19ID (NYX) TOP-OFF RADIATION SAFETY ANALYSIS

APPROVALS

11/2/2016

X Ray Fliller

Ray Fliller
Coordination Group for Top Off Safety Leader
Signed by: Fliller, Raymond

11/7/2016

X Timur Shaftan

Timur Shaftan
Interim Accelerator Division Director
Signed by: Shaftan, Timur

11/8/2016

X

Paul Zschack
Photon Science Division Director
Signed by: Zschack, Paul

11/2/2016

X

Steve Moss
Authorization Basis Manager
Signed by: Moss, Steven H

11/4/2016

X

Robert Lee
ESH Manager
Signed by: Lee, Robert J

X

Joseph Lidestri
NYSBC NYX Lead Bemaline Scientist

NSLS-II TECHNICAL NOTE BROOKHAVEN NATIONAL LABORATORY	NUMBER: **NSLSII-TOS-RPT-009**
AUTHORS: M. Benmerrouche, X. Yang, R. Fliller and Y. Li	DATE: 11/1/2016
19ID (NYX) Top-Off Radiation Safety Analysis	

1. Introduction

The primary radiological safety concern for Top-Off injection, with the front end (FE) safety shutters open, is the scenario where injected electrons could be transported down to the beamline through the FE due to an erroneous combination of lattice magnetic field settings and beam energy. These electrons will scatter off the FE components and the resulting radiation will scatter off the components in the First Optics Enclosure (FOE), possibly leading to high dose rates outside of the FOE walls. The radiological consequences of this fault condition specifically for 19-ID (NYX) are analyzed and discussed in this report. For this beamline, all FE components, the ratchet wall collimators and many FOE components lie along the short straight (SS) centerline. The goal of the simulations documented here was to estimate the radiation dose levels generated outside the FOE during this Top-Off fault condition, thus evaluating the efficacy of the FE radiation safety components and the FOE shielding. This beamline was not covered by the Top-Off design report issued in 2014 [1].

The layout of the 19-ID (NYX) FE components is presented in Figure 1. One ARM is located near the sliding door of the FE. Another ARM is located on the sidewall of the FOE near the hutch door.

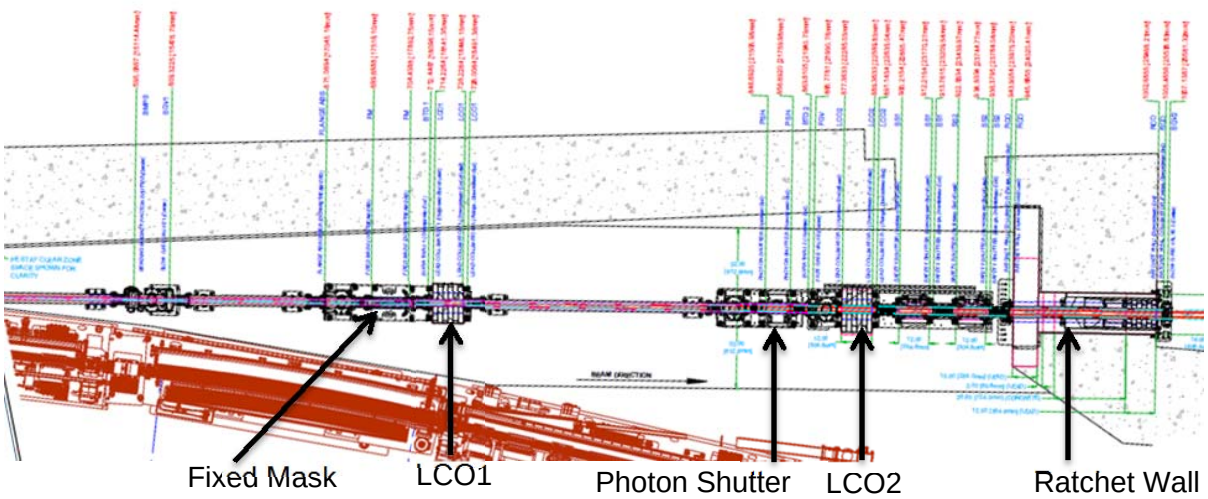


Figure 1: Layout of 19-ID (NYX) FE showing major components consisting of Masks, Collimators, Safety Shutters, and Ratchet Wall Collimator

Backward particle tracking analysis was performed for 19-ID (NYX) and has determined that the injected electrons will not travel beyond the lead collimator 2 (LCO2) in the FE. FLUKA simulations were performed with a pencil beam of electrons traveling from downstream aperture of fixed mask 1 (FM1) to the upstream face of LC02, both inboard and outboard at 5mm from the aperture edge.

The Top-Off backward particle tracking analysis for 19-ID (NYX) is discussed in section 2, the FLUKA model is described in section 3 and the results of the simulations are discussed in section 4. A summary and conclusions are presented in section 5.

This report can be used as a basis to approve the Top-Off Operation of the 19-ID (NYX) beamline, provided that the FE, beamline and shielding configuration are not changed. The

Top-Off Operation of new beamlines and the approval process shall be in accordance with procedure PS-C-ASD-PRC-183 [2].

2. Top-Off Particle Tracking Analysis

At NSLS-II, the Top-Off Safety System guarantees that the injected electron beam does not channel down the FE and into the beamline FOE. Particle tracking analysis for the 19-ID (NYX) FE has shown that the safe endpoint for the injected electron beam is the LCO2. To ensure this safe point for 19-ID (NYX), the apertures and tolerances are exactly the same as those called out in the TOSS interlock specification [1]:

- FM1, +/-2 mm horizontally
- LCO2, +/-5 mm horizontally

Figures 2(a), (b) and (c) show the particle tracking simulations for 19-ID (NYX). The two apertures shown in the figures at positions ~13 m and ~27 m from the center of the straight represent the apertures through the FM1 and LCO2, respectively. In these simulations, the aperture of FM1 was assumed to be 43.7 mm and the aperture of LC02 was assumed to be 79.2 mm. Based on the backward particle tracking simulation [1], the electron beam will have a distance of at least 5 mm from the LC02 aperture edge.

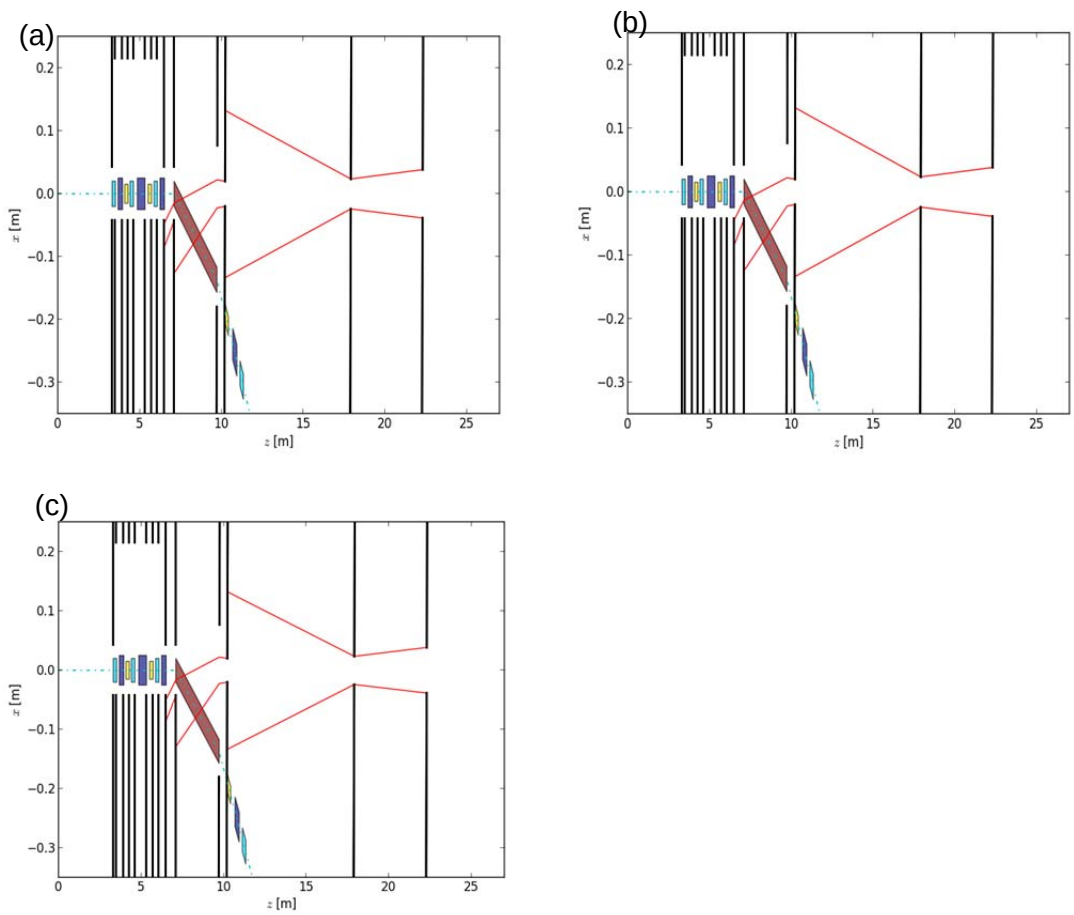


Figure 2(a): On momentum envelope of backward particle tracking trajectories for the NYX Beamline. **2(b)**: Off (+3%) momentum envelope of backward particle tracking trajectories for the NYX Beamline. **2(c)**: Off (-3%) momentum envelope of backward particle tracking trajectories for the NYX Beamline.

3. Description of the FLUKA Model

The plan and elevation views of the FLUKA geometry used for the Top-Off simulations of the 19-ID (NYX) Beamline are shown in Figures 3(a) and (b). The input used to generate the FLUKA model is listed in Appendix 1. The FLUKA input and output files are kept in the Radiation Physics folder. A plane view the FLUKA geometry with all beamline FOE components used in the 19ID (NYX) Top-Off analysis is provided in Figure 4.

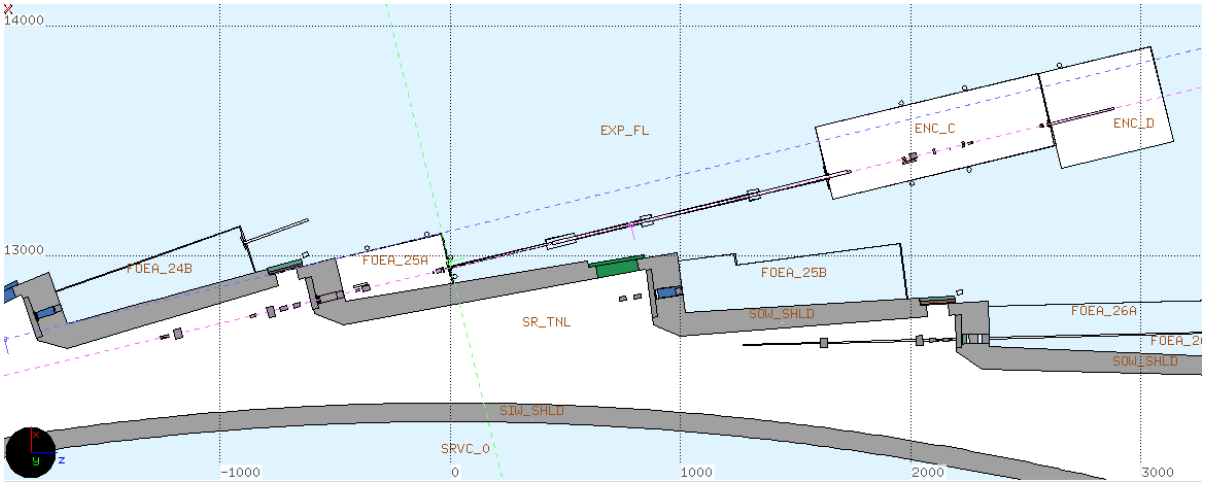


Figure 3(a): Plan view of the FLUKA geometry used in Top-Off simulation of the 19-ID (NYX) Beamline

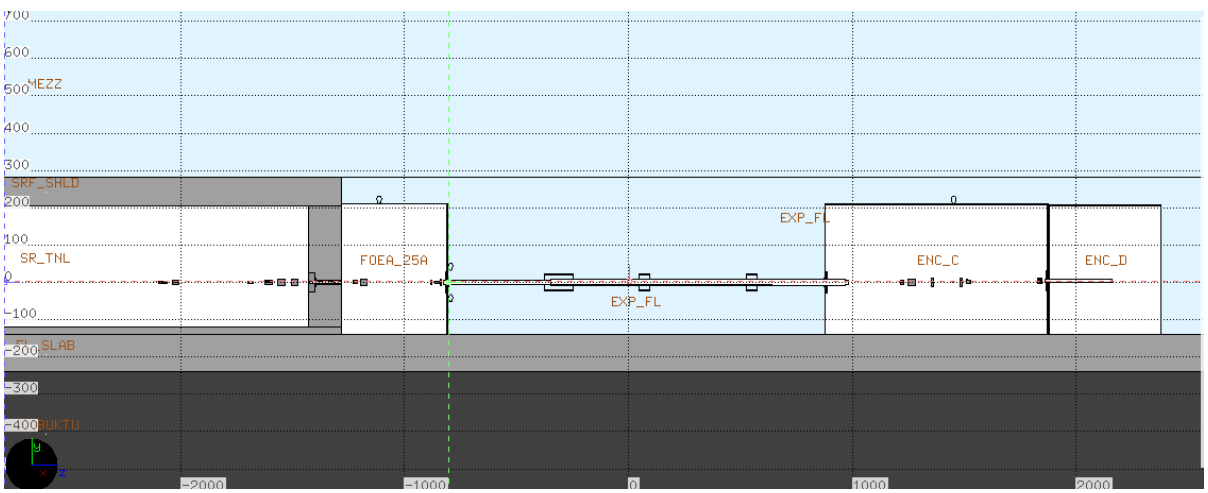


Figure 3(b): Elevation view of the FLUKA geometry used in Top-Off simulation of the 19-ID (NYX) Beamline

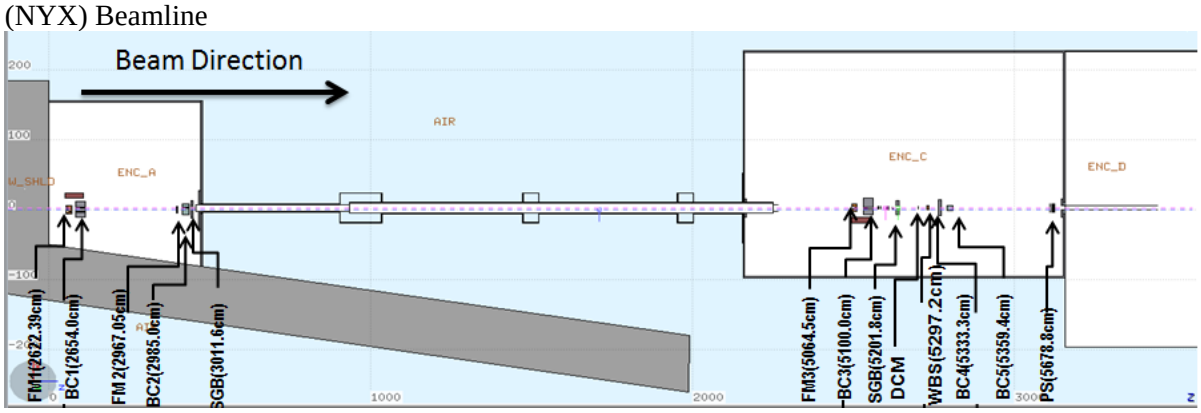


Figure 4: Plane view of the NYX Beamline components in the FOE used in the FLUKA geometry for Top-Off simulation of the 19-ID (NYX) Beamline.

ACRONYMS:

FM Fixed Mask

BC Beam Collimator

SGB Secondary Gas Bremsstrahlung Shielding

PS Photon Shutter

DCM Double Crystal Monochromator

4. Results for Top-Off FLUKA Simulations

In all FLUKA simulations, a pencil beam of 3 GeV electrons is assumed for the injected beam and all dose rates are normalized to a booster to storage ring injection charge rate of 45 nC/min. Based on the backward particle tracking analysis described in section 2, the beam is assumed lost at the safe endpoint (5 mm from the upstream aperture edge of LC02).

The amount of radiation transmitted into the FOE is primarily determined by the aperture of the FE collimator LC02 and the ratchet wall collimator RCO. The aperture dimensions for 19-ID (NYX) are compared to those of other NSLS-II beamlines in Table 1 [3].

Table 1. CO2 and RWC aperture dimensions

	LCO2 Dimensions X (mm)	LCO2 Dimensions Y (mm)	RCO Dimensions X (mm)	RCO Dimensions Y (mm)
04ID-ISR	**79.33**	**28.22**	**88.16**	**30.56**
05ID-SRX	**79.2**	**28.4**	**78.44**	**21.80**
08ID-ISS	**79.2**	**28.4**	**44.74**	**17.03**
12ID-SMI	**83.88**	**27.24**	**95.29**	**31.09**
19ID-NYX	**79.2**	**28.4**	**115.7**	**65.7**

The horizontal and vertical dimensions of the 19-ID (NYX) RCO apertures are larger than those for the other beamlines. The NYX simulations were undertaken to ensure that the larger horizontal and vertical RCO apertures do not result in high dose rates on the FOE walls and roof.

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

1. **Case 1: i_i** - Injected beam starting at the inboard side of the downstream aperture of FM1 and directed toward the front face of LC02 at 5 mm from the inboard side of the aperture.
2. **Case 2: o_o** - Injected beam starting at the outboard side of the downstream aperture of FM1 and directed toward the front face of LC02 at 5 mm from the outboard side of the aperture.
3. **Case 3: i_o** - Injected beam starting at the inboard side of the downstream aperture of FM1 and directed toward the front face of LC02 at 5 mm from the outboard side of the aperture.
4. **Case 4: o_i** - Injected beam starting at the outboard side of the downstream aperture of FM1 and directed toward the front face of LC02 at 5 mm from the inboard side of the aperture.

The dose rates on the downstream FOE wall were found to be larger for cases 3 and 4 than for cases 1 and 2.

4.1 Case 1: i_i

In this simulation, the injected electron beam was started downstream of the horizontal aperture on the inboard side of the FM1 and directed toward the front face of LCO2 at 5 mm from the inboard side of the horizontal aperture.

The total dose distributions (mrem/h) in the FE and FOE are shown in Figure 5.

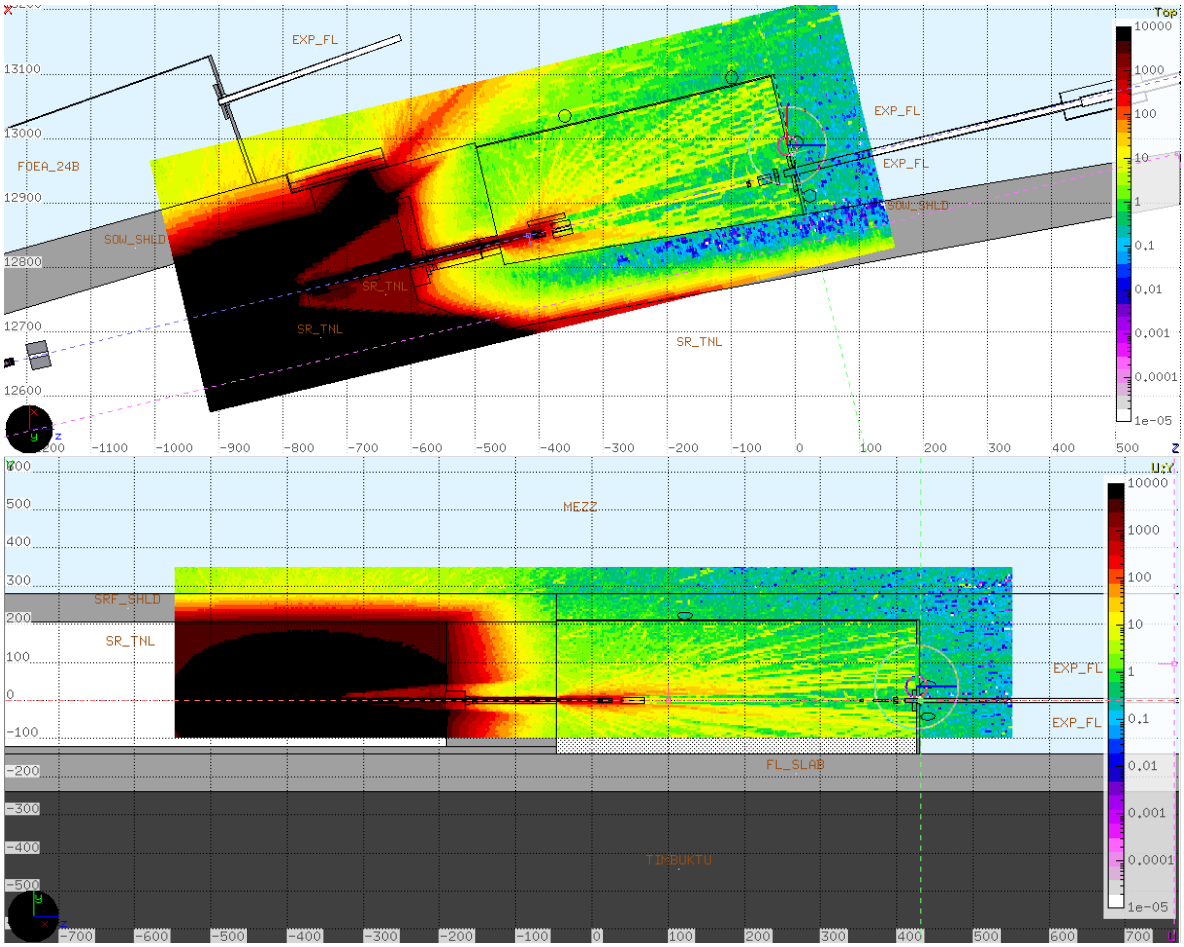


Figure 5: Total dose rate distributions (mrem/h). The Top view at y=0 is shown in the top figure and the elevation view in the bottom figure.

Total dose rates on the roof, sidewall and the downstream wall of the FOE were plotted and found to be well below 100 mrem/h goal set in reference 4. An example of the dose distribution on contact with the downstream wall are presented in Figure 6. The dose rates were less than 6 mrem/hr. The dose rate along the sidewall and the roof were less than 10 mrem/hr.

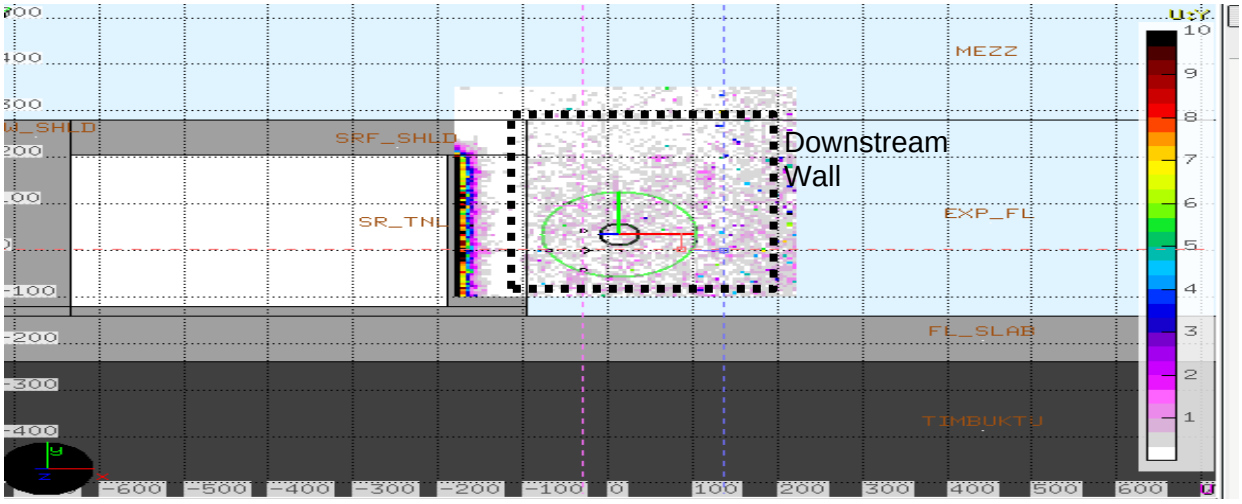
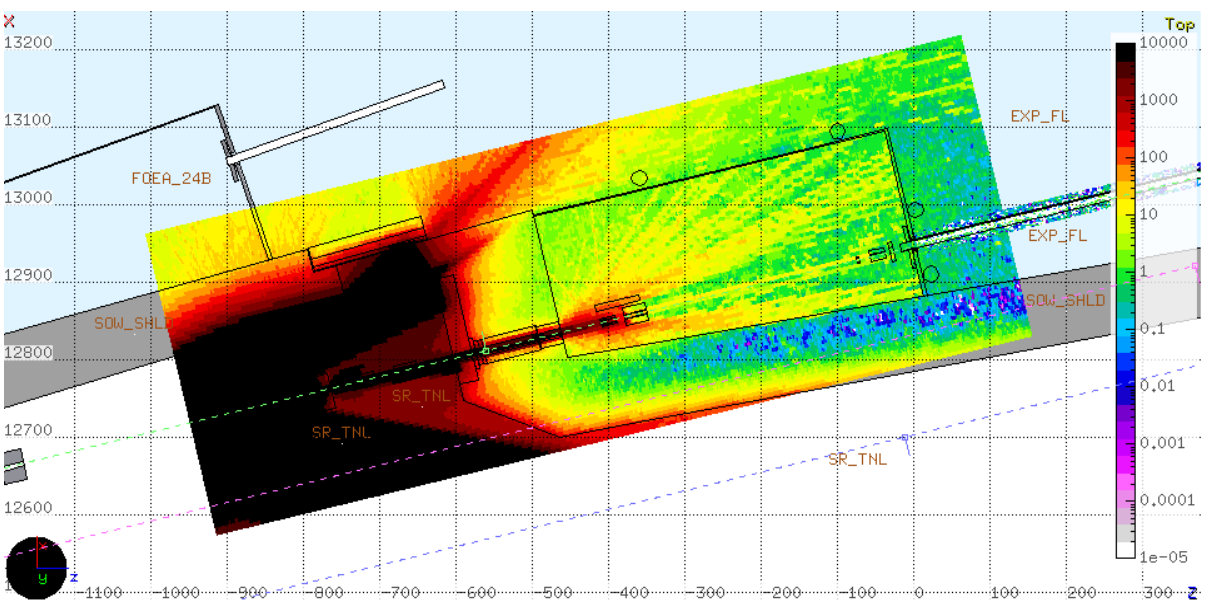


Figure 6: Total dose rate distributions on contact with the downstream wall (mrem/h) shown in black dashed-line square.

4.2 Case 2: o_o

In this simulation, the injected electron beam was started downstream of the horizontal aperture on the outboard side of the FM1 and directed toward the front face of LCO2 at 5 mm from the outboard side of the horizontal aperture.

Figure 7 shows the dose rate distributions (mrem/h) in the FE and the FOE.



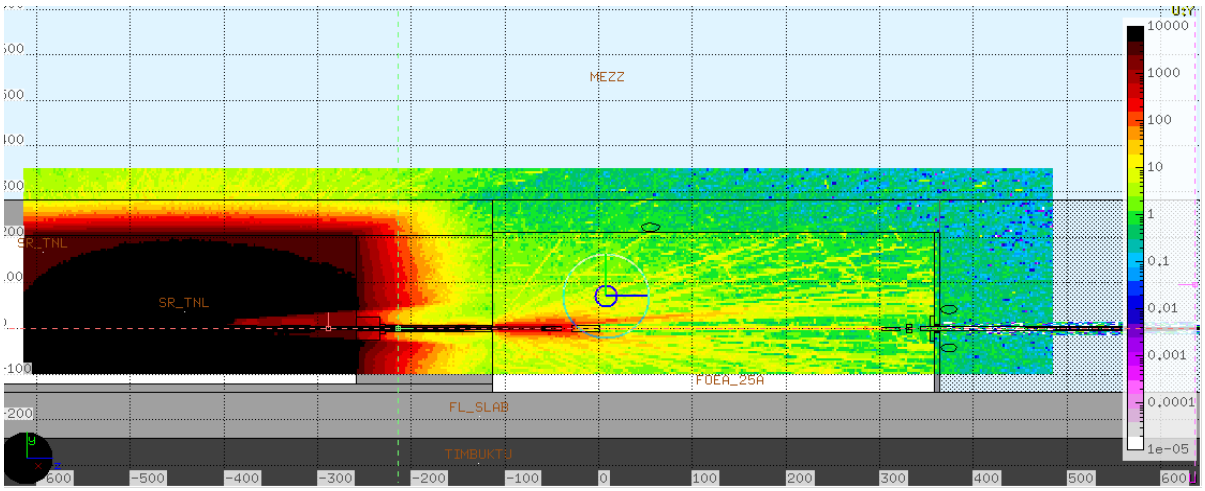


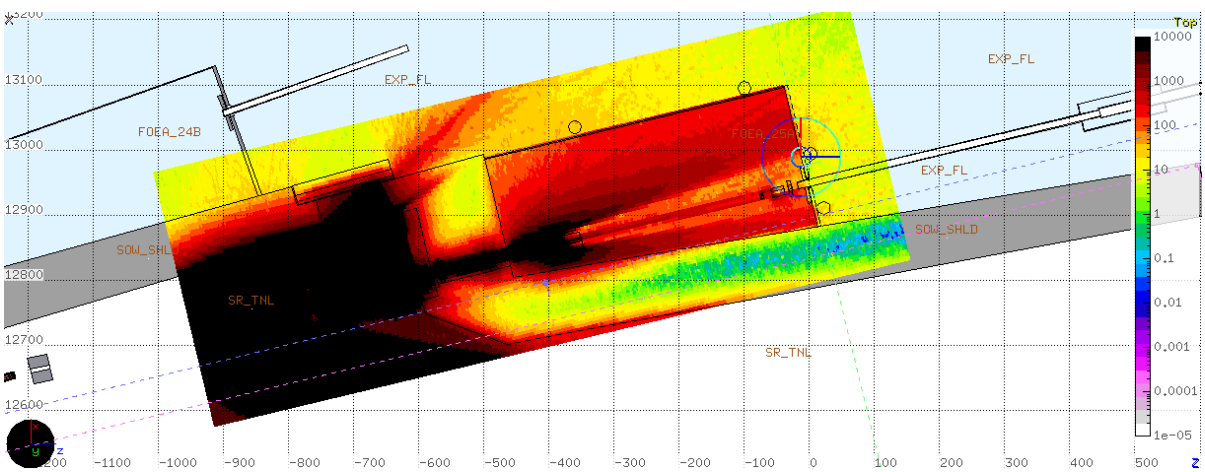
Figure 7: Total dose rate distributions (mrem/h). The Top view at y=0 is shown in the top figure and the elevation view in the bottom figure.

These dose rate distributions are very similar to those for case i_i. In both cases, the total dose rates on the FOE walls and roof are below 100 mrem/hr for this fault condition. The maximum dose rates were calculated to be less than 13 mrem/hr at the upstream edge of the sidewall. The dose rates at the downstream wall were less than 8 mrem/hr.

4.3 Case 3: i_o

In this simulation, the injected electron beam was started downstream of the horizontal aperture on the inboard side of the FM1 and directed toward the front face of LCO2 at 5 mm from the outboard side of the horizontal aperture.

Figure 8 shows the dose rate distributions (mrem/h) in the FE and the FOE. The total dose rates on the FOE walls and roof are below 100 mrem/hr for this fault condition. The maximum dose rates at the downstream wall are 70 mrem/hr. For the sidewall, the contact dose rates ranged from 40 mrem/hr near the ratchet wall to less than 10 mrem/hr near the downstream wall. The maximum dose rates on contact at the roof are 50 mrem/hr.



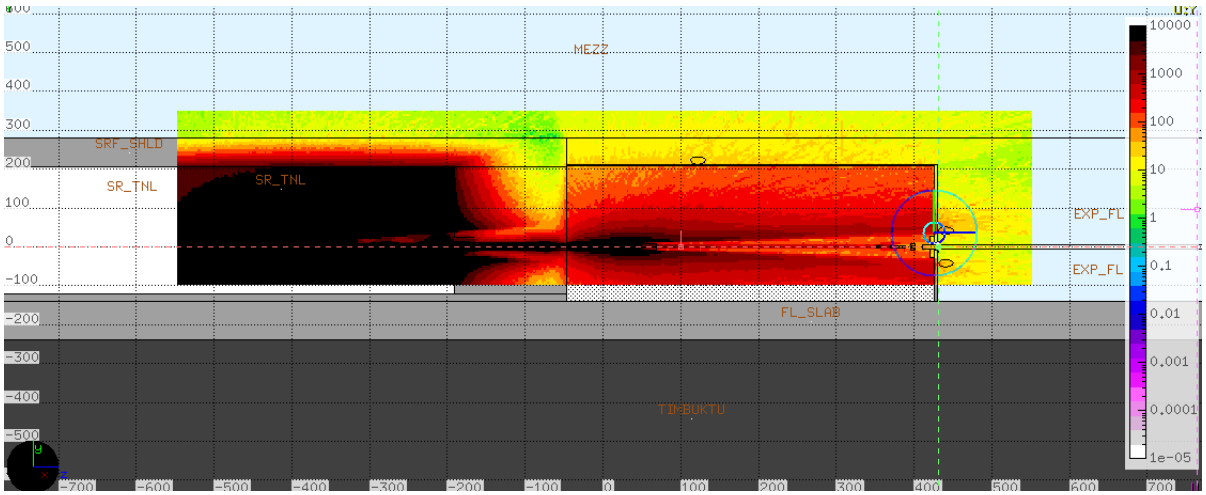
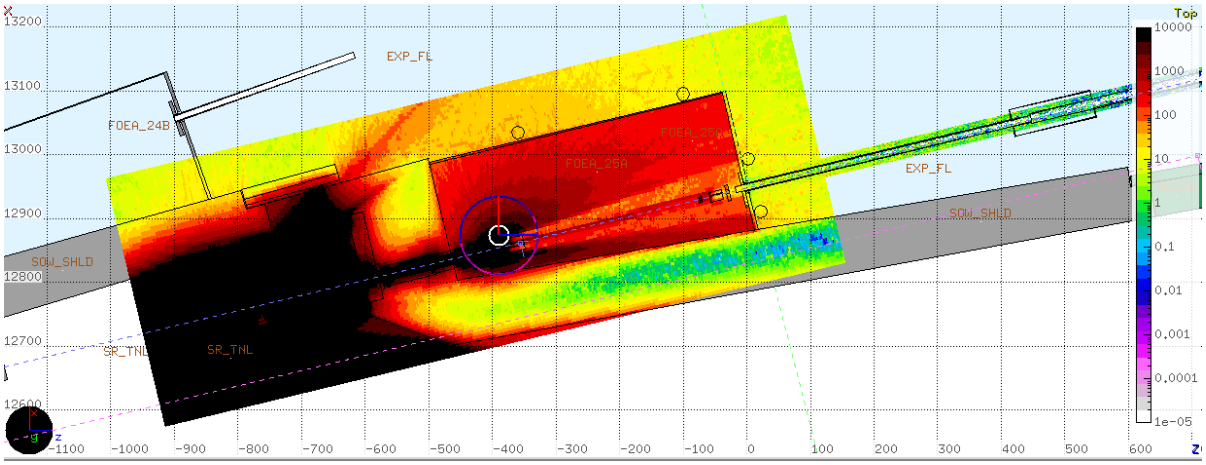


Figure 8: Total dose rate distributions (mrem/h). The elevation view at y=0 is shown in the top figure and the plane view in the bottom figure.

4.4 Case 4: o_i

In this simulation, the injected electron beam was started downstream of the horizontal aperture on the outboard side of the FM1 and directed toward the front face of LCO2 at 5 mm from the inboard side of the horizontal aperture.

The total dose rate distributions are shown in Figure 9. The dose rates reached a maximum value of 80 mrem/hr at the downstream wall. For the sidewall, the contact dose rates started from 60 mrem/hr near the ratchet wall and decreased to less than 15 mrem/hr near the downstream wall. The maximum dose rate on contact with the roof is 50 mrem/hr.



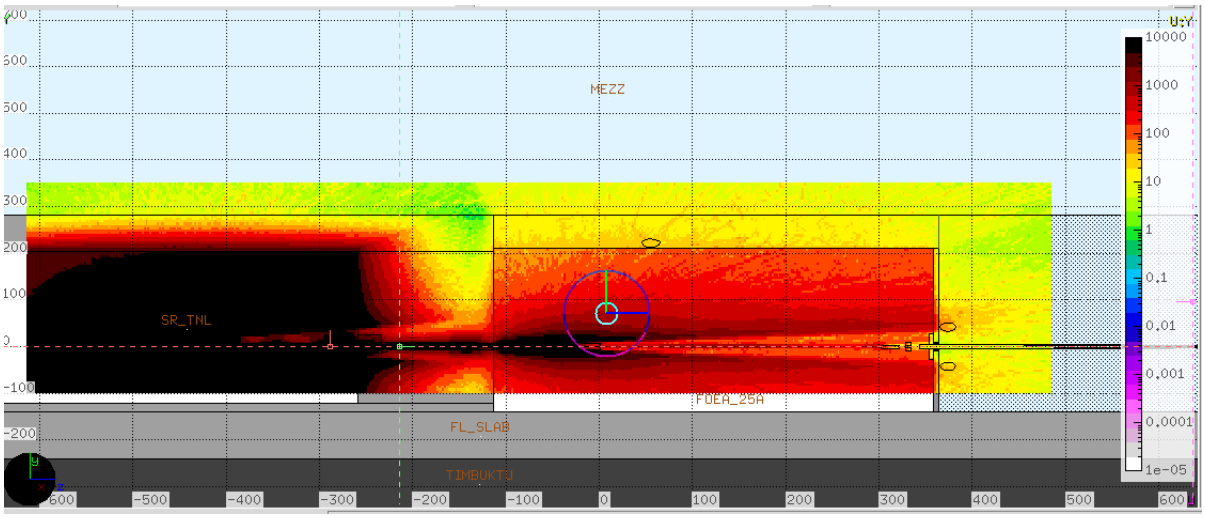


Figure 9: Total dose rate distributions (mrem/h). The elevation view at y=0 is shown in the top figure and the plane view in the bottom figure.

5. Summary and Conclusions

Based on the FLUKA simulations described in subsections 4.1-4.4 of this technical note, none of the cases studied resulted in radiation dose rates at the exterior of the FOE greater than 100 mrem/hr.

The results of the calculations indicate that the FOE shielding of 19ID (NYX) falls within the shielding policy established in ref. 4. The beamline is equipped with an ARM at the ratchet wall plug door, which will turn off the electron beam in the event of a Top-Off accident when the dose rate exceeds 5 mrem/hr, which again is consistent with the shielding policy stated in ref. 4.

6. References

[1] Top-Off Safety Analysis and Requirement of Hazard Mitigation for NSLS-II Facility, PS-RASD-RPT-DRV-001, 2014.

[2] Approval of New and Modified NSLS-II Beamline Front Ends for Top Off Safety, PS-C-ASD-PRC-183, Jan 14, 2015.

[3] Top-Off Safety Analysis for ISR, ISS and SMI Beamlines, PS-C-ASD-TOS-RPT-003, Aug. 17, 2015.

[4] Photon Sciences Shielding Policy, PS-C-ASD-POL-005, March 26, 2014.

7. Acknowledgements:

We would like to thank Douglas Holmes and Chris Amundsen for providing all the beamline geometry information listed in Appendix 1.

Appendix 1

19-ID (NYX) Beamline
Input provided by Douglas Holmes Holmes and Chris Amundsen.

Co-ordinate system

The NYX beam centerline is used as the z or beamline axis for the following tabulated data, with positions from the center of straight. 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 19-ID-A Ratchet Wall	2568.8 cm		
D/S End of FOE (19-ID-A) Backwall (outside)	3046.5 cm	5.0 cm	Lead
Distance of FOE Outboard Sidewall (outside) from NYX CENTERLINE	156.0 cm	1.8 cm	Lead
Distance of FOE Inboard Sidewall from NYX CENTERLINE	Ratchet Wall		
Distance of FOE Roof (Inside) from NYX CENTERLINE	209.0 cm	1.0 cm	Lead
Distance of FOE Floor from NYX CENTERLINE	140.0 cm		
U/S End of C hutch (19-ID-C) Wall (outside)	4728.0 cm	1.8 cm	Lead
D/S End of C hutch (19-ID-C) Wall (outside)	5728.0 cm	5.0 cm	Lead
Distance of C hutch outboard Sidewall (outside)from NYX CENTERLINE	225.0 cm	1.8 cm	Lead
Distance of C hutch inboard Sidewall (outside)from NYX CENTERLINE	100.0 cm	1.8 cm	Lead
Distance of C hutch Roof (Inside) from NYX CENTERLINE	209.0 cm	1.0 cm	lead
U/S End of D hutch (19-ID-D) Wall (inside)	5728.0 cm	6mm	Steel
D/S End of D hutch (19-ID-D) Wall (outside)	6228.0 cm	6mm	Steel
Distance of D hutch outboard Sidewall (outside)from NYX CENTERLINE	225.0 cm	6mm	Steel
Distance of D hutch inboard Sidewall (outside)from NYX CENTERLINE	200.0 cm	6mm	Steel
Distance of D hutch Roof (Inside) from NYX CENTERLINE	206.0 cm	6mm	Steel

Table 1.2: Beamline Transport Pipes :

Transport Pipe between FOE & C hutch (from Z Position 3046.5cm to 3505.7cm)	ID= 3.83 OD=4.00 inches Material: Stainless Steel	Shielding Thickness 7.0mm Shielding Material: Lead	Coincident with Z axis

Transport Pipes between FOE & C-Hutch (from Z Position 3505.7cm to 4728.0cm)	ID= 5.76 OD=6.00 inches Material: Stainless Steel	Shielding Thickness 7.0mm Shielding Material: Lead	Coincident with Z axis

Table 1.3: NYX A Hutch Beamline Components and SGB shield.

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

The NYX beam centerline is used as the z or beamline axis for the following tabulated data, with positions from the center of straight. Y is the vertical axis and x the horizontal axis orthogonal to the y and z axes.

Components	Z = Distance from center of straight	Dimensions (specify units)		Offset (vertical/ horizontal w.r.t NYX CENTERLINE & Rotation	Material	Associated Drawings
		Outer dimensions (W)x(H)x(L)	Aperture (W)x(H) or (R)			
Poly Shield (SGB)	US: 2619.9 cm	7.62cm (x) (+16.16cm +23.78cm) (x) 28.48cm (y) (+16.0cm - 12.48cm) (Y) 58.96cm (z)	N/A	No aperture shield center: +19.97cm (X) 1.76cm (Y) wrt NYX Centerline	polyethylene	1453-00301
Dual Aperture NYX/LAX Fixed Mask DS of ratchet wall	US: 2622.39 cm	10.8cm (x) (-7.76cm +3.04cm) (x) 8.50cm (y) 20.00cm (z)	Two tapered apertures US:3.0cm(x),3.0cm(y) DS:0.43cm(x)0.22cm(y) Z=2639.9 Aperture Taper angle wrt NYX Centerline Horizontal: 4.05^{o}	NYX aperture 0.00 (X) 0.00 (Y) wrt NYX Centerline LAX aperture -5.17 (X)	Glidcop (Copper)	1453-00064

			Aperture Taper angle wrt NYX Centerline Vertical: 4.4^{o}	0.00 (Y) wrt NYX Centerline Glidcop block -2.36 (X) 0.00 (Y) wrt NYX Centerline		
Bremsstrahlung Collimator 1 (Dual aperture)	US: 2654.0 cm	23.0 cm (x) (-13.42cm +9.58cm) (x) 15.0 cm (y) 30.0 cm (z)	Double aperture 0.9 cm (round)(ss) 1.2 cm (round)(lead)	NYX Aperture Center: +0.028cm (X) 0.00cm (Y) wrt NYX Centerline LAX Aperture Center: -5.257cm (X) 0.00cm (Y) wrt NYX Centerline Lead Block Center: -1.92cm(X) 0.00cm (Y) wrt NYX Centerline	Lead	1453-00064
LAX White Beam stop and NYX aperture	US: 2967.05 cm	9.0cm diameter 4.0cm (z) centered at -2.62cm (x) 0.0cm (y)	One tapered aperture (NYX) US:2.05cm(x), 11.5cm(y) DS:0.50cm(x), 0.30cm(y) Z=2970.05	NYX Aperture Center: +0.000cm (X) wrt NYX Centerline LAX Beamstop Center:	Copper	1453-00064

			Aperture Taper angle wrt NYX Centerline Horizontal: 14.5^{o} Aperture Taper angle wrt NYX Centerline Vertical: 8.05^{o} One tapered Beamstop (LAX) US:1.90cm(x), 1.15cm(y) DS:0.50cm(x), 0.30cm(y) Z=2971.05 Beamstop sidewall Taper angle wrt NYX Centerline Horizontal: 10.0 Beamstop Bottom face Taper angle wrt NYX Centerline Vertical: 17.8^{o} Beamstop Top face Taper angle wrt NYX Centerline Vertical: 6.2^{o}	US: -5.827cm (X) 0.00cm (Y) wrt NYX Centerline DS: -5.827cm (X) +.859cm(Y) wrt NYX Centerline Copper cylinder Center: -2.62cm(X) 0.00cm (Y) wrt NYX Centerline		
Bremsstrahlung Collimator 2 (Single aperture)	US: 2985.0 cm	15.1 cm (x) (-9.65cm +5.45 cm) (x) 6.85 cm (y) 20.0 cm (z)	Single aperture 0.82 cm (x) 0.58 cm (y)	Aperture Center: +0.0085cm (X) 0.00cm (Y) wrt NYX Centerline Lead Block Center: -2.1cm(X)	Tungsten	1453-00064

				0.00cm(Y) wrt NYX Centerline		
SGB01 shield	US : 3011.6cm	25.2 cm (x) 17.0 cm (y) 5 cm (z)	6.4cm aperture (diameter)	Aperture Center: 0.00cm (X) 0.00cm (Y) wrt NYX Centerline Lead Block Center: -2.1cm (X) 0.00cm (Y) wrt NYX Centerline	lead	1453-00064

Table 1.4: NYX C Hutch Beamline Components and SGB shield.

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

The NYX beam centerline is used as the z or beamline axis for the following tabulated data, with positions from the center of straight. Y is the vertical axis and x the horizontal axis orthogonal to the y and z axes.

Components	Z = Distance from center of straight	Dimensions (specify units)		Offset (vertical/ horizontal w.r.t NYX CENTERLINE & Rotation	Material	Associated Drawings
		Outer dimensions (W)x(H)x(L)	Aperture (W)x(H) or (R)			
Poly Shield (SGB)	US 5063.2 cm	7.62cm (x) (-15.24cm - 22.86cm) (x) 28.16cm (y)		No aperture shield center: +19.05cm (X) 2.07cm (Y) wrt NYX	polyethy lene	1453-00302

		(+16.3cm - 12.16cm) (Y) 58.96cm (z)		Centerline		
Single Aperture NYX Movable Mask	US 5064.5 cm	11.0cm (x) 11.0cm (y) 15.0cm (z)	US:6.5cm(x) (-2.7cm +3.8cm)(x) ,3.47cm(y) DS:0.80cm(x),0.40cm(y), Z=5078.3 Aperture Taper angle wrt NYX Centerline Horizontal: 13.84^{o} INBD 9.46^{o} OUTBD Aperture Taper angle wrt NYX Centerline Vertical: 6.37^{o}	NYX aperture (US) +0.55 (X) 0.00 (Y) wrt NYX Centerline NYX aperture (DS) 0.00 (X) 0.00 (Y) wrt NYX Centerline Glidcop block 0.00 (X) 0.00 (Y) wrt NYX Centerline	Glidcop (Copper)	1453-00074
Bremsstrahlung Collimator 3 (Single aperture)	US 5100.0 cm	23.5 cm (x) (-9.5cm +14.0cm) (x) 15.6 cm (y) 30.0 cm (z)	Single aperture 1.7 cm (round)(ss) 2.0 cm (round)(lead)	NYX Aperture Center: +0.00cm (X) 0.00cm (Y) wrt NYX Centerline Lead Block Center: +2.25cm(X) 0.00cm (Y) wrt NYX Centerline	Lead	1453-00074

Vertical Slit#1	US 5146.5cm US : 5147.7cm	3.2 cm (x) 4.6 cm (y) 1.2 cm (z) 3.2 cm (x) 4.6 cm (y) 0.2 cm (z)	No aperture No aperture	0.00cm (X) 0.00cm (Y) wrt NYX Centerline 0.00cm (X) 0.00cm (Y) wrt NYX Centerline	Cu W	ASM0187
Vertical Slit#2	US : 5153.5cm US : 5154.7cm	3.2 cm (x) 4.6 cm (y) 1.2 cm (z) 3.2 cm (x) 4.6 cm (y) 0.2 cm (z)	No aperture No aperture	0.00cm (X) 0.00cm (Y) wrt NYX Centerline 0.00cm (X) 0.00cm (Y) wrt NYX Centerline	Cu W	ASM0187
Filter#1	US : 5171.5cm	4.5 cm (x) 8.9 cm (y) 1.1 cm (z)	0.8 cm (x) 0.4 cm (y)	0.00cm (X) 0.00cm (Y) wrt NYX Centerline	Cu	ASM0080
Filter#2	US : 5178.2cm	4.5 cm (x) 8.9 cm (y) 1.1 cm (z)	0.8 cm (x) 0.4 cm (y)	0.00cm (X) 0.00cm (Y) wrt NYX Centerline	Cu	ASM0080
Diamond Screen Aperture	US : 5191.9cm	5.0 cm (x) 4.0 cm (y) 1.7 cm (z)	1.47 cm (x) 0.5 cm (y)	0.00cm (X) 0.00cm (Y) wrt NYX Centerline	Cu	AQM0097
SGB02 shield	US : 5201.8cm	20.6 cm (x) 20.6 cm (y) 9 cm (z)	3.4cm aperture (diameter)	Aperture Center: 0.00cm (X) 0.00cm (Y) wrt NYX Centerline Lead Block Center: 0.0cm (X) 0.00cm (Y) wrt NYX Centerline	lead	1453-00074
Silicon DCM 1st Crystal (tangential)	Center: 5269.7cm	4.0 cm (x) 0.6 cm (y) 6.5 cm (z)	No Aperture	0.00cm (X) -0.3cm (Y) wrt NYX Centerline Bragg Angle Rotaion	Si	ADM0203

				-14.98 degrees (about X axis)		
Silicon DCM 2nd Crystal (sagittal)	Center: 5279.0cm	4.0 cm (x) 0.6 cm (y) 6.5 cm (z)	No Aperture	0.00cm (X) +3.3cm (Y) wrt NYX Centerline Bragg Angle Rotaion -14.98 degrees (about X axis)	Si	AHD4515
Bremsstrahlung Collimator 4 (Single aperture)	US: 5359.4 cm	7.5 cm (x) 6.5 cm (y) (-3.7cm to +4.8cm) (y) 20.0 cm (z)	Single aperture 1.2 cm (x) 1.2 cm (y) square	Aperture Center: 0.0cm (X) +3.0cm (Y) wrt NYX Centerline W Block Center: 0.00cm(X) +0.55cm(Y) wrt NYX Centerline	Tungsten	1453-00064
SGB04 shield	US : 5359.4cm	7.5 cm (x) 3.5 cm (y) (+4.8cm to +8.3cm) (y) 6 cm (z)	No Aperture	N/A	tungsten	1453-00064
Photon Shutter	5686.8cm to center	See shutter spec.	See shutter spec.	Aperture Center: 0.00 cm (X) +4.00cm (Y) wrt NYX Centerline	Cu and W	PD-COM-PSH-1000 S/N 14001-017

Table 1.5: 19 ID NYX FOE components

Front End	Z location (m) (Distance	Dimensions	Offset (vertical or horizontal)		Associated

Component	from Source Point) (U), (D) or center (C)	Outer dimensions (W),(H),(L)	Collimator or Mask Apertures, mm (W)x(H) or (R)	From beam centerline	Material	Drawings
Fixed Mask FM	17518.10 mm (U)	111.31 mm(W) x 82.55 mm (H) x 374.65 mm (L)	Inboard US: 32.43 mm (W) x 33.60 mm (H) Cen to Cen: -17.60 horz Inboard DS 8.14 mm (W) x 5.41 mm (H) Cen to Cen: 17.91 horz Inboard angle 2.02 degrees Outboard US 35.30 (W) x 33.60 mm (H) Cen to Cen: 17.65 horz Outboard DS 9.50 mm (W) x 5.41 mm (H) Cen to Cen: 16.66 horz Outboard angle 2.16 degrees	None	Glidcop Al-15	SR-FE-MSK-3906
Lead collimator LC01	18141.21 mm (U)	406.40 mm (W) x 101.60 mm (H) x 304.80 (L)	63.00 mm (W) x 23.00 mm (H)	None	Lead	SR-FE-CO-3820

Photon Shutter PSH	21505.98 mm (U)	107.95 mm (W) x 82.55 (H) x 254.00 (L)	Upstream 66.68 mm (W) x 37.46 mm (H) Downstream 66.68 mm (W) x 22.70 mm (H) Angle 3.50 degrees	Cen of downstream vert aperture is centered on beam in open position. Cen of downstream vert aperture is -19.05 mm in closed position	Glidcop Al-15	SR-FE-PSH-2701
Lead collimator LC02	22285.03 mm (U)	457.20mm (W) x 127.00mm (H) x 304.80mm (L)	79.20 mm (W) x 28.40 (H)	Cen of lead is -25.4 mm horiz from cen of aperture	Lead	SR-FE-CO-3800
Safety Shutter SS1	22868.84 mm (U)	177.80(W) x 165.10 (H) x 304.80mm(L)	Stainless steel tube aperture 94.00 mm (W) x 34.00 mm (H)	Cen of vert aperture is centered on beam in open position. Cen of vert aperture is -83.0 mm in closed position	Lead	SR-FE-3PW-SS-4000