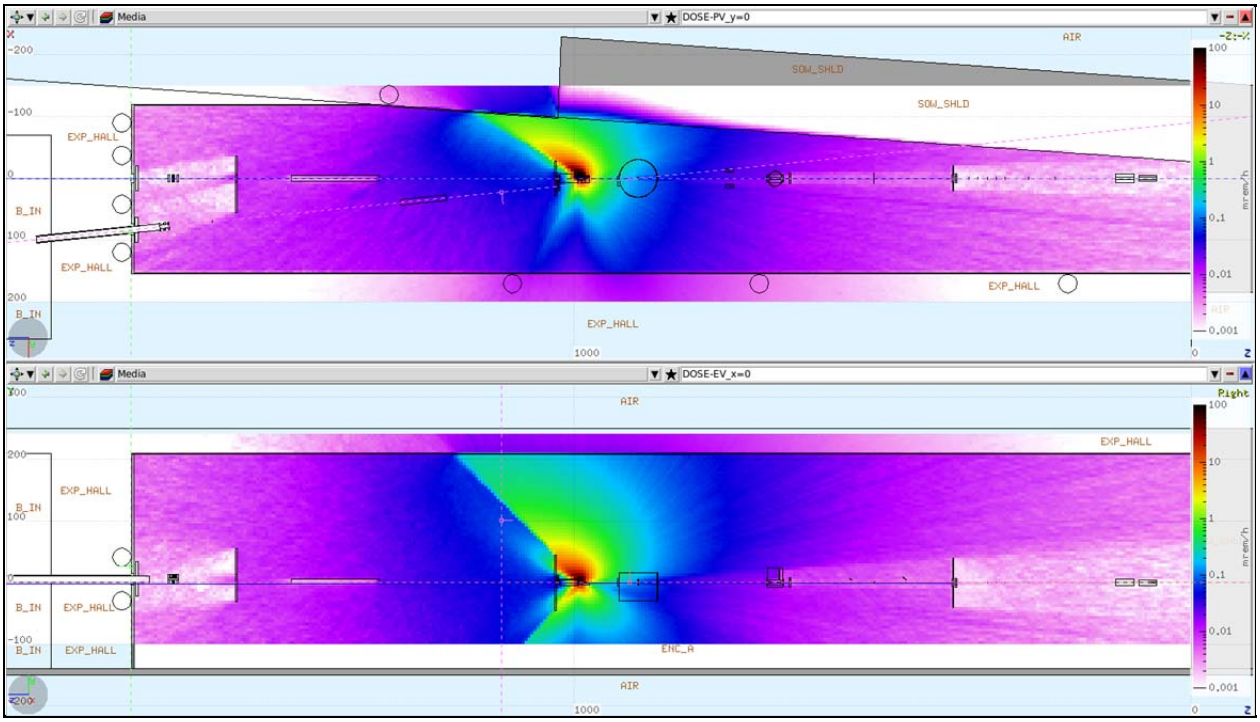


Figure 21a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes the inboard side of the white beam stop (case 18). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

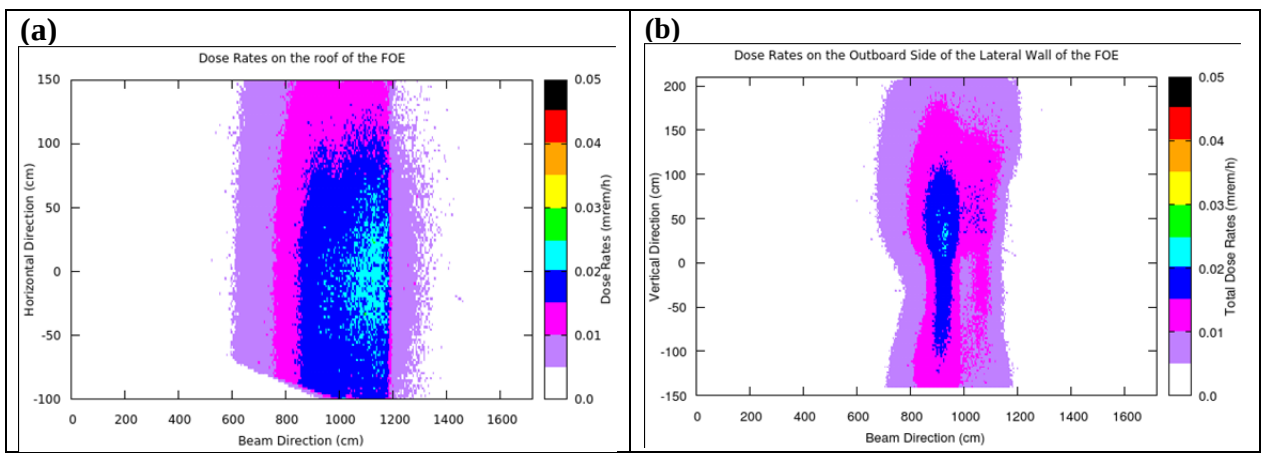


Figure 21b: Total ambient dose rate distributions (mrem/h) on contact with the roof (a) and lateral wall (b) when the beam is incident on the inboard side of the white beam stop (case 18).

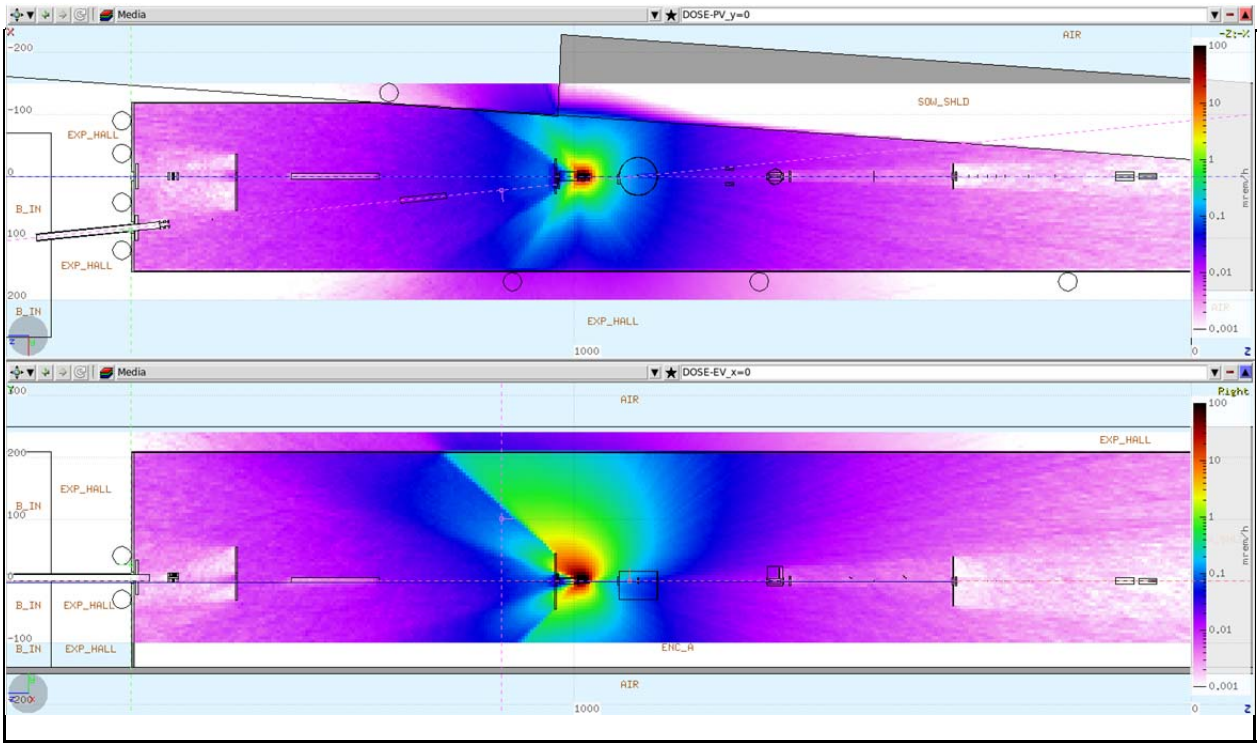


Figure 22a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes the bottom side of the white beam stop (case 19). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

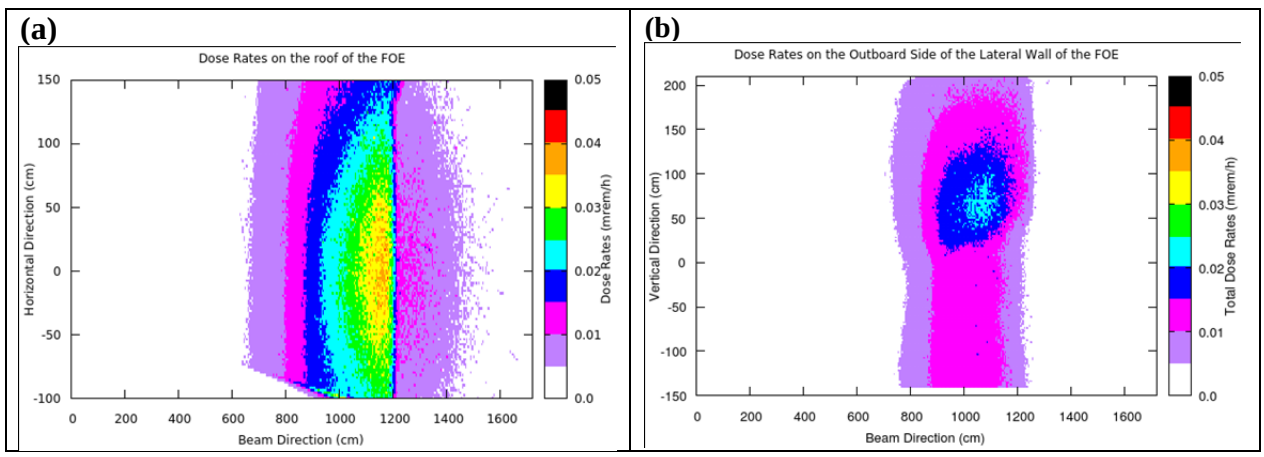


Figure 22b: Total ambient dose rate distributions (mrem/h) on contact with the roof (a) and lateral wall (b) when the beam is incident on the bottom side of the white beam stop (case 19).

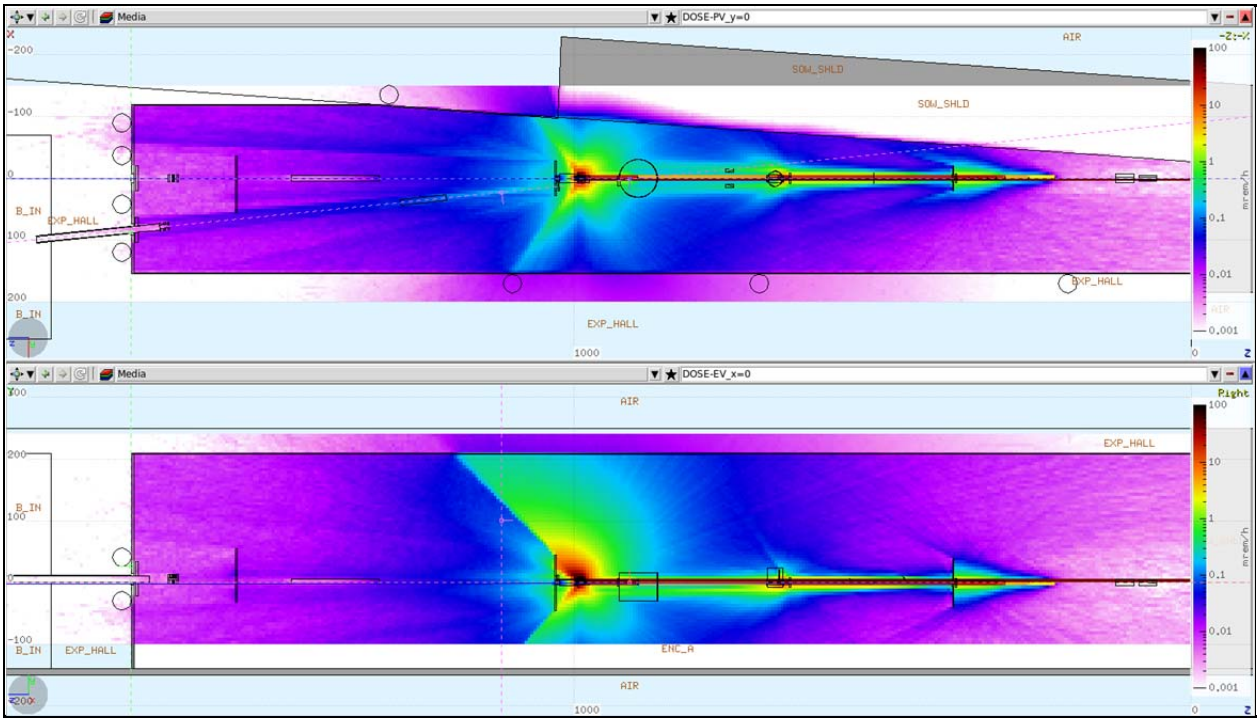


Figure 23a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes the center of the white beam stop (case 20). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

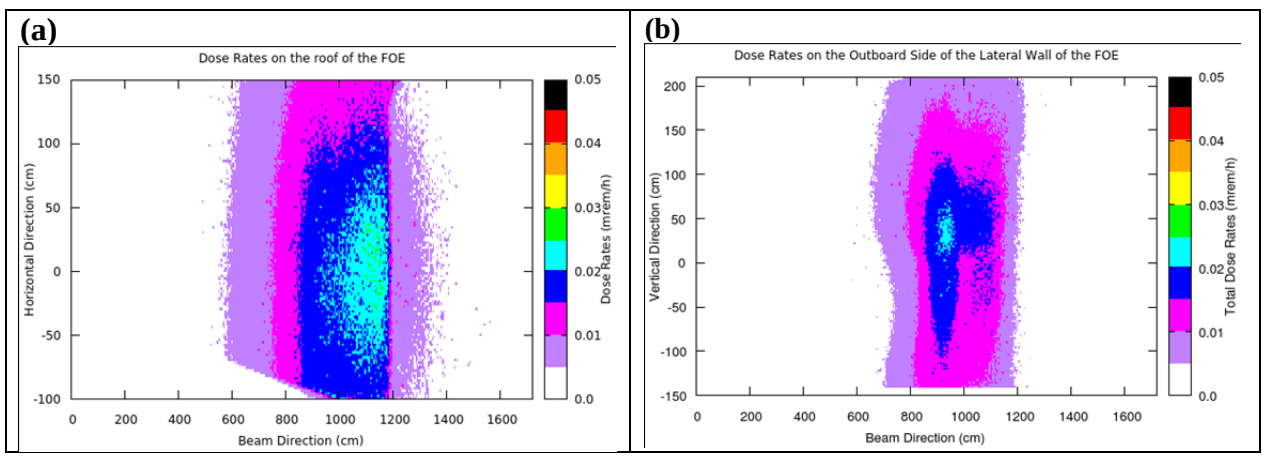


Figure 23b: Total ambient dose rate distributions (mrem/h) on contact with the roof (a) and lateral wall (b) when the beam is incident on the center of the white beam stop (case 20).

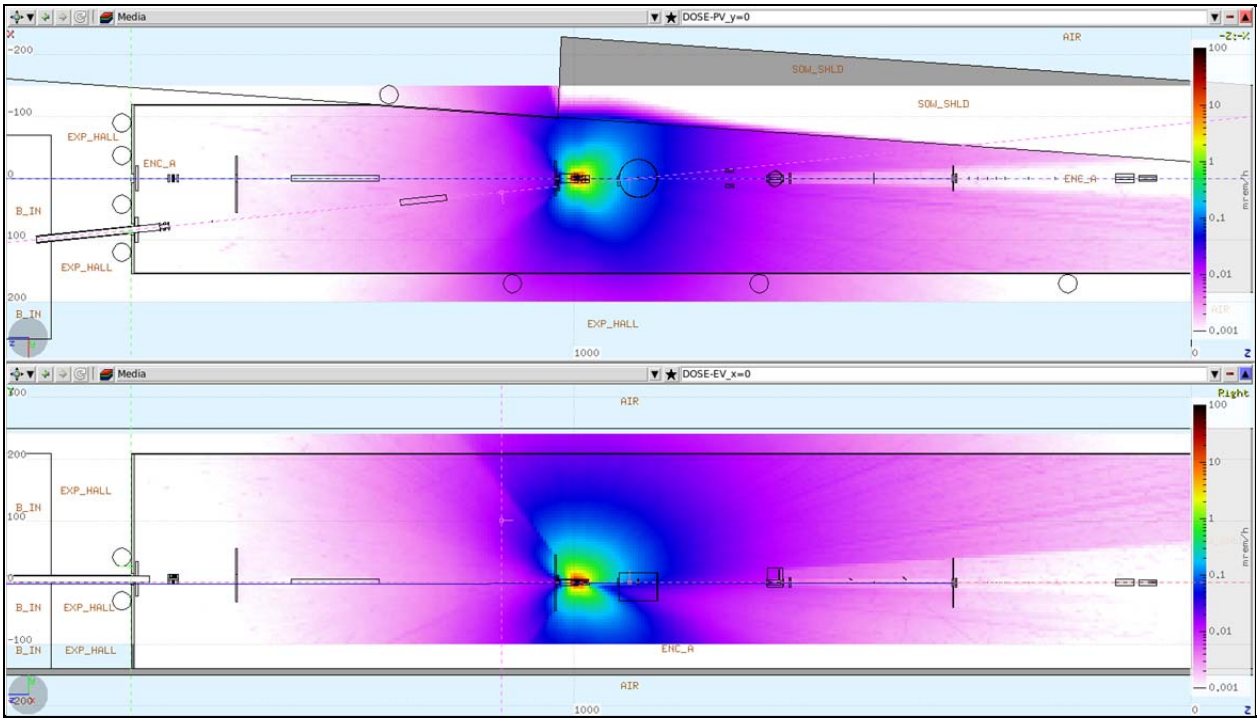


Figure 24a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes the front face top side of BRS (case 21). The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

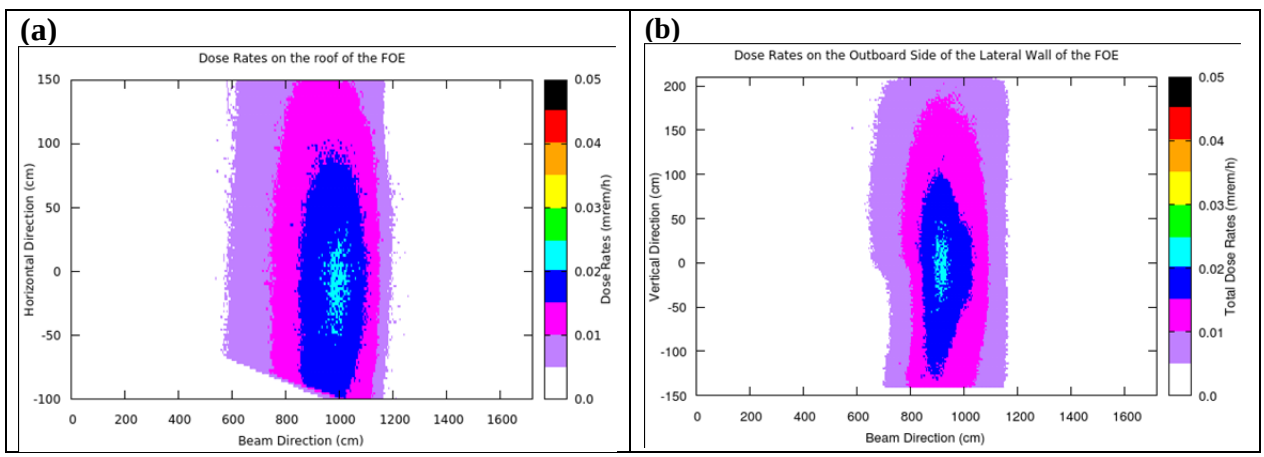


Figure 24: Total ambient dose rate distributions (mrem/h) on contact with the roof (a) and lateral wall (b) when the beam is incident on the top side of the front face of the BRS (case 21).

With SBM Vacuum Chamber as Credited Shielding

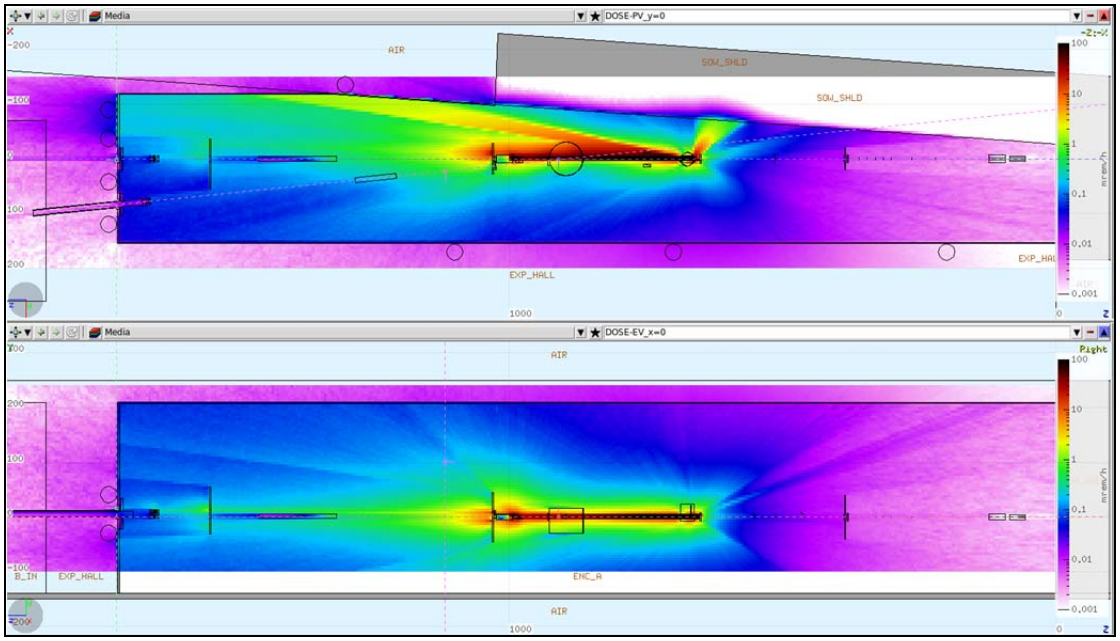


Figure 25a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes near the aperture of FMK2 on the outboard side (case 7) with SBM vacuum chamber included as shielding. The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

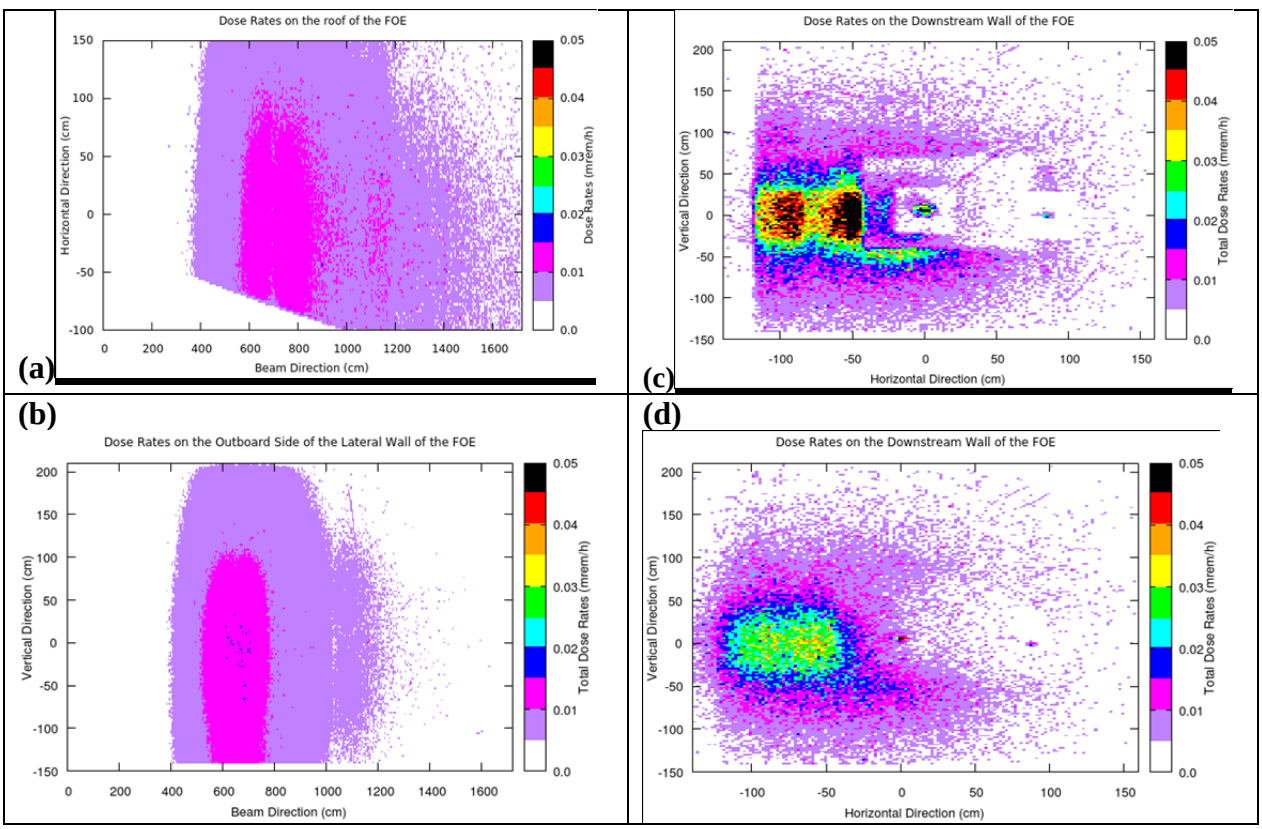


Figure 25b: Total ambient dose rate distributions (mrem/h) on contact with the roof, (a), lateral wall (b), downstream wall (c) and at 30 cm distance from the downstream wall (d) when the beam is incident near the aperture of FMK2 on the outboard side (case 7) with SBM vacuum chamber included as shielding.

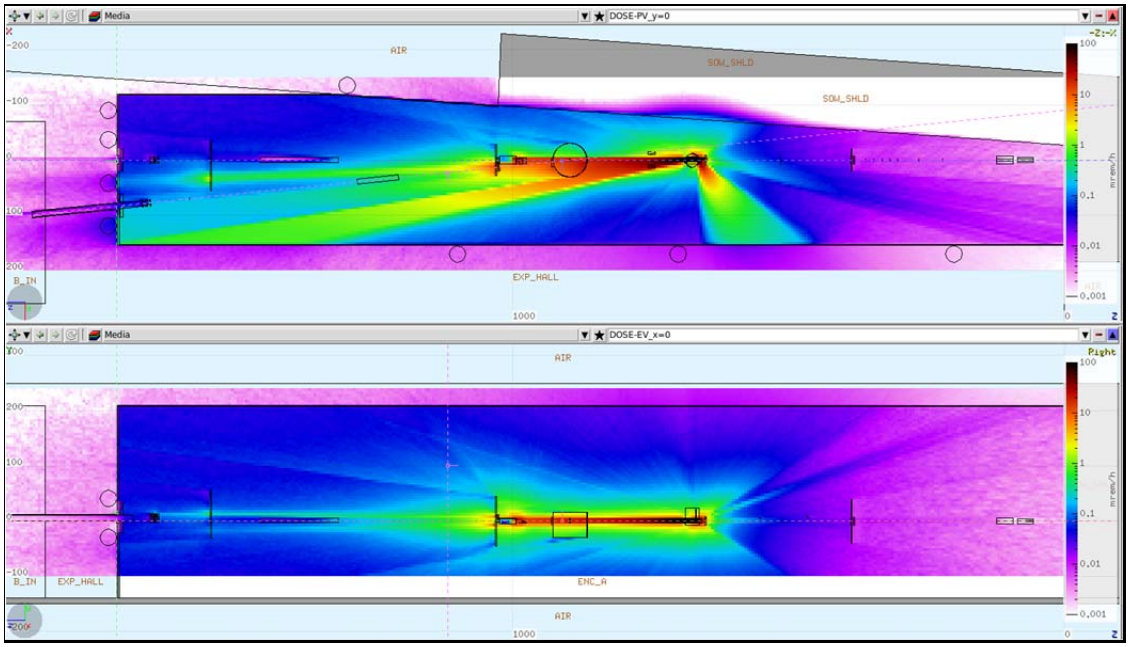


Figure 26a: Total ambient dose equivalent rates (mrem/h) in and around the FOE when the GB strikes near the aperture of FMK2 on the inboard side (case 8) with SBM vacuum chamber included as shielding. The top figure shows the horizontal view (y=0) and the bottom figure shows the vertical view at x=0.0.

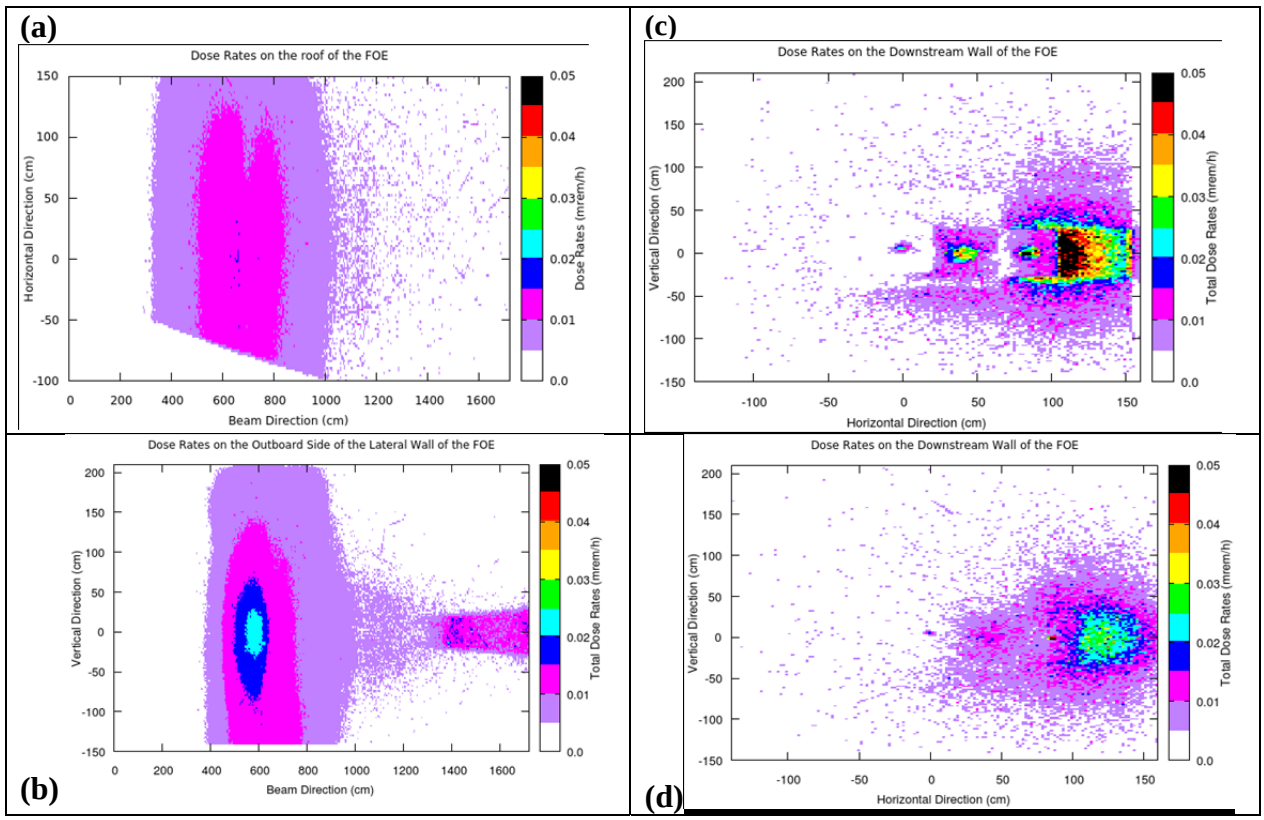


Figure 26b: Total ambient dose rate distributions (mrem/h) on contact with the roof, (a), lateral wall (b), downstream wall (c) and at 30 cm distance from the downstream wall (d) when the beam is incident near the aperture of FMK2 on the inboard side (case 8) with SBM vacuum chamber included as shielding.

Table 1: Summary of the total ambient dose rates outside the 28-ID-A (FOE), transport pipes and 28-ID-B for various beam conditions with GB as the source of radiation. When applicable, the values shown in parentheses are a distance of 30 cm away from the downstream wall of the FOE.

Case #	**Scatter Target**	**Total ambient dose equivalent rate (mrem/h)**				
		Downstream wall (FOE)	Lateral wall (FOE)	Roof (FOE)	Transport Pipes	PDF ESE (28ID-B)
1	On the aperture of FMK1, outboard side	< 0.05	< 0.04	< 0.03	< 0.01	< 0.01
2	On the aperture of FMK1, top side	< 0.01	< 0.03	< 0.03	< 0.01	< 0.01
3	On FMK1, front face outboard side	< 0.01	< 0.04	< 0.02	< 0.01	< 0.01
4	On FMK1, front face inboard side	< 0.01	< 0.03	< 0.02	< 0.01	< 0.01
5	On FMK1, front face top side	< 0.01	< 0.03	< 0.03	< 0.01	< 0.01
6	On the SCW1 (Screen Copper Holder)	< 0.09 (< 0.05)	< 0.02	< 0.03	< 0.01	< 0.01
7	On the aperture of FMK2, outboard side	< 0.16 (**< 0.08**) < 0.08 (< **0.04**)$	< 0.02	< 0.02	< 0.01	< 0.01
8	On the aperture of FMK2, inboard side	< 0.14 (**< 0.07**) < 0.07 (< **0.04**)$	< 0.03	< 0.02	< 0.01	< 0.01
9	On the aperture of FMK2, top side	< 0.08 (< 0.04)	< 0.02	< 0.02	< 0.01	< 0.01
10	On the aperture of FMK2, bottom side.	< 0.06 (< 0.03)	< 0.02	< 0.02	< 0.01	< 0.01
11	On FMK2, front face outboard side	< 0.01	< 0.04	< 0.02	< 0.01	< 0.01
12	On FMK2, front face inboard side	< 0.02	< 0.03	< 0.02	< 0.01	< 0.01
13	On FMK2, front face top side	< 0.02	< 0.03	< 0.03	< 0.01	< 0.01
14	On FMK2, front face bottom side	< 0.01	< 0.03	< 0.02	< 0.01	< 0.01
15	On SLW2 (White Beam Slits), closed position	< 0.08 (< 0.05)	< 0.02	< 0.03	< 0.01	< 0.01
16	On SLW2 (White Beam Slits), open position	< 0.08 (< 0.05)	< 0.03	< 0.03	< 0.01	< 0.01
17	On STW (White Beam Stop), outboard side	< 0.01	< 0.03	< 0.03	< 0.01	< 0.01

18	On STW (White Beam Stop), inboard side	< 0.01	< 0.03	< 0.03	< 0.01	< 0.01
19	On STW (White Beam Stop), bottom side	< 0.01	< 0.03	< 0.04	< 0.01	< 0.01
20	On STW (White Beam Stop), center	< 0.01	< 0.03	< 0.03	< 0.01	< 0.01
21	On BRS, front face top side	< 0.01	< 0.03	< 0.03	< 0.01	< 0.01

[$] Dose rate with the SBM Stainless Steel Vacuum Chamber included as shielding.

From the figures and the table, the total ambient dose rates on contact with lateral walls and roof of 28-ID-A (FOE), transport pipes, and inside the 28-ID-B enclosure are less than 0.05 mrem/h for all beam conditions considered. For the downstream wall of the 28-ID-A enclosure, the total ambient dose rates exceed 0.05 mrem/h on contact with the exterior surface of the wall for cases 6, 7, 8, 9, 10, 15 and 16, but are less than 0.05 mrem/h at 30 cm away, except for cases 7 and 8. As per the ALARA policy [1], the dose rates on contact with the downstream wall should not exceed 0.5 mrem/h on contact and 0.05 mrem/h at a distance of 30 cm from the exterior surface of the wall. The dose rates in Table 1 meet this requirement for all scenarios except when the beam is incident near the aperture of FMK2 on both inboard and outboard side. Here, the maximum contact dose rates are 0.16 mrem//h and 0.08 mrem/h at 30 cm distance, as shown in Figures 10b and 11b. FLUKA simulations were carried out for cases 7 and 8 with the SBM cylindrical vacuum chamber assuming 5 mm thick stainless steel as shielding (ignoring the top and bottom lids). The ambient total dose rate with SBM vacuum chamber included as a shielding is given in Figures 25 and 26. As seen from Figures 25b and 26b, the total ambient dose rates have now reduced to less than 0.08 mrem/h on contact and 0.04 mrem/h at 30 cm distance. It is therefore recommended to have the SBM vacuum chamber under configuration control and add it to the 28-ID-PDF/XPD radiation safety component checklist.

2.4. Summary

The FLUKA simulations for the GB radiation source shows that the SBM vacuum chamber of at least 5 mm thick stainless steel is required shielding to keep the total ambient dose rates on the 28-ID-A (FOE) downstream wall to less than 0.05 mrem/h at 30 cm away. The SBM vacuum chamber without the top and bottom lids should be kept under configuration control and added to the 28-ID-PDF/XPD beamlines radiation component checklist.

With the above shielding in place, the ambient total dose equivalent rates outside the FOE, beam transport pipe and 28-ID-B enclosure are below the levels stipulated by the NSLS-II Shielding Policy.

3. Synchrotron Radiation Scattering Analysis

The 08-ID (ISS) beamline is a Damping Wiggler (DW100) source, parameters are taken from reference [3] and are reproduced in Table 2 below. The maximum horizontal opening angle for the 28-ID wiggler source fan is given in column 2. The critical energy (column 6) and the total power (column 7) are based on stored electron beam parameters of 3 GeV and 500 mA.

Table 2: Source parameters used for 28ID-PDF synchrotron calculations.

Source	Max. source opening	No. Of periods	Max. B_{eff} (T)	Period (mm)	E_c (keV)	STAC 8 Total Power (kW) @ 500mA
DW100	6.0 mrad-H	70	1.85	100	11	63

The analytic code STAC8 [4] was used to calculate the ambient dose equivalent rates in the occupied areas outside of 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 that the distance from the scatter target to dose point is the same. The shielding calculations for the 28-ID-PDF monochromatic beam transport pipe and end station enclosure 28-ID-B, assumes that primary gas bremsstrahlung has been completely stopped in the FOE (28-ID-A).

3.1 First Optics Enclosure (FOE) 28ID-A

There are two cases considered: case 1 - white beam on optimum scatter target and case 2 - mis-steered monochromatic beam striking the walls of the FOE.

In case 1, the scattering target is assumed to be an optimum silicon target. The position of the scatter target is assumed to be located at the SBM crystal, approximately 821 cm from the FOE downstream wall, 155 cm from the lateral wall and 200 cm from the roof. The ambient dose rates on the downstream wall, lateral wall, and roof of the 28-ID-A enclosure are found to be less than 0.01 mrem/h.

In case 2, the dose rates are calculated by assuming the monochromatic beam striking the 50 mm Pb thick downstream wall and 19 mm Pb thick lateral wall using the “NICK” card in STAC8. The calculated dose rates for direct beam on the downstream wall and the lateral wall is estimated to be less than 0.01 mrem/h.

3.2 Monochromatic Transport Pipe

The dose rates outside of the beam pipe when the pink beams are scattered from an air column are discussed here. The lead thickness is assumed to be 12 mm wrapped around a 2 mm thick, 5 cm radius SS beam pipe. The monochromatic beam exiting the FOE can scatter off an air column in the event of a loss of vacuum condition. The ambient dose rates were calculated for the 4 operational energies of the 28-ID-PDF beamline corresponding to 39, 64, 75 and 117 keV, including higher harmonics and assuming the VFM out of the beam, which is more conservative. The estimated maximum ambient dose rates on contact with the surface of the lead shielded pipe is much less than 0.01 mrem/h.

3.3 End station Enclosure 28ID-B

The lateral and downstream walls of the 28-ID-B enclosure are made of 4 mm Pb, while the roof is made of 3 mm Pb. Monochromatic beam stops have been installed on the downstream wall of the 28-ID-B enclosure to intercept a direct monochromatic and/or forward scatter and consist of 2.54 cm thick Lead square area 31.75cm×31.75cm. PDF monochromatic beam scattering off an Al target placed in the beam path is used to estimate the dose rates outside the walls and the roof, with the 4 operational beam energies (see section 3.2) used as the source. The minimum distance to the lateral wall is assumed to be 130 cm and 200 cm to the roof. For the downstream wall, the target is assumed to be in the middle of the enclosure. The ambient dose equivalent rates are estimated to be less than 0.05 mrem/h on contact with all the walls and the roof of the 28-ID-B.

3.4 Summary

The estimated ambient dose equivalent rates are below 0.05 mrem/h outside of the 28-ID-A and 28-ID-B enclosures, and PDF transport pipe for all assumed sources and scattering targets.

4. Overall summary

The radiation shielding analysis of the 28-ID-PDF beamline has been carried out with FLUKA Monte Carlo radiation transport code and the analytical STAC8 code. The analysis indicates the need to include the SBM vacuum chamber, which is 5mm thick stainless steel as required shielding to conform to the NSLS-II radiation shielding and ALARA policies.

5. References

1. Guidelines for the NSLS-II Beamline Radiation Shielding Design LT-C-ESH-STD-001, November 7, 2014.
2. R. Lee, NSLS-II Issue and Decision Paper: ALARA Analysis for Installations of Secondary Bremsstrahlung Shields in the First Optics Enclosure, PS-C-ESH-STD-005, (06/01/2016).
3. 28ID XPD Beamline Radiation Shielding Analysis, NSLS-II Technical Note No. 139, (08/07/2014).
4. Y. Asano, “A study on radiation shielding and safety analysis for a synchrotron radiation beamline,” JAERI-Research-2001-006, March 2001.

Appendix A

28-ID-PDF/XPDXPD Beamlines Data for FLUKA Simulations (03/03/2018)

28-ID Enclosures

Shielding Information (dimensions in mm) *	Distance/Position (m)	Thickness (mm)	Material
28-ID SR Ratchet Wall; US inside face of FE ratchet wall	See SR dwgs	See SR drawings	Concrete / Lead
DS face of ratchet wall (inside FOE)	Z = 26.73	See SR drawings	Concrete / Lead
Distance: FOE OB wall/inside Pb face to white beam centerline	1.53	19.05 (.75”)	Lead
Min distance from white beam centerline to FOE roof Pb	2.08	10	Lead
Min distance: white beam Z-axis to SR wall outer face	0.70 m	See SR drawings	Concrete
Angle betw SR wall & white photon beam Z-axis: 4 degrees			
FOE Back wall, inside US face of lead	Z ~ 43.855	50.8 (reqmt=50)	Lead
B-enclosure shielding: walls/roof (see PD-XPD-HU-1210)	US wall inner Pb face Z = 45.205 DS wall inner Pb face Z = 52.693	4mm / 3mm 4mm	Lead Lead
B-enclosure distance: (IB, OB] wall/inside Pb	0.75, 2.57	4mm	Lead

face to white beam centerline			
C- enclosure shielding: walls/roof (see PD-XPD-HU-1310)	DS wall inner Pb face Z = ~59.71	4mm / 3mm	Lead
D- enclosure shielding: walls/roof (see PD-XPD-HU-1410)	DS wall inner Pb face Z = ~67.71	4mm / 3mm	Lead

* dimensions indicated are from drawings or 3D models; measurements are in *italic* typeface.

Notes:

1- The X axis is positive outboard, the Y axis is positive upward, and the Z axis is collinear with the 28-ID nominal white beam centerline with origin at the 28-ID Damping Wiggler Source Point. The Ray Trace drawing (PD-XPD-RAYT-0001) has beamline and shielding information, drawing PD-XPD-BL-1100 shows the layout of the XPD components, and drawing PD-PDF-BL-1000 shows the layout of the PDF branch beamline.

2- A filter assembly (FLT1) located downstream of WIN2, houses five SiC filters that may be used selectively in any combination. The thicknesses are 4.1 mm, 2.1 mm, 1.0 mm, 0.5 mm, and 0.3 mm.

3- The XPD Double Laue Monochromator (DLM) deflects the Vertical Focusing Mirror (inside the FOE, centered at Z = 40.675 m) deflects the XPD 28-ID monochromatic beam 50 mm upward from the white beam centerline.

4- The PDF Side-Bounce Monochromator, located downstream of the Double Laue Monochromator (DLM) at 38.569 m, deflects the white beam 5.8° horizontally outboard. The PDF VFM (centered at Z = 38.800 m) deflects the PDF monochromatic photon beam 0 – 4.1 milliradians upward.

5- Two 50.8 mm thick lead guillotines are attached directly to the inside/downstream FOE wall with 102 mm I.D. beampipe opening; one for the XPD beamline and one for the PDF beamline. The upstream face of the guillotine lead is located at ~Z = 43.768 m. The guillotine prevents radiation leakage by overlapping the 7” diameter hole in the downstream FOE wall.

6- Two shielded beam transport pipes extend between the A and B butches; the PDF pipe has 12 mm of lead shielding and the XPD pipe has 7 mm of shielding. Both have stainless steel covers to prevent exposed lead.

XPD Beamline Components for FLUKA Calculations (Upstream of SBM)

First Optical Enclosure Component	Z location, m (Distance from Source Point) (US), (DS) or center (C)	Dimensions (mm)		Offset (horiz &/or vert) w.r.t 28-ID white beam CL	Material	Associated Drawings
		Outer Mtl dimensions (W)x(H)x(L)	Lead CO or Mask Aperture, mm (W)x(H) or (Dia)			
FMK	27.32 (US)	90 x 90 x 292	31.15 x 3.58 (DS) 45.2 x 16.27 (US)	-	WC Cu (GlidCop)	PD-PDF-RAYT-0001 AAM0002, AAM0007 (FMB-O)
BRC1	27.687 (US)	141 x 100 x 300	41.48 x 13.60	-	Lead	AAM0002 (SHT2), ACC0075 (FMB-O)
WIN1	28.940 (C)	36 x 6 x 1	-	-	CVD WC Carbon [Diamond]	FMB-O FDR Report S2681, pg17 AWM0001, AWM0003
WIN2	29.365 (C)	35 x 5 x 1	-	-	CVD WC Carbon [Diamond]	FMB-O FDR Report S2681, pg17 AWM0001, AWM0003

FLT1 (5 filters)	29.744 (US) 29.884 (US) 30.034 (US) 30.184 (US) 30.334 (US)	t_1 = 4.1 t_2 = 2.1 t_3 = 1.0 t_4 = 0.5 t_5 = 0.3			SiC	AFM0019 (FMB-O)
SBRS1	30.58 (US) Collar: 30.54 (US)	400 x 800 x 20 Ø140 x 20	120 Dia 66 Dia	-	Lead	AFM0019 (FMB-O)
SCW1	31.308 (C)	60 x 70 x 10	40 x 7	(45° taper)	Cu (WC)	AFM0020 (FMB-O)
DLM	31.878 (C) 32.25 (C, nominal)	*40 x 160 LG x 0.7 t*	[nominal angle: 55°]	-	WC Si Si, uncooled	1st crystal 2nd crystal (moveable)
FMK2	33.110 (US)	171.5 x 151.6 x 19.8	Lwr Aperture: 38 x 10 DS 54 x 10 US (25° taper relative to	-	WC Cu (GlidCop)	PD-XPD-BL-MSK-1101

			Centerline) Upr Aperture (mono pass thru): 50.8 x 16	Y = 50 mm		
BRC2	33.371 (US) (LWR) 33.40 (US) (UPR)	137 x 76 x 200 (LWR) 137 x 175 x 20t (UPR)	42.7 x 10.9 lower/white 42.7 x 16.6 upper/mono [*PDF white beam passes*	- Y = 50 mm *thru lwr aperture*]	Tungsten	ACC0031 (FMB-O) AZM0008 (FMB-O)
SLW2 (PDF)	34.21 (C)					AQM0009 (FMB-O, dwg not on file)
SBM	35.69 (C)	99 x 55 x 5 or 99 x 55 x 3 (both 37.9° from orthogonal to white beam)	N/A	-	Si (t=5 mm: 022, 311, 155; t=3 mm: 111)	PD-PDF-SBM-1000 ADM0145 (FMB-O), crystals: ADC1493, 1494, 1495, 1359 (FMB-O)

STW	36.548 (C) 36.48 (US)	>48 x >15 x 130	[beam contacts top surf @ 6.6°]	See dwg	WC Cu	ASM0004 (FMB-O)
BRS	36.66 (US)	134 x 100 x 300	*[4 mm dp x 42-43 mm groove for beam tube]*	See dwg	Lead	AAC0024 (FMB-O)
SBRS2 collar Shield plate	36.98 (US) XPD collar PDF collar 37.02 (US) plate	135 OD x 20t XPD 142 OD x 20t PDF 560 x 900 x 20	44 x 12 53 ID 2x 125 Dia	Y=+50 (XPD collar & plate aperture) X= 144, Y=0 (PDF collar & plate aperture)	Lead	AAM0005, AAC0074 (FMB-O)
PDF VFM	38.80 (C) (3127.5 mm from SBM)	90 x 65 x 1500	N/A	X=+316, Y=0	Si	PD-PDF-MIR-1000 WX6469-105-INT1, WX6469-110-INT1 (Winlight-X)
XPD VFM	40.60 (C)	80 x 75 x 1420 @ 0-2.05 mrad	N/A	X=0, Y=+50	Si	PD-XPD-MIR-1000 WX6383-100-INT1

SBRS3 (XPD only)	42.19 (US)	920 x 870 betw holes x 30	155 Dia (not centered, see dwg)	X=0, Y= +50	Lead	PD-XPD-TL-SHLD-1203
SLITS (PDF BDM Mono slits)	42.59 (C)	20 x 40 x 5 t (when closed)	Variable opening	X=+316 Y depends on VFM angle	W	16-00-999268-00 16-00-999284-00 (Axilon)
XPD PSH PDF PSH	43.15 (US) 43.29 (US)	125 x 150 x 19.05t (x 2)	40 x 25 centered (two plates per PSH)	X=0, Y=+56 X=+772, Y=+9	W	PD-XPD-RAYT-0001, PD-PDF-BL-LAY-1010
PDF Guillotine XPD Guillotine	43.79 (US) 43.79 (US)	*16″ x 22″ x 2″t*	4″ I.D.	+830mm,+9mm 0, +58mm	Lead	[*Guillotines measured*]

Shielded Beam Transport Component	**Z location, m (Distance from Source Point) (US),(DS)or center (C)**	**Dimensions (mm)**		**Offset (horiz &/or vert) w.r.t 28-ID white beam CL**	**Material**	**Associated Drawings**
		Outer dimension (W)x(H)x(L)	Lead CO or Mask Aperture, mm (W)x(H) or (Dia)			
XPD SBT	43.90 (US)	115.6 OD/ 101.6 ID x 1.37 m LG	4″ I.D.	See guillotine offsets	Lead	Axilon / InnoSpec
PDF SBT	43.90 (US)	125.6 OD/ 101.6 ID x 1.37 m LG	4″ I.D.	See guillotine offsets	Lead	Axilon /InnoSpec D485-01

Hutch B Component	Z location, m (Distance from Source Point) (US), (DS) or center (C)	Dimensions (mm)		Offset (horiz &/or vert) w.r.t 28-ID white beam CL	Material	Associated Drawings
		Outer Mtl dimensions (W)x(H)x(L)	Lead CO or Mask Aperture, mm (W)x(H) or (Dia)			
SHT2 (PDF Mono Fast Shutter)	46.33 (C)	2x (10 x 10 x 1.1 t when fully closed)	10 x 10 when fully open [Note- fast shutter rotates, beam passes thru 2 walls when closed]	X=+1080, Y depends on VFM angle	W?	16-00-999220-00_OCM (Axilon 3D model)
SLM4 (Mono Clean-up Slits)	46.84 (C)	20 x 40 x 5 t (when closed)	Variable opening	X=+1132, Y depends on VFM angle	W	16-00-999220-00_OCM 16-00-999284-00 (Axilon 3D model, FDR report, & per A.Schacht)

Be Window1 Be Window2	46.197 (US) 46.975 (US)	Ø39 mm x 0.500 mm Ø39 mm x 0.500 mm	N/A	X1=1.067, Y1=1380-1480 X2=1.146, Y2=1380-1480	Be / SST flange	Axilon
PDF Beam Stop (center)	52.66 (US)	304.8 mm SQ x 25.4 mm t	N/A	X = +1722 mm Y = +42 mm	Pb (steel-covered)	PD-PDFBL-LAY-1010

Glossary of Abbreviations:

BDA = Beam Defining Aperture
BDM = Beam Diagnostic Module
BL = Beamline
BM = Bending Magnet
CO = Collimator
DLM = Double Laue Monochromator
DS = Downstream
FOE = First Optical Enclosure
LWR = Lower
MSK = Mask
OCM = Optical Conditioning Module
PDF = Pair Distribution Function
RCO = Ratchet Wall Collimator
SBRS = Secondary Bremsstrahlung Shield
SBM = Side-Bounce Monochromator
UPR = Upper
US = Upstream
WC = Water-Cooled
w.r.t. = with respect to
XPD = X-ray Powder Diffraction