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17-ID AMX-FMX Beamline Radiation Shielding Analysis	

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 NSLS-II 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.

Beamlines are required to shield against the two primary sources of radiation, the primary gas bremsstrahlung (GB) and the synchrotron radiation (SR), 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 first optical enclosure (FOE) walls as well as dimensions of the supplementary shielding required to reduce the dose on the downstream FOE walls. 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 Flexible Access Macromolecular Crystallography (AMX) and Frontier Macromolecular Crystallography (FMX) beamlines (17ID-AMX/FMX) 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 the SGB shielding. The Fluka simulations were used to determine the position and dimensions of the SGB shielding. The simulations show that the SGB shields are needed to ensure that the dose rates outside the FOE are lower than 0.05 mrem/hr.

The layout of the 17ID-AMX-FMX beamlines is presented in figure 1. These drawings were extracted from the Beamline Ray Trace Layout [PD-AMX-FMX-RAYT-0001]. The ray trace drawings list the major components in the beamline and provide the position of each component.

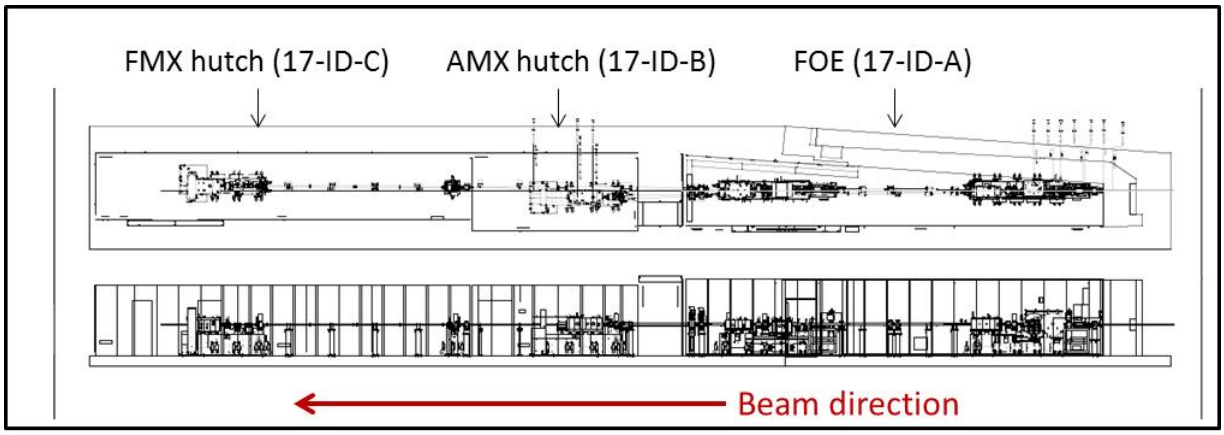


Figure 1. The 17ID-AMX-FMX layout. The beam travels from right to left. The top figure is the plan view and the bottom figure the elevation view

Since AMX and FMX are canted beamlines their layout is somewhat complex. The AMX white beam travels at an angle of 1.011 mrad with respect to the front end (FE) centerline and the FMX white beam travels at an angle of -0.989 mrad with respect to the FE centerline. The FE layout is shown in figure 2 was extracted from the Beamline Setup Table 6276-0001_NSLS-II_FMX-AMX-BLs_SetupTable_v30_2015-07-02_C. The positions of the major components were also extracted from the Beamline Setup Table.

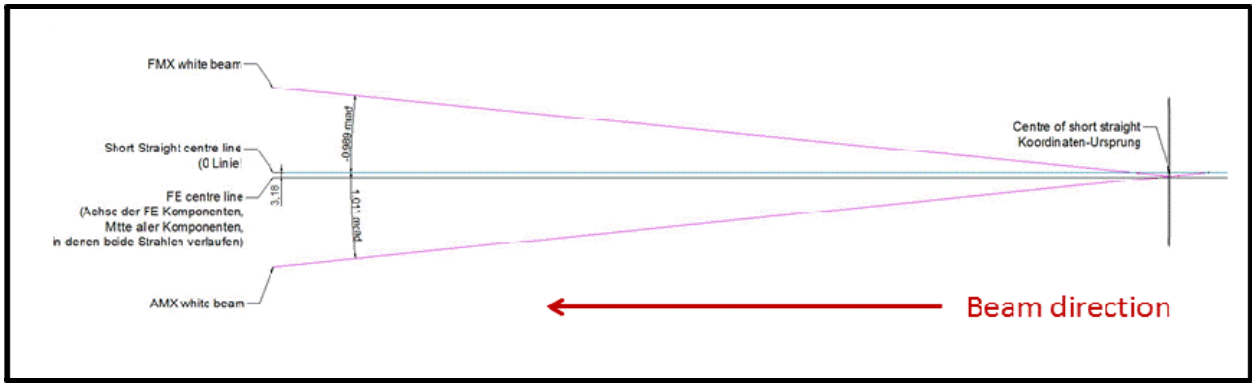


Figure 2. The layout of the AMX and FMX beams with respect to the FE and short straight (SS) centerlines.

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 ID straight section	15.5 m
Pressure in straight section	1 ntorr

The beam is normalized at 17μW incident power, for the long (15.5m) 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 attached as Appendix 2.

The Fluka model is described in section 2 and a sample Fluka input file is included in Appendix 3. The positions, dimensions, materials and drawings of the main components are included in Appendix 1. The following simulations were performed using these dimensions for the primary Gas Bremsstrahlung (GB) beam:

1. GB on AMX aperture of the dual aperture fixed mask
2. GB on FMX aperture of the dual aperture fixed mask
3. GB on AMX white beam slit1
4. GB on AMX white beam slit 2
5. GB on AMX DCM crystal
6. GB on PPS mask upstream of Brem collimator 2
7. GB on FMX white beam slit 1
8. GB on FMX white beam slit 2
9. GB on silicon crystal

   Simulations 1-9 performed with both SGB1 and SGB2 shields

10. GB on AMX white beam slit1 – SGB2 but no SGB1
11. GB on AMX white beam slit2 – SGB2 but no SGB1
12. GB on FMX white beam slit2 – SGB1 but no SGB2

The results of these simulations are described in section 3.

Additional simulations with modified design parameters:

- Increased diameter of the apertures in shield SGB2
- Modified dimensions of the guillotine
- Increased diameter of the aperture in shield SGB1

After the simulations had been finished the dual aperture SGB shield SGB2 was ordered to be built according to the specifications in Table 1.4 in Appendix 1. This lead shield was designed to have lateral dimensions 70 cm x 70 cm and a thickness of 5cm. The AMX and FMX apertures had a diameter of 10.0 cm. When the manufacturer's drawings arrived it was noticed that the shielding near the two apertures had the specified thickness only outside a diameter of 12.0 cm. This fact was modeled by increasing the diameters of the apertures from 10.0 to 12.0 cm. At the same time it was noted that dimensions of the guillotine were inverted. The guillotine should have been 84 cm wide and 80 cm high instead of 80 cm wide and 84 cm high.

The results of simulations 1-9 had shown dose rates close to or larger than 0.05 mrem/h in only three cases. These three cases were re-done taking into account the larger values of the apertures in shield SGB2 and the changed dimensions of the guillotine. The results have been appended to the end of section 3 as sections 3.7-3.9. It was found that the dose on the downstream FOE wall did not change substantially in response to the first two changes.

The aperture of shield SGB1 had to be increased to 14.0 cm from 12.7 cm due to the change in the diameter of the bellows. Simulation 3.7 was redone again with the increased aperture and these results have been edited into the text including the summary and table 5.

The results of the synchrotron radiation simulations are presented in section 4. Based on these calculation, the dose rates outside of the beam transport pipe and beamline enclosures are less than 0.05 mrem/hr on contact with the walls, roof and transport pipes.
A summary of all simulation results is presented in Section 5.

2. Description of the Fluka model

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 17μW incident power, for the long (15.5m) 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.

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 first optical enclosure (FOE) walls as well as dimensions of the supplementary shielding required to reduce the dose on the downstream FOE walls. The shielding recommended for the lateral and roof panels is 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 17ID-AMX-FMX 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 (157 cm distance from beam), roof 10 mm Pb (200 cm above beam) and downstream FOE wall 50 mm Pb (~1904 cm from the ratchet wall).

The FLUKA geometry of the AMX-FMX beams is shown in figures 3(a) (Horizontal cut). For the Fluka models the Z axis represents the beam axis, 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.

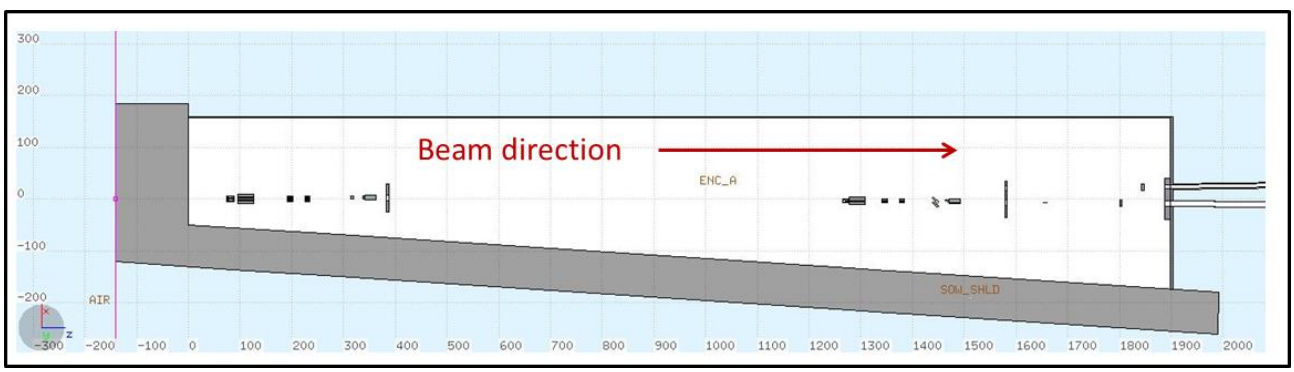


Figure 3(a). Horizontal cut of AMX/FMX FLUKA geometry at beam height

In order to show some more detail the AMX components are shown in figure 3(b) and the FMX components in figure 3(c).

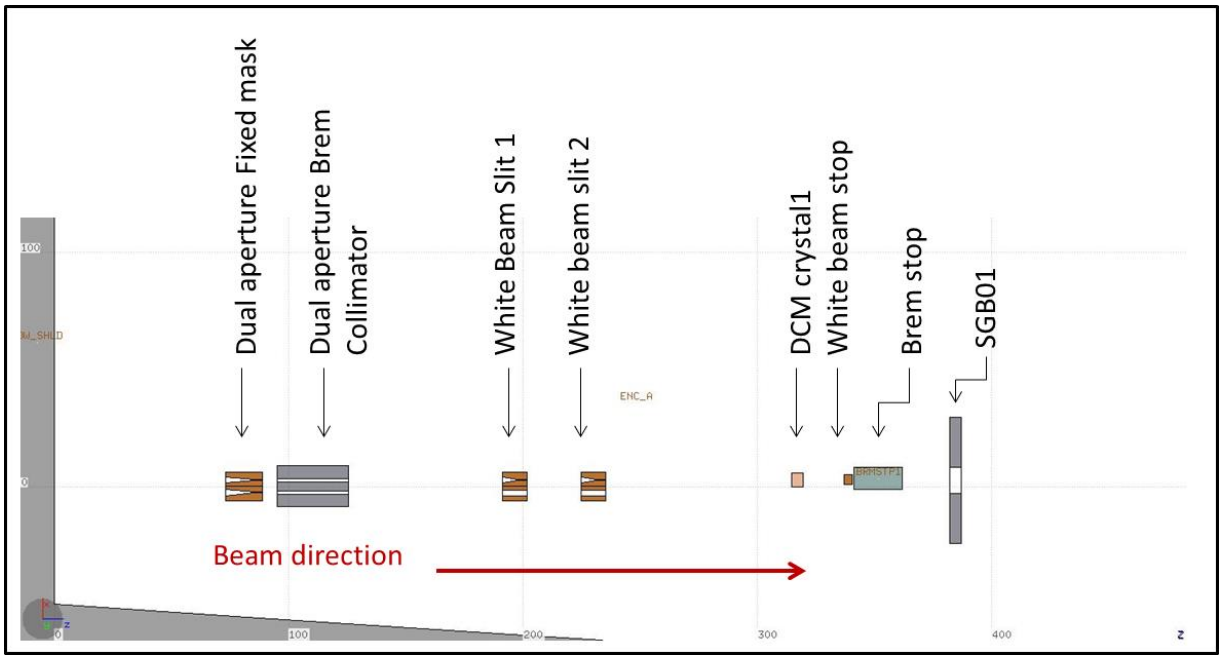


Figure 3(b). The positions of the dual aperture and AMX components.

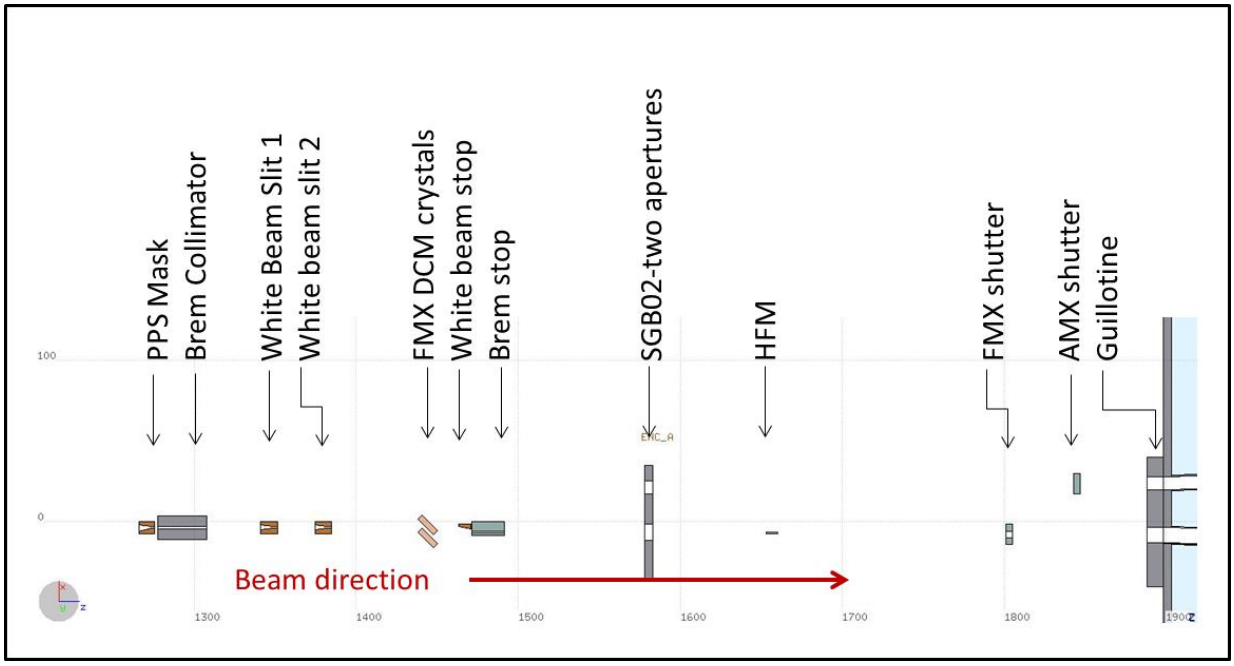


Figure 3(c). The positions FMX and downstream components.

The positions, dimensions, materials and drawings of the main components are included in Appendix 1. The bremsstrahlung source file is attached as Appendix 2. A sample Fluka input file is included in Appendix 3.

3. Results for primary gas Bremsstrahlung (GB) simulations

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. The recommended shielding for lateral and roof panels is sufficient for most white beam component configurations. However, the recommended shielding for the downstream panels may not be sufficient to protect against secondary bremsstrahlung. In these cases, additional shielding against secondary bremsstrahlung for the downstream panel will be needed.

Simulations performed for [1] "show that significant amount of secondary (scattered) bremsstrahlung is created when the primary bremsstrahlung is incident on substantial white beam components. These white beam components primarily disperses the primary bremsstrahlung without significant energy loss; thereby greatly increasing the angular extent of very high-energy bremsstrahlung photons. Simulations show that it is necessary to intercept this secondary bremsstrahlung *before* they hit the downstream FOE wall.

3.1 GB on the AMX and FMX apertures of the dual aperture fixed mask

The Fluka image of the fixed mask is shown in figure 4. Both apertures are tapered in both x and y direction. In simulation 1 the GB impinges on the outboard tapered plane close to the neck of the AMX aperture. In simulation 2 the GB impinges on the outboard tapered plane close to the neck of the FMX aperture. Both SGB1 and SGB2 shields were included in the simulation.

Figure 4. The dual aperture fixed mask with AMX and FMX apertures. The dual aperture Bremsstrahlung collimator 1 is immediately downstream of the FM.

The total dose rate (mrem/h) distribution at the transverse beam plane (y=±4cm) is shown in figure 5 for the two cases. When the GB hits the AMX aperture the secondary GB travels down the AMX beam centerline. When the GB hits the FMX aperture the secondary GB travels down the FMX beam centerline. All components downstream of the GB starting position become SGB sources. In the AMX case additional shielding is provided by FMX components. Since some of the FMX components are relatively close to the FOE wall the dose on the FOE wall is higher in this case.

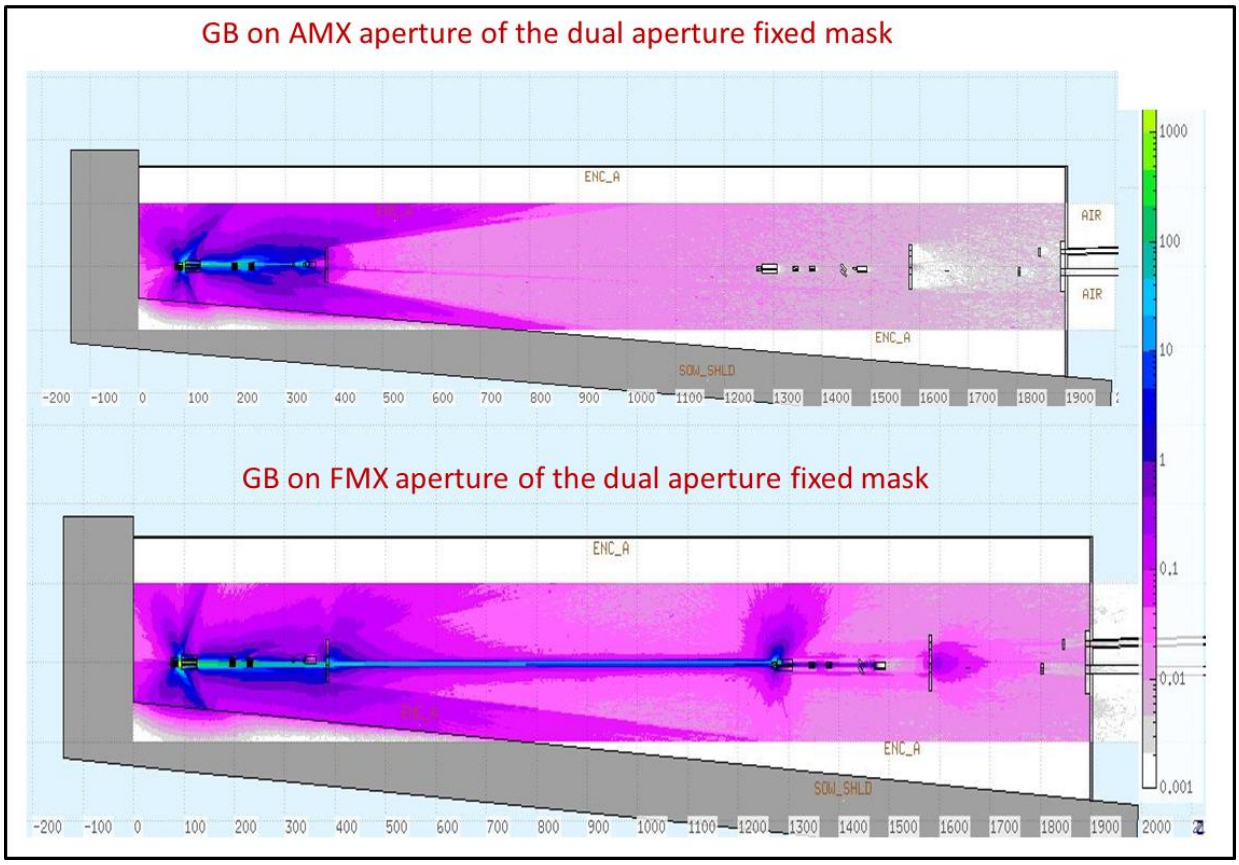


Figure 5. The total dose rate (mrem/h) distributions at the transverse beam plane (y=±4cm) when GB impinges on the AMX aperture (top) and FMX aperture (bottom).

The dose distributions on the DS FOE wall are shown in figure 6 for the two cases. The maximum dose is much lower than the 0.05 mrem/h allowed by the NSLS-II shielding policy.

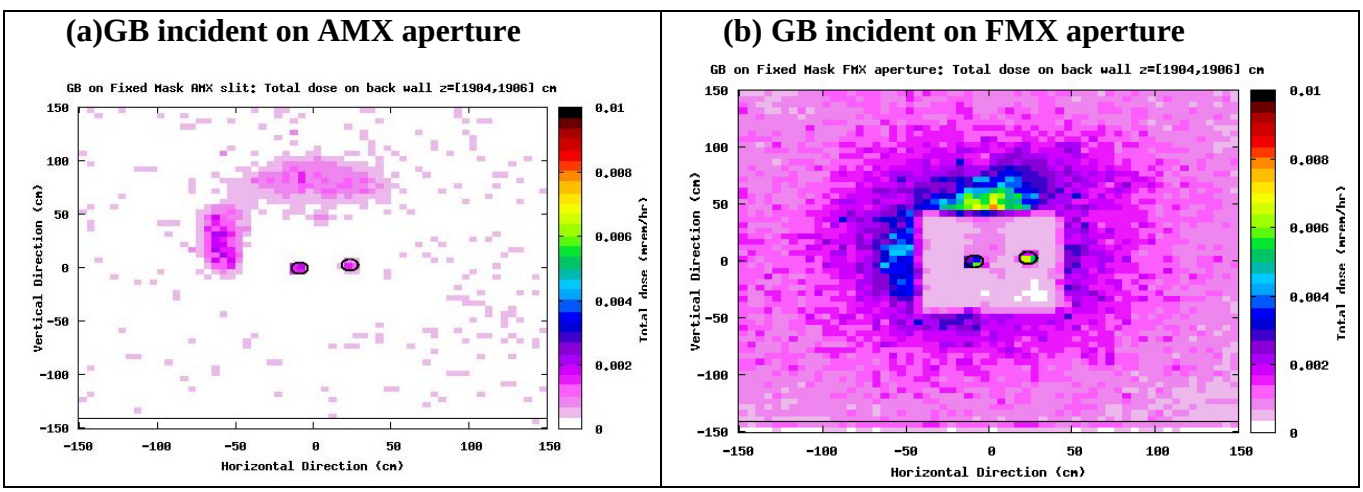


Figure 6. The dose distributions on the DS FOE wall: (a) GB incident on the AMX aperture and (b) GB incident on the FMX aperture.

The dose distributions on the roof and the sidewall look very similar for the two cases, therefore only the dose distributions for FMX aperture are presented in figure 7.

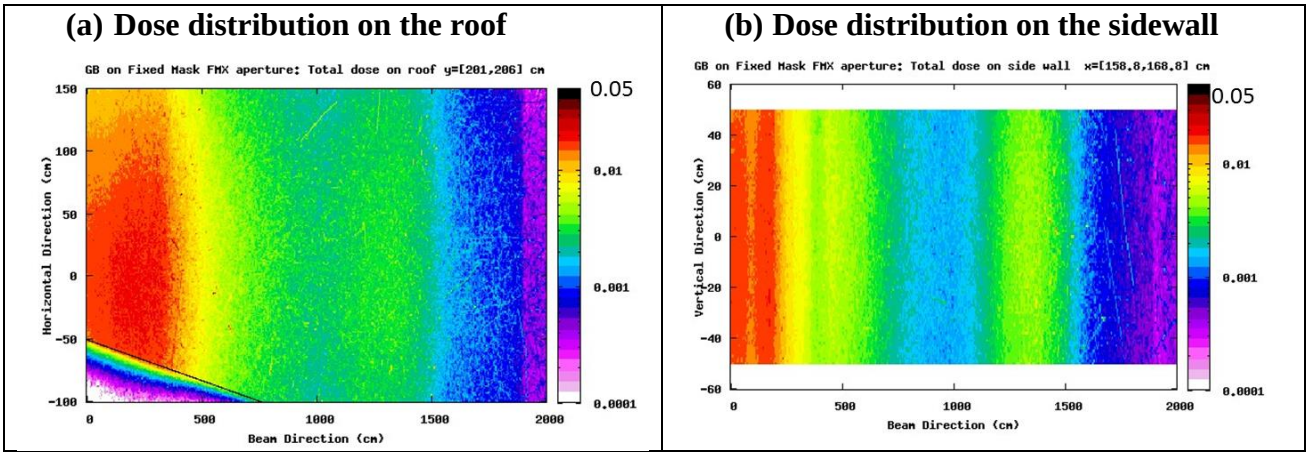


Figure 7. The dose distributions on the FOE roof and sidewall when the GB impinges on the FMX aperture.

In both cases the dose rate on the roof and the sidewall was less than 0.05 mrem/h.

3.2 GB on the AMX aperture of the dual aperture white beam slits S1 and S2 often called AMX slits 1 and 2.

In these simulations the GB was incident on the outboard plane of the AMX tapered aperture close to the neck. The beam still passed through approximately 3-4 cm of copper. Both SGB1 and SGB2 shields were included in the simulation. The dose distributions in the transverse plane and on the DS FOE wall for slit1 are shown in figure 8. The dose on the roof, sidewall and the DS FOE wall was found to be less than 0.05 mrem/h.

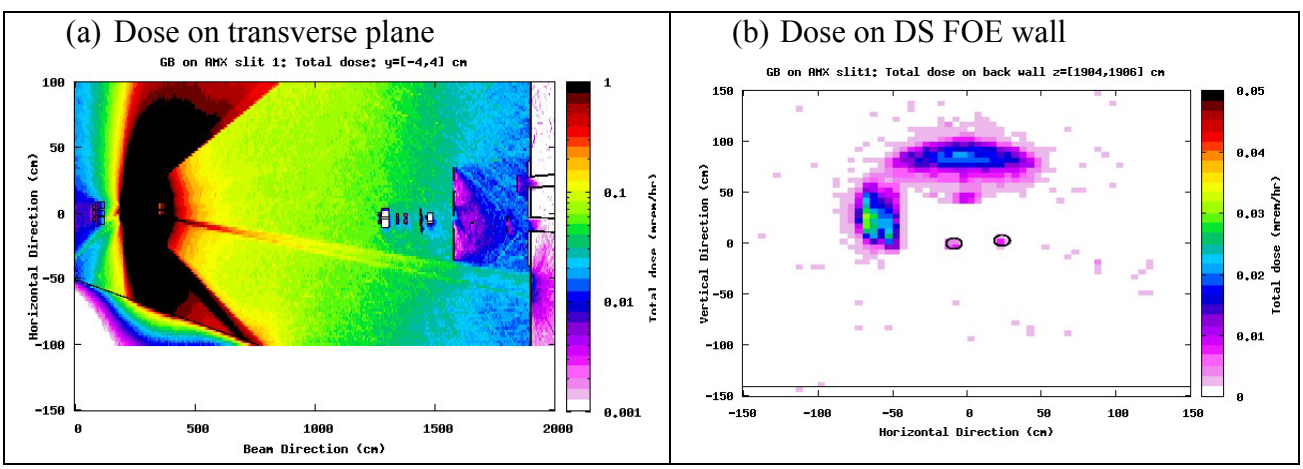


Figure 8. The dose distributions in the transverse plane and on the DS FOE wall for AMX slit1.

The dose distribution on the FOE wall for the AMX white beam slit 2 is shown in figure 9(a). The dose distribution 30 cm DS of the FOE wall is shown in figure 9(b).

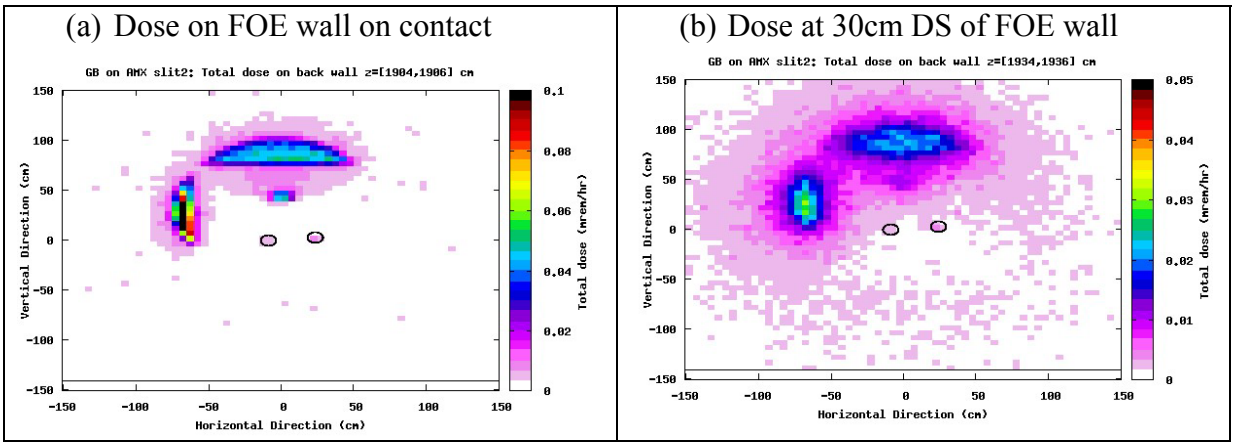


Figure 9. The dose distribution on the FOE wall for the AMX slit 2 on contact (a) and 30 cm downstream of the wall (b).

The maximum dose on the DS FOE wall is ~0.1 mrem/h on contact but it reduces to less than 0.05 at 30 cm. The dose on the roof and the sidewall of the FOE was found to be less than 0.05 mrem/h.

3.3 GB on the AMX DCM silicon crystal 1

The dose distributions on the FOE wall and the transverse beam plane for the GB hitting the AMX DCM silicon crystal is shown in figures 10(a) and (b).

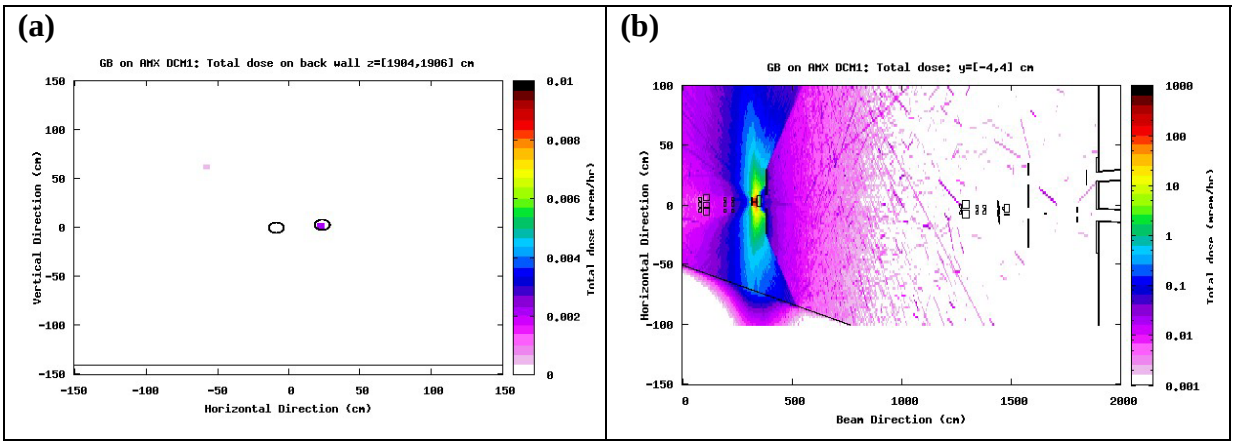


Figure 10. The dose distributions on the DS FOE wall (a) and in the transverse plane (b) for GB incident on slit1.

The GB is scattered by the Si crystal. However the gammas travelling in the forward direction are intercepted by the white beam stop, the bremsstrahlung stop and the SGB1 shield (see figure 2b) thereby drastically reducing the dose on the downstream FOE wall.

3.4 GB on the FMX PPS Mask

The positions of the FMX components are shown in figure 3(c). The PPS mask is immediately upstream of bremsstrahlung collimator 2. The GB impinges on the inboard tapered plane close to the neck of the FMX aperture. The dose distributions on the FOE wall and the transverse beam plane are shown in figures 11(a) and (b). The dose on the DS FOE

wall was found to be less than 0.02 mrem/h. The dose on the roof and the sidewall were found to be less than 0.05 mrem/h.

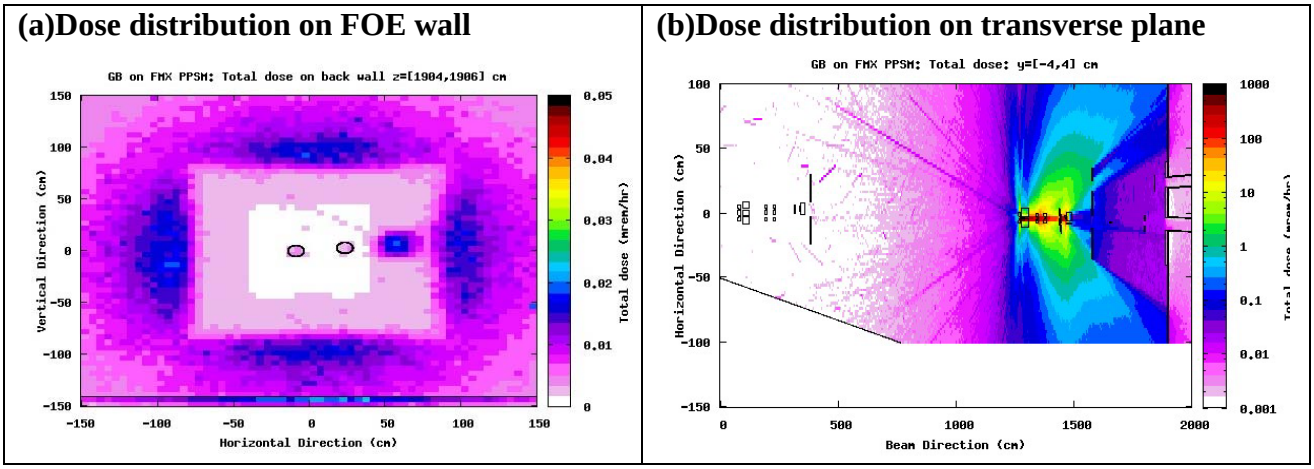


Figure 11. The dose distributions on the DS FOE wall (a) and in the transverse plane (b) for GB beam incident on the FMX PPSM mask

3.4 GB on the FMX white beam slits 1 and 2

The FMX white beam slits 1 and 2 are immediately downstream of bremsstrahlung collimator 2 (see figure 3(c). The apertures are tapered. The GB impinges on the outboard tapered plane close to the neck of the aperture. The position of the beam has some impact on the dose distribution on the Foe wall, the location of the maximum varies with the beam position. However, the maximum value of the dose does not change substantially. Dose rate distributions on the FOE DS wall, the roof and the sidewall are shown in figure 12.

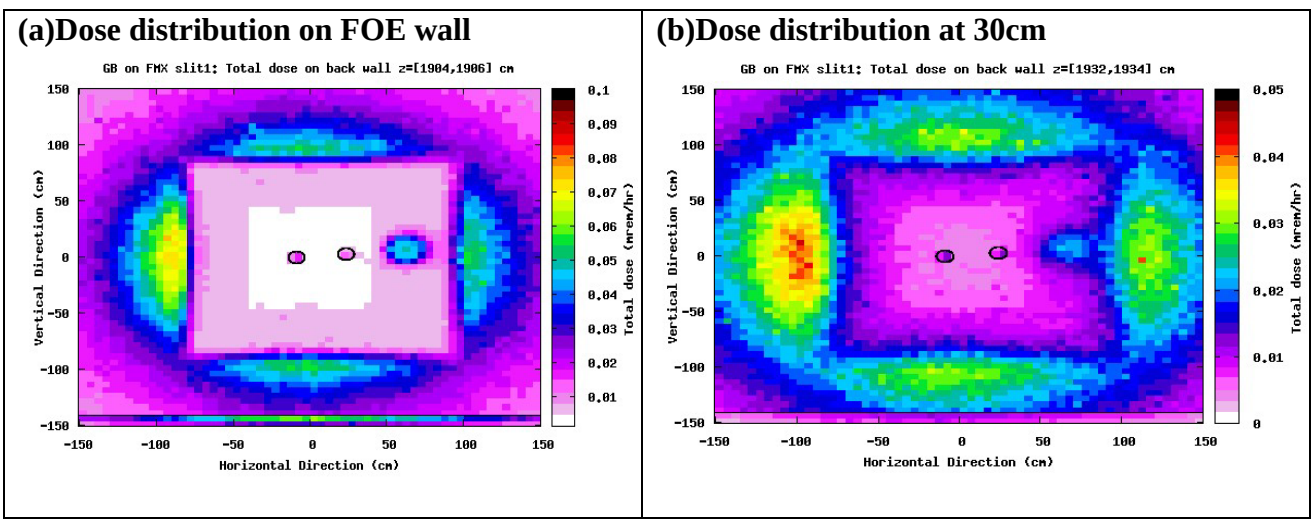


Figure 12. The dose rate distributions on the DS FOE wall for slit1: (a) on contact with the wall, (b) at 30 cm DS of the wall.

The dose rate on contact with the wall is ~0.07 but the dose rate reduces to less than 0.05 at 30 cm from the wall. The position of the beam has some impact on the dose distribution on the FOE wall, the location of the maximum varies with the beam position. However, the maximum value of the dose does not change substantially.

Dose rate distributions on the FOE DS wall, the roof and the sidewall are shown in figure 13 when the GB beam is incident on the white beam slit 2.

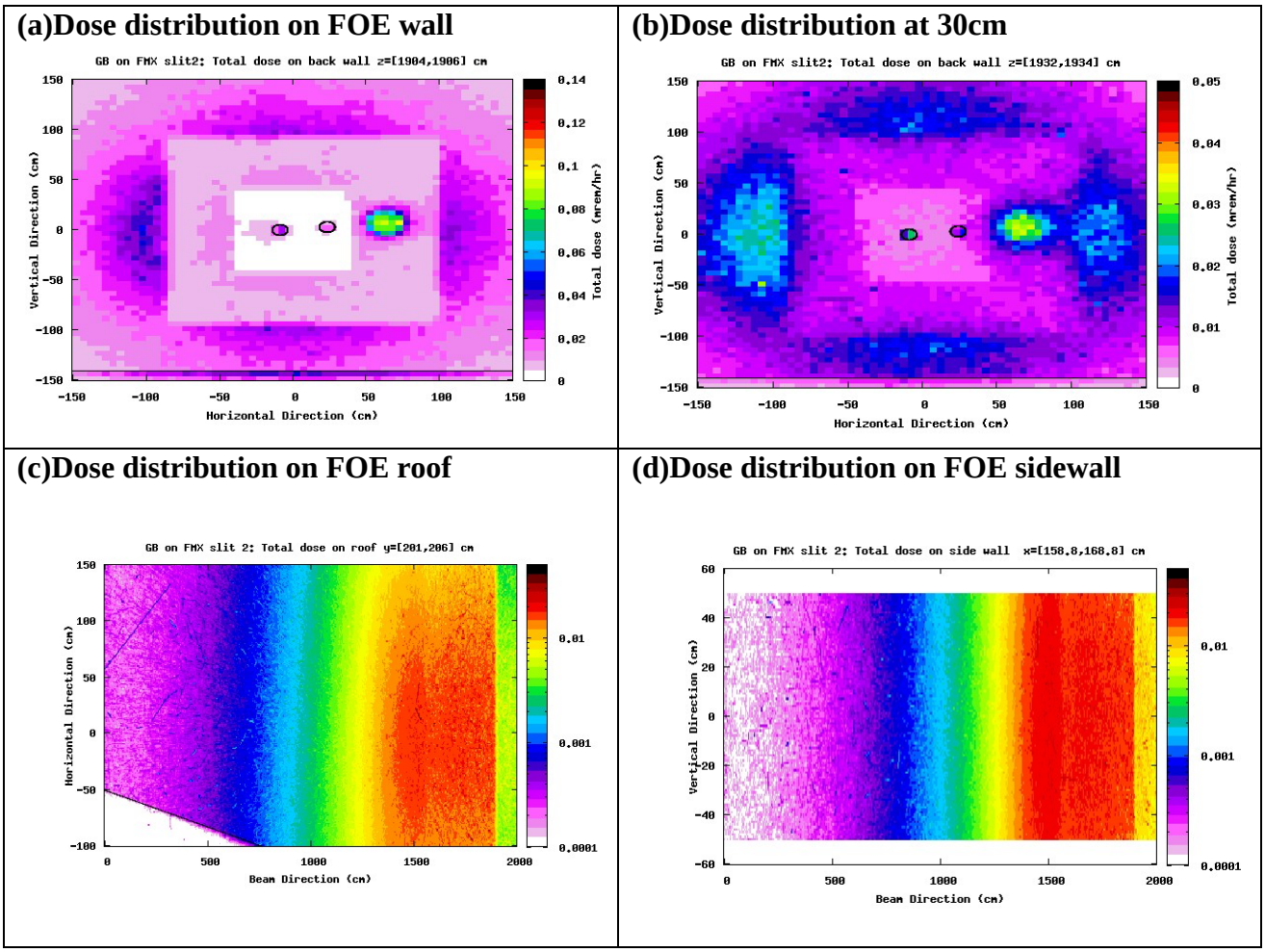


Figure 13. The dose rate distributions on the DS FOE wall for slit2: (a) on contact with the wall, (b) at 30 cm DS of the wall, (c) on the roof and (d) on the sidewall of the FOE.

For both cases (GB hitting slit 1 or slit 2) the maximum dose rate on contact on the FOE wall is higher than 0.05 mrem/h but decreases to below 0.05 mrem/h at 30 cm form the wall. The high-dose rate spots observed on the right of the AMX aperture are due to leakage through the AMX aperture in SGB2. Both the SGB2 shield and the guillotine are required to reduce the dose to acceptable levels on the FOE wall.

The dose rate distributions on the roof and sidewall are shown for slit 2 in figure 13(c) and (d). The maximum values of the dose rate on the roof and the sidewall of the FOE are lower than 0.05 mrem/h. The dose rate distributions and the maximum values of the dose are very similar for the case of GB on slit1.

3.5 GB on the FMX DCM crystal 1

The positions of the FMX components including the FMX DCM are shown in figure 3(c). The DCM is immediately downstream of the white beam slit 2. The GB impinges on the front face of the outboard crystal. A narrow band of energies are reflected off the crystal but

most other photons are scattered or transmitted through the crystal. This scattered/transmitted beam is intercepted by the white beam stop, the Brem stop and the SGB2 shield. The dose distributions on the FOE wall and on the transverse beam plane are shown in figures 14(a) and (b).

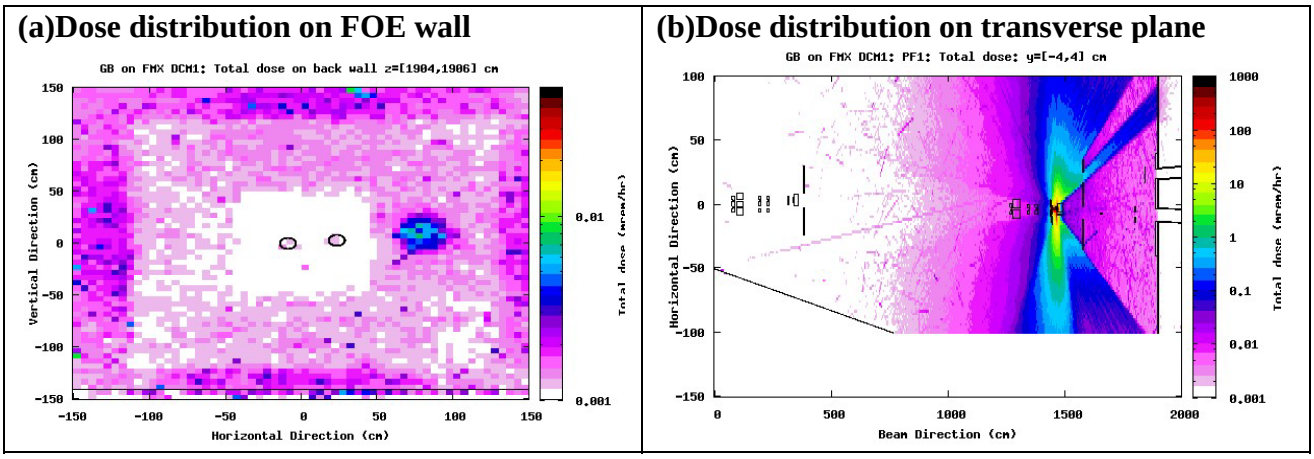


Figure 14. The dose distributions in the transverse plane and on the DS FOE wall for GB impinging on DCM1

The maximum dose rate on contact on the FOE wall is lower than 0.01 mrem/h. The blue high-dose rate spot observed on the right of the AMX aperture is due to leakage through the AMX aperture in SGB2. The maximum values of the dose rates on the roof and the sidewall of the FOE were found to be lower than 0.05 mrem/h.

3.5 GB on AMX slits 1 and 2 without SGB1: simulations to show that SGB1 shield is required to reduce the dose on the downstream FOE wall.

These simulations were performed to check whether the SGB1 shield is required to reduce the dose on the downstream FOE wall. The dose rate distribution on the FOE DS wall (on contact) is shown in figure 15(a) for GB incident on AMX slit 1. The maximum value of the dose rate is approximately 0.06 mrem/h. However at 30 cm from the wall the dose rate reduces to less than 0.04 mrem/h (see figure 15(b)). This would lead to the conclusion that in this case the SGB1 shield may not be necessary.

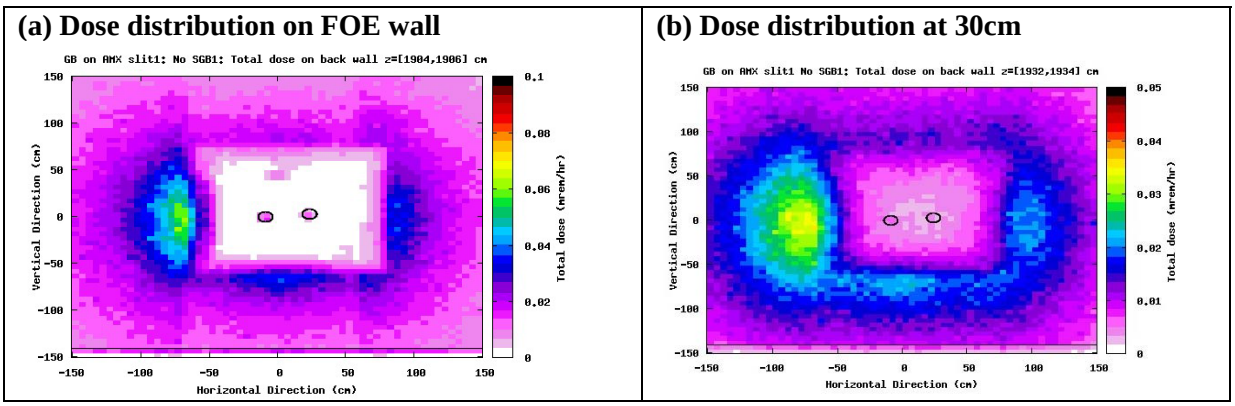


Figure 15. The dose rate distributions for GB impinging on AMX slit 1 on (a) the DS FOE wall and (b) 30 cm from the wall. Shield SGB1 was not included in this simulation.

The simulation was also done for GB incident on AMX slit 2 and again shield SGB 1 was removed. The dose rate distribution on the FOE DS wall (on contact) is shown in figure 16(a) for GB incident on AMX slit 2. The maximum value of the dose rate is > 0.2 mrem/h. At 30 cm from the wall the dose rate reduces to approximately 0.1 mrem/h (see figure 16(b)).

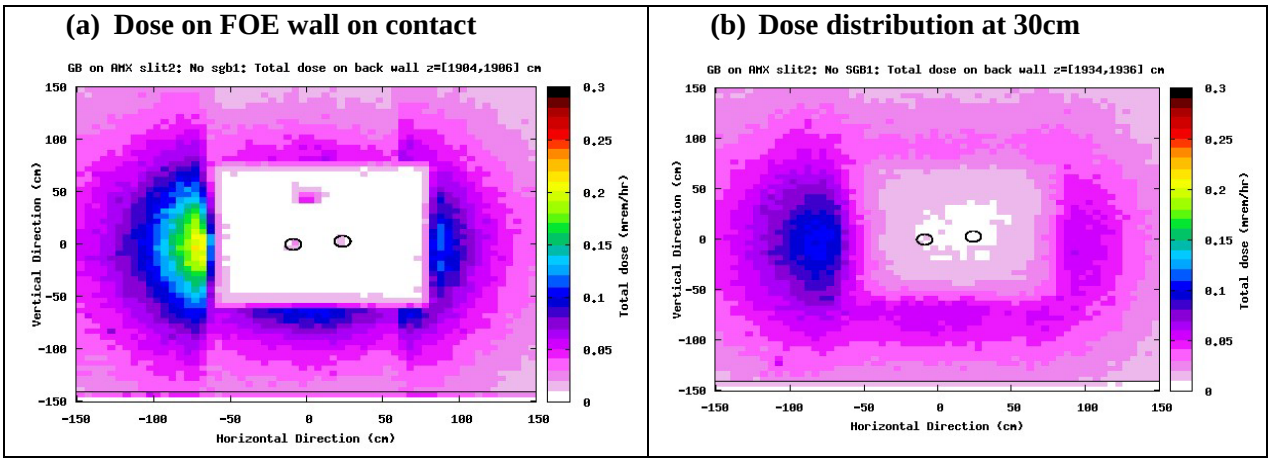


Figure 16. The dose rate distributions for GB impinging on AMX slit 2 on (a) the DS FOE wall and (b) 30 cm from the wall. Shield SGB1 was not included in this simulation.

Since a dose rate of ~0.1 mrem/h is not acceptable according to the NSLS2 shielding policy the SGB1 shield is required to reduce the dose rate on the FOE wall.

3.6 GB on FMX slit 2 without SGB2: simulations to show that SGB2 shield is required to reduce the dose on the downstream FOE wall.

This simulation was performed to show that shield SGB2 is required to reduce the dose on the downstream FOE wall. Shield SGB1 was included in this simulation even though it has no impact on dose rates for GB incident on any of the FMX components. The simulation was identical to the one presented in section 3.4 except that SGB2 was effectively removed. The dose rate distribution on the FOE DS wall (on contact) is shown in figure 17(a) for GB incident on FMX slit 2. The maximum value of the dose rate is <0.3 mrem/h. At 30 cm from the wall the dose rate reduces to approximately 0.1 mrem/h (see figure 17(b)).

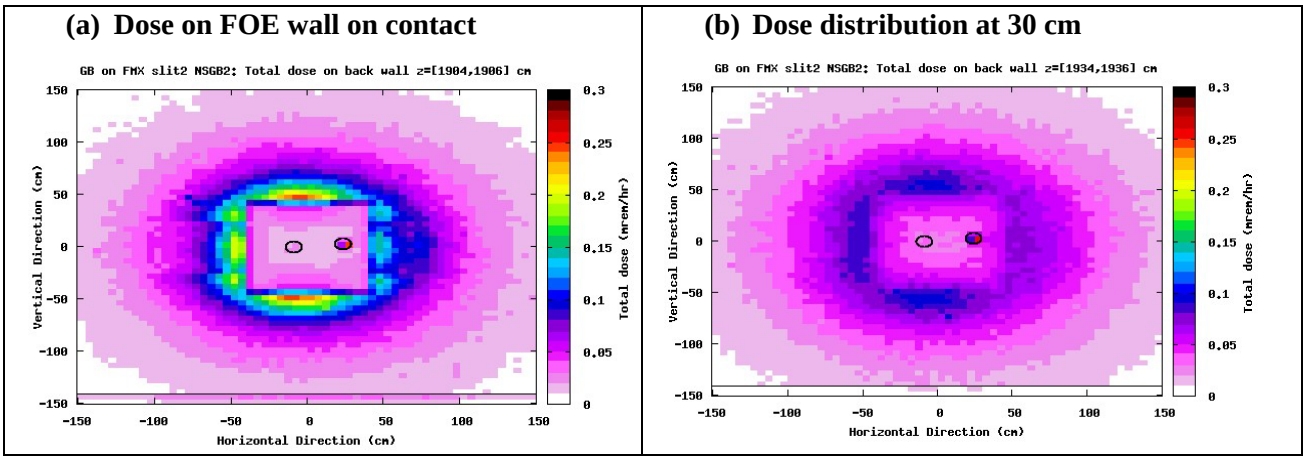


Figure 17. The dose rate distributions for GB impinging on FMX slit 2 on (a) the DS FOE wall and (b) 30 cm from the wall. Shield SGB2 was not included in this simulation.

Since a dose rate of ~0.1 mrem/h is not acceptable according to the NSLS2 shielding policy it was decided that shield SGB2 is required to reduce the dose rate on the FOE wall.

The FLUKA simulations show that the secondary GB shields SGB1 and SGB2 are necessary to reduce the total dose rate to less than 0.05 mrem/hr at 30cm from the downstream wall of the FOE as required by NSLS-II shielding policy. The dose rates on the roof and the side wall of the FOE are always lower than 0.5 mrem/h.

3.7 GB on the AMX white beam slits 2: Diameter of both apertures in the dual-aperture shield SGB2 is increased from 10.0 to 12 cm, dimensions of guillotine modified. Diameter of SGB1 shield increased from 12.7 to 14.0 cm

The total dose rates on the DS FOE wall are shown in figure 18(a) for dose on contact and 18(b) for dose at 30 cm from the wall. These dose rates should be compared with the dose rates in figure 9(a) and (b).

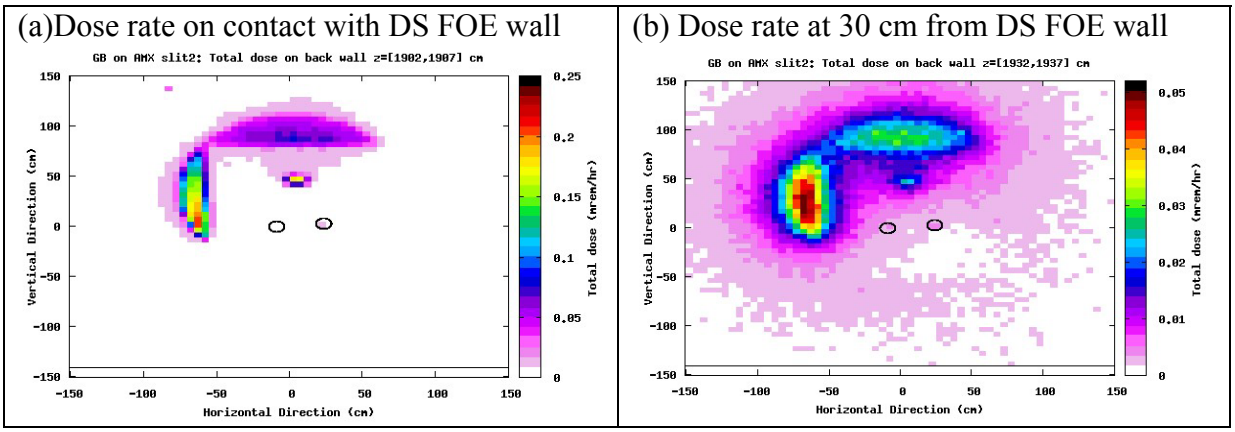


Figure 18. The dose rate distributions on the DS FOE wall for GB on AMX slit2: (a) on contact with the wall, (b) at 30 cm DS of the wall.

The on-contact dose rate increased from ~0.10 to ~0.16 whereas the dose rate at 30 cm increased from 0.03 to 0.035 mrem/h. The dose distributions on the roof and the side wall of the FOE remain unchanged.

3.8 GB on the FMX aperture of the Fixed mask: Diameter of apertures in the dual-aperture shield SGB2 and dimensions of guillotine modified

The total dose rates on the DS FOE wall are shown in figure 19(a) for dose on contact and 19(b) for dose at 30 cm from the wall. These dose rates should be compared with the dose rates in figure 13(a) and (b). The high-dose rate spots observed on the right of the AMX aperture are due to leakage through the AMX aperture in SGB2. Both the SGB2 shield and the guillotine are required to reduce the dose to acceptable levels on the FOE wall.

The on-contact dose rate remains ~0.10 and the dose rate at 30 cm is still ~0.035 mrem/h. The dose distributions on the roof and the side wall of the FOE remain unchanged.

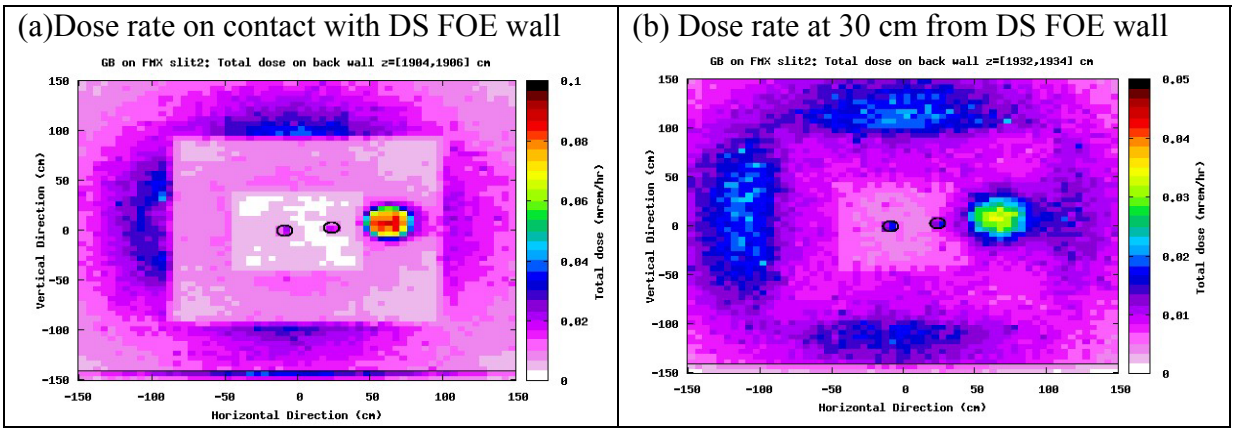


Figure 19. The dose rate distributions on the DS FOE wall for GB on AMX slit2: (a) on contact with the wall, (b) at 30 cm DS of the wall.

3.9 GB on the FMX white beam slits 2: Diameter of both apertures in the dual-aperture shield SGB2 is increased from 10.0 to 12 cm, dimensions of guillotine modified

The total dose rates on the FOE downstream wall shown in figure 20 (a). These dose rates should be compared with the dose rate in figure 6(b). The dose rate distribution in the FOE is shown in figure 20(b). This is the vertical cut at the SS centerline, and shows higher dose rates above the guillotine**.** This is due to the fact that the GB was incident on the bottom plane of the aperture. If the GB had been lost on the top plane of the aperture the higher dose area would have been below the guillotine. The maximum dose rate on the FOE DS wall is approximately ~0.01 mrem/h, well below the allowed 0.05 limit.

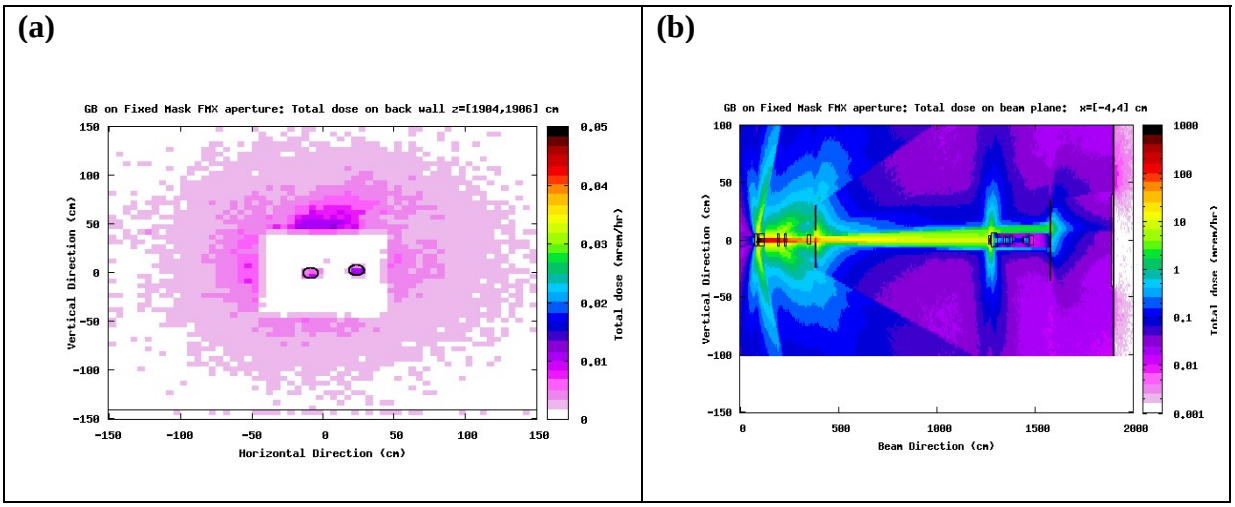


Figure 20. (a) The dose rate distributions on the DS FOE wall for GB on the FMX aperture of the fixed mask. (b) the dose rate distribution in the FOE - vertical cut at the SS centerline.

The last three simulations show that increasing the diameter of the AMX and FMX apertures of SGB2 from 10.0 to 12.0 cm and changing the dimensions of the guillotine does not have a significant impact on the dose rates on the FOE walls.

4. Synchrotron Radiation Calculation

The ID17 (AMX/FMX) beamline is an IVU21 source with its parameters given in Table 2 [2]. The horizontal opening angle for the 17ID source fan entering the first optics enclosure (FOE) is given in column 2. In addition, the NSLS-II stored electron beam parameters of 3 GeV and 500 mA (See Table 1) have been assumed to calculate the critical energy (column 6) and total integrated power (column 7).

Table 2: Source parameters used for 17ID (AMX/FMX) synchrotron calculations.

Source	Max. source opening	No. Of periods	Max. B_{eff} (T)	Period (mm)	E_c (keV)	STAC 8 Total Power (kW) @ 500mA
IVU 21	1.0 mrad-H	74	0.921	21	5.5	3.9

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 monochromatic beam pipe and experimental enclosures (17ID-B and 17ID-C) assumes that bremsstrahlung has been completely stopped in the FOE.

4.1 First Optics Enclosure (FOE)

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 FMX DCM approximately 450 cm from the FOE downstream wall, 158 cm from the lateral wall and 200 cm from the roof. The minimum required shielding for the SR source (no credit has been given to the SGB shielding or Guillotine) and the corresponding ambient dose rates are given in Table 3. The dose rate from SR is negligible on downstream wall, lateral wall, and roof with existing FOE shielding. The existing shielding thicknesses of the FOE walls and roof as given in Appendix 1 is more than adequate to meet the design requirement of 0.05 mrem/h.

Table 3: SR shielding design requirements for 17ID-A (FOE).

	Distance (cm)	Required Shielding	Ambient Dose rate (mrem/h)
Lateral wall	158	4 mm Pb	0.0252
Roof	200	4 mm Pb	0.0158
Downstream Wall (> 1°)	450	7 mm Pb	0.0173

4.2 Monochromatic Beam Transport Pipe

From the ray-tracing drawing (PD-AMX-FMX-RAYT-0001), the synchrotron max-fan for FMX when propagated through the monochromator (with HFM out of the beam) strike normal incidence the lead shielded junction box (used to transition from the 4” pipe to the 2” pipe) on its upstream face. This can be extrapolated from the ‘AMX/FMX MAX SYNCHROTRON, HORIZONTAL’ ray tracings given in Sheet 2 of PD-AMX-FMX-RAYT-0001. The relevant detail is shown in Figure 20. The drawings show that no portion

of this monochromatic max-fan can strike beam pipe walls. The max-fan is entirely stopped by the junction box faces that are perpendicular to the beam direction. There are the two layers of 5 mm lead sheeting that line the entire inner surface of the connector box for a total of 10 mm lead thickness in the direction of the fan. Additional shielding of about 10 mm provided by the two collars around the pipe has not been taken into account. Assuming five higher harmonic reflections (111, 333, 444, 555, and 777) of the fundamental mode of 22 keV with corresponding bandwidths [4, 5], the dose is calculated directly downstream of the junction box by the "NICK" card in STAC8. The calculated dose rate is 1.3E-03 mrem/hr which is below the design criteria of 0.05 mrem/hr.

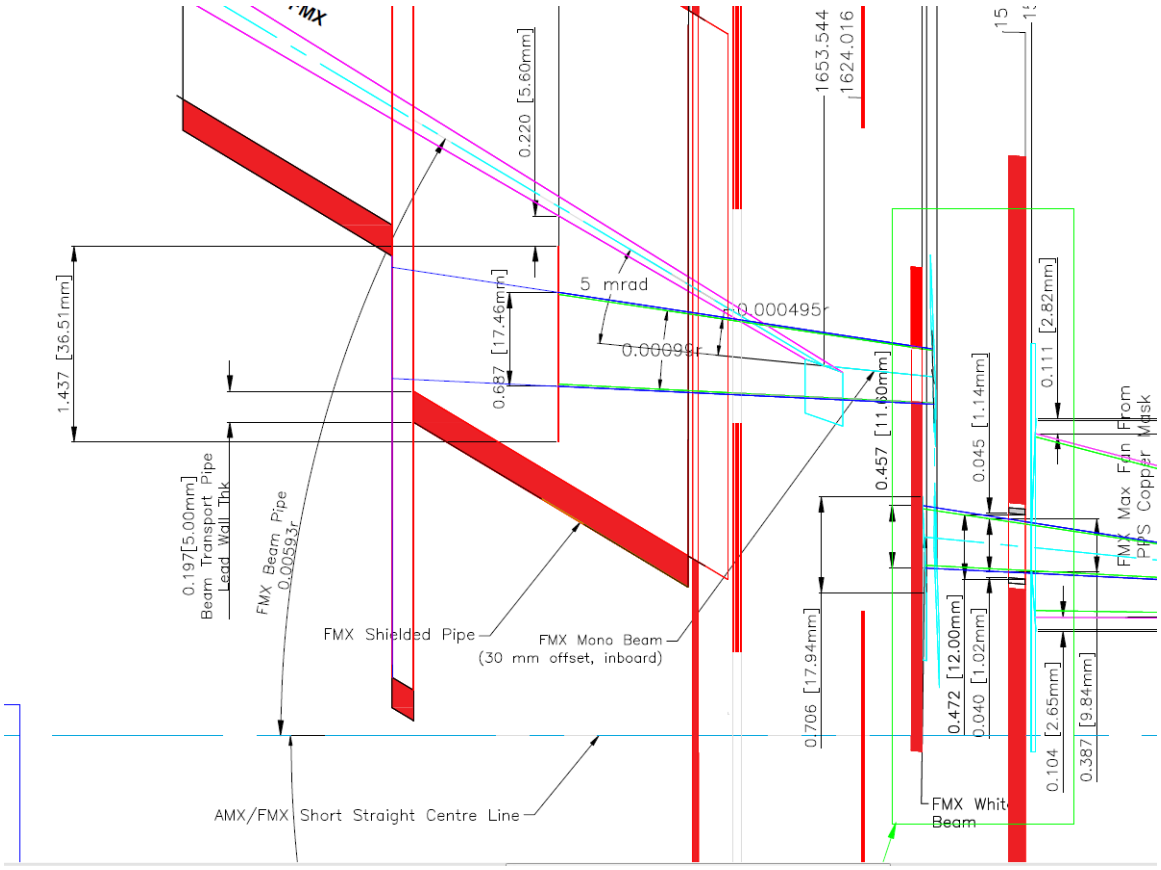


Figure 21: Layout illustrating where FMX monochromatic beam strikes when HFM mirror is out of the beam. It shows that monochromatic beam from FMX DCM will strike the lead shielded junction box used to transition from the 4" pipe to the 2" pipe.

The FMX/AMX transport pipes are both 4" diameter stainless steel pipe wrapped by 5 mm lead (see Table 1.2). Both AMX and FMX have DCM following by mirror(s) to reflect the monochromatic beam to transport pipe and experimental enclosures (17ID-B and 17ID-C). The STAC8 calculation was carried using 10 m of air at one atmosphere as the potential scatterer inside the beam transport pipe, simulating a vacuum loss accident. The same beam harmonic energies and bandwidths discussed above have been used. The maximum dose rate on contact with the pipe is 5.3E-04 mrem/hr. With platinum coated mirror at 0.14 degree [2] to the incident beam, the dose rates are reduced by approximately a factor of 100.

4.3 End Station Enclosures (17ID-B and 17ID-C)

The side, downstream and roof panels of FMX/AMX enclosures are made of 6 mm Steel. Monochromatic beam stops have been installed on the downstream wall of the 17ID-B and 17ID-C enclosures to intercept a direct monochromatic and consist of 30 cm × 30 cm × 2.54 cm thick Pb. The minimum distance between the scattering targets and the walls is given in Table 4. The scattering target is assumed to be a 10 cm radius, 2 cm thick silicon disk, tilted at 0.155 degree to the incident beam located at 100 cm from the downstream wall. The calculation was carried out in STAC8 code using the same beam harmonic energies and bandwidths described above.

The dose rates on the lateral wall and roof are listed in Table 4. The dose rates for the downstream wall exceed 0.05 for scattering angles less than 20° reaching a dose rate of about 1.5 mrem/hr at 8°. However a reflecting mirror must be inserted to bring the monochromatic beam into the experimental enclosures and assuming platinum coated mirror at 2.5 mrad to the incident beam [2] the dose rates reduce to 0.026 mrem/hr on contact with the downstream wall without taking into account the monochromatic beam stop which cover scattering angles less than 8.5^o for scattering target location of 100 cm.

Table 4 Maximum dose rate on lateral wall and roof

	Distance (cm)	Shielding	Dose rate (mrem/h)
Lateral Wall	130	6 mm Steel	8.97E-03
Roof	200	6 mm Steel	3.79E-03

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 17μW incident power. This value corresponds to the estimated bremsstrahlung power generated by a 500mA electron beam of 3GeV, assuming that the vacuum in the 15.5 m long straight sections is better than 10^{-9}Torr. Based on the GB ray tracings for 17ID, beamline components that intercept the primary GB were selected as scattering targets in the simulations. The FLUKA simulations show that the secondary GB shields SGB1 and SGB2 are necessary to reduce the total dose rate to less than 0.05 mrem/hr at 30cm from the downstream wall of the FOE as required by NSLS-II shielding policy.

A summary of the simulation results is presented in Table 5.

Additional simulations with modified design parameters:

- Increased diameter of the apertures in shield SGB2
- Modified dimensions of the guillotine
- Increased diameter of the aperture in shield SGB1

After the simulations had been finished the dual aperture SGB shield SGB2 was ordered to be built according to the specifications in Table 1.4 in Appendix 1. This lead shield was designed to have lateral dimensions 70 cm x 70 cm and a thickness of 5cm. The AMX and FMX apertures had a diameter of 10.0 cm. When the manufacturer's drawings arrived it was noticed that the shielding near the two apertures did not have the full thickness. However outside a diameter of 12.0 cm the shield did have the specified thickness. This fact was modeled by increasing the diameters of the apertures from 10.0 to 12.0 cm. At the same time it was noted that dimensions of the guillotine were inverted. The guillotine should have been 84 cm wide and 80 cm high instead of 80 cm wide and 80 cm high.

The results of simulations 1-9 had shown dose rates close to or larger than 0.05 mrem/h in only three cases. These three cases were re-done taking into account the larger values of the apertures in shield SGB2 and the changed dimensions of the guillotine. The results have been appended to the end of section 3 as sections 3.7-3.9. It was found that the dose on the downstream FOE wall did not change substantially in response to the first two changes.

The aperture of shield SGB1 had to be increased to 14.0 cm from 12.7 cm due to the change in the diameter of the bellows. Simulation 3.7 was redone again with the increased aperture and these results have been edited into the text including the summary and table 5.

Based on the STAC8 calculation, the dose rates outside of the beam transport pipe and beamline enclosures are less than 0.05 mrem/hr on contact with the walls, roof and transport pipes.

All radiation 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. This is especially important in view of the fact that all simulations were not repeated with the modified parameters.

Table 5. Maximum total dose rates (mrem/hr) on the roof, sidewall and downstream FOE wall on contact. The numbers in parentheses are the dose rates at 30 cm downstream of the FOE wall. Simulations 1-9 performed with both SGB1 and SGB2 shields. A: Simulations with the larger values of the apertures in shield SGB2 and the changed dimensions of the guillotine. B: Larger values of the apertures in SGB1 and SGB2 and changed dimensions of guillotine.

#	Simulation	**Maximum dose (mrem/hr)**		
		Roof	Sidewall	DS FOE wall on contact
1	GB on AMX aperture of the dual aperture fixed mask	< 0.05	< 0.05	~0.002
2	GB on FMX aperture of the dual aperture fixed mask (FM)	< 0.05	< 0.05	~0.007
2A	GB on FMX aperture of the FM Modified SGB2 and Guillotine	< 0.05	< 0.05	~0.007
3	GB on AMX/FMX white beam slit1 With SGB1 and SGB2	< 0.05	< 0.05	< 0.05
4	GB on AMX/FMX white beam slit2 With SGB1 and SGB2	< 0.05	< 0.05	~0.1 (< 0.03)
4B	GB on AMX/FMX white beam slit2 Modified SGB2 and Guillotine	< 0.05	< 0.05	~0.15 (~0.05)
5	GB on AMX DCM crystal 1	< 0.05	< 0.05	<0.01
6	GB on PPS mask upstream of Brem collimator 2	< 0.05	< 0.05	~0.02
7	GB on FMX white beam slit1 With SGB1 and SGB2	< 0.05	< 0.05	~0.07 (< 0.05)
8	GB on FMX white beam slit2 SGB2 Aperture diameter 10.0 cm	< 0.05	< 0.05	~0.11 (<0.04)
8A	GB on FMX white beam slit2 Modified SGB2 and Guillotine	< 0.05	< 0.05	~0.10 (<0.04)
9	GB on FMX DCM crystal 1	< 0.05	< 0.05	<0.01
10	GB on AMX/FMX white beam slit1 With SGB2 no SGB1	< 0.05	< 0.05	~0.06
11	GB on AMX/FMX white beam slit2 With SGB2 no SGB1	< 0.05	< 0.05	~0.2 (~0.1)
12	GB on FMX white beam slit2 With SGB1 no SGB2	< 0.05	< 0.05	<0.3 (0.1)

6. References:

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

[2] Email from D. Schneider to M. Benmerrouche (December 29, 2015).

[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).

[5] Private communication from Lonny Berman (January 07, 2016).

Appendix 1
Beamline Enclosures

Co-ordinate system

For non-canted beamlines the z axis lies along the long or short straight centerline. The positions (z co-ordinates) of the various components are defined with respect to the center of the straight. For canted beamlines like the AMX/FMX beamline the z axis can be placed along the short straight centerline or the front end (FE) centerline. The FE centerline is parallel to the short straight centerline but shifted outward along the x axis by x0 = 3.18 mm (6276-0001-NSLS-II_FMX-AMX-BLs_SetupTable_v30_2015-0702-c.xls. The positions of the Front End components are defined with respect to the FE centerline whereas the positions of most of the components in the FOE are defined with respect to the short straight (SS) centerline.

The SS centerline was used as the z or beamline axis for the Fluka models. Y is the vertical axis and x the horizontal axis orthogonal to the y and z axes.

Table 1.1 Beamline Enclosures

Wall	Position	Thickness	Material
D/S End of 17-ID-A Ratchet Wall	2546.821 cm		
D/S End of FOE (17-ID-A) Backwall	4450.021 cm	5.0 cm	Lead
Distance of FOE Sidewall from SS CENTERLINE	158.0 cm	1.8 cm	Lead
Distance of FOE Roof from SS CENTERLINE	200.0 cm	1.0 cm	Lead
Distance of FOE Floor from SS CENTERLINE	140.0 cm		
U/S End of AMX hutch (17-ID-B) Wall	4650 cm	6mm	Steel
D/S End of AMX hutch (17-ID-B) Wall	5400 cm	6mm	Steel
Distance of AMX hutch outboard Sidewall from SS CENTERLINE	180.34 cm	6mm	Steel
Distance of AMX hutch inboard Sidewall from SS CENTERLINE	167.64 cm	6mm	Steel
Distance of AMX hutch Roof from SS CENTERLINE	200.0 cm	6mm	Steel
U/S End of FMX hutch (17-ID-C) Wall	5400 cm	6mm	Steel
D/S End of FMX hutch (17-ID-C) Wall	7100 cm	6mm	Steel
Distance of FMX hutch outboard Sidewall from SS CENTERLINE	129.54 cm	6mm	Steel
Distance of FMX hutch inboard Sidewall from SS CENTERLINE	165.10 cm	6mm	Steel
Distance of FMX hutch Roof from SS CENTERLINE	200.0 cm	6mm	Steel

Table 1.2 Beamline Transport Pipes:

Transport Pipes between FOE & SOE for the AMX beamline	ID= 3.888 OD=4.00 inches Material: Stainless Steel	Shielding Thickness 5.0mm Shielding Material: Lead	Angle 0.86 deg wrt Z axis
Transport Pipes between FOE & SOE for the FMX beamlines	ID= 3.888 OD=4.00 inches Material: Stainless Steel	Shielding Thickness 5.0mm Shielding Material: Lead	Angle -0.34 deg wrt Z axis

Table 1.3 AMX/FMX Beamline Components and SGB shields.

Components	Z = Distance from SS centerline U,D or C	Dimensions (specify units)		Offset (vertical/ horizontal w.r.t FE CENTERLINE & Rotation	Material	Associated Drawings
		Outer dimensions (W)x(H)x(L)	Aperture (W)x(H) or (R)			
Dual Aperture AMX/FMX Fixed Mask DS of ratchet wall	2619.88 cm (U)	12cm (x) 10.6cm (y) 15.61cm (z)	Two tapered apertures US:2.5cm(x),2.5cm(y) DS:0.35cm(x)0.35cm(y) Z1=1.3in,Z2=4.846 in	Cu block centered wrt FE See fig 1.1 for aperture offsets	Glidcop (Copper)	C02a_6276_NSLS-II_AMX+FMX-BLs_TechSpec-Masks+Stops_Rev2.pdf
Bremsstrahlung Collimator 1 (Dual aperture)	US: 2641.88 cm	17.5 cm (x) 10.5cm (y) 30.48 cm (z)	Both apertures 1.2 cm (x) 1.2 cm (y)	Block centered wrt FE See fig 1.2 for aperture offsets	Lead	C02b_6276_NSLS-II_AMX+FMX-BLs_TechSpec-BScollimators_Rev2.pdf
AMX/FMX White Beam Slits (H)	2737.98 cm	12cm (x) 10.6cm (y) 10.6 cm (z)		See fig 1.3 for details	Copper	C08a_6276_NSLS-II_AMX+FMX-BLs_TechSpec-HighHeatLoadSlits_Rev4.pdf
AMX/FMX White Beam Slits (V)	2771.58cm	12cm (x) 10.6cm (y) 10.6 cm (z)		See figure 1.3 for details	Copper	C08a_6276_NSLS-II_AMX+FMX-BLs_TechSpec-HighHeatLoadSlits_Rev4.pdf
AMX DCM crystal 1	2862.182 cm	13.2cm (z) 5.9cm (x) 3.5cm (y)		Rotate 45 deg. wrt x axis DX:31mm DY:-1.75cm	silicon	
AMX DCM crystal 2	2862.182 cm	13.2cm (z) 5.9cm (x) 3.5cm (y)		Rotate 45 deg. wrt x axis DX:31mm DY:4.75cm	silicon	
AMX White Beam	2880.08 cm	Wedge:dx=4cm		Yoffset=-0.904in	copper	

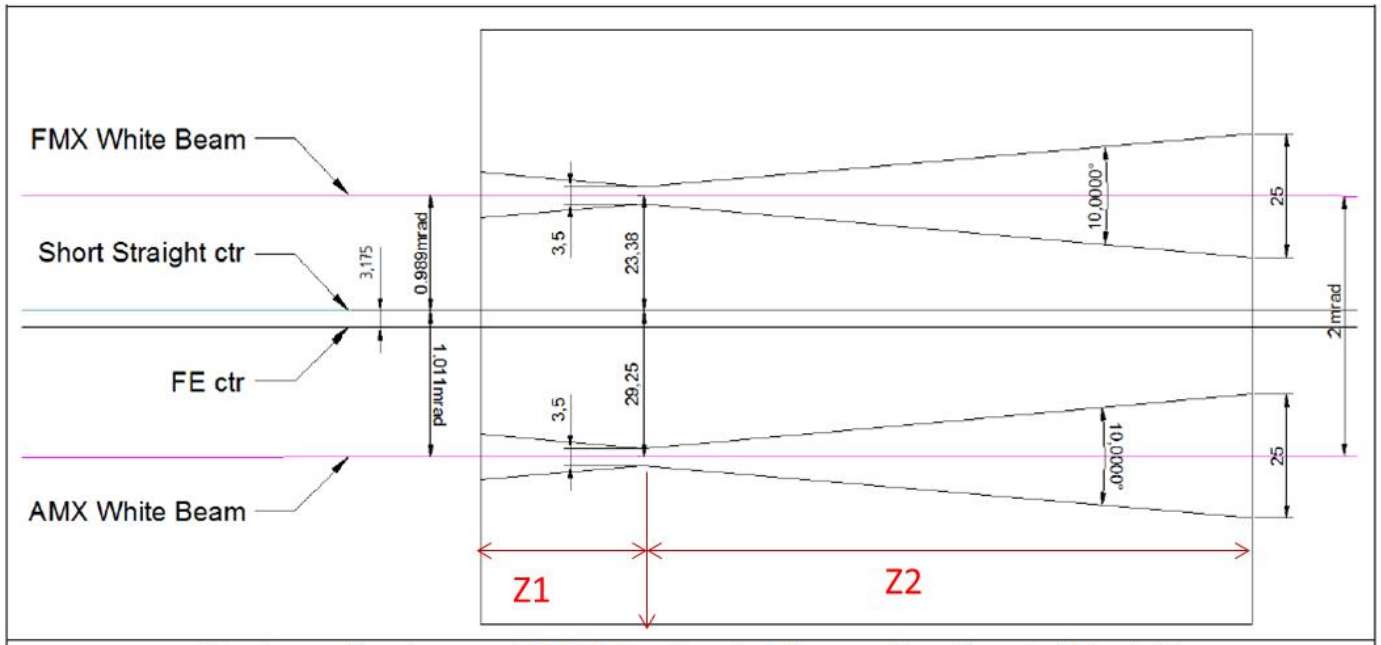
stop	(U)	y1=0.607 in y2=1.2013 in (z)= 7.5cm		Xoffset=1.2521in Of SS centerline See fig 1.4(a)		
AMX Bremsstrahlung Stop (W)	2888.18 cm (U)	9.2cm(W) 8.8cm(H) 20.5cm(L)	10mm X 10mm	See figure 1.5(a)	Tungsten	C02b_6276_NSLS-II_AMX+FMX-BLs_TechSpec-BScollimators_Rev2.pdf
SGB01 shield	2929cm (U)	54.0 cm (x) 54.0 cm (y) 5 cm (z)	12.7cm aperture (diameter)centered wrt block	Offset Y=30mm X-Offset=1.144in	lead	
AMX TDM Mirror 1	3078.325 cm(C)	1cm x 1cm x 50cm		Y-Offset=3 cm X-offset= 1.3 in rotated 3.5 mrad wrt y axis	Silicon	
FMX PPS mask	3812.6 cm (U)	7.62 cm (x) 7.62 cm (y) 9.5 cm (z)	Asymmetric UP Aperture 4.065cm(x)2.483cm(y) DS: 0.85 x 0.85 cm	Centered on FMX centerline Offset = -3.5062 See figure 1.6(b)	Glidcop (Copper)	PPS-mask_0010_P94649_Z187743.pdf
FMX Bremsstrahlung Collimator	3824.153 cm (U)	14.5 cm (x) 12cm (y) 30.48 cm (z)	1.6 cm (x) 1.6 cm (y Centered wrt collimator block	Dx = -3.518 cm	Lead	C02b_6276_NSLS-II_AMX+FMX-BLs_TechSpec-BScollimators_Rev2.pdf
FMX White Beam Slits (H)	3887.653 cm	7.6cm (x) 7.6 cm (y) 10.5cm (z)	UP 2.92cmx2.92cm DS: 1.1x1.1cm Z2=74.1mm Z1=29.4mm	DX=-3.59 cm	Copper	C08a_6276_NSLS-II_AMX+FMX-BLs_TechSpec-HighHeatLoadSlits_Rev4.pdf
FMX White Beam Slits (V)	3921.253 cm	7.6cm (x) 7.6 cm (y) 10.5cm (z)	UP 2.92cmx2.92cm DS: 1.1x 1.1cm Z2=74.1mm Z1=29.4mm	DX=-3.63 cm	Copper	C08a_6276_NSLS-II_AMX+FMX-BLs_TechSpec-HighHeatLoadSlits_Rev4.pdf
FMX DCM crystal 1	3991 cm	13.2cm (L) 5.9cm (W) 3.5cm (H)		45 degrees wrt Y axis inward DX=-3.64 cm	silicon	
FMX DCM crystal 2	3991 cm DX = FMX-3.0cm	13.2cm (L) 5.9cm (W) 3.5cm (H)		45 degrees wrt Y Face to face separation 3 cm DX=-6.64cm	silicon	
FMX White Beam stop	US:4010.0 cm	Wedge:DY=4cm x1=0.607 in x2=1.2013 in		Xoffset = -6.704 Yoffset=0.0 of FMX centerline	copper	

		(z)= 7.5cm		See fig 1.4(b)		
FMX Bremsstrahlung Stop (W)	4018 cm (U)	9cm(W) 8cm(H) 20.5cm(L)	1cm x 1cm	See figure 1.5(b)	Tungsten	C02b_6276_NSLS-II_AMX+FMX-BLs_TechSpec-BScollimators_Rev2.pdf
HFM Mirror 1	4200.0 cm(C)	1cm x 1cmx 7cm		DX = -6.889	Silicon	
FMX photon Shutter	4348.2 cm (U)	12.5 cm W 15 cm H 3.8 cm L	40 mm × 25 mm Centered wrt block	X_{FMX} = -7.867 cm Y_{FMX} = 0.0	Tungsten	
AMX photon Shutter	4390 cm (U)	12.5 cm W 15 cm H 3.8 cm L	40 mm × 25 mm Centered wrt block	X_{AMX} + 23.327 cm Y_{FMX} = 3.0	Tungsten	PD-COM-PSH-1000 (unreleased)
AMX/FMX Guillotine	4435 cm (U)	80cm W 84cm H 10 cm L Changed to 84cm W 80cm H	Dual aperture 4inch diameter	See figure 1.6(a)	Lead	

Table 1.4. Beamline SGB Shielding

Shielding	Z = Distance from SS centerline U,D or C	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)			
SGB1 shield See fig 1.8	2929cm (U)	54.0 cm (x) 54.0 cm (y) 5 cm (z)	Aperture diameter increased from 12.7 to 14.0cm	Offset Y = 30 mm Offset X=1.144in Aperture centered wrt block fig 1.7a	lead	
New SGB2 shield See fig 1.8	4125.0 cm (U)	70.0 (x) 70.0(y)5.0(z) centered on SS centerline	AMX aperture diameter 10.0cm increased to 12.0 cm	Xoffset = 21.318 Yoffset = 3.0 cm fig 1.7(b)	Lead	
			FMX aperture diameter 10.0cm increased to 12.0 cm	Xoffset = -6.682 Yoffset = 0.0 cm fig 1.7(b)		

Selected drawings for major components



*) schematic view on MASK (horizontal, beam direction right to left)

Mask outside dimensions: 12 cm (x)10.6 cm (y) 15.61 cm (z)
US aperture: 2.5 cm (x) 2.5 cm (y): Smallest aperture at z1: 0.35 (x) 0.35 (y)
Z1=1.3 in=3.302 cm z2=4.846 in = 12.309 cm z1+z2= 15.61 cm

Figure 1.1. Dual Aperture AMX/FMX Fixed Mask DS of ratchet wall

Ref C02a_6276_NSLS-II_AMX+FMX-BLs_TechSpec-Masks+Stops_Rev2.pdf

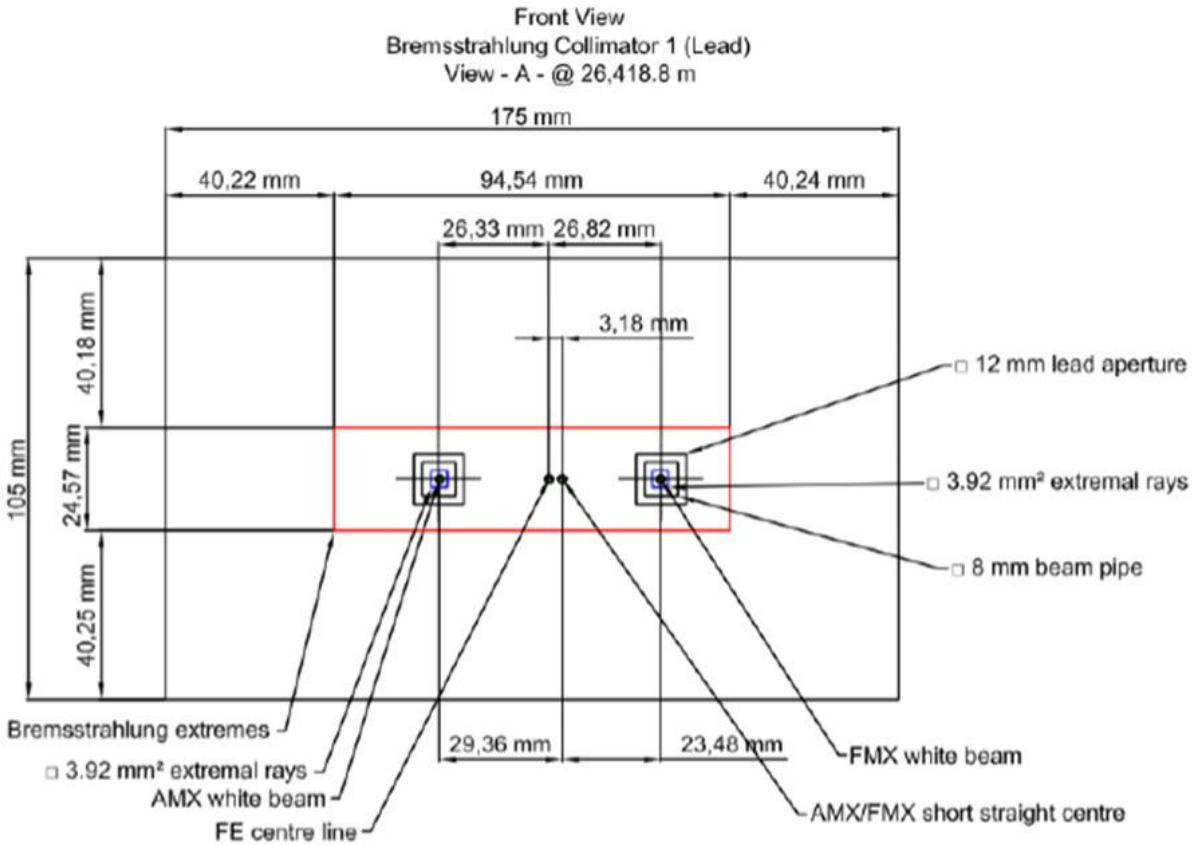


Figure 1.2. Dual aperture Bremsstrahlung collimator 1

Ref: C02b_6276_NSLS-II_AMX+FMX-BLs_TechSpec-BScollimators_Rev2.pdf

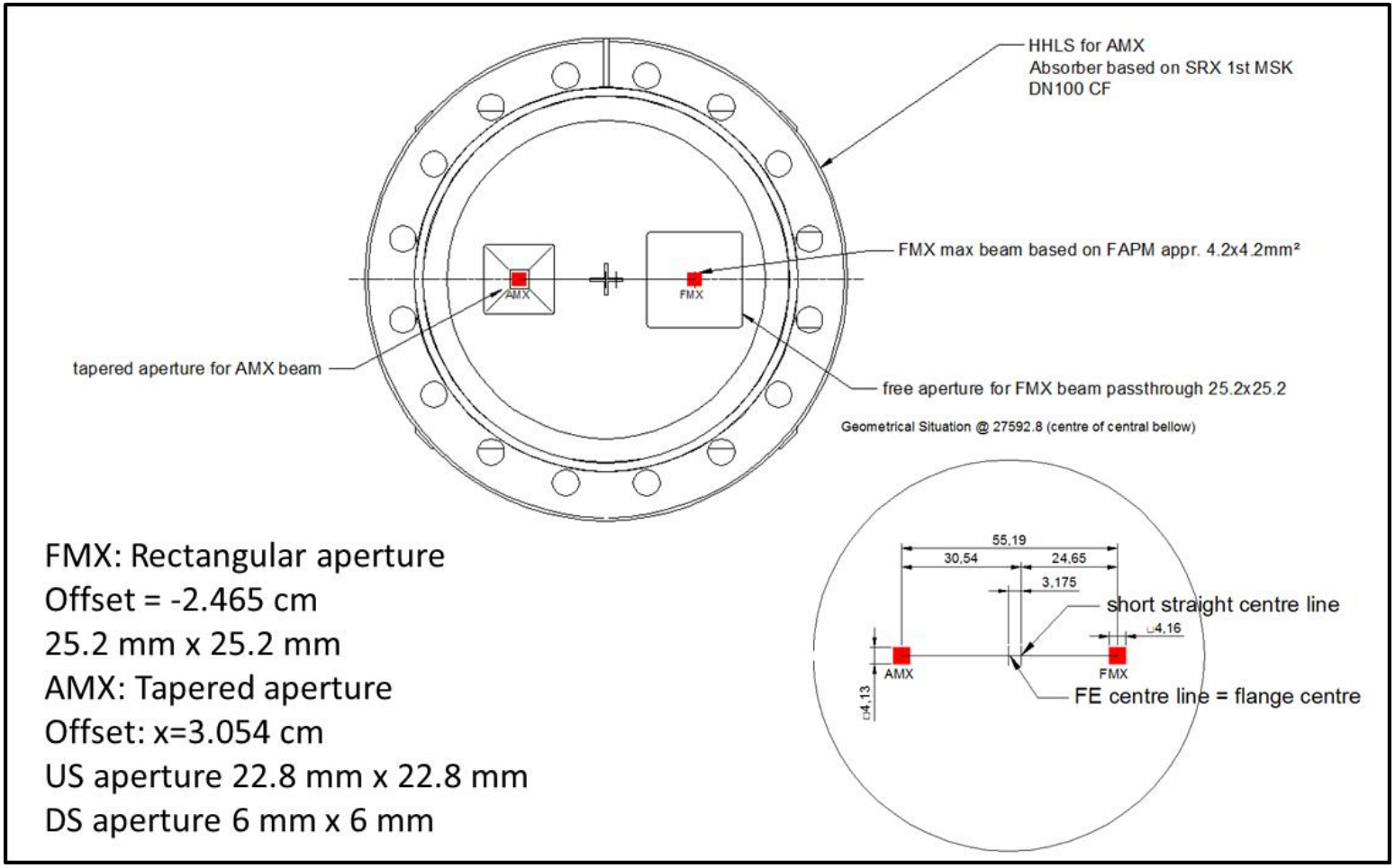


Figure 1.3. Dual aperture Copper slits: FMX: Rectangular aperture AMX: Tapered aperture

Reference: C08a_6276_NSLS-II_AMX+FMX-BLs_TechSpec-HighHeatLoadSlits_Rev4.pdf

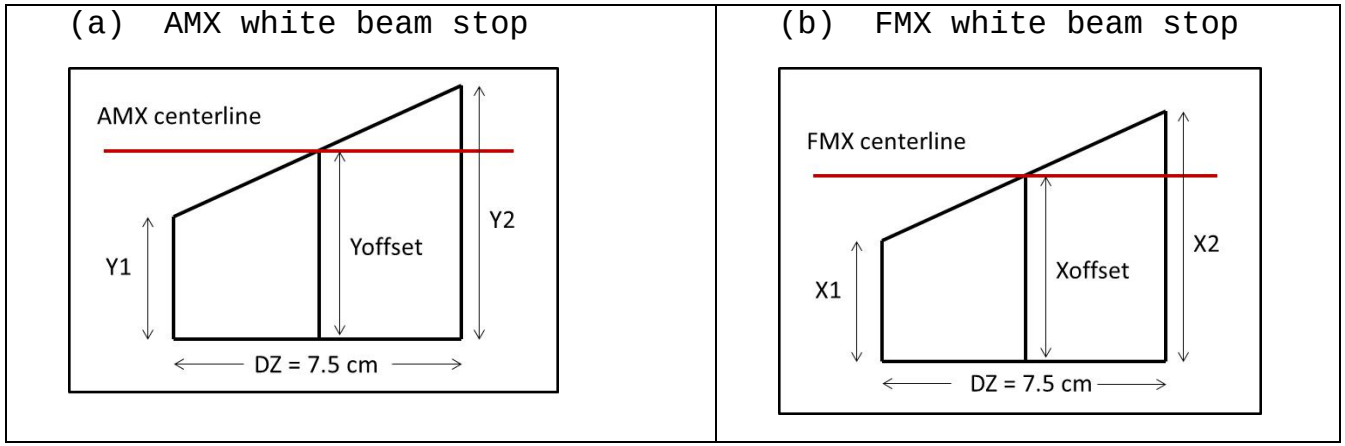


Figure 1.4. (a) AMX white beam stop (b) FMX white beam stop

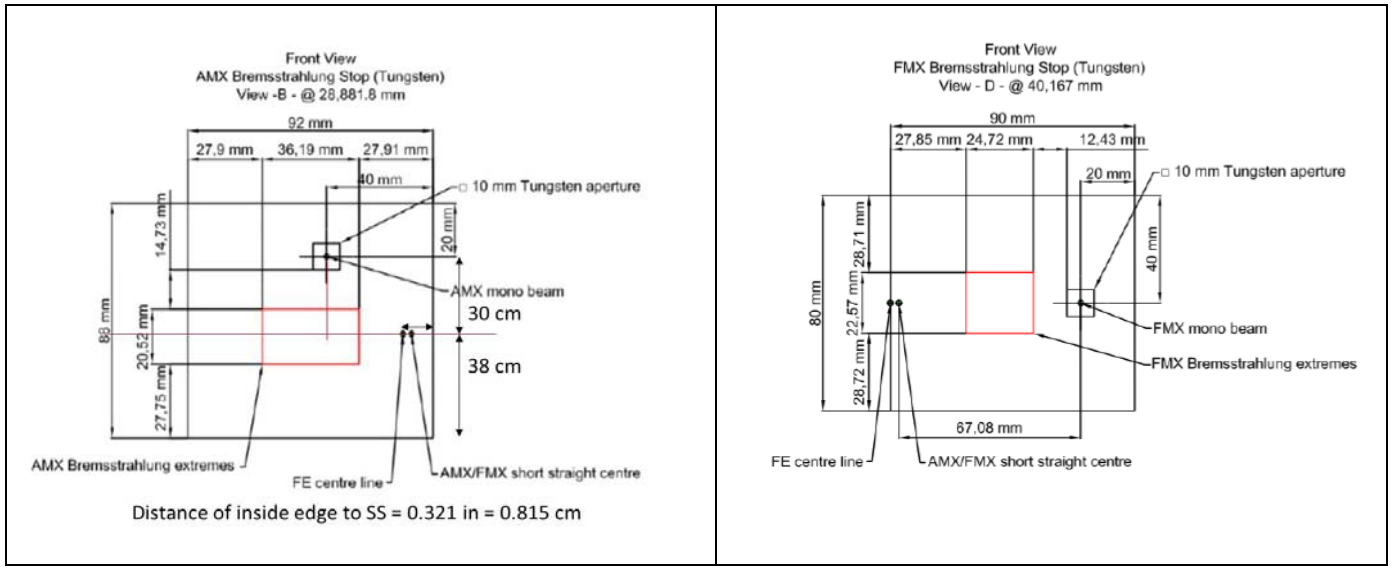
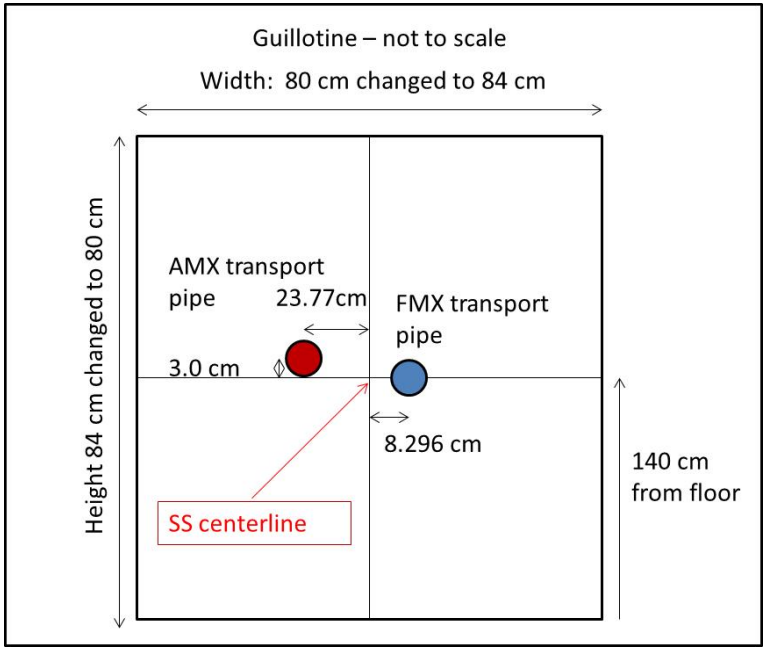


Figure 1.5. (a)AMX and (b) FMX: Bremsstrahlung stops Ref : C02b_6276_NSLS-II_AMX+FMX-BLs_TechSpec-BScollimators_Rev2.pdf

(a) **Guillotine with AMX and FMX apertures**



(b) **PPS mask for FMX**

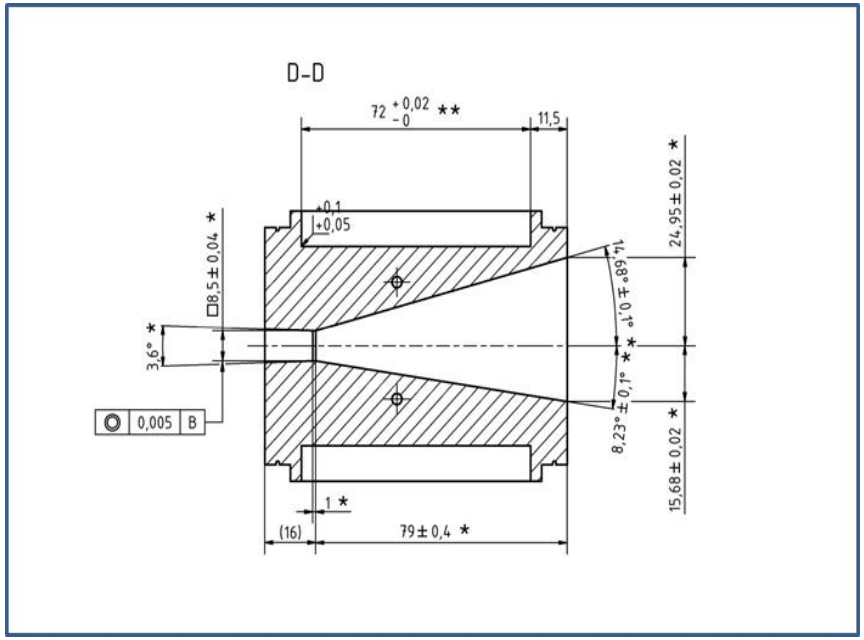


Figure 1.6. (a)Guillotine with AMX and FMX apertures (b)PPS mask for FMX. Beam goes from right to left. Note that the upstream aperture is asymmetric with respect to the FMX beam centerline.

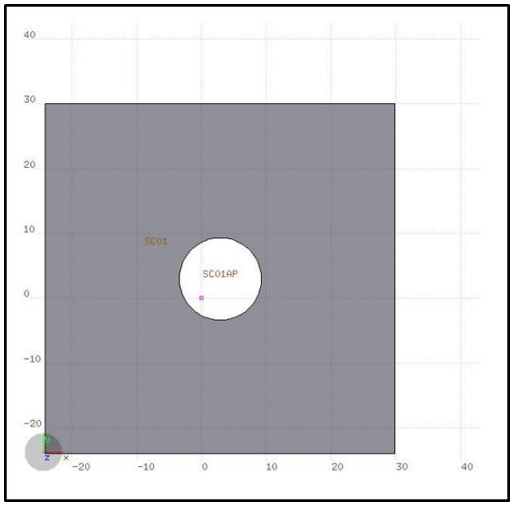
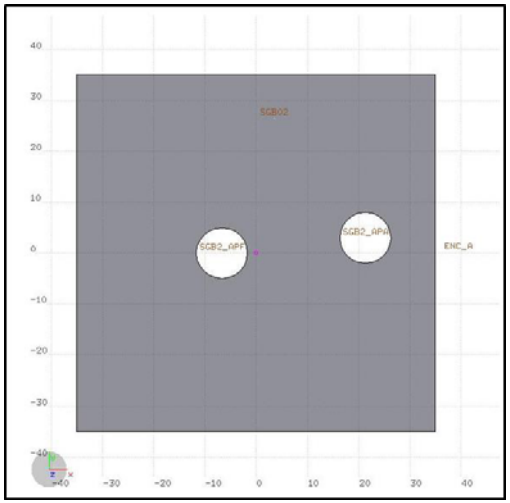
(a)lead shield SGB1	(b)Lead shield SGB2
	

Figure 1.7. (a) SGB1 is centered on the AMX beam centerline and (b)Dual aperture SGB 2 is centered on the SS centerline.

Appendix 2: Gas Bremmstrahlung Source File: src_bl2.f

```
*$ CREATE SOURCE.FOR
*COPY SOURCE
*
*=== source ============================================================*
*
      SUBROUTINE SOURCE ( NOMORE )

      INCLUDE '(DBLPRC)'
      INCLUDE '(DIMPAR)'
      INCLUDE '(IOUNIT)'
*
*----------------------------------------------------------------------*
*                                                                      *
*     Copyright (C) 1990-2010      by    Alfredo Ferrari & Paola Sala  *
*     All Rights Reserved.                                             *
*                                                                      *
*                                                                      *
*     New source for FLUKA9x-FLUKA20xy:                                *
*                                                                      *
*     Created on 07 January 1990   by    Alfredo Ferrari & Paola Sala  *
*                                                   Infn - Milan       *
*                                                                      *
*     Last change on  17-Oct-10    by    Alfredo Ferrari               *
*                                                                      *
*  This is just an example of a possible user written source routine.  *
*  note that the beam card still has some meaning - in the scoring the *
*  maximum momentum used in deciding the binning is taken from the     *
*  beam momentum.  Other beam card parameters are obsolete.            *
*                                                                      *
*       Output variables:                                              *
*                                                                      *
*              Nomore = if > 0 the run will be terminated              *
*                                                                      *
```

```
*----------------------------------------------------------------------*
*
      INCLUDE '(BEAMCM)'
      INCLUDE '(FHEAVY)'
      INCLUDE '(FLKSTK)'
      INCLUDE '(IOIOCM)'
      INCLUDE '(LTCLCM)'
      INCLUDE '(PAPROP)'
      INCLUDE '(SOURCM)'
      INCLUDE '(SUMCOU)'
*
      LOGICAL LFIRST
*
      SAVE LFIRST
      DATA LFIRST / .TRUE. /
*======================================================================*
*                                                                      *
*                 BASIC VERSION                                        *
*                                                                      *
*======================================================================*
      NOMORE = 0
*  +-------------------------------------------------------------------*
*  |  First call initializations:
      IF ( LFIRST ) THEN
*  |  *** The following 3 cards are mandatory ***
         TKESUM = ZERZER
         LFIRST = .FALSE.
         LUSSRC = .TRUE.
*  |  *** User initialization ***
      GB_LO = WHASOU (1)
      GB_HI = WHASOU (2)
*     IF (WHASOU(2) .LE. WHASOU(1) )STOP 'Emax <= Emin'
      WRITE(LUNOUT,*)
      WRITE(LUNOUT,'(A,132A)') ("*",I=1,132)
      WRITE(LUNOUT,*)
      WRITE(LUNOUT,*)"GB Low and high energy limits: GB_LO,GB_HI"
```

```
      WRITE(LUNOUT,*)GB_LO,GB_HI
      WRITE(LUNOUT,*)
*     END IF
      END IF
*  +-------------------------------------------------------------------*
*  Push one source particle to the stack. Note that you could as well
*  push many but this way we reserve a maximum amount of space in the
*  stack for the secondaries to be generated
*  Npflka is the stack counter: of course any time source is called it
*  must be =0
      NPFLKA = NPFLKA + 1
*  Wt is the weight of the particle
      TKEFLK (NPFLKA) = GB_LO + (GB_HI -GB_LO) * FLRNDM(XDUMMY)
      WTFLK  (NPFLKA) = 1/TKEFLK(NPFLKA)
      WEIPRI = WEIPRI + WTFLK(NPFLKA)
*  Particle type (1=proton.....). Ijbeam is the type set by the BEAM
*  card
*  +-------------------------------------------------------------------*
*  |  (Radioactive) isotope:
      IF ( IJBEAM .EQ. -2 .AND. LRDBEA ) THEN
         IARES  = IPROA
         IZRES  = IPROZ
         IISRES = IPROM
         CALL STISBM ( IARES, IZRES, IISRES )
         IJHION = IPROZ  * 1000 + IPROA
         IJHION = IJHION * 100 + KXHEAV
         IONID  = IJHION
         CALL DCDION ( IONID )
         CALL SETION ( IONID )
*  |
*  +-------------------------------------------------------------------*
*  |  Heavy ion:
      ELSE IF ( IJBEAM .EQ. -2 ) THEN
         IJHION = IPROZ  * 1000 + IPROA
         IJHION = IJHION * 100 + KXHEAV
         IONID  = IJHION
```

```
         CALL DCDION ( IONID )
         CALL SETION ( IONID )
         ILOFLK (NPFLKA) = IJHION
*  |  Flag this is prompt radiation
         LRADDC (NPFLKA) = .FALSE.
*  |  Group number for "low" energy neutrons, set to 0 anyway
         IGROUP (NPFLKA) = 0
*  |
*  +-------------------------------------------------------------------*
*  |  Normal hadron:
      ELSE
         IONID = IJBEAM
         ILOFLK (NPFLKA) = IJBEAM
*  |  Flag this is prompt radiation
         LRADDC (NPFLKA) = .FALSE.
*  |  Group number for "low" energy neutrons, set to 0 anyway
         IGROUP (NPFLKA) = 0
      END IF
*  |
*  +-------------------------------------------------------------------*
*  From this point .....
*  Particle generation (1 for primaries)
      LOFLK  (NPFLKA) = 1
*  User dependent flag:
      LOUSE  (NPFLKA) = 0
*  No channeling:
      LCHFLK (NPFLKA) = .FALSE.
      DCHFLK (NPFLKA) = ZERZER
*  User dependent spare variables:
      DO 100 ISPR = 1, MKBMX1
         SPAREK (ISPR,NPFLKA) = ZERZER
 100  CONTINUE
*  User dependent spare flags:
      DO 200 ISPR = 1, MKBMX2
         ISPARK (ISPR,NPFLKA) = 0
 200  CONTINUE
```

```
*  Save the track number of the stack particle:
      ISPARK (MKBMX2,NPFLKA) = NPFLKA
      NPARMA = NPARMA + 1
      NUMPAR (NPFLKA) = NPARMA
      NEVENT (NPFLKA) = 0
      DFNEAR (NPFLKA) = +ZERZER
*  ... to this point: don't change anything
*  Particle age (s)
      AGESTK (NPFLKA) = +ZERZER
      AKNSHR (NPFLKA) = -TWOTWO
*  Kinetic energy of the particle (GeV)
*     TKEFLK (NPFLKA) = SQRT ( PBEAM**2 + AM (IONID)**2 ) - AM (IONID)
*  Particle momentum
*     PMOFLK (NPFLKA) = PBEAM
      PMOFLK (NPFLKA) = SQRT ( TKEFLK (NPFLKA) * ( TKEFLK (NPFLKA)
     &                       + TWOTWO * AM (IONID) ) )
*  Cosines (tx,ty,tz)
      TXFLK  (NPFLKA) = UBEAM
      TYFLK  (NPFLKA) = VBEAM
      TZFLK  (NPFLKA) = WBEAM
*     TZFLK  (NPFLKA) = SQRT ( ONEONE - TXFLK (NPFLKA)**2
*    &                       - TYFLK (NPFLKA)**2 )
*  Polarization cosines:
      TXPOL  (NPFLKA) = -TWOTWO
      TYPOL  (NPFLKA) = +ZERZER
      TZPOL  (NPFLKA) = +ZERZER
*  Particle coordinates
      XFLK   (NPFLKA) = XBEAM
      YFLK   (NPFLKA) = YBEAM
      ZFLK   (NPFLKA) = ZBEAM
*  Calculate the total kinetic energy of the primaries: don't change
      IF ( ILOFLK (NPFLKA) .EQ. -2 .OR. ILOFLK (NPFLKA) .GT. 100000 )
     &   THEN
         TKESUM = TKESUM + TKEFLK (NPFLKA) * WTFLK (NPFLKA)
      ELSE IF ( ILOFLK (NPFLKA) .NE. 0 ) THEN
         TKESUM = TKESUM + ( TKEFLK (NPFLKA) + AMDISC (ILOFLK(NPFLKA)) )
```

```
     &          * WTFLK (NPFLKA)
      ELSE
         TKESUM = TKESUM + TKEFLK (NPFLKA) * WTFLK (NPFLKA)
      END IF
      RADDLY (NPFLKA) = ZERZER
*  Here we ask for the region number of the hitting point.
*     NREG (NPFLKA) = ...
*  The following line makes the starting region search much more
*  robust if particles are starting very close to a boundary:
      CALL GEOCRS ( TXFLK (NPFLKA), TYFLK (NPFLKA), TZFLK (NPFLKA) )
      CALL GEOREG ( XFLK  (NPFLKA), YFLK  (NPFLKA), ZFLK  (NPFLKA),
     &              NRGFLK(NPFLKA), IDISC )
*  Do not change these cards:
      CALL GEOHSM ( NHSPNT (NPFLKA), 1, -11, MLATTC )
      NLATTC (NPFLKA) = MLATTC
      CMPATH (NPFLKA) = ZERZER
      CALL SOEVSV
      RETURN
*=== End of subroutine Source =========================================*
      END
```

Appendix 3: Sample input file: 17ID-d5-FMXppsm.inp
In the input file SGB1 is referred to as SC01, SGB2 as SGB2.

```
TITLE
17ID-AMX-FMX Radiation Analysis
* Version History
* 10/23/2015: Modification of LIX-d5-fm to generate AMFMX-d1 (Vinita Ghosh)
* 11/16/2015: Changed angles of the transport pipes
* 11/30/2015: Version d4: Increased SGB01 to 54 x 54, SGB02 to 20 x 20, Guillotine apertures diameter = 3.888
inch, rotated the FMX WBS, added FMX PPS mask
* 12/02/2015: GB incident on FMX slit 2: FMX-d4-slit2.inp
* 12/03/2015: Corrections based on Mo's input
* 12/08/2015: Add Picture frame SGB3: Rerun slit 2: PF2 Decrease size of apertue, No SGB2
DEFAULTS                                                              NEW-DEFA
* Define the beam characteristics
BEAM            -3.0                 -.4                              PHOTON
* Define the beam position for FMX PPSM
BEAMPOS         -4.0       0.0    1273.0 -.0010013       0.0
* Define the beam position for AMX DCM crystal 1
*BEAMPOS          3.0       0.0     313.0 0.0010013       0.0
* Define the beam position for FM FMX aperture
*BEAMPOS         -2.0       0.0      83.0 0.0010013       0.0
* Define the beam position for FM AMX aperture
*BEAMPOS          3.2       0.0      83.0 0.0010013       0.0
* Define the beam position for AMX slit2
*BEAMPOS          3.4       0.0     230.0 0.0010013       0.0
* Define the beam position for AMX slit1
*BEAMPOS          3.4       0.0     197.0 0.0010013       0.0
* Define the beam position for FMX slit2
*BEAMPOS         -4.3       0.0    1379.0 -.0010013       0.0
* Define the beam position for FMX slit1
*BEAMPOS         -4.3       0.0    1344.0 -.0010013       0.0
* Define the beam position for test
*BEAMPOS         -3.5       0.0    1330.0 -.0010013       0.0
* Define the beam position for FMX dcm1
```

```
*BEAMPOS         -3.5       0.0    1440.0 -.0010013       0.0
SOURCE          1E-5       3.0   0.00017
* Define the beam position for dcm (using horizontal max fan from Ray Tracings)
*BEAMPOS          1.5       0.0     590.0    0.0033       0.0
* Define the beam position for dcm (using vertical max fan from Ray Tracings)
*BEAMPOS          0.0    1.0778     590.0       0.0  0.001315
* Define the beam position for fixed mask
*BEAMPOS          0.3       0.0      99.0       0.0       0.0
* Define the beam position for white beam mirror
*BEAMPOS          0.0       0.0     220.0       0.0       0.0
* Define the beam position for wbs
*BEAMPOS          0.0       0.0     355.0       0.0       0.0
!@what.3=3.5*mrad
*ROT-DEFI        200.       0.0     .0035       0.0       0.0       0.0WBMrot
*ROT-DEFI        200.       0.0       0.0       0.0       0.0      500.WBMrot
*ROT-DEFI        100.               -12.5                      -270.788Mirror
GEOBEGIN                                                              COMBNAME
    0    0
* Black body
SPH blkbody    0.0 0.0 0.0 4000.0
* Void sphere
SPH air        0.0 0.0 0.0 3000.0
#if 0
RCC Pipe       0.0 0.0 -2999.0 0.0 0.0 2999.0 1.0
#endif
* Ratchet Wall simplified for ID beamlines
XYP rwxxA_i    -140.0
XYP rwxxA_o    0.0
YZP rwxxA_s    185.0
* Sidewall simplified for ID beamlines
PLA swxxA_o    .99788010596582 0.0 .0650791373456 -50.0 0.0 0.0
PLA swxxA_i    .99782149649341 0.0 .06597166918965 -130.0 0.0 0.0
PLA swxxA_s    -.0407823695143 0.0 .99916805310057 -5.0 0.0 2000.0
* SR Roof
XZP rfxxA_t    250.0
* Distance of roof from centerline
```

```
XZP brfxxA_b   200.0
* Experimental floor 140 cm below centerline
XZP flxxA_b    -150.0
XZP flxxA_t    -140.0
* Beamline enclosure sidewall, roof and backwall
!@what.1=b(bswxxA_i,1)+1.8
YZP bswxxA_o   159.80000000000001
* Distance of sidewall from Straight Centerline
YZP bswxxA_i   158.0
* US of FOE downstream wall
!@what.1=4450.021-zro-5.0
XYP bbwxxA_i   1898.1999999999998
* Thickness of FOE DS wall 5cm
!@what.1=b(bbwxxA_i,1)+5.0
XYP bbwxxA_o   1903.1999999999998
!@what.1=b(brfxxA_b,1)+1.0
XZP brfxxA_t   201.
* US end of AMX hutch DS wall
!@what.1=(5400.0-zro)-5.0
XYP bfwxxB_o   2848.1790000000001
* DS end of AMX hutch DS wall
!@what.1=(5400.0-zro)
XYP bfwxxB_d   2853.1790000000001
* Front End beam pipe outer/outer shell, 2 mm thick beam SS pipe
!@what.3=-zro
!@what.6=zro
!@what.7=4.*inch/2.
RCC fep_o      0.0 0.0 -2546.8209999999999 0.0 0.0 2546.8209999999999
              5.0800000000000001
!@what.3=-zro
!@what.6=zro
!@what.7=3.87*inch/2.
RCC fep_i      0.0 0.0 -2546.8209999999999 0.0 0.0 2546.8209999999999
              4.9149000000000003
* AMX Beamline transport pipe inner shell: rotated 0.86 deg towards outboard side
!@what.7=3.888*inch/2.
```

```
RCC blp_i      23.77 3.0 1897.7 14.423591321394 0.0 960.87075012948
              4.9377599999999999
* AMX Beamline transport pipe outer shell, 2 mm thick beam SS pipe
!@what.7=4.000*inch/2.
RCC blp_o      23.77 3.0 1897.7 14.423591321394 0.0 960.87075012948
              5.0800000000000001
* AMX Beamline transport pipe shielding, 5 mm lead
!@what.7=b(blp_o,7)+0.5
RCC blp_shd    23.77 3.0 1897.7 14.423591321394 0.0 960.87075012948
              5.5800000000000001
#if 0
* AMX Beamline transport pipe inner shell: unrotated
!@what.1=23.77
!@what.2=3.0
!@what.3=b(bbwxxA_i,1)-0.5
!@what.6=b(bfwxxB_d,1) - b(bbwxxA_i,1)+5.0+1.0
!@what.7=3.888*inch/2.
RCC blp_i      23.77 3. 1897.6999999999998 0.0 0.0 960.97900000000027
              4.9377599999999999
#endif
#if 0
* AMX Beamline transport pipe outer shell, 2 mm thick beam SS pipe
!@what.1=b(blp_i,1)
!@what.2=b(blp_i,2)
!@what.3=b(blp_i,3)
!@what.6=b(blp_i,6)
!@what.7=4.000*inch/2.
RCC blp_o      23.77 3. 1897.7 0.0 0.0 960.87075012948003 5.0800000000000001
#endif
#if 0
* AMX Beamline transport pipe outer shell, 2 mm thick beam SS pipe
!@what.1=b(blp_i,1)
!@what.2=b(blp_i,2)
!@what.3=b(blp_i,3)
!@what.6=b(blp_i,6)
!@what.7=b(blp_o,7)+0.5
```

```
RCC blp_shd    23.77 3. 1897.7 0.0 0.0 960.87075012948003 5.5800000000000001
#endif
* FMX Beamline transport pipe inner shell: rotated 0.34 deg towards inboard side
!@what.7=3.888*inch/2.
RCC blpf_i     -8.296 0.0 1897.7 -11.26111240182 0.0 1897.6665875089
              4.9377599999999999
* FMX Beamline transport pipe outer shell, 2 mm thick beam SS pipe
!@what.7=4.000*inch/2.
RCC blpf_o     -8.296 0.0 1897.7 -11.26111240182 0.0 1897.6665875089
              5.0800000000000001
* FMX Beamline transport pipe shielding, 5 mm lead
!@what.7=b(blpf_o,7)+0.5
RCC blpf_shd   -8.296 0.0 1897.7 -11.26111240182 0.0 1897.6665875089
              5.5800000000000001
#if 0
* FMX Beamline transport pipe inner shell: unrotated
!@what.1=-8.296
!@what.2=0.0
!@what.3=b(bbwxxA_i,1)-0.5
!@what.6=b(bfwxxB_d,1) - b(bbwxxA_i,1)+5.0+1.0
!@what.7=3.888*inch/2.
RCC blpf_i     -8.2959999999999994 0.0 1897.6999999999998 0.0 0.0
              960.97900000000027 4.9377599999999999
#endif
#if 0
* FMX Beamline transport pipe outer shell, 2 mm thick beam SS pipe
!@what.1=b(blpf_i,1)
!@what.2=b(blpf_i,2)
!@what.3=b(blpf_i,3)
!@what.6=b(blpf_i,6)
!@what.7=4.000*inch/2.
RCC blpf_o     -8.2959999999999994 0.0 1897.7 0.0 0.0 1897.6665875089
              5.0800000000000001
#endif
#if 0
* FMX Beamline transport pipe outer shell, 2 mm thick beam SS pipe
```

```
!@what.1=b(blpf_i,1)
!@what.2=b(blpf_i,2)
!@what.3=b(blpf_i,3)
!@what.6=b(blpf_i,6)
!@what.7=b(blpf_o,7)+0.5
RCC blpf_sh    -8.2959999999999994 0.0 1897.7 0.0 0.0 1897.6665875089
              5.5800000000000001
#endif
* Fixed Mask: DS RW: AMX: copper block
!@what.3=-10.6/2.
!@what.4=-w(3)
!@what.5=(2619.88 - zro)
!@what.6=w(5)+15.61
RPP fm_af1     0.31800000000000006 6.3179999999999996 -5.2999999999999998
              5.2999999999999998 73.059000000000196 88.669000000000196
* Fixed Mask: DS RW: FMX: copper block
!@what.1=xro -6.0
!@what.2=xro
!@what.3=-10.6/2.
!@what.4=-w(3)
!@what.5=(2619.88 - zro)
!@what.6=w(5)+15.61
RPP fm_af2     -5.6820000000000004 0.318 -5.2999999999999998 5.2999999999999998
              73.059000000000196 88.669000000000196
* Fixed Mask: DS RW: small aperture block for AMX
!@what.1=2.925-0.35/2.
!@what.2=2.925+0.35/2.
!@what.3=-0.35/2.
!@what.4=0.35/2.
!@what.5=b(fm_af1,5)-1.0
!@what.6=b(fm_af1,6)+1.0
RPP fma_in1    2.75 3.0999999999999996 -0.17499999999999999 0.17499999999999999
              72.059000000000196 89.669000000000196
* Fixed Mask: DS RW: large aperture block for AMX
!@what.1=2.925-2.5/2.
!@what.2=2.925+2.5/2.
```

```
!@what.3=-2.5/2.
!@what.4=+2.5/2.
!@what.5=b(fm_af1,5)-1.0
!@what.6=b(fm_af1,6)+1.0
RPP fma_ou1    1.6749999999999998 4.1749999999999998 -1.25 1.25
              72.059000000000196 89.669000000000196
* Fixed Mask: DS RW: small aperture block for FMX
!@what.1=-2.338-0.35/2.
!@what.2=-2.338+0.35/2.
!@what.3=-0.35/2.
!@what.4=0.35/2.
!@what.5=b(fm_af1,5)-1.0
!@what.6=b(fm_af1,6)+1.0
RPP fma_in2    -2.5129999999999999 -2.1630000000000003 -0.17499999999999999
              0.17499999999999999 72.059000000000196 89.669000000000196
* Fixed Mask: DS RW: large aperture block for FMX
!@what.1=-2.338-2.5/2.
!@what.2=-2.338+2.5/2.
!@what.3=-2.5/2.
!@what.4=+2.5/2.
!@what.5=b(fm_af1,5)-1.0
!@what.6=b(fm_af1,6)+1.0
RPP fma_ou2    -3.5880000000000001 -1.0880000000000001 -1.25 1.25
              72.059000000000196 89.669000000000196
* Fixed Mask: DS RW: position of neck
!@what.1=b(fm_af1,6)-3.302
XYP fm_zc1     85.367000000000189
* Fixed Mask: DS RW:
!@what.4=2.925+0.35/2.
!@what.6=b(fm_af1,6)-3.302
PLA fma_xo1    99.6208023 0.0 8.7003301 3.0999999999999996 0.0
              85.367000000000189
* Fixed Mask: DS RW:
!@what.4=-2.338+0.35/2.
!@what.6=b(fm_af1,6)-3.302
PLA fma_xo2    99.6208023 0.0 8.7003301 -2.1630000000000003 0.0
```

```
              85.367000000000189
* Fixed Mask: DS RW:
!@what.1=b(fma_xo1,1)
!@what.2=b(fma_xo1,2)
!@what.3=-b(fma_xo1,3)
!@what.4=2.925-0.35/2.
!@what.5=b(fma_xo1,5)
!@what.6=b(fma_xo1,6)
PLA fma_xi1    99.620802299999994 0.0 -8.7003301000000004 2.75 0.0
              85.367000000000189
* Fixed Mask: DS RW:
!@what.1=b(fma_xo2,1)
!@what.2=b(fma_xo2,2)
!@what.3=-b(fma_xo2,3)
!@what.4=-2.338-0.35/2.
!@what.5=b(fma_xo2,5)
!@what.6=b(fma_xo2,6)
PLA fma_xi2    99.620802299999994 0.0 -8.7003301000000004 -2.5129999999999999
              0.0 85.367000000000189
* Fixed Mask: DS RW:
!@what.5=0.35/2.0
!@what.6=b(fm_af1,6)-3.302
PLA fma_yt1    0.0 99.6208023 8.7003301 0.0 0.17499999999999999
              85.367000000000189
* Fixed Mask: DS RW:
!@what.1=b(fma_yt1,1)
!@what.2=b(fma_yt1,2)
!@what.3=-b(fma_yt1,3)
!@what.4=b(fma_yt1,4)
!@what.5=-b(fma_yt1,5)
!@what.6=b(fma_yt1,6)
PLA fma_yb1    0.0 99.620802299999994 -8.7003301000000004 0.0
              -0.17499999999999999 85.367000000000189
* Bremsstrahlung Collimator dual aperture for both beams
!@what.1=xro -17.5/2.0
!@what.2=xro +17.5/2.0
```

```
!@what.3=-10.5/2.0
!@what.4=-w(3)
!@what.5=2641.88-zro
!@what.6=w(5)+30.48
RPP brmcol     -8.4320000000000004 9.0679999999999996 -5.25 5.25
              95.059000000000196 125.5390000000002
* Bremsstrahlung Collimator aperture for AMX
!@what.1=2.936-0.6
!@what.2=w(1)+1.2
!@what.5=2641.88-zro
!@what.6=w(5)+30.48
RPP brmcolap   2.3359999999999999 3.5359999999999996 -0.60 0.6
              95.059000000000196 125.5390000000002
* Bremsstrahlung Collimator aperture for FMX
!@what.1=-2.348-0.6
!@what.2=w(1)+1.2
!@what.5=2641.88-zro
!@what.6=w(5)+30.48
RPP brmcolaf   -2.948 -1.748 -0.60 0.6 95.059000000000196 125.5390000000002
* AMX White Beam Slit  1 block F
!@what.1=xro -12.0/2.
!@what.2=xro
!@what.3=-10.6/2.
!@what.4=-w(3)
!@what.5=2737.98 - zro
!@what.6=w(5)+10.6
RPP s1bf       -5.6820000000000004 0.318 -5.2999999999999998 5.2999999999999998
              191.15900000000011 201.7590000000001
* AMX White Beam Slit  2 block F
!@what.1=xro -12.0/2.
!@what.2=xro
!@what.3=-10.6/2.
!@what.4=-w(3)
!@what.5=2771.58 - zro
!@what.6=w(5)+10.6
RPP s2bf       -5.6820000000000004 0.318 -5.2999999999999998 5.2999999999999998
```

```
              224.75900000000001 235.35900000000001
* AMX White Beam Slit  1 block F aperture
!@what.5=2737.98 - zro
!@what.6=w(5)+10.6
RPP s1bfap     -3.725 -1.205 -1.26 1.26 191.15900000000011 201.7590000000001
* AMX White Beam Slit  2 block F aperture
!@what.1=s1bfapOS-2.52/2.
!@what.2=s1bfapOS+2.52/2.
!@what.3=-2.52/2.
!@what.4=-w(3)
!@what.5=2771.58 - zro
!@what.6=w(5)+10.6
RPP s2bfap     -3.7249999999999996 -1.2049999999999998 -1.26 1.26
              224.75900000000001 235.35900000000001
* AMX White Beam Slit  1 block A
!@what.1=xro
!@what.2=xro +12.0/2.
!@what.3=-10.6/2.
!@what.4=-w(3)
!@what.5=2737.98 - zro
!@what.6=w(5)+10.6
RPP s1ba       0.318 6.3179999999999996 -5.2999999999999998 5.2999999999999998
              191.15900000000011 201.7590000000001
!@what.1=s1baapOS-0.6/2.
!@what.2=s1baapOS+0.6/2.
!@what.3=-0.6/2.
!@what.4=-w(3)
!@what.5=b(s1ba,5)-1.0
!@what.6=b(s1ba,6)+1.0
RPP s1ba_in    2.754 3.3539999999999996 -0.29999999999999999 0.29999999999999999
              190.15900000000011 202.7590000000001
!@what.1=s1baapOS-2.28/2.
!@what.2=s1baapOS+2.28/2.
!@what.3=-2.28/2.
!@what.4=-w(3)
!@what.5=b(s1ba,5)-1.0
```

```
!@what.6=b(s1ba,6)+1.0
RPP s1ba_ou    1.9139999999999999 4.194 -1.1399999999999999 1.1399999999999999
              190.15900000000011 202.7590000000001
!@what.4=s1baapOS+0.6/2.
!@what.6=b(s1ba,6)-3.74
PLA s1ba_xo    99.2586389 0.0 12.1541190 3.3539999999999996 0.0
              198.01900000000009
!@what.1=b(s1ba_xo,1)
!@what.2=b(s1ba_xo,2)
!@what.3=-b(s1ba_xo,3)
!@what.4=s1baapOS-0.6/2.
!@what.5=b(s1ba_xo,5)
!@what.6=b(s1ba_xo,6)
PLA s1ba_xi    99.258638899999994 0.0 -12.154119 2.754 0.0 198.01900000000009
!@what.5=0.6/2.0
!@what.6=b(s1ba,6)-3.74
PLA s1ba_yt    0.0 99.2586389 12.1541190 0.0 0.29999999999999999
              198.01900000000009
!@what.1=b(s1ba_yt,1)
!@what.2=b(s1ba_yt,2)
!@what.3=-b(s1ba_yt,3)
!@what.4=b(s1ba_yt,4)
!@what.5=-b(s1ba_yt,5)
!@what.6=b(s1ba_yt,6)
PLA s1ba_yb    0.0 99.258638899999994 -12.154119 0.0 -0.29999999999999999
              198.01900000000009
!@what.1=b(s1ba,6)-3.74
XYP s1ba_zc    198.01900000000009
* AMX White Beam Slit 2 Block A
!@what.1=xro
!@what.2=xro +12.0/2.
!@what.3=-10.6/2.
!@what.4=-w(3)
!@what.5=2771.58 - zro
!@what.6=w(5)+10.6
RPP s2ba       0.318 6.3179999999999996 -5.2999999999999998 5.2999999999999998
```

```
              224.75900000000001 235.35900000000001
!@what.1=s1baapOS-0.6/2.
!@what.2=s1baapOS+0.6/2.
!@what.3=-0.6/2.
!@what.4=-w(3)
!@what.5=b(s2ba,5)-1.0
!@what.6=b(s2ba,6)+1.0
RPP s2ba_in    2.754 3.3539999999999996 -0.29999999999999999 0.29999999999999999
              223.75900000000001 236.35900000000001
!@what.1=s1baapOS-2.28/2.
!@what.2=s1baapOS+2.28/2.
!@what.3=-2.28/2.
!@what.4=-w(3)
!@what.5=b(s2ba,5)-1.0
!@what.6=b(s2ba,6)+1.0
RPP s2ba_ou    1.9139999999999999 4.194 -1.1399999999999999 1.1399999999999999
              223.75900000000001 236.35900000000001
!@what.4=s1baapOS+0.6/2.
!@what.6=b(s2ba,6)-3.74
PLA s2ba_xo    99.2586389 0.0 12.1541190 3.3539999999999996 0.0 231.619
!@what.1=b(s2ba_xo,1)
!@what.2=b(s2ba_xo,2)
!@what.3=-b(s2ba_xo,3)
!@what.4=s1baapOS-0.6/2.
!@what.5=b(s2ba_xo,5)
!@what.6=b(s2ba_xo,6)
PLA s2ba_xi    99.258638899999994 0.0 -12.154119 2.754 0.0 231.619
!@what.5=0.6/2.0
!@what.6=b(s2ba,6)-3.74
PLA s2ba_yt    0.0 99.2586389 12.1541190 0.0 0.29999999999999999 231.619
!@what.1=b(s2ba_yt,1)
!@what.2=b(s2ba_yt,2)
!@what.3=-b(s2ba_yt,3)
!@what.4=b(s2ba_yt,4)
!@what.5=-b(s2ba_yt,5)
!@what.6=b(s2ba_yt,6)
```

```
PLA s2ba_yb    0.0 99.258638899999994 -12.154119 0.0 -0.29999999999999999
              231.619
!@what.1=b(s2ba,6)-3.74
XYP s2ba_zc    231.619
#if 0
* AMX DCM crystal 1 not rotated
!@what.1=-5.9/2.
!@what.2=-w(1)
!@what.3=-3.5/2.+3.5
!@what.4=w(3)+3.5
!@what.5=-13.2/2.0
!@what.6=-w(5
RPP dcma1      -2.9500000000000002 2.9500000000000002 1.75 5.25
              -6.5999999999999996 0.0
#endif
* AMX DCM crystal 1 rotated 45 wrt x axis and translated z=2862.182-zro, y=-1.75, x=3.1cm
BOX dcma1      .15 -7.654341622908 311.93053211124 5.9 0.0 0.0 0.0
              2.4748737341529 -2.474873734153 0.0 9.3338095116624
              9.3338095116624
#if 0
* AMX DCM crystal 2 not rotated
!@what.1=-5.9/2.
!@what.2=-w(1)
!@what.3=-3.5/2.+3.5
!@what.4=w(3)+3.5
!@what.5=-13.2/2.0
!@what.6=-w(5
RPP dcma2      -2.9500000000000002 2.9500000000000002 1.75 5.25
              -6.5999999999999996 0.0
#endif
* AMX DCM crystal 2 rotated 45 wrt x axis and translated z=2862.182-zro, y=4.75+1.5, x=3.1cm
BOX dcma2      .15 .345658377092 311.93053211124 5.9 0.0 0.0 0.0 2.4748737341529
              -2.474873734153 0.0 9.3338095116624 9.3338095116624
* AMX white beamstop US Z
!@what.1=2880.08-zro
XYP wbsta_zu   333.25900000000001
```

```
* AMX wbs DS Z
!@what.1=2880.08-zro+7.5
XYP wbsta_zd   340.75900000000001
* AMX wbs xin
!@what.1=1.2521*inch-2.0
YZP wbsta_xi   1.1803340000000002
* AMX wbs xout
!@what.1=1.2521*inch+2.0
YZP wbsta_xo   5.1803340000000002
* AMX wbs Y bottom
!@what.1=-0.904*inch
XZP wbsta_yb   -2.29616
#if 0
* AMX wbs Y bottom
!@what.1=0.904*inch
XZP wbsta_yt   2.29616
#endif
* AMX wbs Y top of wedge
!@what.4=1.2521*inch
!@what.5=1.2013*inch-0.904*inch
!@what.6=2880.08-zro+7.5
PLA wbsta_yt   0.0 98.034 -19.732 3.1803340000000002 0.7551420000000002
              340.75900000000001
* AMX Brem Stop
!@what.1=-0.815
!@what.2=8.385
!@what.3=-3.80
!@what.4=5.0
!@what.5=2888.18-zro
!@what.6=w(5) + 20.5
RPP brms       -0.81499999999999995 8.3849999999999998 -3.7999999999999998 5.
              341.35899999999992 361.85899999999992
* AMX Brem stop aperture
!@what.1=1.253*inch-1.0/2.
!@what.2=w(1)+1.0
!@what.3=3.0-0.5
```

```
!@what.4=w(3)+1.0
!@what.5=b(brms,5)
!@what.6=w(5)+20.5
RPP brms_ap    2.6826199999999996 3.6826199999999996 2.5 3.5 341.35899999999992
              361.85899999999992
* SGB Shield SC01
!@what.1=-54.0/2.+sgb01xo
!@what.2=-w(1)+2.*sgb01xo
!@what.3=-54.0/2.+sgb01yo
!@what.4=-w(3)+2.*sgb01yo
!@what.5=2929.0-zro
!@what.6=w(5)+5.0
RPP sgb01      -24.094239999999999 29.905760000000001 -24. 30.
              382.17900000000009 387.17900000000009
* SC01 aperture
!@what.1=sgb01xo
!@what.2=sgb01yo
!@what.3=2929.0-zro
!@what.7=12.7/2.0
RCC sgb01_ap   2.9057599999999999 3. 382.17900000000009 0.0 0.0 5.0
              6.3499999999999996
* AMX TDM mirror 1  rotated
BOX tdm1       2.2143004616869 2.5 507.00590788775 .99999384658212 0.0
              -.0035081046009 0.0 1.0 0.0 .17540523004399 0.0 49.999692329106
#if 0
* AMX TDM mirror 1  unrotated
!@what.5=3078.325-zro-50./2.
!@what.6=w(5)+50.0
RPP tdm1       -0.5 0.5 -0.5 0.5 506.50399999999991 556.50399999999991
#endif
* FMX PPS mask
!@what.1=ppsmos-7.62/2.
!@what.2=ppsmos+7.62/2.
!@what.3=-7.62/2.
!@what.4=-w(3)
!@what.5=3812.6 - zro
```

```
!@what.6=w(5)+9.5
RPP ppsmfmx    -7.3162000000000003 0.30379999999999985 -3.8100000000000001
              3.8100000000000001 1265.779 1275.279
* FMX PPS mask
!@what.1=ppsmos-0.85/2.
!@what.2=ppsmos+0.85/2.
!@what.3=-0.85/2.
!@what.4=-w(3)
!@what.5=b(ppsmfmx,5)-1.0
!@what.6=b(ppsmfmx,6)+1.0
RPP ppsm_in    -3.9312 -3.0812000000000004 -0.42499999999999999
              0.42499999999999999 1264.779 1276.279
* FMX PPS mask
!@what.1=ppsmos-2.495
!@what.2=ppsmos+1.568
!@what.3=-2.483/2.
!@what.4=-w(3)
!@what.5=b(ppsmfmx,5)-1.0
!@what.6=b(ppsmfmx,6)+1.0
RPP ppsm_ou    -6.0012000000000008 -1.9382000000000001 -1.2415 1.2415 1264.779
              1276.279
* FMX PPS mask
!@what.4=ppsmos+0.85/2.
!@what.6=b(ppsmfmx,6)-1.6
PLA ppsm_xo    98.9694848 0.0 14.3192558 -3.0812000000000004 0.0
              1273.6790000000001
* FMX PPS mask
!@what.2=b(ppsm_xo,2)
!@what.3=-25.3468522
!@what.4=ppsmos-0.85/2.
!@what.5=b(ppsm_xo,5)
!@what.6=b(ppsm_xo,6)
PLA ppsm_xi    96.7343635 0.0 -25.346852200000001 -3.9312 0.0 1273.6790000000001
* FMX PPS mask
!@what.4=ppsmos
!@what.5=0.85/2.0
```

```
!@what.6=b(ppsmfmx,6)-1.6
PLA ppsm_yt    0.0 99.4701344 10.2806791 -3.5062000000000002 0.42499999999999999
              1273.6790000000001
* FMX PPS mask
!@what.1=b(ppsm_yt,1)
!@what.2=b(ppsm_yt,2)
!@what.3=-b(ppsm_yt,3)
!@what.4=b(ppsm_yt,4)
!@what.5=-b(ppsm_yt,5)
!@what.6=b(ppsm_yt,6)
PLA ppsm_yb    0.0 99.470134400000006 -10.2806791 -3.5062000000000002
              -0.42499999999999999 1273.6790000000001
* FMX PPS mask
!@what.1=b(ppsmfmx,6)-1.6
XYP ppsm_zc    1273.6790000000001
* FMX Brem Collimator 2
!@what.1=brmcol2x-14.5/2.
!@what.2=brmcol2x+14.5/2.
!@what.3=-12.0/2.
!@what.4=-w(3)
!@what.5=3824.153-zro
!@what.6=w(5) + 30.48
RPP brmcol2    -10.768000000000001 3.7320000000000002 -6. 6. 1277.3319999999999
              1307.8119999999999
* FMX Brem collimator aperture
!@what.1=brmcol2x-1.6/2.
!@what.2=brmcol2x+1.6/2.
!@what.3=-1.6/2.
!@what.4=-w(3)
!@what.5=b(brmcol2,5)
!@what.6=b(brmcol2,6)
RPP brmcol2a   -4.3179999999999996 -2.718 -0.80000000000000004
              0.80000000000000004 1277.3319999999999 1307.8119999999999
#if 0
* FMX Amy's copper target
!@what.1=s1fOS-2.54/2.
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```
!@what.2=s1fOS+2.54/2.
!@what.3=-2.54/2.
!@what.4=-w(3)
!@what.5=3887.653 - zro -3.00
!@what.6=w(5)+2.54
RPP cutarg     -4.8599999999999994 -2.3199999999999998 -1.27 1.27
              1337.8319999999999 1340.3719999999998
#endif
* FMX White Beam Slit 1
!@what.1=s1fOS-7.6/2.
!@what.2=s1fOS+7.6/2.
!@what.3=-7.6/2.
!@what.4=-w(3)
!@what.5=3887.653 - zro
!@what.6=w(5)+10.35
RPP s1fmx      -7.3899999999999997 0.20999999999999996 -3.7999999999999998
              3.7999999999999998 1340.8319999999999 1351.1819999999998
!@what.1=s1fOS-1.1/2.
!@what.2=s1fOS+1.1/2.
!@what.3=-1.1/2.
!@what.4=-w(3)
!@what.5=b(s1fmx,5)-1.0
!@what.6=b(s1fmx,6)+1.0
RPP s1f_in     -4.1399999999999997 -3.04 -0.55000000000000004
              0.55000000000000004 1339.8319999999999 1352.1819999999998
!@what.1=s1fOS-2.92/2.
!@what.2=s1fOS+2.92/2.
!@what.3=-2.92/2.
!@what.4=-w(3)
!@what.5=b(s1fmx,5)-1.0
!@what.6=b(s1fmx,6)+1.0
RPP s1f_ou     -5.0499999999999998 -2.1299999999999999 -1.46 1.46
              1339.8319999999999 1352.1819999999998
!@what.4=s1fOS+1.1/2.
!@what.6=b(s1fmx,6)-2.94
PLA s1f_xo     99.2546152 0.0 12.1869343 -3.04 0.0 1348.2419999999997
```

```
!@what.1=b(s1f_xo,1)
!@what.2=b(s1f_xo,2)
!@what.3=-b(s1f_xo,3)
!@what.4=s1fOS-1.1/2.
!@what.5=b(s1f_xo,5)
!@what.6=b(s1f_xo,6)
PLA s1f_xi     99.254615200000003 0.0 -12.186934300000001 -4.1399999999999997
              0.0 1348.2419999999997
!@what.5=1.1/2.0
!@what.6=b(s1fmx,6)-2.94
PLA s1f_yt     0.0 99.2546152 12.1869343 0.0 0.55000000000000004
              1348.2419999999997
!@what.1=b(s1f_yt,1)
!@what.2=b(s1f_yt,2)
!@what.3=-b(s1f_yt,3)
!@what.4=b(s1f_yt,4)
!@what.5=-b(s1f_yt,5)
!@what.6=b(s1f_yt,6)
PLA s1f_yb     0.0 99.254615200000003 -12.186934300000001 0.0
              -0.55000000000000004 1348.2419999999997
!@what.1=b(s1fmx,6)-2.94
XYP s1f_zc     1348.2419999999997
* FMX White Beam Slit 2
!@what.1=s2fOS-7.6/2.
!@what.2=s2fOS+7.6/2.
!@what.3=-7.6/2.
!@what.4=-w(3)
!@what.5=3921.253 - zro
!@what.6=w(5)+10.35
RPP s2fmx      -7.4299999999999997 0.16999999999999993 -3.7999999999999998
              3.7999999999999998 1374.4320000000002 1384.7820000000002
!@what.1=s2fOS-1.1/2.
!@what.2=s2fOS+1.1/2.
!@what.3=-1.1/2.
!@what.4=-w(3)
!@what.5=b(s2fmx,5)-1.0
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```
!@what.6=b(s2fmx,6)+1.0
RPP s2f_in     -4.1799999999999997 -3.0800000000000001 -0.55000000000000004
              0.55000000000000004 1373.4320000000002 1385.7820000000002
!@what.1=s2fOS-2.92/2.
!@what.2=s2fOS+2.92/2.
!@what.3=-2.92/2.
!@what.4=-w(3)
!@what.5=b(s2fmx,5)-1.0
!@what.6=b(s2fmx,6)+1.0
RPP s2f_ou     -5.0899999999999999 -2.1699999999999999 -1.46 1.46
              1373.4320000000002 1385.7820000000002
!@what.4=s2fOS+1.1/2.
!@what.6=b(s2fmx,6)-2.94
PLA s2f_xo     99.2546152 0.0 12.1869343 -3.0800000000000001 0.0
              1381.8420000000001
!@what.1=b(s2f_xo,1)
!@what.2=b(s2f_xo,2)
!@what.3=-b(s2f_xo,3)
!@what.4=s2fOS-1.1/2.
!@what.5=b(s2f_xo,5)
!@what.6=b(s2f_xo,6)
PLA s2f_xi     99.254615200000003 0.0 -12.186934300000001 -4.1799999999999997
              0.0 1381.8420000000001
!@what.5=1.1/2.0
!@what.6=b(s2fmx,6)-2.94
PLA s2f_yt     0.0 99.2546152 12.1869343 0.0 0.55000000000000004
              1381.8420000000001
!@what.1=b(s2f_yt,1)
!@what.2=b(s2f_yt,2)
!@what.3=-b(s2f_yt,3)
!@what.4=b(s2f_yt,4)
!@what.5=-b(s2f_yt,5)
!@what.6=b(s2f_yt,6)
PLA s2f_yb     0.0 99.254615200000003 -12.186934300000001 0.0
              -0.55000000000000004 1381.8420000000001
!@what.1=b(s2fmx,6)-2.94
```

```
XYP s2f_zc     1381.8420000000001
#if 0
* SGB Shield SC02
!@what.1=sgb02OS-20.0/2.
!@what.2=sgb02OS+20.0/2.
!@what.3=-20.0/2.
!@what.4=-w(3)
!@what.5=3946.0-zro
!@what.6=w(5)+5.0
RPP sgb02      -13.699999999999999 6.2999999999999998 -10. 10.
              1399.1790000000001 1404.1790000000001
#endif
#if 0
* SC02 aperture
!@what.1=sgb02OS
!@what.3=b(sgb02,5)
!@what.7=5.0/2.
RCC sgb02_ap   -3.7000000000000002 0.0 0.0 0.0 0.0 5.0 2.5
#endif
#if 0
* FMX DCM crystal 1 not rotated
!@what.1=-3.5/2.
!@what.2=-w(1)
!@what.3=-5.9/2.
!@what.4=-w(3)
!@what.5=-13.2/2.
!@what.6=-w(5)
RPP dcmf1      -1.75 1.75 -2.9500000000000002 2.9500000000000002
              -6.5999999999999996 6.5999999999999996
#endif
* FMX DCM crystal 1 rotated 45 wrt y axis, translated z=1444.179, x=-1.89
BOX dcmf1      1.5394678887548 -2.95 1438.2746583771 2.4748737341529 0.0
              2.4748737341529 0.0 5.9 0.0 -9.333809511662 0.0 9.3338095116624
#if 0
* FMX DCM crystal 2 not rotated
!@what.1=-3.5/2.
```

```
!@what.2=-w(1)
!@what.3=-5.9/2.
!@what.4=-w(3)
!@what.5=-13.2/2.
!@what.6=-w(5)
RPP dcmf2      -1.75 1.75 -2.9500000000000002 2.9500000000000002
              -6.5999999999999996 6.5999999999999996
#endif
* FMX DCM crystal 2 rotated 45 wrt y axis, translated z=1444.179, x=-8.39-1.5
BOX dcmf2      -6.460532111245 -2.95 1438.2746583771 2.4748737341529 0.0
              2.4748737341529 0.0 5.9 0.0 -9.333809511662 0.0 9.3338095116624
* FMX wbs US Z
!@what.1=4010.0-zro
XYP wbstf_zu   1463.1790000000001
* FMX wbs DS Z
!@what.1=b(wbstf_zu,1)+7.5
XYP wbstf_zd   1470.6790000000001
#if 0
* FMX wbs xin
!@what.1=-3.6831 -3.0513+2.2962
YZP wbstf_xi   -4.4382000000000001
#endif
* FMX wbs xout
!@what.1=-3.6831+2.2962
YZP wbstf_xo   -1.3869000000000002
* FMX wbs Y bottom
!@what.1=-4.0/2.
XZP wbstf_yb   -2.
* FMX wbs Y bottom
!@what.1=4.0/2.
XZP wbstf_yt   2.
#if 0
* FMX wbs Y top of wedge
!@what.4=-6.704
!@what.5=1.2013*inch-0.904*inch
!@what.6=b(wbstf_zu,1)+7.5
```

```
PLA wbstf_yt   0.0 98.034 -19.732 -6.7039999999999997 0.7551420000000002
              1470.6790000000001
#endif
* FMX wbs inner surface of wedge
!@what.4=-3.6831+2.2962 -1.5418
!@what.6=b(wbstf_zu,1)
PLA wbstf_xi   98.0341143 0.0 19.7310016 -2.9287000000000001 0.0
              1463.1790000000001
#if 0
* FMX wbs xin
!@what.1=-6.704-2.0
YZP wbstf_x1   -8.7040000000000006
#endif
* FMX Brem Stop
!@what.1=-8.682
!@what.2=0.318
!@what.3=-4.0
!@what.4=4.0
!@what.5=4018.0-zro
!@what.6=w(5) + 20.5
RPP brmsfmx    -8.6820000000000004 0.318 -4. 4. 1471.1790000000001
              1491.6790000000001
* FMX Brem Stop aperture
!@what.1=-7.182
!@what.2=-6.182
!@what.3=-1.0/2.
!@what.4=-w(3)
!@what.5=b(brmsfmx,5)
!@what.6=b(brmsfmx,6)
RPP brmsf_ap   -7.1820000000000004 -6.1820000000000004 -0.5 0.5
              1471.1790000000001 1491.6790000000001
* SGB Shield SGB3:
!@what.1=-70.0/2.
!@what.2=-w(1)
!@what.3=-70.0/2.
!@what.4=-w(3)
```

```
!@what.5=4125.0-zro
!@what.6=w(5)+5.0
RPP sgb3       -35. 35. -35. 35. 1578.1790000000001 1583.1790000000001
* SGB3 aperture - AMX beamline
!@what.1=sgb3xos+28.0
!@what.3=b(sgb3,5)
!@what.7=10.0/2.
RCC sgb3_apa   21.317999999999998 3.0 1578.1790000000001 0.0 0.0 5.0 5.
* SGB3 aperture - FMX beamline
!@what.1=sgb3xos
!@what.3=b(sgb3,5)
!@what.7=10.0/2.
RCC sgb3_apf   -6.6820000000000004 0.0 1578.1790000000001 0.0 0.0 5.0 5.
#if 0
* SGB Shield SGB3: Picture frame
!@what.5=4315.0-zro
!@what.6=w(5)+5.0
RPP sgb3pf     -75. 75. -75. 75. 1768.1790000000001 1773.1790000000001
#endif
#if 0
* SGB Shield SGB3: Picture frame
!@what.1=-60.0/2.
!@what.2=-w(1)
!@what.3=-64.0/2.
!@what.4=-w(3)
!@what.5=4315.0-zro
!@what.6=w(5)+5.0
RPP sgb3ap     -30. 30. -32. 32. 1768.1790000000001 1773.1790000000001
#endif
* FMX HFM mirror 1  unrotated
!@what.1=hfm1OS-0.5
!@what.2=hfm1OS+0.5
!@what.5=4200.0-zro
!@what.6=w(5)+7.0
RPP hfm1       -7.3890000000000002 -6.3890000000000002 -0.5 0.5
              1653.1790000000001 1660.1790000000001
```

```
* AMX Photon Shutter
!@what.1=pshOSx-12.5/2.
!@what.2=pshOSx+12.5/2.
!@what.3=-15./2.+pshOS
!@what.4=-w(3)+2.*pshOS
!@what.5=4390.0-zro
!@what.6=w(5)+3.8
RPP psh        17.077000000000002 29.577000000000002 -4.5 10.5
              1843.1790000000001 1846.979
* AMX Shutter aperture
!@what.1=pshOSx-4./2.
!@what.2=pshOSx+4./2.
!@what.3=-2.5/2.+pshOS
!@what.4=-w(3)+2.*pshOS
!@what.5=b(psh,5)
!@what.6=b(psh,6)
RPP psh_ap     21.327000000000002 25.327000000000002 1.75 4.25
              1843.1790000000001 1846.979
* FMX Photon Shutter
!@what.1=pshOSfmx-12.5/2.
!@what.2=pshOSfmx+12.5/2.
!@what.3=-15./2.
!@what.4=-w(3)
!@what.5=4348.2-zro
!@what.6=w(5)+3.8
RPP pshfmx     -14.117000000000001 -1.617 -7.5 7.5 1801.3789999999999
              1805.1789999999999
* FMX Shutter aperture
!@what.1=pshOSfmx-4./2.
!@what.2=pshOSfmx+4./2.
!@what.3=-2.5/2.
!@what.4=-w(3)
!@what.5=b(pshfmx,5)
!@what.6=b(pshfmx,6)
RPP pshf_ap    -9.8670000000000009 -5.867 -1.25 1.25 1801.3789999999999
              1805.1789999999999
```

```
!@what.1=-80./2.
!@what.2=-w(1)
!@what.3=-84./2.+gioOS
!@what.4=-w(3)+2.*gioOS
!@what.5=4435.0-zro
!@what.6=w(5)+10.
RPP giotn      -40. 40. -42. 42. 1888.1790000000001 1898.1790000000001
* Guillotine aperture - AMX beamline
!@what.3=b(giotn,5)
!@what.7=3.888*inch/2.
RCC giotn_ap   23.774 3.0 1888.1790000000001 0.0 0.0 10.0 4.9377599999999999
* Guillotine aperture - FMX beamline
!@what.3=b(giotn,5)
!@what.7=3.888*inch/2.
RCC giotnf_a   -8.296 0.0 1888.1790000000001 0.0 0.0 10.0 4.9377599999999999
END
* Black hole
BLKBODY      5 +blkbody -air
* Void around
AIR          5 +air +rwxxA_i +rwxxA_s +swxxA_s -swxxA_i
               | +air +rwxxA_i +swxxA_s -rwxxA_s -swxxA_i
               | +air +rwxxA_i +rwxxA_s +swxxA_i +swxxA_s
               | +air +swxxA_s -rwxxA_i -rwxxA_s -swxxA_i
               | +air +rwxxA_s +swxxA_i +swxxA_s -rwxxA_i
               | +air -rwxxA_i -rwxxA_s -swxxA_i -swxxA_s
               | +air +rwxxA_s +bfwxxB_o -rwxxA_i -swxxA_i -swxxA_s -blp_shd -blpf_shd
               | +air +rwxxA_s +swxxA_i -rwxxA_i -swxxA_s
               | +air +rwxxA_s +swxxA_s -rwxxA_i -swxxA_i -rfxxA_t
               | +air +rwxxA_s +swxxA_s +flxxA_b -rwxxA_i -swxxA_i
               | +rwxxA_s +rfxxA_t +bbwxxA_o -rwxxA_o -flxxA_t -bswxxA_o
               | +rwxxA_s +swxxA_s +rfxxA_t -swxxA_o -flxxA_t -bbwxxA_o -blp_shd -blpf_shd
               | +rfxxA_t +bswxxA_o +bbwxxA_o -rwxxA_o -swxxA_o -brfxxA_t
               | +air -bfwxxB_o
* DS RW FM block1 AMX
FM_XXA       5 +fm_af1 -fma_in1 -fm_zc1
               | +fm_af1 +fm_zc1 -fma_yt1
```

```
                | +fm_af1 +fma_yb1 +fm_zc1
                | +fm_af1 +fma_yt1 +fm_zc1 -fma_xo1 -fma_yb1
                | +fm_af1 +fma_xi1 +fma_yt1 +fm_zc1 -fma_yb1
* DS RW FM aperture 1 AMX
FMA_XXA       5 +fm_af1+fma_in1 -fm_zc1
                | +fm_af1+fma_xo1 +fma_yt1 +fm_zc1 -fma_xi1 -fma_yb1
* DS RW FM block2 FMX
FM_XXF        5 +fm_af2 -fma_in2 -fm_zc1
                | +fm_af2 +fm_zc1 -fma_yt1
                | +fm_af2 +fma_yb1 +fm_zc1
                | +fm_af2 +fma_yt1 +fm_zc1 -fma_xo2 -fma_yb1
                | +fm_af2 +fma_xi2 +fma_yt1 +fm_zc1 -fma_yb1
* DS RW FM aperture 2 FMX
FMA_XXF       5 +fm_af2+fma_in2 -fm_zc1
                | +fm_af2+fma_xo2 +fma_yt1 +fm_zc1 -fma_xi2 -fma_yb1
* Bremsstrahlubg collimator
BRMCOL        5 +brmcol -brmcolap -brmcolaf
* Bremsstrahlubg collimator aperture for AMX
BRMCOLAP      5 +brmcolap
* Bremsstrahlubg collimator aperture for FMX
BRMCOLAF      5 +brmcolaf
* Slit 1 Block F
S1BF          5 +s1bf -s1bfap
* Slit 1 Block F aperture
S1BFAP        5 +s1bfap
* Slit 2 Block F
S2BF          5 +s2bf -s2bfap
* Slit 2 Block F aperture
S2BFAP        5 +s2bfap
* Slit 1 Block A
S1BA          5 +s1ba -s1ba_in -s1ba_zc
                | +s1ba +s1ba_zc -s1ba_yt
                | +s1ba +s1ba_yb +s1ba_zc
                | +s1ba +s1ba_yt +s1ba_zc -s1ba_xo -s1ba_yb
                | +s1ba +s1ba_xi +s1ba_yt +s1ba_zc -s1ba_yb
* AMX slit1 Block A aperture
```

```
S1BAAP       5 +s1ba +s1ba_in -s1ba_zc
               | +s1ba+s1ba_xo +s1ba_yt +s1ba_zc -s1ba_xi -s1ba_yb
* Slit 2 Block A
S2BA         5 +s2ba -s2ba_in -s2ba_zc
               | +s2ba +s2ba_zc -s2ba_yt
               | +s2ba +s2ba_yb +s2ba_zc
               | +s2ba +s2ba_yt +s2ba_zc -s2ba_xo -s2ba_yb
               | +s2ba +s2ba_xi +s2ba_yt +s2ba_zc -s2ba_yb
* AMX slit2 Block A aperture
S2BAAP       5 +s2ba +s2ba_in -s2ba_zc
               | +s2ba+s2ba_xo +s2ba_yt +s2ba_zc -s2ba_xi -s2ba_yb
* AMX DCM crystal 1
DCMA1        5 +dcma1
* AMX DCM crystal 2
DCMA2        5 +dcma2
* AMX white beamstop
AMXWBS       5 +wbsta_zd +wbsta_yt +wbsta_xo -wbsta_zu -wbsta_yb -wbsta_xi
*  AMX Brem Stop
BRMSTP1      5 +brms -brms_ap
* Brem stop APERTURE
BRMSTPAP     5 +brms_ap
* SBS SC01
SC01         5 +sgb01 -sgb01_ap
* SBS SC01 aperture
SC01AP       5 +sgb01_ap
* AMX TD Mirror1
TDM1         5 +tdm1
* FMX PPS mask Cu block
PPSMFMX      5 +ppsmfmx -ppsm_in -ppsm_zc
               | +ppsmfmx +ppsm_zc -ppsm_yt
               | +ppsmfmx +ppsm_yb +ppsm_zc
               | +ppsmfmx +ppsm_yt +ppsm_zc -ppsm_xo -ppsm_yb
               | +ppsmfmx +ppsm_xi +ppsm_yt +ppsm_zc -ppsm_yb
* FMX PPS mask aperture
PPSMAP       5 +ppsmfmx +ppsm_in -ppsm_zc
               |+ppsmfmx+ppsm_xo +ppsm_yt +ppsm_zc -ppsm_xi -ppsm_yb
```

```
* Bremsstrahlubg collimator 2 for FMX
BRMCOL2      5 +brmcol2  -brmcol2a
* Bremsstrahlubg collimator aperture for FMX
BRMCOL2A     5 +brmcol2a
#if 0
* FMX Amy's copper target
CUTARG       5 +cutarg
#endif
* FMX white beam slit 1 Cu block
S1FMX        5 +s1fmx -s1f_in -s1f_zc
               | +s1fmx +s1f_zc -s1f_yt
               | +s1fmx +s1f_yb +s1f_zc
               | +s1fmx +s1f_yt +s1f_zc -s1f_xo -s1f_yb
               | +s1fmx +s1f_xi +s1f_yt +s1f_zc -s1f_yb
* FMX slit1 aperture
S1FMXAP      5 +s1fmx +s1f_in -s1f_zc
               | +s1fmx+s1f_xo +s1f_yt +s1f_zc -s1f_xi -s1f_yb
* FMX white beam slit 2 block
S2FMX        5 +s2fmx -s2f_in -s2f_zc
               | +s2fmx +s2f_zc -s2f_yt
               | +s2fmx +s2f_yb +s2f_zc
               | +s2fmx +s2f_yt +s2f_zc -s2f_xo -s2f_yb
               | +s2fmx +s2f_xi +s2f_yt +s2f_zc -s2f_yb
* FMX slit2 aperture
S2FMXAP      5 +s2fmx +s2f_in -s2f_zc
               | +s2fmx+s2f_xo +s2f_yt +s2f_zc -s2f_xi -s2f_yb
#if 0
* SBS SC02
SC02         5 +sgb02 -sgb02_ap
#endif
#if 0
* SBS SC02 aperture
SC02AP       5 +sgb02_ap
#endif
* SBS SGB02
SGB02        5 +sgb3 -sgb3_apa -sgb3_apf
```

```
* SBS SGB02 AMX aperture
SGB2_APA     5 +sgb3_apa
* SBS SGB02 FMX aperture
SGB2_APF     5 +sgb3_apf
#if 0
* SBS SGB3 Picture Frame
SGB3PF       5 +sgb3pf -sgb3ap
#endif
#if 0
* SBS SGB3 aperture
SGB3AP       5 +sgb3ap
#endif
* FMX DCM crystal 1
DCMF1        5 +dcmf1
* FMX DCM crystal 2
DCMF2        5 +dcmf2
* FMX white beamstop
FMXWBS       5 +wbstf_zd +wbstf_yt +wbstf_xo -wbstf_zu -wbstf_yb -wbstf_xi
*  FMX Brem Stop
BRMSFMX      5 +brmsfmx -brmsf_ap
* FMX Brem stop APERTURE
BRMSTPA2     5 +brmsf_ap
* FMX HFM Mirror1
HFM1         5 +hfm1
* AMX photon Shutter APERTURE
SHUTERAP     5 +psh_ap
* AMX photon Shutter
SHUTTER      5 +psh -psh_ap
* FMX photon Shutter APERTURE
PSHFMXAP     5 +pshf_ap
* FMX photon Shutter
PSHFMX       5 +pshfmx -pshf_ap
* Guillotine
GILOTINE     5 +giotn -giotn_ap -giotnf_a
* Guillotine APERTURE AMX
GILOAP       5 +giotn_ap
```

```
* Guillotine APERTURE
GILOAPF      5 +giotnf_a
* Storage ring outer shielding
SOW_SHLD     5 +rwxxA_o +rwxxA_s +rfxxA_t -rwxxA_i -swxxA_i -flxxA_t
               | +swxxA_o +swxxA_s +rfxxA_t -rwxxA_o -swxxA_i -flxxA_t
               | +rwxxA_s +swxxA_s +flxxA_t -rwxxA_i -swxxA_i -flxxA_b
ARF_SHD      5 +bswxxA_o +bbwxxA_o +brfxxA_t -rwxxA_o -swxxA_o -brfxxA_b
ENC_A        5 +bswxxA_i +bbwxxA_i +brfxxA_b -rwxxA_o -swxxA_o -flxxA_t -brmcol -dcma1 -dcma2 -psh -brms
               -sgb01 -giotn -fm_af1 -fm_af2
               -(+wbsta_zd +wbsta_yt +wbsta_xo -wbsta_zu -wbsta_yb -wbsta_xi )
               -(+wbstf_zd +wbstf_yt +wbstf_xo -wbstf_zu -wbstf_yb -wbstf_xi )
               -tdm1 -dcmf1 -dcmf2 -brmsfmx -hfm1-pshfmx -sgb3
               -s1fmx -s2fmx -brmcol2 -s1bf -s2bf -s1ba -s2ba -ppsmfmx
ASW_SHD      5 +bswxxA_o +bbwxxA_i +brfxxA_b -rwxxA_o -flxxA_t -bswxxA_i
ABW_SHD      5 +bswxxA_o +bbwxxA_o +brfxxA_b -swxxA_o -flxxA_t -bbwxxA_i-blp_o -blpf_o
* Transport beampipe vacuum- AMX beam
tbp_va       5 +bfwxxB_o +blp_i -bbwxxA_i
* Transport beampipe shell - AMX beam
tbp_ss       5 +bfwxxB_o +blp_o -bbwxxA_i -blp_i
* Transport beampipe shielding - AMX beam
tbp_sh       5 +bfwxxB_o +blp_shd -bbwxxA_o -blp_o
* Transport beampipe vacuum - FMX beam
tbpf_va      5 +bfwxxB_o +blpf_i -bbwxxA_i
* Transport beampipe shell - FMX beam
tbpf_ss      5 +bfwxxB_o +blpf_o -blpf_i -bbwxxA_i
* Transport beampipe shielding - AFX beam
tbpf_sh      5 +bfwxxB_o +blpf_shd -bbwxxA_o -blpf_o
END
GEOEND
MATERIAL                            2.35       26.                    CONCRETE
COMPOUND       -0.01  HYDROGEN      -.54    OXYGEN     -0.02    SODIUMCONCRETE
COMPOUND        -.04  ALUMINUM      -.34   SILICON      -.05   CALCIUMCONCRETE
* ..+....1....+....2....+....3....+....4....+....5....+....6....+....7..
ASSIGNMA    BLCKHOLE   BLKBODY
ASSIGNMA         AIR       AIR
ASSIGNMA      VACUUM     ENC_A
```

```
ASSIGNMA    CONCRETE  SOW_SHLD
ASSIGNMA        LEAD   ARF_SHD
ASSIGNMA        LEAD   ASW_SHD
ASSIGNMA        LEAD   ABW_SHD
ASSIGNMA        LEAD    BRMCOL
ASSIGNMA      VACUUM  BRMCOLAP
ASSIGNMA      VACUUM  BRMCOLAF
*ASSIGNMA         AIR    CUTARG
ASSIGNMA      COPPER      S1BF
ASSIGNMA      VACUUM    S1BFAP
ASSIGNMA      COPPER      S2BF
ASSIGNMA      VACUUM    S2BFAP
ASSIGNMA      COPPER      S1BA
ASSIGNMA      VACUUM    S1BAAP
ASSIGNMA      COPPER      S2BA
ASSIGNMA      VACUUM    S2BAAP
ASSIGNMA        LEAD   BRMCOL2
ASSIGNMA      VACUUM  BRMCOL2A
ASSIGNMA     SILICON      TDM1
ASSIGNMA     SILICON      HFM1
ASSIGNMA     SILICON     DCMA1
ASSIGNMA     SILICON     DCMA2
ASSIGNMA     SILICON     DCMF1
ASSIGNMA     SILICON     DCMF2
ASSIGNMA      VACUUM    SC01AP
ASSIGNMA      COPPER    AMXWBS
ASSIGNMA      COPPER    FMXWBS
ASSIGNMA      COPPER   PPSMFMX
ASSIGNMA      VACUUM    PPSMAP
ASSIGNMA      COPPER     S1FMX
ASSIGNMA      VACUUM   S1FMXAP
ASSIGNMA      COPPER     S2FMX
ASSIGNMA      VACUUM   S2FMXAP
*ASSIGNMA         AIR      SC02
*ASSIGNMA      VACUUM    SC02AP
ASSIGNMA        LEAD     SGB02
```

```
ASSIGNMA      VACUUM  SGB2_APA
ASSIGNMA      VACUUM  SGB2_APF
*ASSIGNMA        LEAD    SGB3PF
*ASSIGNMA      VACUUM    SGB3AP
ASSIGNMA      VACUUM  BRMSTPAP
ASSIGNMA    TUNGSTEN   BRMSTP1
ASSIGNMA      VACUUM  BRMSTPA2
ASSIGNMA    TUNGSTEN   BRMSFMX
ASSIGNMA    TUNGSTEN   SHUTTER
ASSIGNMA      VACUUM  SHUTERAP
ASSIGNMA    TUNGSTEN    PSHFMX
ASSIGNMA      VACUUM  PSHFMXAP
ASSIGNMA      VACUUM    GILOAP
ASSIGNMA      VACUUM   GILOAPF
ASSIGNMA        LEAD  GILOTINE
ASSIGNMA      COPPER    FM_XXA
ASSIGNMA      COPPER    FM_XXF
ASSIGNMA      VACUUM   FMA_XXA
ASSIGNMA      VACUUM   FMA_XXF
ASSIGNMA      VACUUM    tbp_va
ASSIGNMA        IRON    tbp_ss
ASSIGNMA        LEAD    tbp_sh
ASSIGNMA      VACUUM   tbpf_va
ASSIGNMA        IRON   tbpf_ss
ASSIGNMA        LEAD   tbpf_sh
ASSIGNMA        LEAD      SC01
PHOTONUC          1.                      HYDROGEN  @LASTMAT
LAM-BIAS         0.0      0.02    COPPER    PHOTON
LAM-BIAS         0.0      0.02      LEAD    PHOTON
LAM-BIAS         0.0      0.02      IRON    PHOTON
LAM-BIAS         0.0      0.02  TUNGSTEN    PHOTON
LAM-BIAS         0.0      0.02  CONCRETE    PHOTON
LAM-BIAS         0.0      0.02   SILICON    PHOTON
USRBIN           10.   DOSE-EQ      -30.     200.0     200.0    2000.0FOE_T
USRBIN        -200.0    -100.0       0.0       40.       60.      200. &
AUXSCORE      USRBIN  ALL-PART               FOE_T                    AMB74
```

```
USRBIN          10.   DOSE-EQ      -30.     200.0     200.0    2000.0FOE_P
USRBIN       -200.0    -100.0       0.0       40.       60.      200. &
AUXSCORE     USRBIN    PHOTON               FOE_P                    AMB74
USRBIN          10.   DOSE-EQ      -30.     200.0     200.0    2000.0FOE_N
USRBIN       -200.0    -100.0       0.0       40.       60.      200. &
AUXSCORE     USRBIN   NEUTRON               FOE_N                    AMB74
USRBIN          10.   DOSE-EQ      -31.      150.     211.0    2000.0RF_T
USRBIN        -100.     201.0        0.      250.       20.      400. &
AUXSCORE     USRBIN  ALL-PART               RF_T                    AMB74
USRBIN          10.   DOSE-EQ      -31.      150.     211.0    2000.0RF_N
USRBIN        -100.     201.0        0.      250.       20.      400. &
AUXSCORE     USRBIN   NEUTRON               RF_N                    AMB74
USRBIN          10.   DOSE-EQ      -31.     168.8       50.    2000.0SW_T
USRBIN        158.8      -50.        0.       10.      100.      400. &
AUXSCORE     USRBIN  ALL-PART               SW_T                    AMB74
USRBIN          10.   DOSE-EQ      -31.     168.8       50.    2000.0SW_N
USRBIN        158.8      -50.        0.       10.      100.      400. &
AUXSCORE     USRBIN   NEUTRON               SW_N                    AMB74
USRBIN          10.   DOSE-EQ      -32.     150.0     150.0    1940.0BW_T
USRBIN       -150.0    -150.0    1890.0      60.0      60.0      50.0 &
AUXSCORE     USRBIN  ALL-PART               BW_T                    AMB74
USRBIN          10.   DOSE-EQ      -32.     150.0     150.0    1940.0BW_N
USRBIN       -150.0    -150.0    1890.0      60.0      60.0      50.0 &
AUXSCORE     USRBIN   NEUTRON               BW_N                    AMB74
USRBIN          10.   DOSE-EQ      -32.     150.0     150.0    1940.0BW_P
USRBIN       -150.0    -150.0    1890.0      60.0      60.0      50.0 &
AUXSCORE     USRBIN    PHOTON               BW_P                    AMB74
USRBIN          10.   DOSE-EQ      -33.      100.      100.    2000.0MoreT
USRBIN        -100.     -100.       0.0      100.      100.    1000.0 &
AUXSCORE     USRBIN  ALL-PART              MoreT                    AMB74
USRBIN          10.   DOSE-EQ      -33.      100.      100.    2000.0MoreN
USRBIN        -100.     -100.       0.0      100.      100.     1000. &
AUXSCORE     USRBIN   NEUTRON              MoreN                    AMB74
USRBIN          10.   DOSE-EQ      -33.      100.      100.    2000.0MoreP
USRBIN        -100.     -100.       0.0      100.      100.     1000. &
AUXSCORE     USRBIN    PHOTON              MoreP                    AMB74
```

```
USRBIN           10.   DOSE-EQ      -35.      20.0       20.    2400.0TP_T
USRBIN          -20.       -4.    1900.0       40.       24.     500.0 &
AUXSCORE      USRBIN  ALL-PART                TP_T                     AMB74
USRBIN           10.   DOSE-EQ      -35.      20.0       20.    2400.0TP_N
USRBIN          -20.       -4.    1900.0       40.       24.     500.0 &
AUXSCORE      USRBIN   NEUTRON                TP_N                     AMB74
USRBIN           10.   DOSE-EQ      -35.      20.0       20.    2400.0TP_P
USRBIN          -20.       -4.    1900.0       40.       24.     500.0 &
AUXSCORE      USRBIN    PHOTON                TP_P                     AMB74
#define bl 4500
* Distance of DS ratchet wall from Straight Center
#define zro 2546.821
* Distance of Front End (FE) centerline from Straight Centerline
#define xro 0.318
#define sgbOS 0.480
#define s1bfapOS -2.465
#define s1baapOS 3.054
!@what.1=1.144*inch
#define sgb01xo 2.90576
#define sgb01yo 3.0
#define sgb02OS -3.7
#define wbsOS 0.0
#define wbsta_xm 1.2521*inch
#define brsaOS 3.0
* PPS mask offset
#define ppsmos -3.5062
#define brmcol2x -3.518
#define s1fOS -3.59
#define s2fOS -3.63
* SGB3 FMX aperture offset
#define sgb3xos -6.682
#define hfm1OS -6.889
#define pshOS 3.0
#define pshOSx 23.327
#define pshOSfmx -7.867
#define gioOS 0.0
```

```
#define dcmOS 0.0
* Beam poistion and direction
!@what.1=C(BEAMPOS,0,1)
!@what.2=C(BEAMPOS,0,2)
!@what.3=C(BEAMPOS,0,3)
!@what.7=bl*C(BEAMPOS,0,4)
!@what.8=bl*C(BEAMPOS,0,5)
!@what.9=bl*sqrt(1.0-C(BEAMPOS,0,4)**2-C(BEAMPOS,0,5)**2)
!arrow           -4.       0.0     1273.                 500.      220.beam
!arrow      -4.50585       0.04499.99774                              &
* Beam poistion and direction
*!arrow           1.5       0.0     590.0                 500.      220.beam
*!arrow           0.3       0.0     100.0                              &
* Beam poistion and direction
*!arrow        -140.0    1.0778    -530.0                 500.      220.beam
*!arrow           0.0       0.0    4500.0                              &
!@what.2=b(brmcolap,2)
!@what.3=b(brmcolap,5)
!@what.7=b(brms,2)-b(brmcolap,2)-4.613
!@what.9=b(brms_ap,5)-b(brmcolap,5)
*!arrow           0.0     3.536    95.059       0.0       0.0       0.0UMaxRayH
*!arrow          .236       0.0     246.3                              &
!@what.2=b(brmcolap,4)
!@what.3=b(brmcolap,5)
!@what.8=b(brms_ap,3)-b(brmcolap,4)-2.828
!@what.9=b(brms_ap,5)-b(brmcolap,5)
!arrow           0.0        .6    95.059       0.0       0.0       0.0UMaxRayV
!arrow           0.0     -.928     246.3                              &
* Set the random number seed
RANDOMIZ         1.0
* Set the number of primary histories to be simulated in the run
START        200000.
STOP
```