18-ID (FXI) TOP-OFF RADIATION SAFETY ANALYSIS

APPROVALS

9/29/2017

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1. Introduction

The primary radiological safety concern for Top-Off injection, with the Front End (FE) safety shutters (SS) 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 primary electrons will scatter off the FE components resulting in secondary radiation, which will further scatter off components in the First Optical Enclosure (FOE), thereby leading to potentially high dose rates on the FOE wall.

The radiological consequences of this fault condition for the 18-ID-FXI beamline is analyzed and discussed in this report. For this beamline, all FE components downstream of the fixed mask (FM) with the ratchet wall collimators and many FOE components, lie along the long straight centerline.

The layout of the 18-ID (FXI) FE components is presented in Figure 1. One ARM is located near the sliding door of the FE and another one on the downstream wall of the FOE.

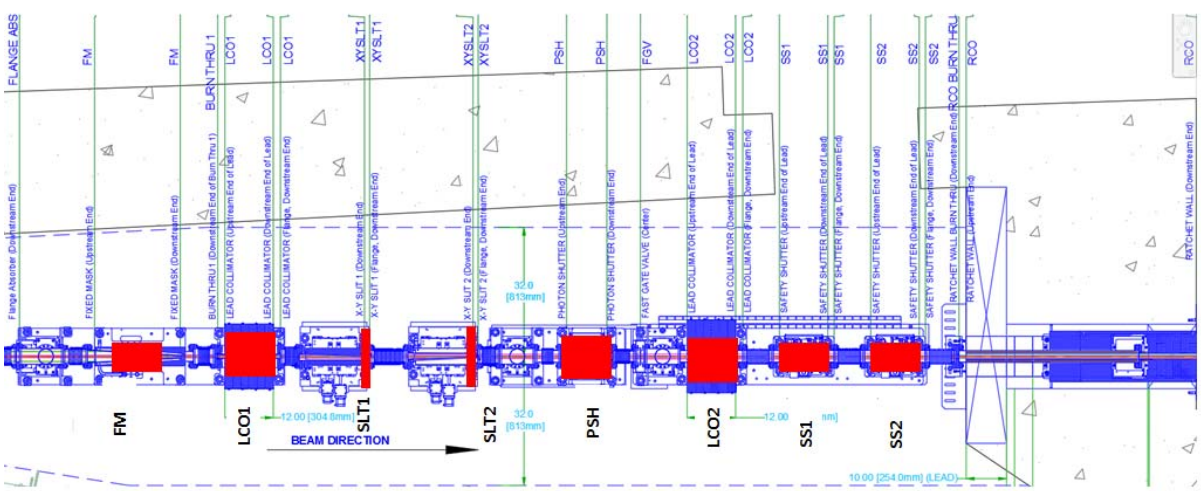

Figure 1: Layout of 18-ID (FXI) FE showing major components. The beam travels from left to right in this figure.

The Top-Off backward particle tracking analysis applicable for 18-ID (FXI) is discussed in Section 2, the FLUKA model and results are described in Section 3 and summary and conclusions are given in Section 4.

This report shows that Top-Off Operation of the 18-ID (FXI) beamline is consistent with the NSLS-II Shielding Policy [1], provided that the FE, beamline, shielding and ARM configurations are not changed.

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. Backward particle tracking that was carried out earlier for 28-ID-XPD [3] covers the FXI beamline also, as the FXI beamline has a smaller aperture (26.62 mrad compared to the 36.00 mrad for the XPD beamline). Because of this, no independent tracking is necessary (Appendix 1) for the FXI beamline. To ensure this safe point for 18-ID (FXI), the apertures and tolerances are the same as those called out in the TOSS interlock specification [3]:

- FM, ±2 mm horizontally
- LCO2: ±2 mm horizontally
- Synchrotron Radiation Absorber: ±5 mm horizontally
- S4 vacuum chamber: ±5 mm horizontally

The beam directions in the FLUKA Monte Carlo simulations are configured for this scenario.

3. Description of FLUKA Model

The plan and elevation views of the FLUKA geometry used for the Top-Off simulations of the 18-ID (FXI) beamline are shown in Figures 2 and 3. The geometry is shown as two separate figures for clarity. Figure 2 shows the FE components and Figure 3 shows the FOE and the components inside. The data input used to generate the FLUKA model is listed in Appendix 2. The slit aperture dimensions are taken from the drawings given in Appendix 3.

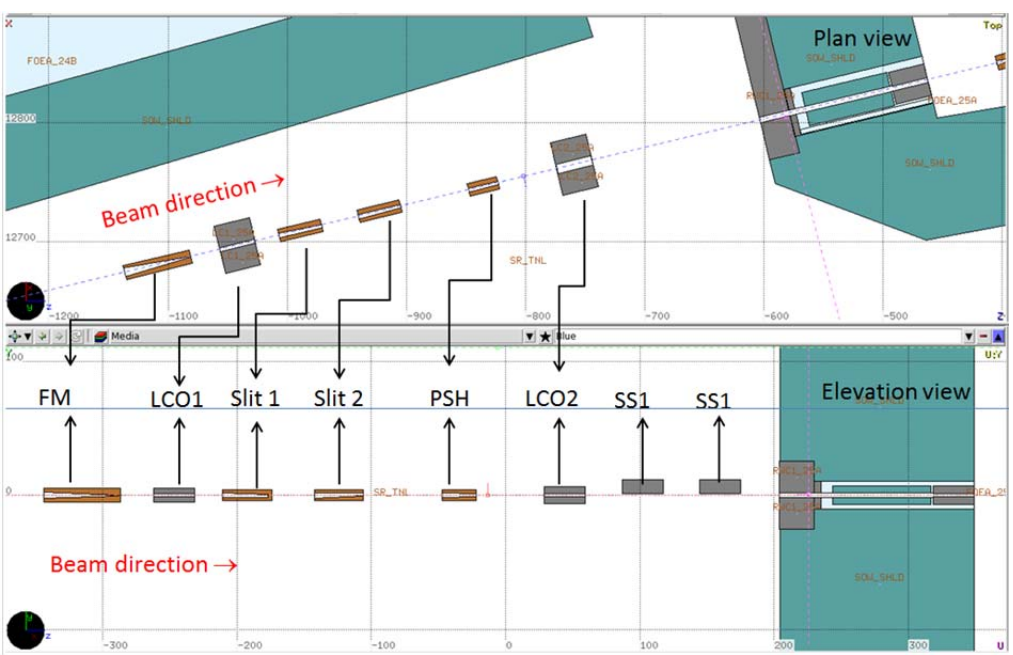

Figure 2: The plan (at Y=0) and elevation view (in line with the ratchet wall collimator aperture) of the FLUKA geometry used in Top-Off simulation of the 18-ID (FXI) beamline. The beam travels from left to right.

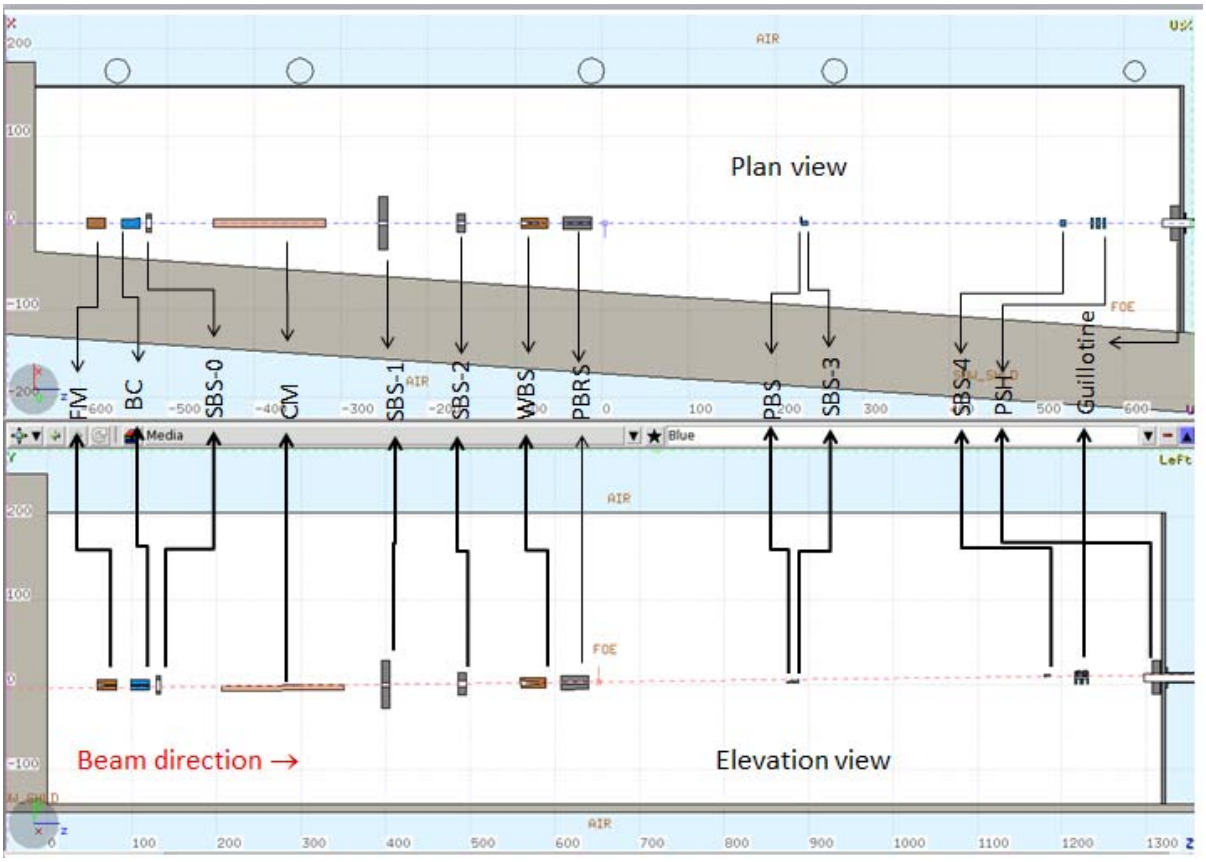

Figure 3: The plan (at Y=0) and the elevation view of the FOE part of the geometry used in Top-Off simulation of the 18-ID (FXI) beamline. The beam travels from left to right.

Based on the discussion in Section 2, the beam is assumed lost at the safe endpoints (2 mm from the upstream aperture edge of LCO2). In all the FLUKA simulations, a pencil beam of 3 GeV electrons is assumed for the injected beam. The results are normalized to a booster to storage ring injection charge rate of 45 nC/min and the total ambient equivalent dose rates are reported in units of mrem/hr.

3.1 Results for Top-Off FLUKA Simulations

Simulations were carried out with and without the lead (Pb) that makes up the secondary bremsstrahlung shields (SBS-0, SBS-1 and SBS-2) in the FOE. For both of these scenarios, the radiation environments were estimated with the FE slits closed and open. The following four scenarios of electron beam interactions were considered in the FLUKA simulation analysis.

1. Injected beam starting at the inboard side of the downstream aperture of FM and directed toward the front face of LCO2 at 2 mm from the inboard side of the aperture (Case 1: i_i).
2. Injected beam starting at the inboard side of the downstream aperture of FM and directed toward the front face of LCO2 at 2 mm from the outboard side of the aperture (Case 2: i_o).

3. Injected beam starting at the outboard side of the downstream aperture of FM and directed toward the front face of LCO2 at 2 mm from the inboard side of the aperture (Case 3: o_i).
4. Injected beam starting at the outboard side of the downstream aperture of FM and directed toward the front face of LCO2 at 2 mm from the outboard side of the aperture (Case 4: o_o).

In total 16 sets of simulations were carried out. The aperture of the FE collimator (LCO2) and the ratchet wall collimator primarily determines the amount of radiation transmitted into the FOE. The results in Figures 4-11 are shown without the lead secondary bremsstrahlung shields (SBS-0, SBS-1 and SBS-2 in the FOE) included the geometry.

3.1.1 Case 1: i_i

In this simulation, the injected electron beam was started downstream of the horizontal aperture on the inboard side of the FM and directed toward the front face of LCO2 at 2 mm from the inboard side of the horizontal aperture. The total ambient equivalent dose rates in the FE and FOE are shown in Figure 4 with the slits withdrawn, and in Figure 5 with the slits inserted.

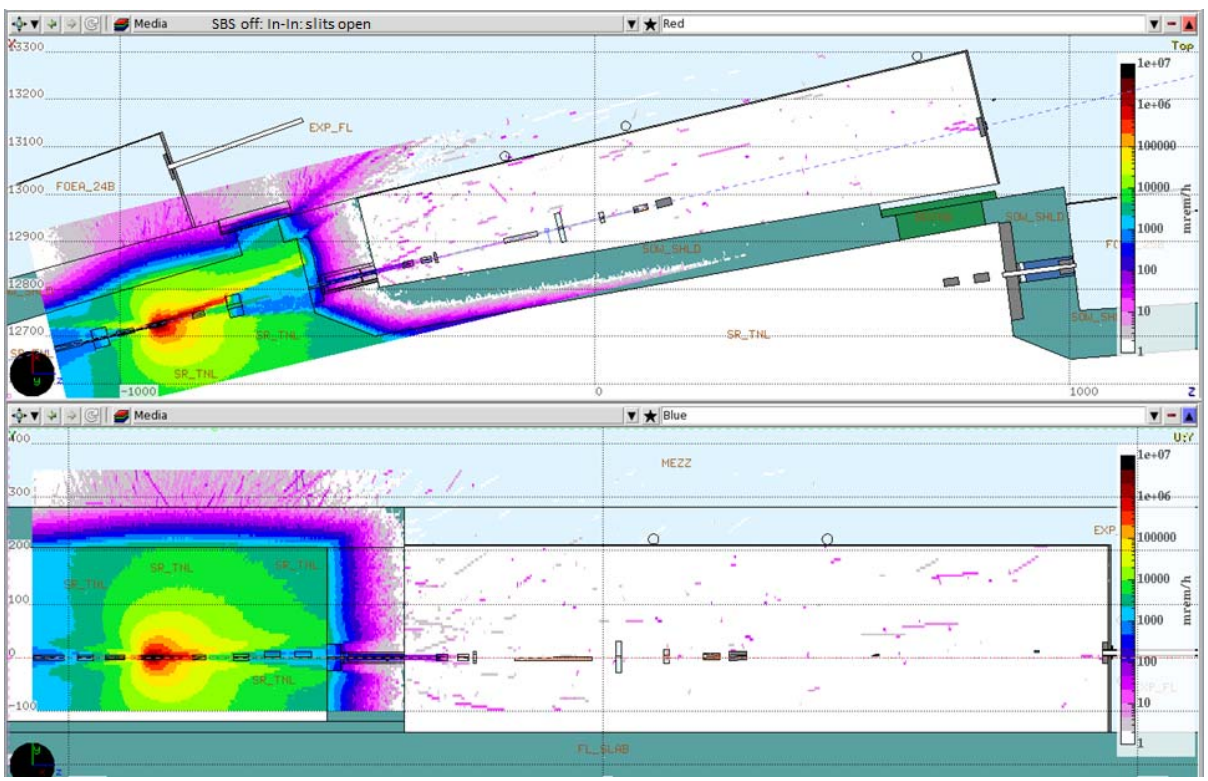

Figure 4: Total ambient equivalent dose rate distributions (mrem/hr) with the slits withdrawn. The plan view (at Y=0) is shown in the top figure and the elevation view (in line with the ratchet wall collimator aperture) in the bottom figure.

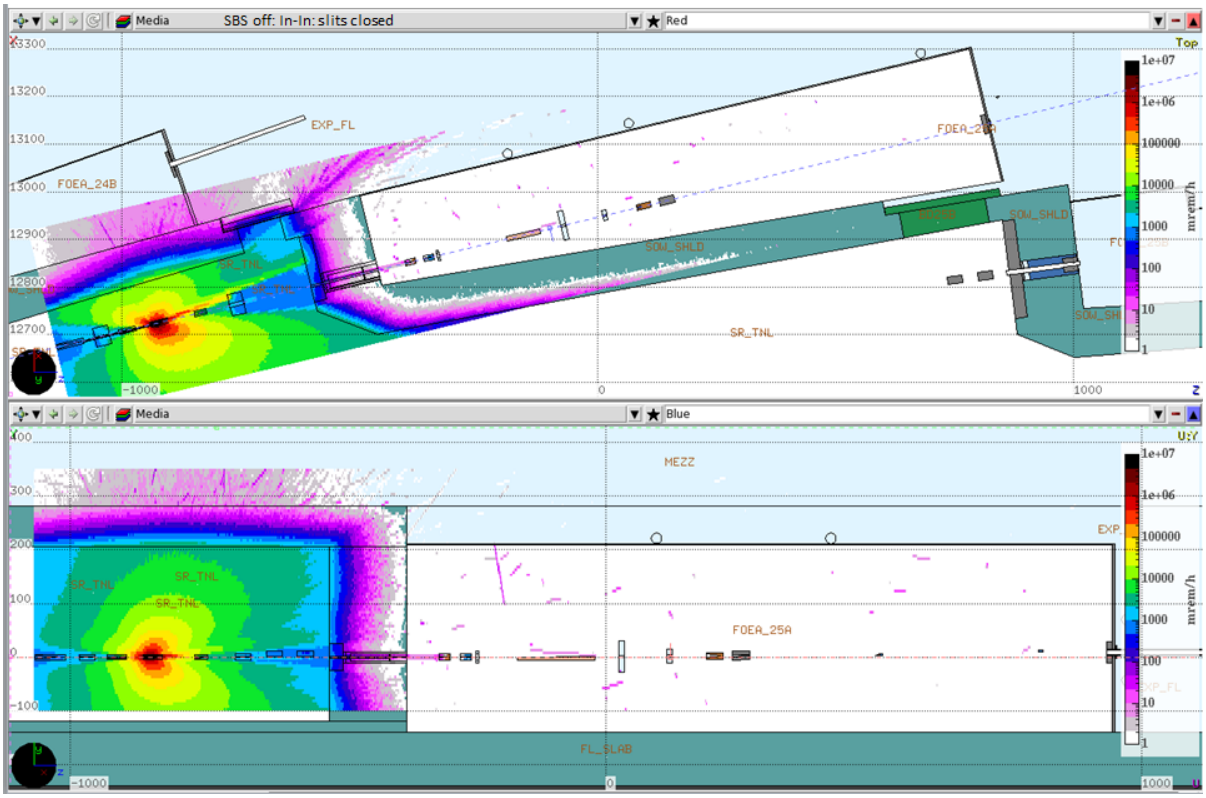

Figure 5: Total ambient equivalent dose rate distributions (mrem/hr) with the slits inserted. The plan view (at Y=0) is shown in the top figure and the elevation view (in line with the ratchet wall collimator aperture) in the bottom figure.

In both cases, the dose rates on contact outside the FOE are found to be less than 10 mrem/hr. On the storage ring door side, the maximum dose rate on contact is estimated to be 100 - 200 mrem/hr when the slits are withdrawn.

3.1.2 Case 2: i_o

Here, the injected electron beam was started downstream of the horizontal aperture on the inboard side of the FM and directed toward the front face of LCO2 at 2 mm from the outboard side of the horizontal aperture. The total ambient equivalent dose rates in the FE and FOE are shown in Figure 6 with the slits withdrawn, and in Figure 7 with the slits inserted.

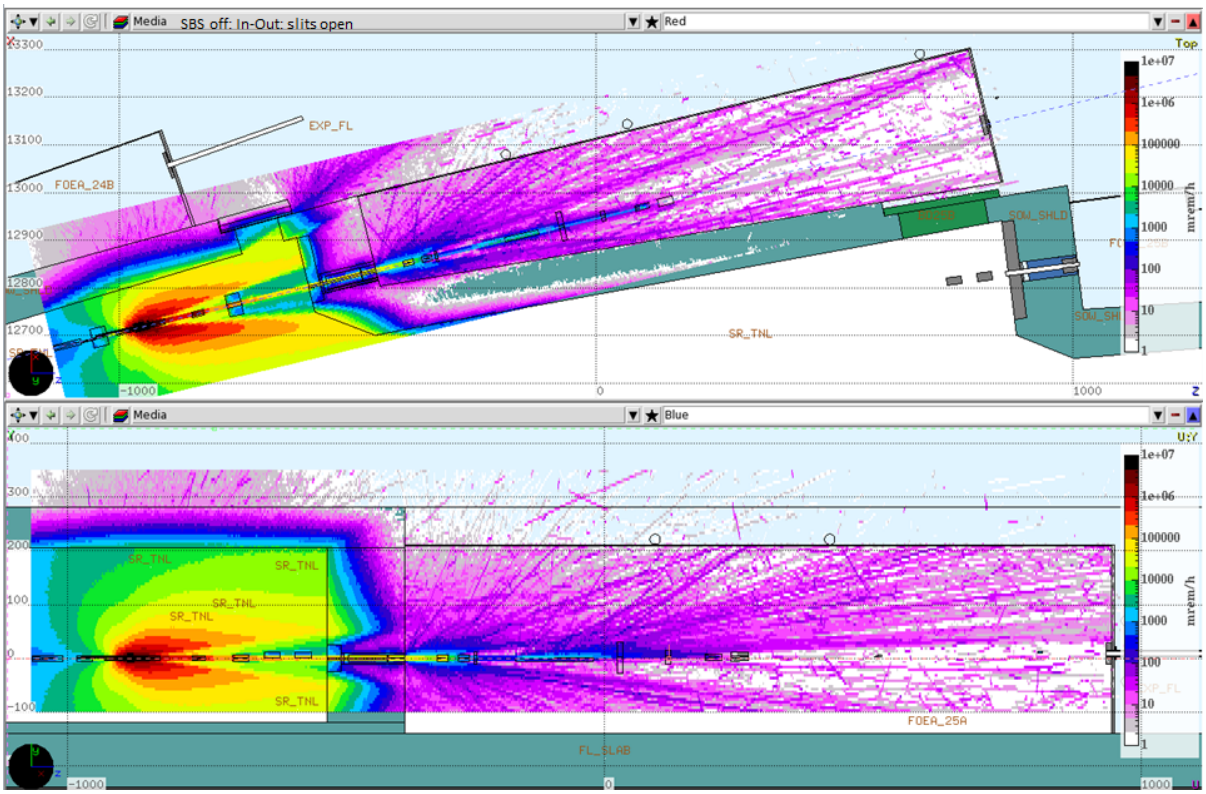

Figure 6: Total ambient equivalent dose rate distributions (mrem/hr) with the slits withdrawn. The plan view (at Y=0) is shown in the top figure and the elevation view (in line with the ratchet wall collimator aperture) in the bottom figure.

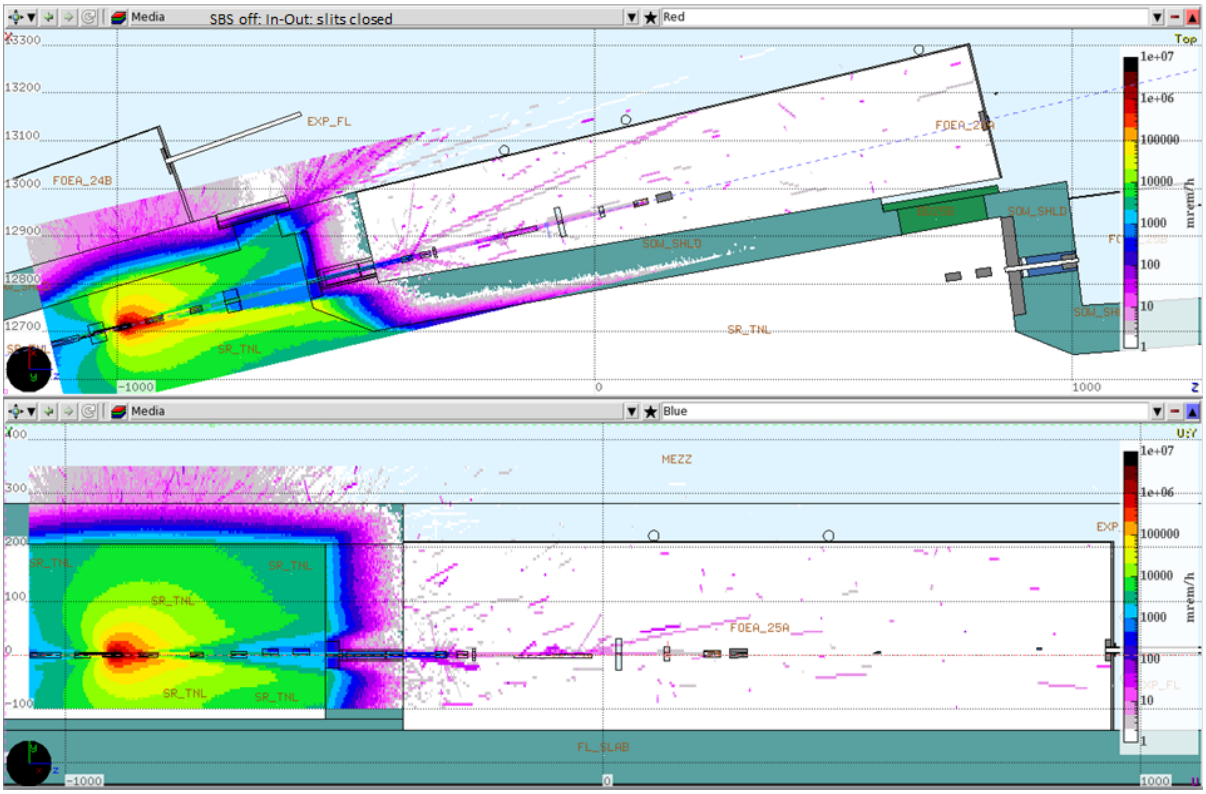

Figure 7: Total ambient equivalent dose rate distributions (mrem/hr) with the slits inserted. The plan view (at Y=0) is shown in the top figure and the elevation view (in line with the ratchet wall collimator aperture) in the bottom figure.

Some part of the shower is seen to leak through the apertures into the FOE when the slits are withdrawn. This then interacts with the FM and the collimating mirror (CM) in the FOE. The dose rates on contact outside the FOE are estimated to be less than 50 mrem/hr. The dose rates outside the storage ring door on contact is estimated to be about 200 mrem/hr when the slits are in the withdrawn position.

3.1.3 Case 2: o_i

In this case, the injected electron beam was started downstream of the horizontal aperture on the outboard side of the FM and directed toward the front face of LCO2 at 2 mm from the inboard side of the horizontal aperture. The total ambient equivalent dose rates in the FE and FOE are shown in Figure 8 with the slits withdrawn, and in Figure 9 with the slits inserted.

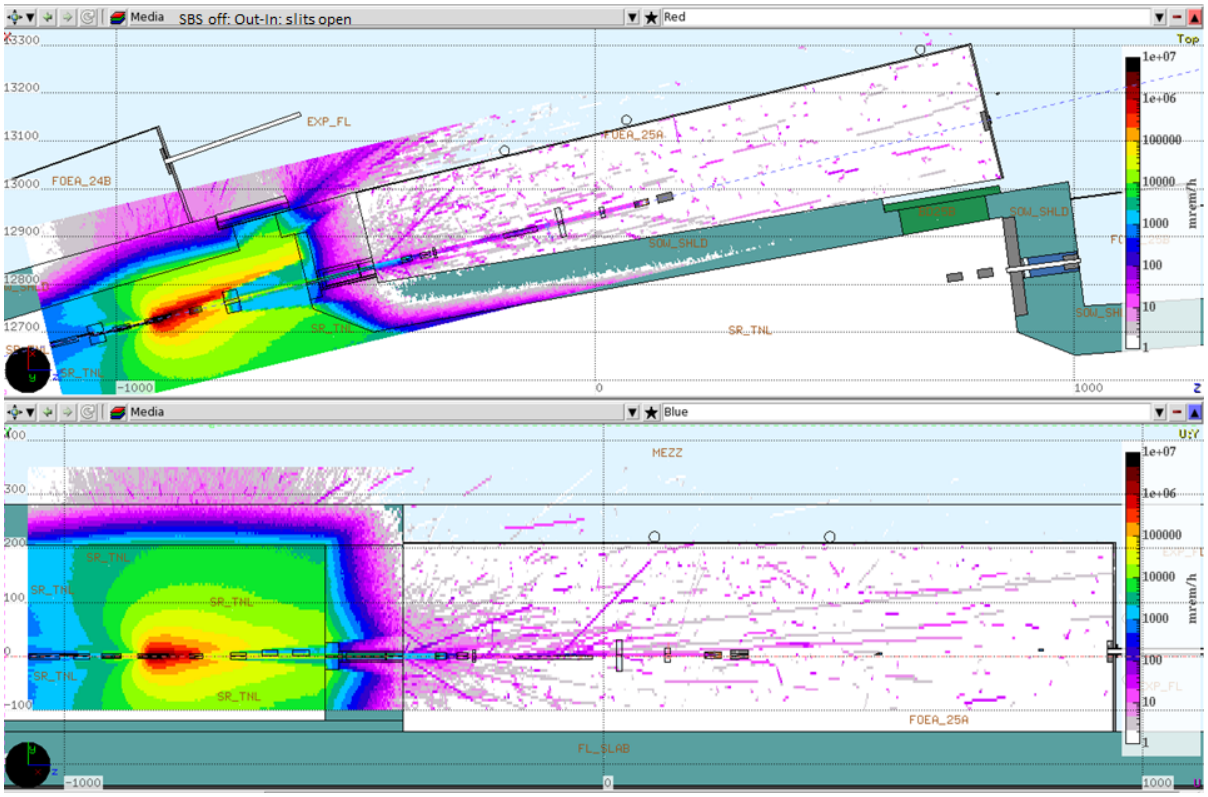

Figure 8. Total ambient equivalent dose rate distributions (mrem/hr) with the slits withdrawn. The plan view (at Y=0) is shown in the top figure and the elevation view (in line with the ratchet wall collimator aperture) in the bottom figure.

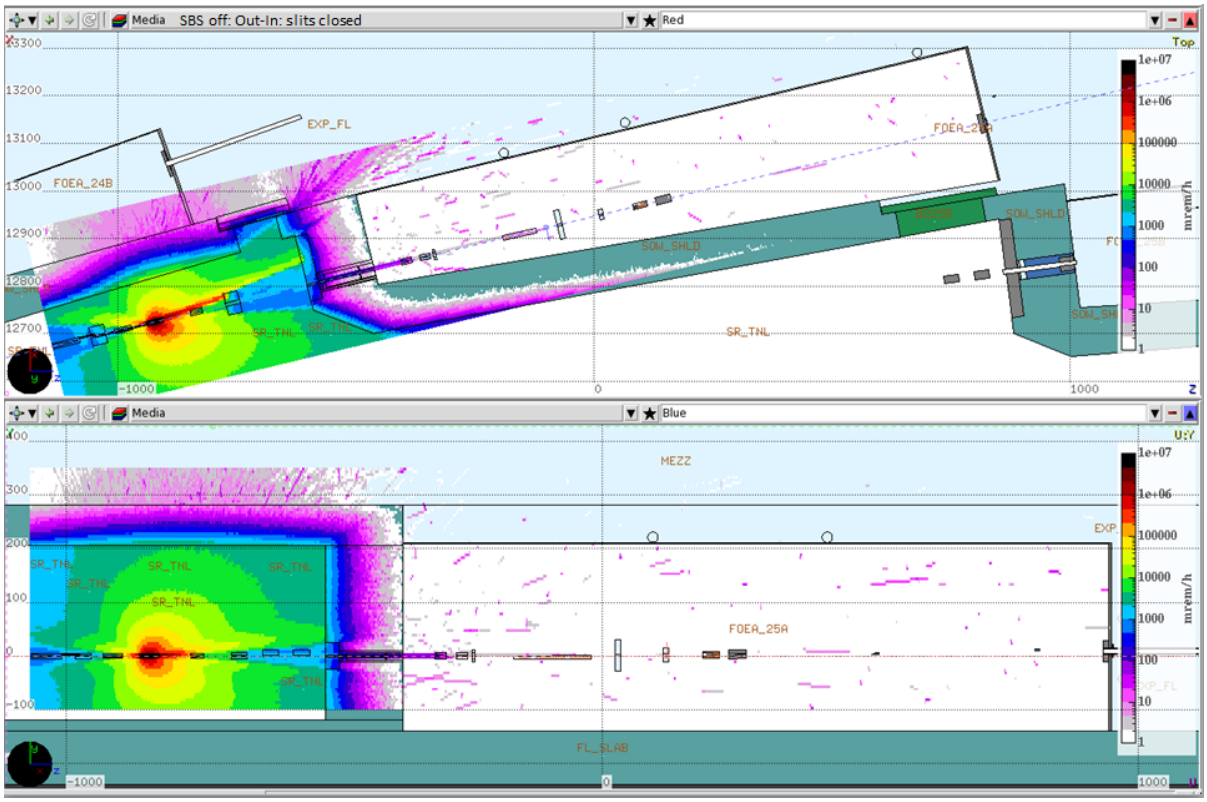

Figure 9: Total ambient equivalent dose rate distributions (mrem/hr) with the slits inserted. The plan view (at Y=0) is shown in the top figure and the elevation view (in line with the ratchet wall collimator aperture) in the bottom figure.

In both cases, the total ambient equivalent dose rates outside the FOE on contact are estimated to be less than 10 mrem/hr. The dose rates on contact outside the storage ring door is estimated to be 300-400 mrem/hr when the slits are withdrawn and about 100-200 mrem/hr when the slits are inserted.

3.1.4 Case 2: o_o

In this case, the injected electron beam was started downstream of the horizontal aperture on the outboard side of the FM and directed toward the front face of LCO2 at 2 mm from the outboard side of the horizontal aperture. The total ambient equivalent dose rates in the FE and FOE are shown in Figure 10 with the slits withdrawn, and in Figure 11 with the slits inserted.

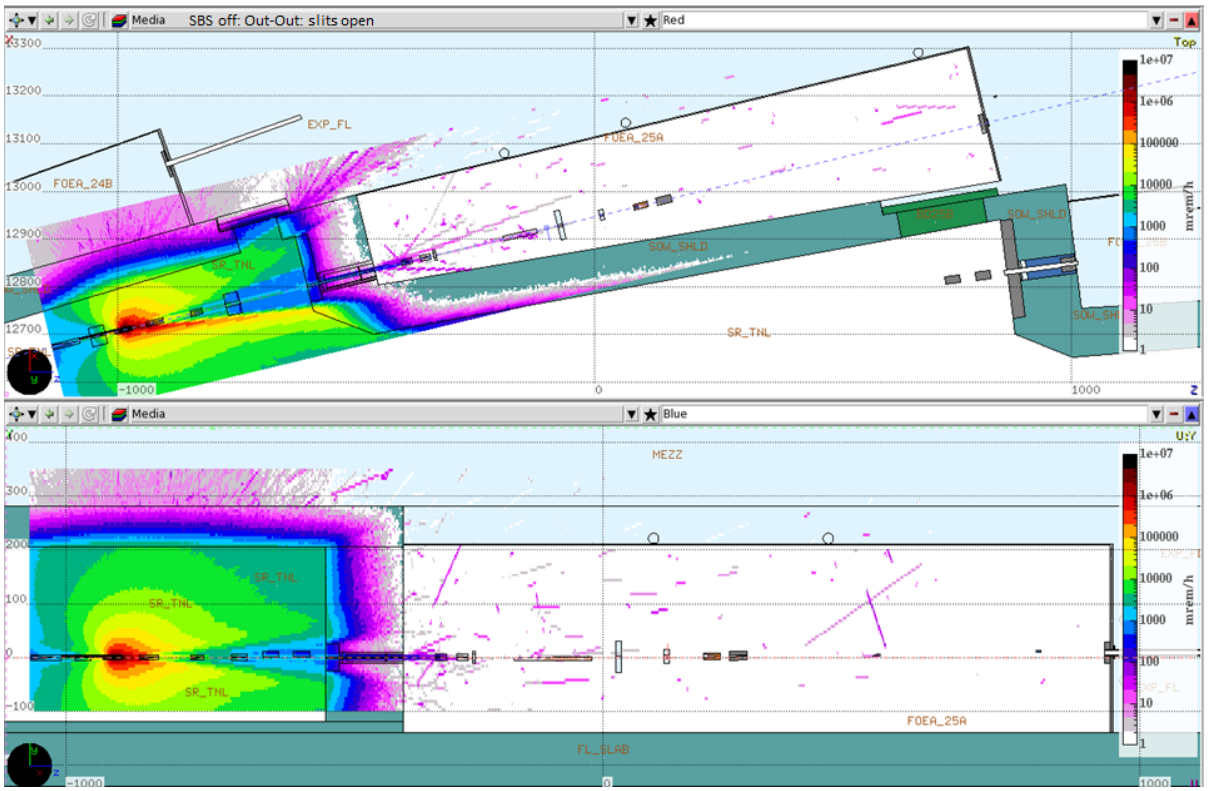

Figure 10. Total ambient equivalent dose rate distributions (mrem/hr) with the slits withdrawn. The plan view (at Y=0) is shown in the top figure and the elevation view (in line with the ratchet wall collimator aperture) in the bottom figure.

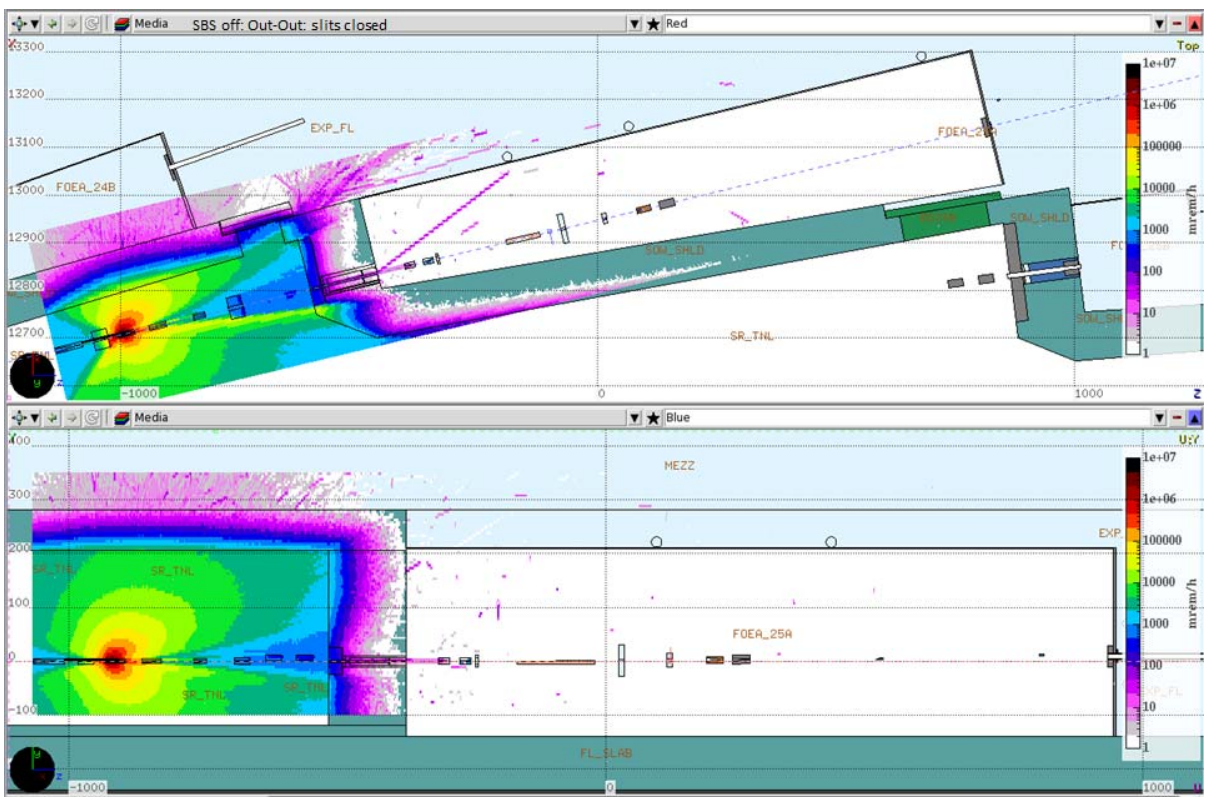

Figure 11: Total ambient equivalent dose rate distributions (mrem/hr) with the slits inserted. The plan view (at Y=0) is shown in the top figure and the elevation view (in line with the ratchet wall collimator aperture) in the bottom figure.

The dose rates outside the FOE are expected to be less than 10 mrem/hr when the slits are inserted and withdrawn. The dose rates outside the storage ring door are expected to be less than 100 mrem/hr for both scenarios for this beam condition.

3.1.5 Area Radiation Monitor

An area radiation monitor (ARM) is located next to the door of the storage ring and this is also modeled in the simulations here (Figure 12).

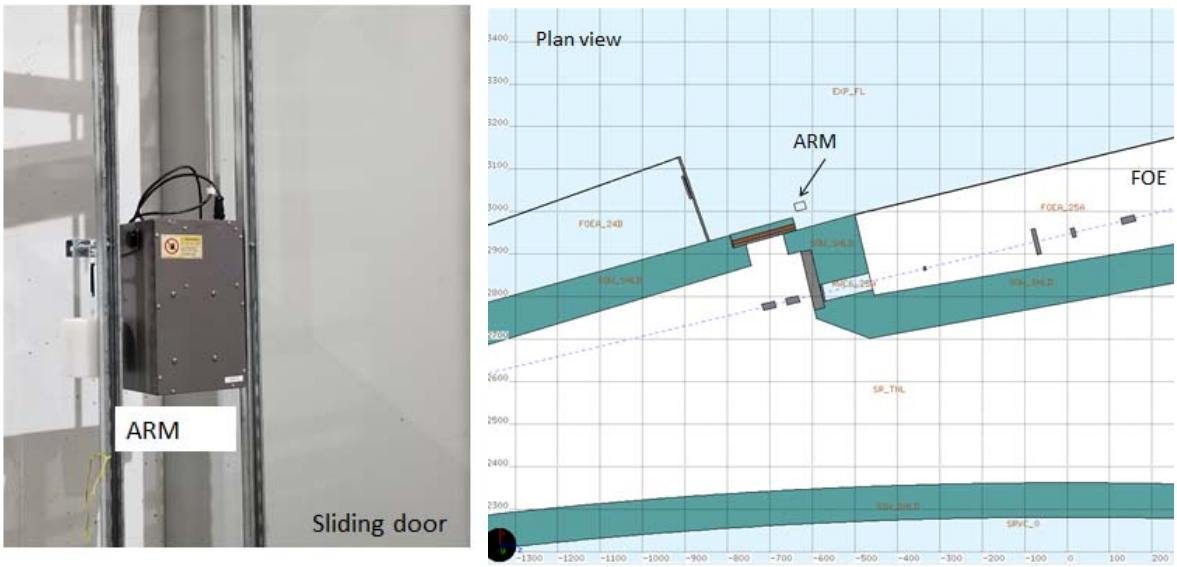

Figure 12: The photograph of the installed ARM (left) and the plan view of the FLUKA geometry showing the location of the ARM (right).

The dose rates as estimated by the detector in the simulations are given in the Table 1. The uncertainties reported are statistical in nature.

Table 1: The Total Ambient Equivalent Dose Rates Estimated at the ARM Location

Beam conditions	Dose rates (mrem/hr)	
	Slits withdrawn	Slits inserted
Case 1 (i_i)	10.0 ± 0.9	6.5 ± 0.7
Case 2 (i_o)	23.1 ± 1.8	7.2 ± 1.1
Case 3 (o_i)	21.1 ± 1.5	8.2 ±0.7
Case 4 (o_o)	5.2 ± 0.6	6.3 ± 0.7

In case of a Top-Off accident, the dose rates estimated by the ARM in this simulation exceeds the 5 mrem/hr set point, at which point it will turn off the electron beam consistent with the NSLS-II Shielding Policy.

4. Summary and Conclusions

The Top-Off radiation safety analysis of the 18-ID (FXI) beamline has been carried out using the FLUKA Monte Carlo radiation transport code. Based on the results obtained, the radiation dose rates at the exterior of the FOE are estimated to be less than 50 mrem/hr for all of the cases studied here. The lead secondary bremsstrahlung shields (SBS-0, SBS-1 and SBS-2) in the FOE do not play any role in the dose rates observed outside the FOE, as far as the Top-Off conditions are concerned. In all the cases, the highest dose rates observed are not from radiation penetrating the FOE walls from within the FOE, but what penetrates the plug door in the ratchet wall upstream of the FOE.

The results of the calculations indicate that the FOE shielding of 18-ID (FXI) falls within the NSLS-II Shielding Policy [1], with the ARM identified as a single credited control for the case when the dose potential exceeds 100 mrem/hr. The ARM located at the ratchet wall sliding door will turn off the electron beam in the event of a Top-Off accident, when the dose rate exceeds 5.0 mrem/hr, which again is consistent with the NSLS-II Shielding Policy [1].

5. Acronyms

ARM	Area Radiation Monitor
BC	Bremsstrahlung Collimator
CM	Collimating Mirror
FE	Front End
FM	Fixed Mask
FOE	First Optical Enclosure
FXI	Full Field X-ray Imaging
GeV	Giga Electron Volts
ID	Insertion Device
LCO	Lead Collimator
MSK	Mask
NSLS-II	National Synchrotron Light Source II
PSH	Photon Shutter
RCO	Ratchet Wall Collimator
SBS	Secondary Bremsstrahlung Shield
SLT	XY Slit
SS	Safety Shutter
TOSS	Top-Off Safety System
WBS	White Beam Stop

6. References

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

[2] Guidelines foe NSLS-II Beamline Front End Design for Top Off Safety, NSLS-II Technical Note 153, Y. Li and R. Fliller, Jan 21, 2015. Email from Fliller, Raymond, July 28, 2017

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

Appendix A

From: Fliller, Raymond
Sent: Friday, July 28, 2017 1:33 PM
To: Amundsen, Christopher; Benmerrouche, Mohamed; Li, Yongjun
Subject: RE: FXI TOSS

Thanks.

Based on these dimensions, I calculate that the opening angle for ISS and XPD is 30.6mrad. The opening angle for FXI is 26.62 mrad. Because of this, FXI's top off tracking is covered by XPD. Therefore FXI is safe from a top off tracking perspective and no independent tracking is necessary.

Ray

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Fax:631-344-3029

From: Amundsen, Christopher
Sent: Friday, July 28, 2017 1:12 PM
To: Fliller, Raymond; Benmerrouche, Mohamed; Li, Yongjun
Subject: RE: FXI TOSS

Ray,
Collimator 2 was moved 20 mm upstream to allow the RCO burn-thru to be moved out of the ratchet wall. Attached is the layout.

Chris

From: Fliller, Raymond
Sent: Friday, July 28, 2017 11:59 AM
To: Amundsen, Christopher; Benmerrouche, Mohamed; Li, Yongjun
Subject: RE: FXI TOSS

Chris,

Thanks. Just to confirm, other than this change, the distance between the fixed mask and collimator 2 on all the front ends is the same, and the aperture of collimator 2 is the same on all three front ends?

Ray

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Upton, NY 11973-5000
Phone: 631-344-2356
Fax:631-344-3029

From: Amundsen, Christopher
Sent: Friday, July 28, 2017 11:01 AM
To: Fliller, Raymond; Benmerrouche, Mohamed; Li, Yongjun
Subject: FXI TOSS

Ray,
The fixed mask aperture for 28ID and 8ID is 22.39 mm Horiz and 3.05 mm Vert.
The fixed mask aperture for 18ID is 9.32mm Horiz and 5.25 mm Vert.
See attached. Dimensions in red are for the aperture.

Chris

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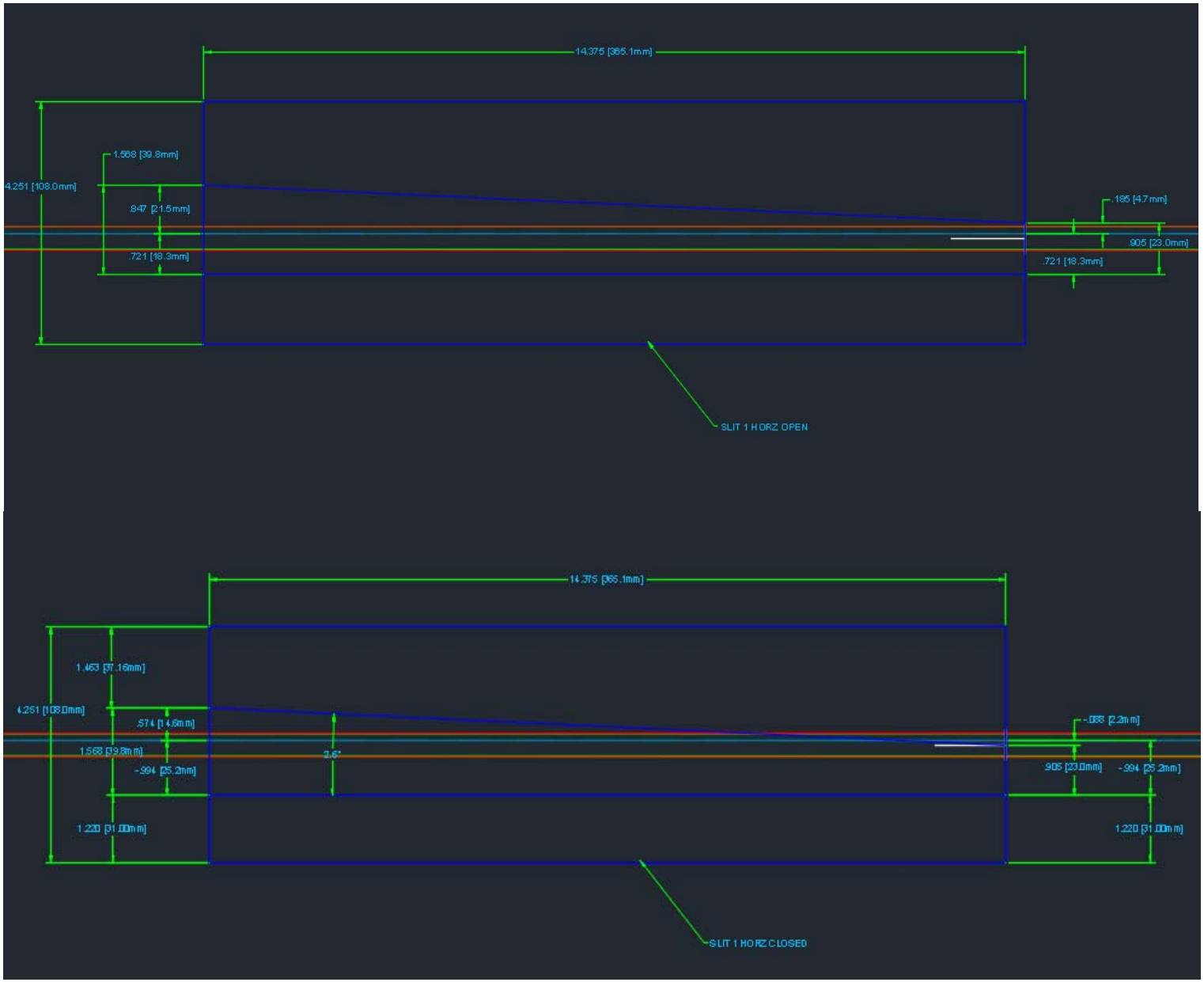
Appendix B

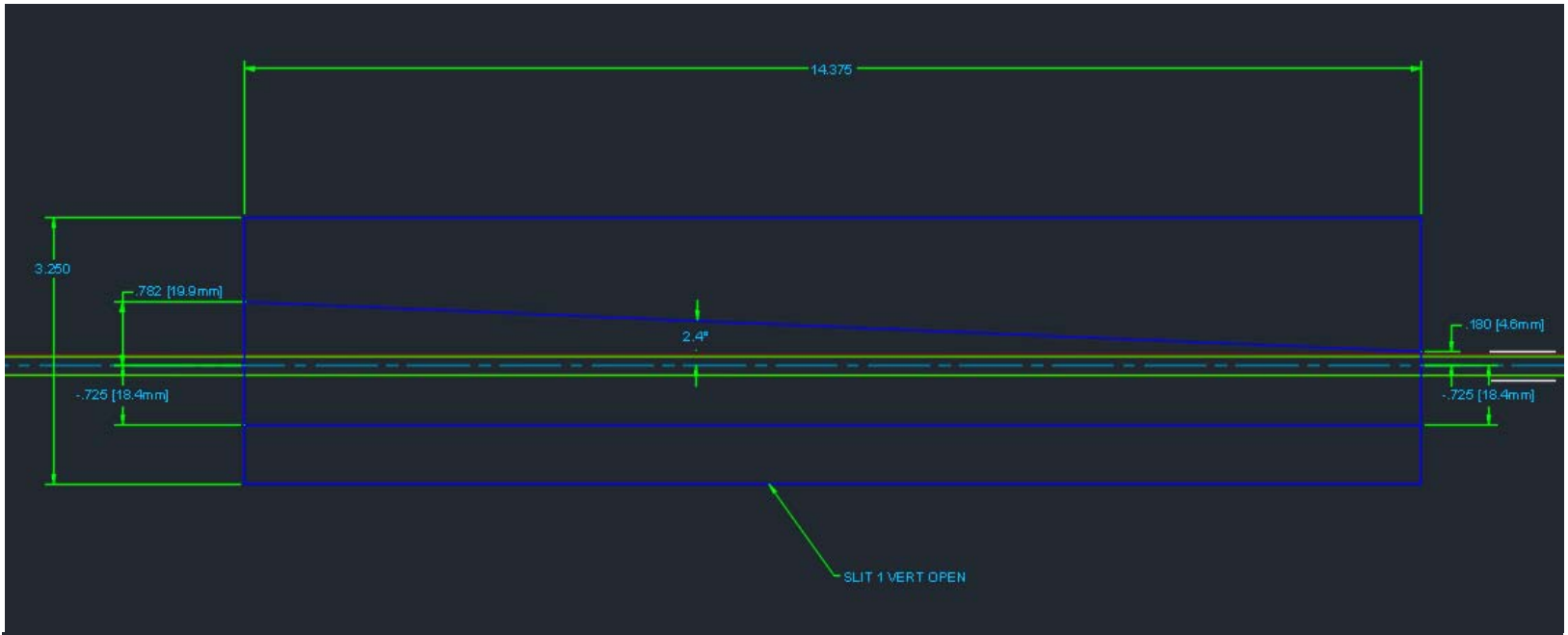
Front End Component	Z location, m (Distance from Source Point) (U), (D) or center (C)	Dimensions		Offset (vertical or horizontal) w.r.t 18 ID white beam CL	Material	Associated Drawings
		Outer dimensions (W)x(H)x(L)	Lead CO or Mask Aperture, mm (W)x(H) or (Dia)			
Crotch Absorber (at beam CL)	11021 (US)	45.0 W x 42.0 H x 254.0 L	75.0(W) x 18.0(H)	-	AL-15 GlidCop	SR-VA-ABS-1080
Exit Absorber	11255.8 (US)	139.7 W x 47.6 H x 638.0 L	70.0(W) x 25.4(H) (US) 30.0(W) x 25.4(H) (DS)	-	AL-15 GlidCop	SR-FE-ABS-4020
FE Flange Absorber1 (MSK2)	19313.0 (DS)	171.5 W x 151.6 H x 20 L	70.7 (W) x 37.2 (H) Thru	-	AL-15 GlidCop	SR-FE-ABS-1300
FE Fixed Mask (FM)	19785.8 (US)	117.5 W x 100.0 H x 570.5 L	73.7(W) x 42.0 (H) (US) 9.3(W) x 5.3(H) (DS)	(DS) -2.0 (W)	AL-15 GlidCop	SR-FE-MSK-3601
FE LCO1 (BC1)	20605.0 (US)	406.0 W x 102.0 H x 305.0 L	28.9 (W) x 19.4 (H) Thru	-	Lead	SR-FE-CO-3620
FE Slit 1 (Open)	21295.2 (C)	108.0 W x 82.5 H x 378.0 L	See drawings in Appendix 3	+5.0 (W) x +4.7 (H)	AL-15 GlidCop	SR-FE-SLT-3600
FE Slit 2 (Open)	21977.9 (C)	108.0 W x 82.5 H x 378.0 L	See drawings in Appendix 3	-9.0 (W) x -4.7 (H)	AL-15 GlidCop	SR-FE-SLT-3650
FE Photon Shutter	22881.7 (C)	108.0 W x 82.5 H x 254.0 L	32.5(W) x 38.0 (H) (US) 32.5(W) x 25.4(H) (DS)	0.0 (open) -19.0 (closed)	AL-15 GlidCop	SR-FE-PSH-3600

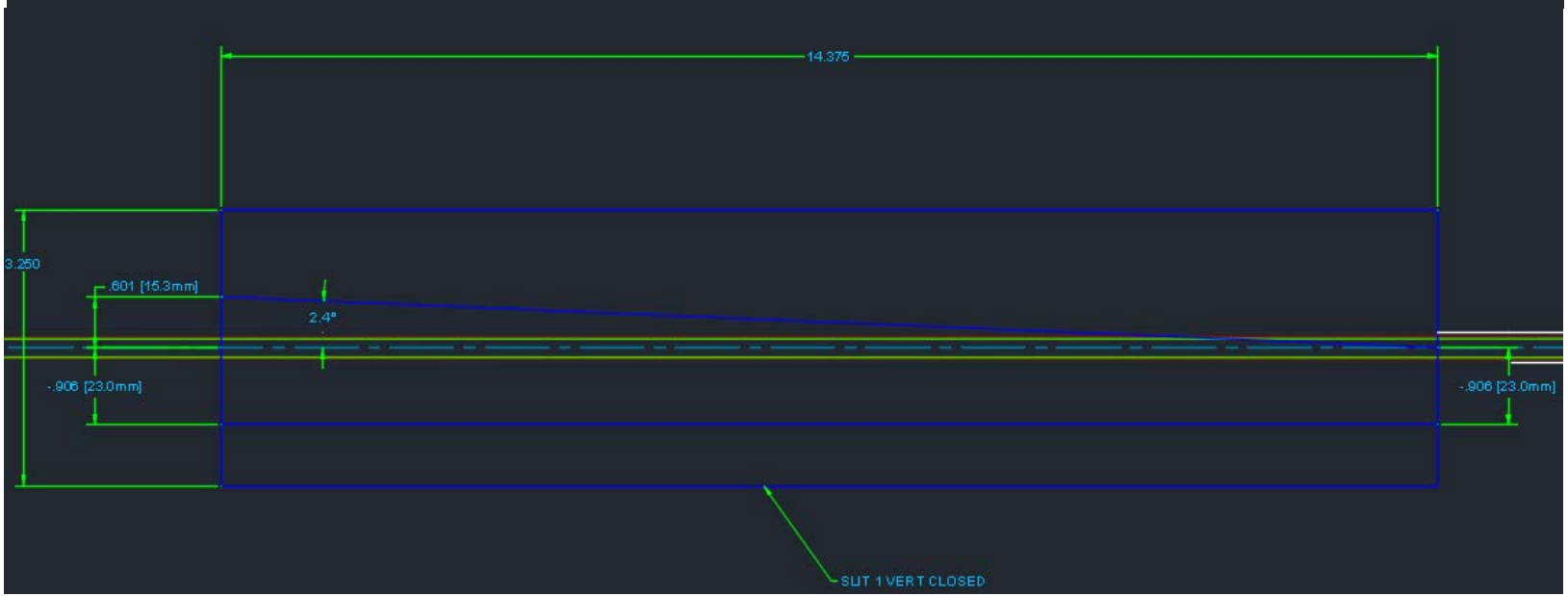
Front End Component	Z location, m (Distance from Source Point) (U), (D) or center (C)	Dimensions		Offset (vertical or horizontal) w.r.t 18 ID white beam CL	Material	Associated Drawings
		Outer dimensions (W)x(H)x(L)	Lead CO or Mask Aperture, mm (W)x(H) or (Dia)			
FE LCO2 (BC2)	23514.0 (US)	454.0 W x 127.0 H x 305.0 L	78.2 (W) x 27.4 (H) Thru		Lead	SR-FE-CO-3600
FE Safety Shutter 1	24097.6 (US)	152.4 W x 101.6 H x 305.0 L	Lead raised above beam in open position. Lead dropped to block beam when closed.	+12.5 (open) -51.0 (closed)	Lead	SR-FE-SS-2900
FE Safety Shutter 2	24672.1 (US)	152.4 W x 101.6 H x 305.0 L	Lead raised above beam in open position. Lead dropped to block beam when closed.	+12.5 (open) -51.0 (closed)	Lead	SR-FE-SS-3000
Shield Wall Lead	25269.2 (US)	1380.0 W x 498.5 H x 254.0 L	46.3 (W) x 31.3 (H) Thru		Lead	SR-FE-RCO-3600
Upstream Penetration Lead	25523.2 (US)	403.2 W x 200.0 H x 50.8 L	46.3 (W) x 31.3 (H) Thru		Lead	SR-FE-RCO-3600
Concrete Filler	25662.9 (US)	284.0 W x 133.4 H x 734.0 L	46.3 (W) x 31.3 (H) Thru		Concrete	SR-FE-RCO-3601
RCO	26717.0 (DS)	286.0 W x 139.7 H x 304.8 L	41.0 (W) x 27.0 (H) Thru		Lead	SR-FE-RCO-3601

Appendix C

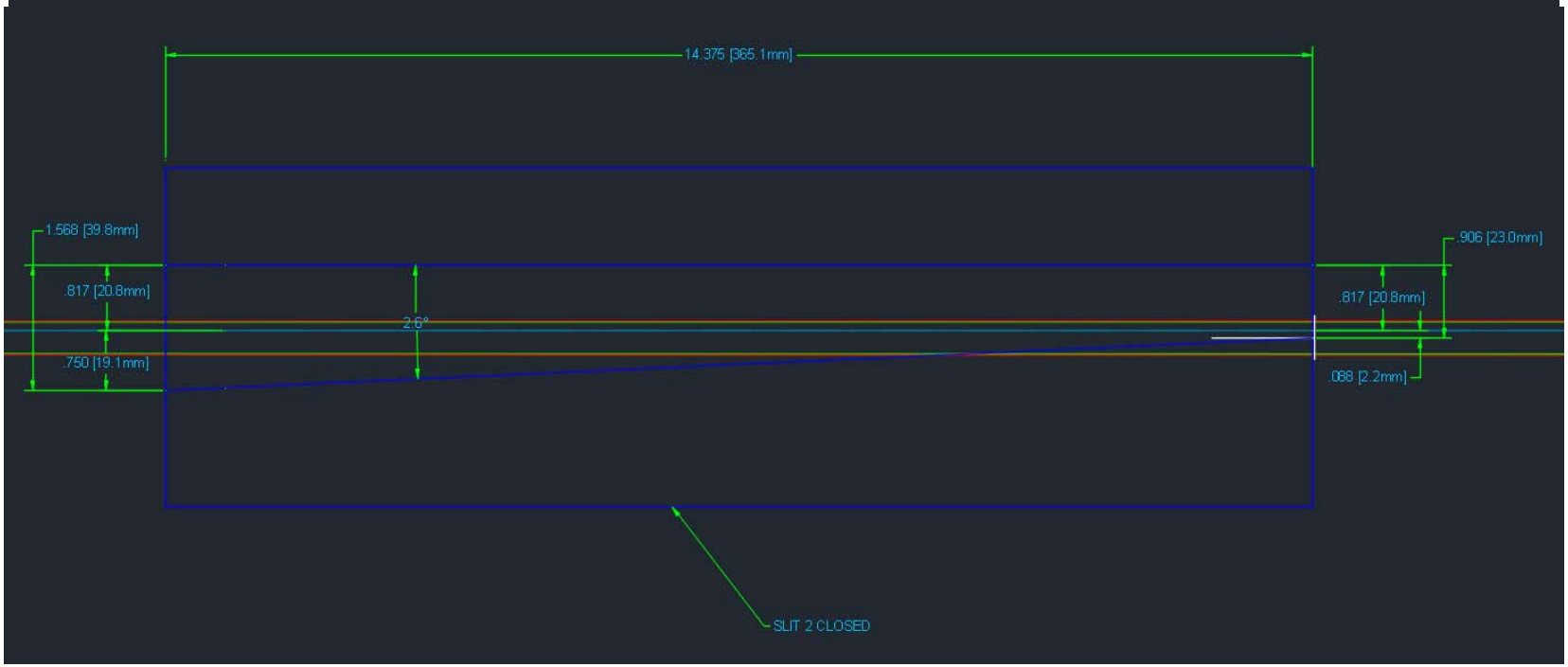
Aperture of the slits in open and closed positions from Amundsen, Christopher.

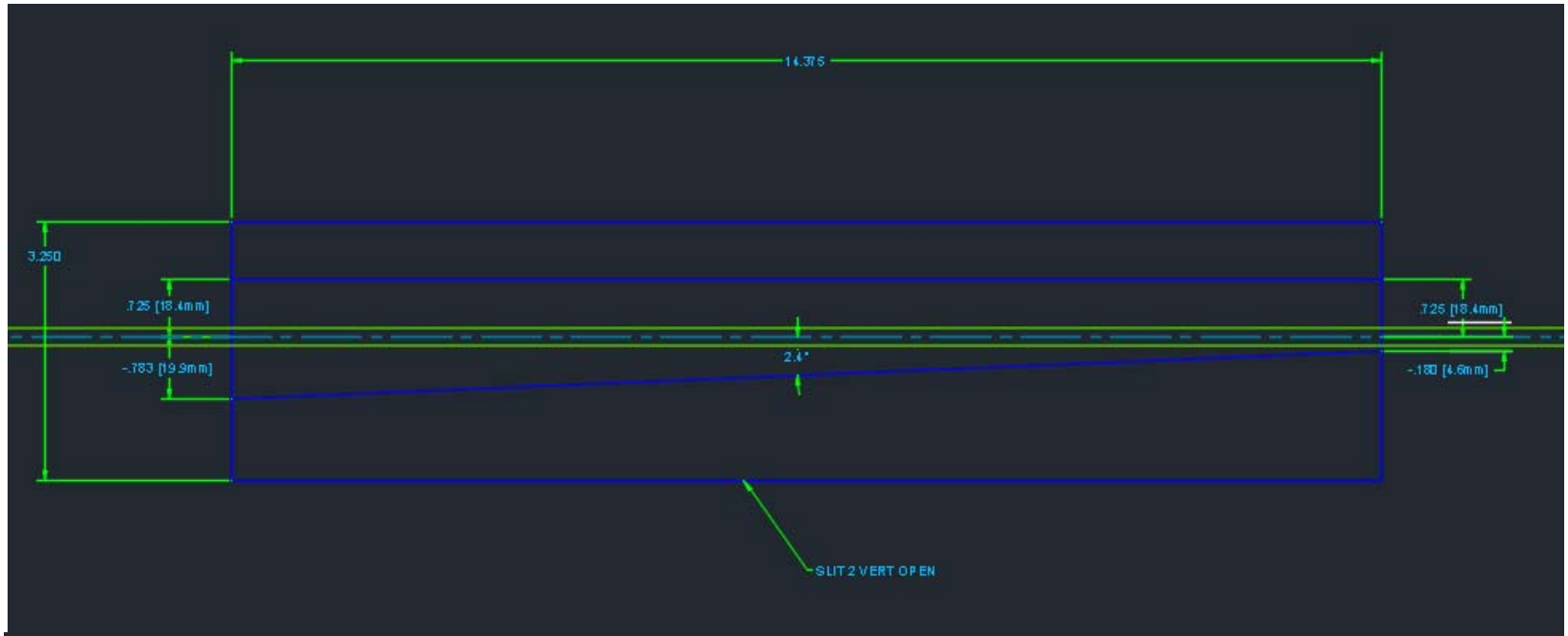


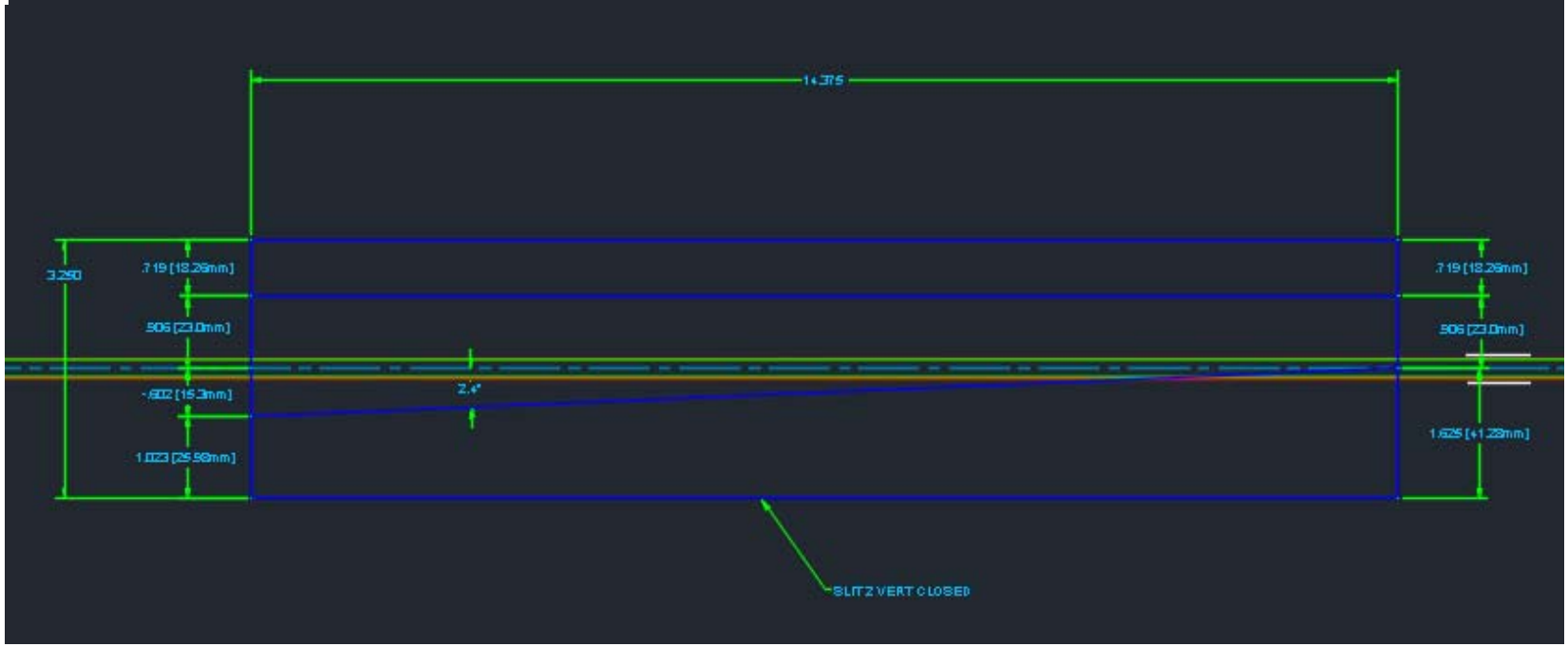

14.375
3.250
.782 [19.9mm]
2.4°
.180 [4.6mm]
-.725 [18.4mm]
-.725 [18.4mm]
SLIT 1 VERT OPEN


14.375
3.250
.601 [15.3mm]
2.4°
-.906 [23.0mm]
-.906 [23.0mm]
SLIT 1 VERT CLOSED

14.375 [365.1mm]
1.568 [39.8mm]
.542 [13.8mm]
1.025 [26.0mm]
2.6°
.542 [13.8mm]
.905 [23.0mm]
.363 [9.2mm]
SLIT 2 HORZ OPEN


14.375 [365.1mm]
1.568 [39.8mm]
.817 [20.8mm]
.750 [19.1mm]
2.6°
.906 [23.0mm]
.817 [20.8mm]
.088 [2.2mm]
SLIT 2 CLOSED


14.375
3.250
.725 [18.4mm]
-.783 [19.9mm]
2.4°
.725 [18.4mm]
-.180 [4.6mm]
SLIT 2 VERT OPEN


14.375
3.250
.719 [18.26mm]
.906 [23.0mm]
-.602 [15.3mm]
1.023 [25.99mm]
2.4°
.719 [18.26mm]
.906 [23.0mm]
1.625 [41.28mm]
SLIT 2 VERT CLOSED