Top-off radiological analysis for NSLS-II beamlines

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Top-off radiological analysis for NSLS-II beamlines

- NSLS-II (National Synchrotron Light Source II) is a new state-of-the-art 3rd generation synchrotron.
- The NSLS-II accelerators finished commissioning in the fall of 2014 and beamline commissioning underway.
- Part of the design for the NSLS-II is to operate in top off mode in the near future.
- The Top Off radiological calculations are presented on the base of the tracking results from the accelerator group.

Top-off radiological safety concern

- During the top-off injection the safety shutters are in open position and the first optical enclosure (FOE) will be secured with no access to the personnel.
- The primary radiological safety concern for the top-off injection, with the beam line front end safety shutters open, is the scenario where injected electrons could be conveyed down to the beam line through the front end.

Shielding Policy

- It is required by the NSLS-II shielding policy [1] that
- 1) The radiation dose rate in the continuously occupied areas should be less than 0.5mrem/hour (normal loss, not a concern for top off).
- 2) For uncontrolled areas the integrated dose should not be greater than 20mrem during a fault.
- 3) The integrated dose should be kept within 100mrem for the controlled areas in an unplanned abnormal condition.
- 4) Radiation doses less than 100mrem/hour can be mitigated via administrative controls only when the use of area radiation monitors (ARM) is not practical. A secondary independent system is required if the does rate could be greater than 2000mem/hour.

- *[1] R. Lee, Photon Sciences Shielding Policy, PS-C-ASD-POL-005*

Electrons entering FOE

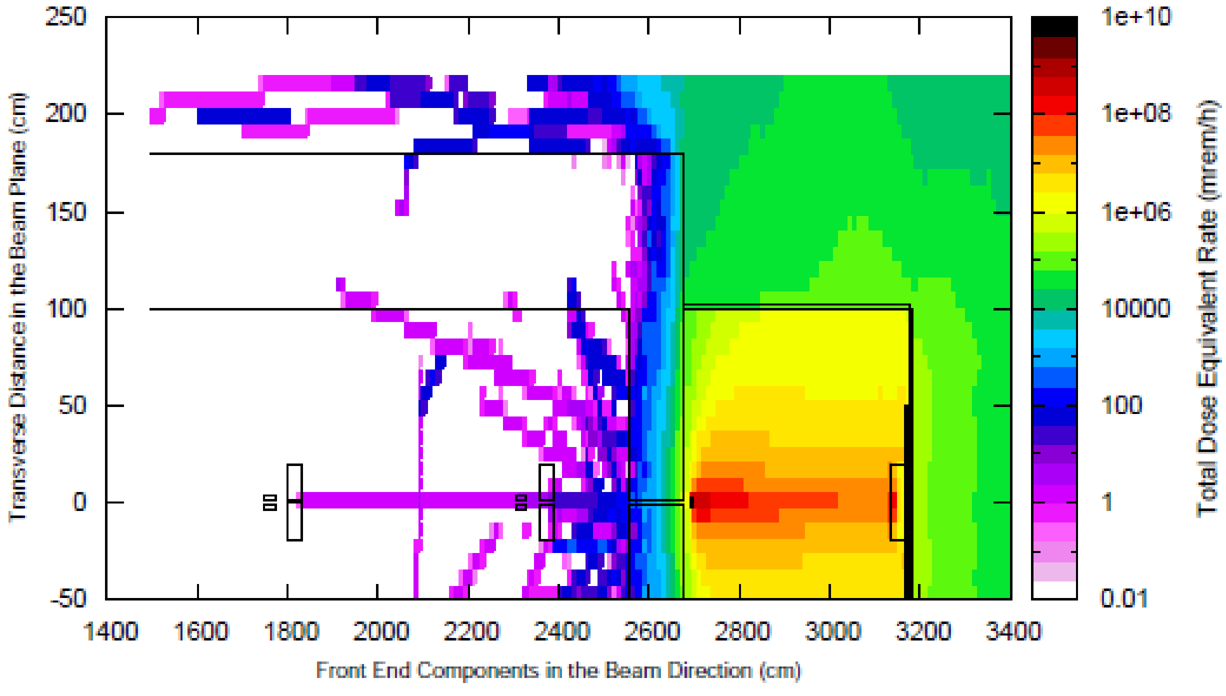


Figure 1. 3 GeV, 15 nC/s electron beam entering the First Optics Enclosure (FOE) [2]

- *[2] P.K. Job, TN 77, Radiological Considerations of Top-off Operation at NSLS-II, 2010*

3 GeV, 15 nC/s electron beam entering the First Optics Enclosure (FOE) [2]

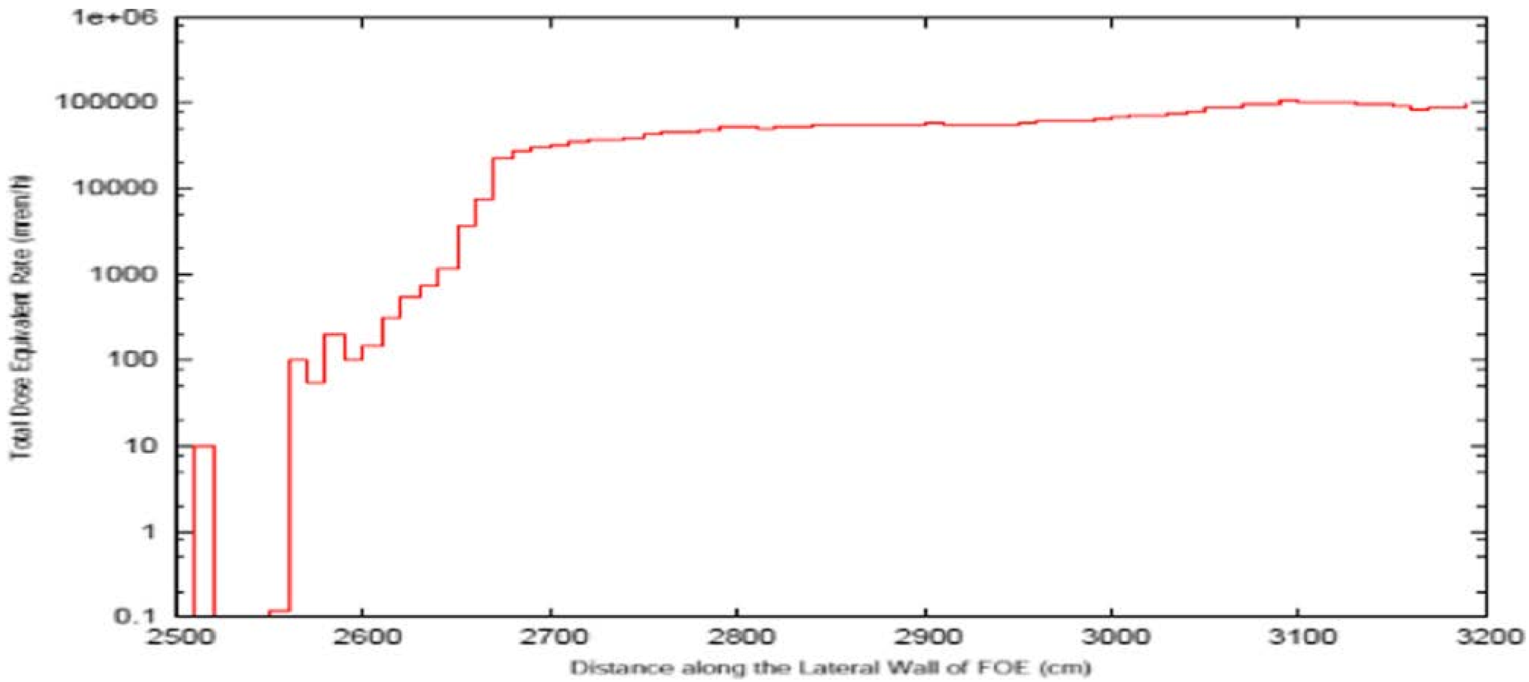
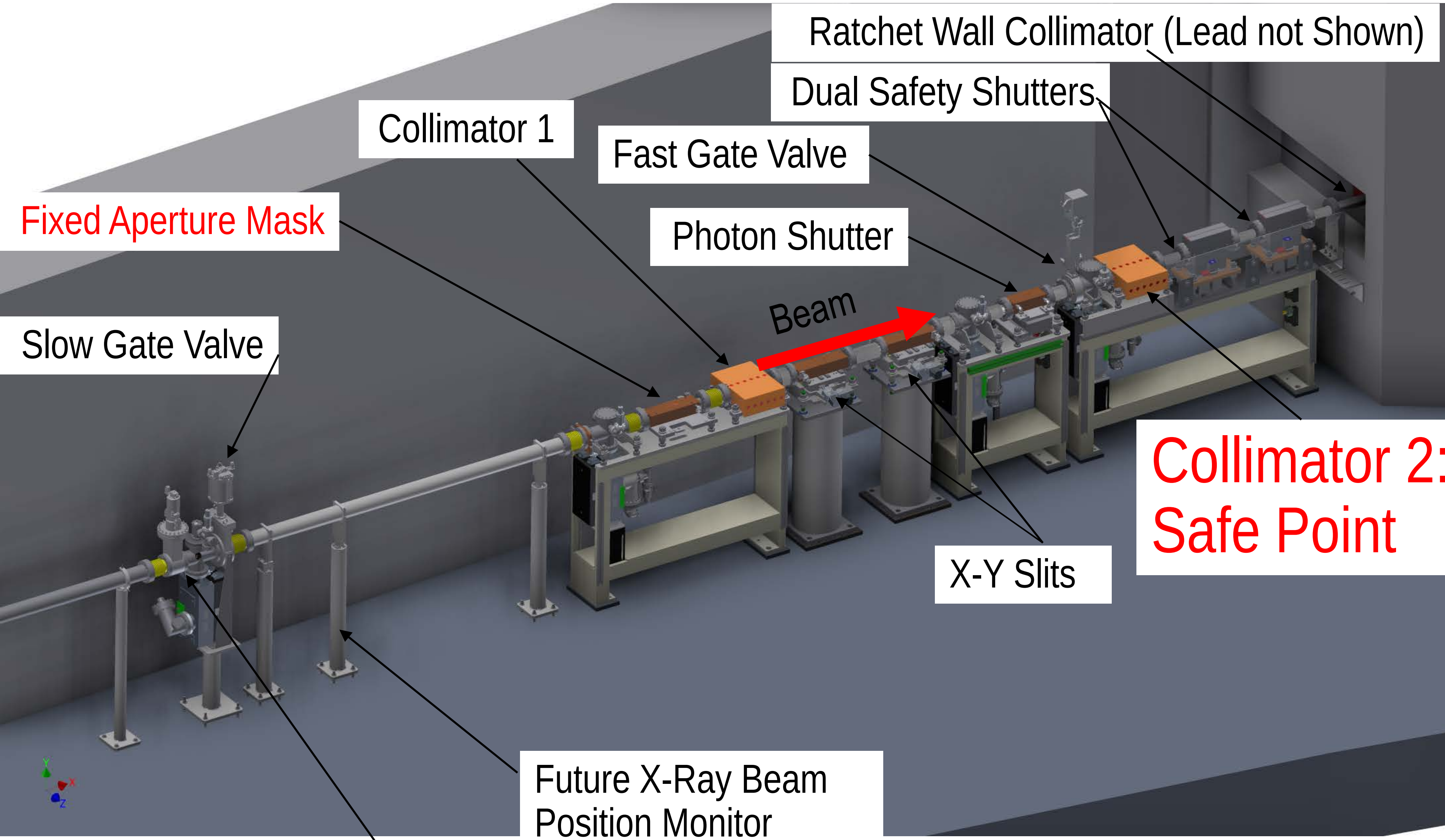


Figure 2. Total ambient dose equivalent rate distribution along the exterior of the lateral wall of the First Optics Enclosure at beam height for 15 nC/s injected beam incident on a copper mask in the FOE, **Lateral wall ~ 100 rem/h. (80 mrem per pulse of 15 nC)**

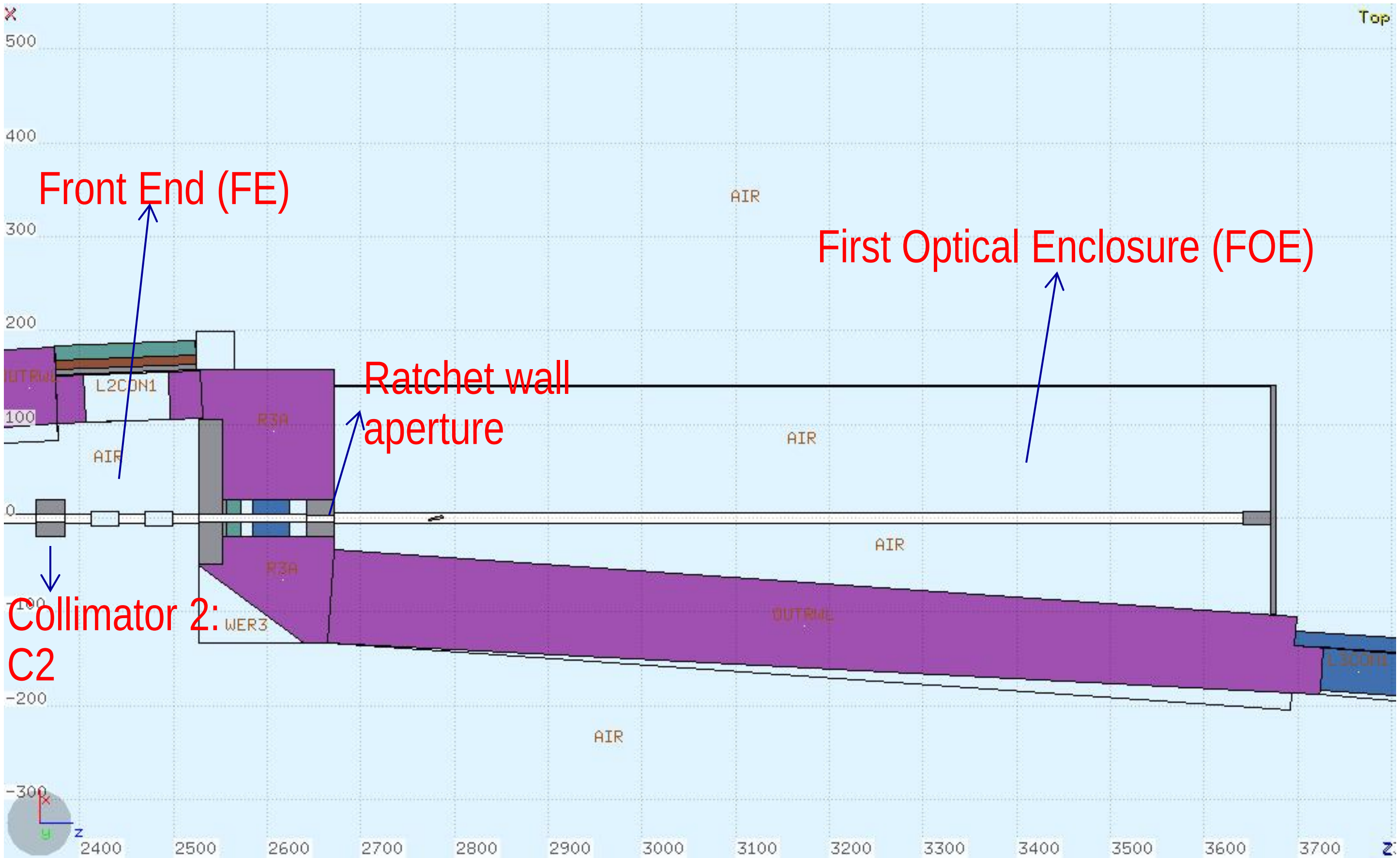
Particle tracking simulations

- Particle tracking simulations proved that an errant injected electron beam can be confined to the beam-line frontend inside the storage ring tunnel by use of appropriate apertures and interlocks.
- Photon shutter collimator 2 (C2) was selected as the safe point. Particle tracking simulations showed that with the interlocks no errant particle beam can strike C2 within 5mm of the aperture edge.

Typical Non-Canted Front End Configuration



FLUKA geometry (Electron beam confined in Front End)



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Key aperture parameters in FE

So far, we analyzed 6 PROJECT beamlines. The following tables list the key aperture parameters in FE (Ray trace parameters).

PROJECT BLs	Dimensions X (mm)	Dimensions Y (mm)
Safe point: photon shutter collimator (C2)	+/- 39.6	+/-14.2

Ratchet wall aperture dimensions

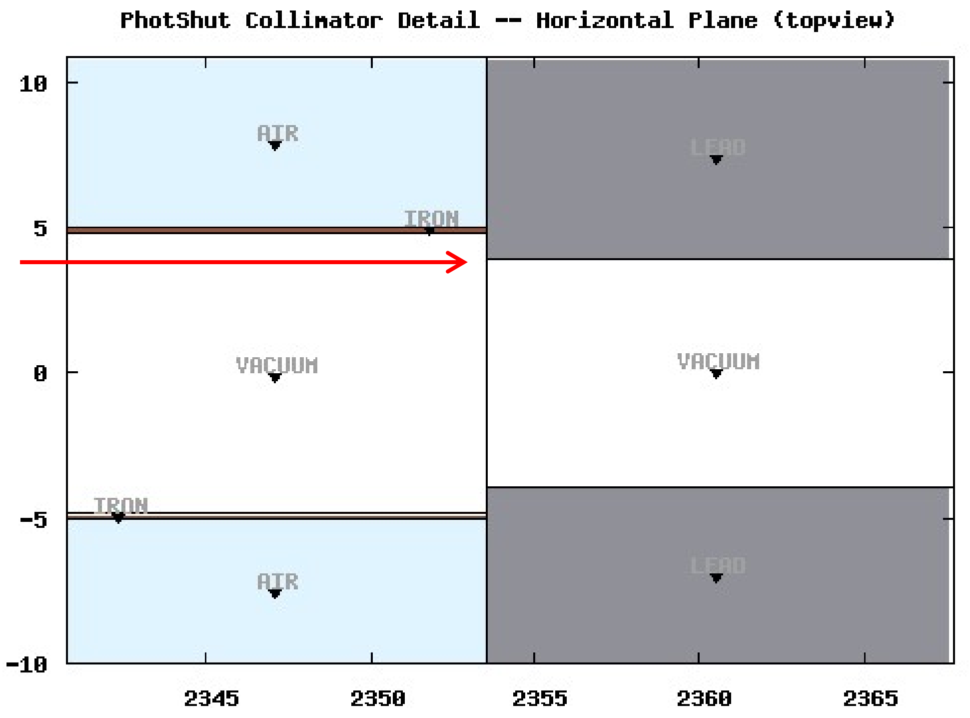
	Dimensions X (mm)	Dimensions Y (mm)
SRX	+/- 39.22	+/- 10.90
IXS	+/- 14.02	+/- 10.74
HXN	+/- 13.50	+/- 10.40
CHX	+/- 13.48	+/- 10.41
CSX	+/- 13.60	+/- 13.64
XPD	+/- 22.37	+/- 8.52

Parameters in FLUKA model

Collimator 2 aperture	X direction : +/- 3.96 cm	Y direction: +/- 1.42 cm
Ratchet wall collimator aperture	X direction : +/- 3.92 cm	Y direction: +/- 1.09 cm
FOE Lateral wall	139.7 cm from target with 18 mm Pb	
FOE Downstream wall	10 m from SR ratchet wall with 50 mm Pb	
FOE Scattering target	1” × 1” × 6” long copper rotated at 15 degree	
FOE bremsstrahlung stop	13.415 cm H × 9.06 cm V ×30 cm thick Pb	
FE and FOE Beam pipe	4” O.D. (outer diameter) with 2 mm Fe	

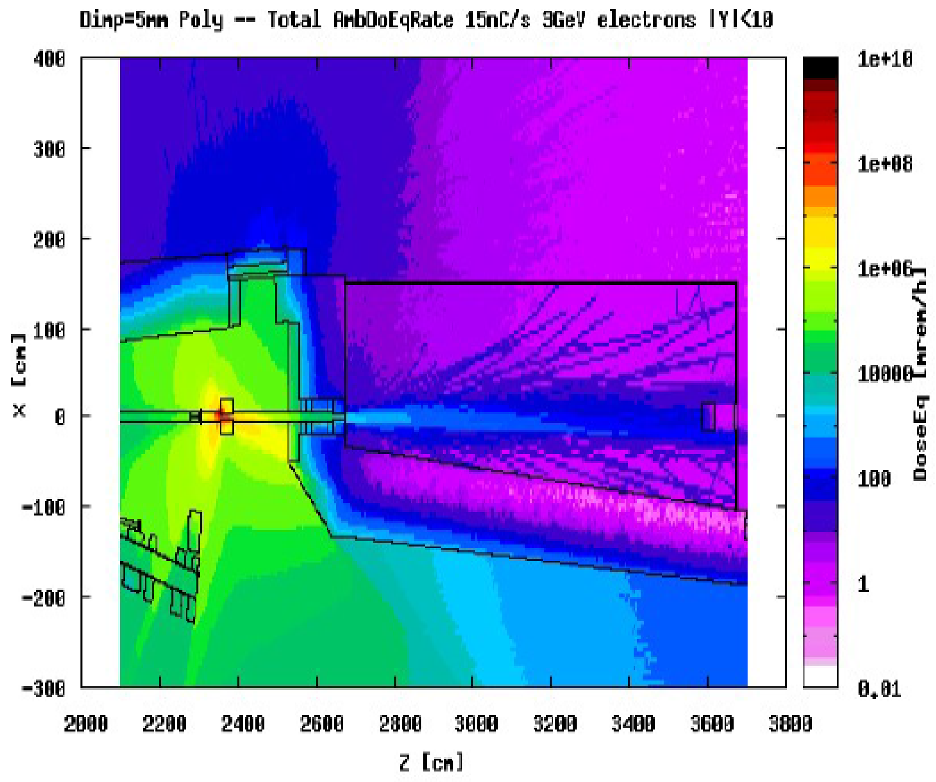
**The apertures sizes / FOE lateral wall distance are from 5-ID SRX beamline, which has the largest ratchet wall aperture among project beamlines.*

Beam impact on C2



Based on particle track simulation: Beam impact > 5mm away from C2 aperture edge. Maximum incident angle ~ 5mrad by Front End geometry.

FLUKA results (only GB stop in FOE)



3 GeV, 15 nC/s electron beam impact location of 5 mm from the Edge of C2 Aperture:

The maximum dose on the downstream wall of the FOE at the beam height is ~55mrem/h.

The maximum dose rate is <20 mrem/h at lateral wall. The injected beam loss rate is 15 nC/s.

Note: GB stop 30×30×30 cm Pb block in this FLUKA simulation.

[3] P.K. Job, Technical Note 148, Radiological Consequences of Beam Loss on Beamline Front End Collimator during Top-off Injection into the Storage Ring, 9/15/2014.

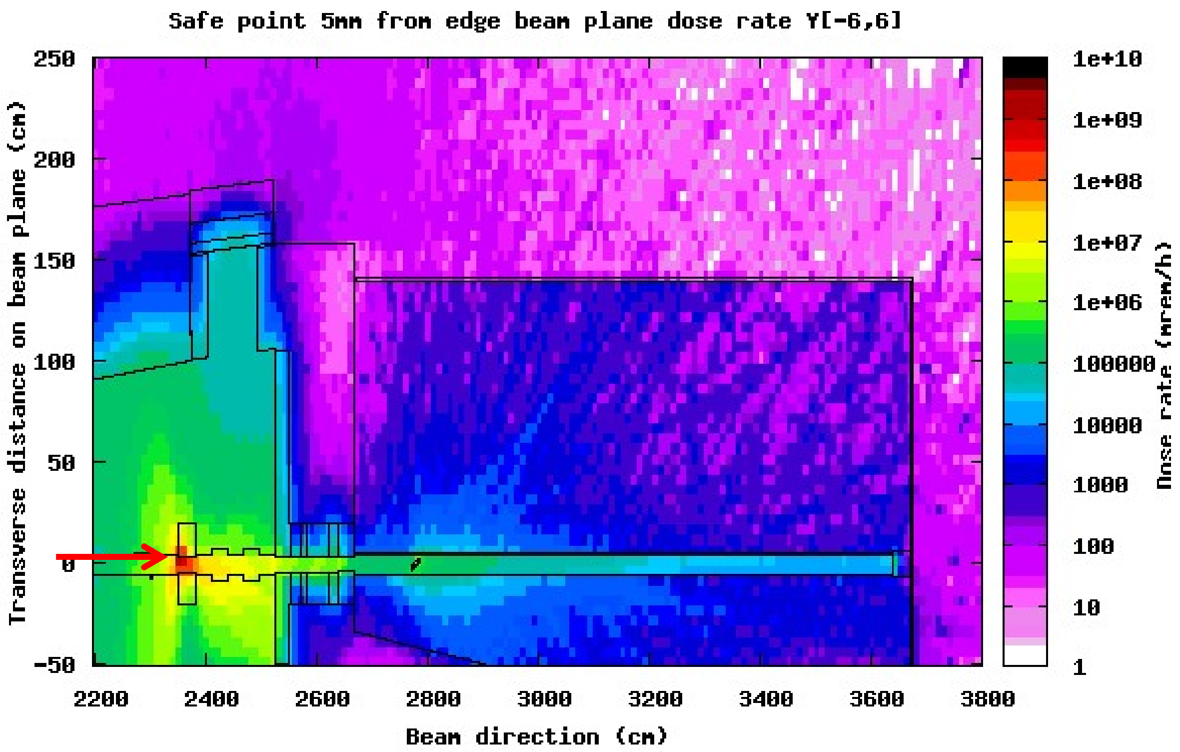
Additional FLUKA results

Four scenarios (with additional FOE components: mask scatterer, 2 mm Fe pipe and beam stop)

- 1. safe point 5 mm outboard from aperture, beam incident angle 5 mrad.
- 2. safe point 5 mm inboard from aperture, beam incident angle 5 mrad.
- 3. beam scrape beam pipe outboard side at 5 mrad, 40 cm upstream of collimator 2 (*scraping point closest to C2 aperture and go through full pipe thickness before reaching C2, ~ 12 mm from C2 aperture*).
- 4. beam scrape beam pipe inboard side at 5 mrad, 40 cm upstream of collimator 2.

[4] Z. Xia, Technical Note 150, Radiological Consequences of Beam Loss at Front End by FLUKA during Top-off Injection into the Storage Ring for PROJECT beamlines, 11/4/2014.

Scenario 1: 3 GeV, 15 nC/s electron 5 mm outboard from aperture



Maximum dose rate:

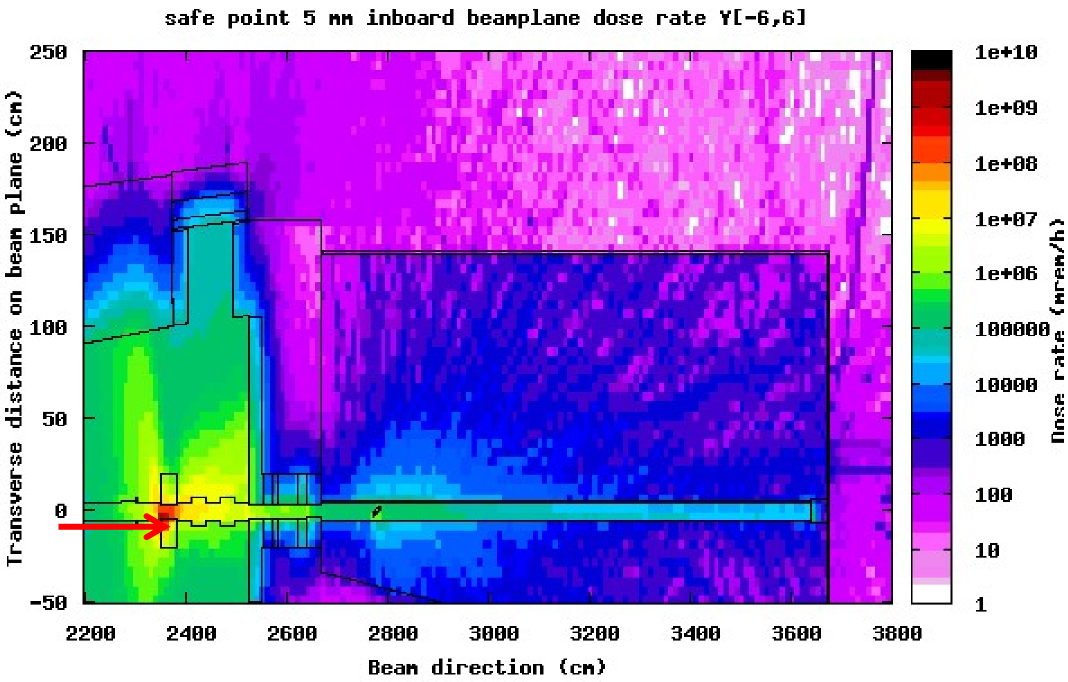
FOE down wall: 500 mrem/h

FOE lateral wall: 40 mrem/h

SR @ corner: 800 mrem/h

Dose rate on beam plane (3 GeV, 15 nC/s electron beam 5 mm outboard from aperture, beam incident angle 5 mrad, 15 nC/s)

Scenario 2: 3 GeV, 15 nC/s electron 5 mm inboard from aperture



Maximum dose rate:

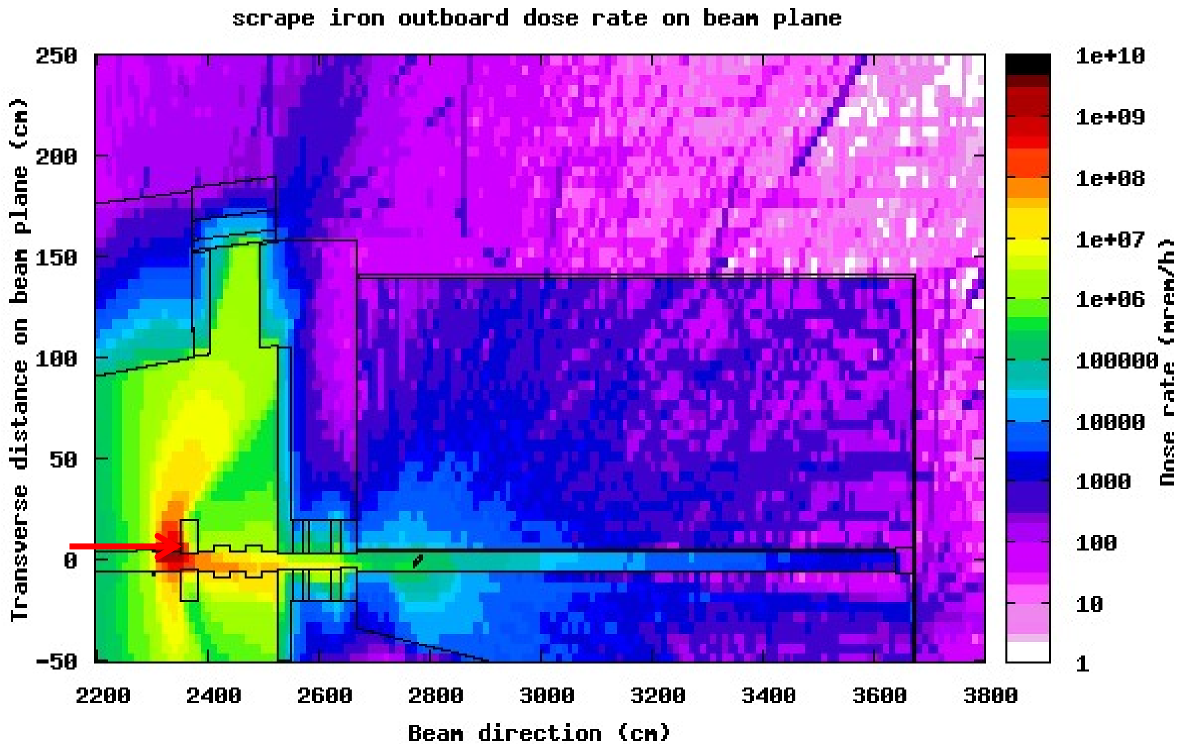
FOE down wall: 1000 mrem/h

FOE lateral wall: 50 mrem/h

SR @ corner: 800 mrem/h

Dose rate on beam plane (3 GeV, 15 nC/s electron beam 5 mm inboard from aperture, beam incident angle 5 mrad, 15 nC/s)

Scenario 3: 3 GeV, 15 nC/s electron scrape iron pipe outboard



Maximum dose rate:

FOE down wall: 700 mrem/h

FOE lateral wall: 100 mrem/h

SR @ corner: 2500 mrem/h

Dose rate on beam plane (3 GeV, 15 nC/s electron beam scrape iron pipe outboard side 40 cm upstream of C2 at 5 mrad)

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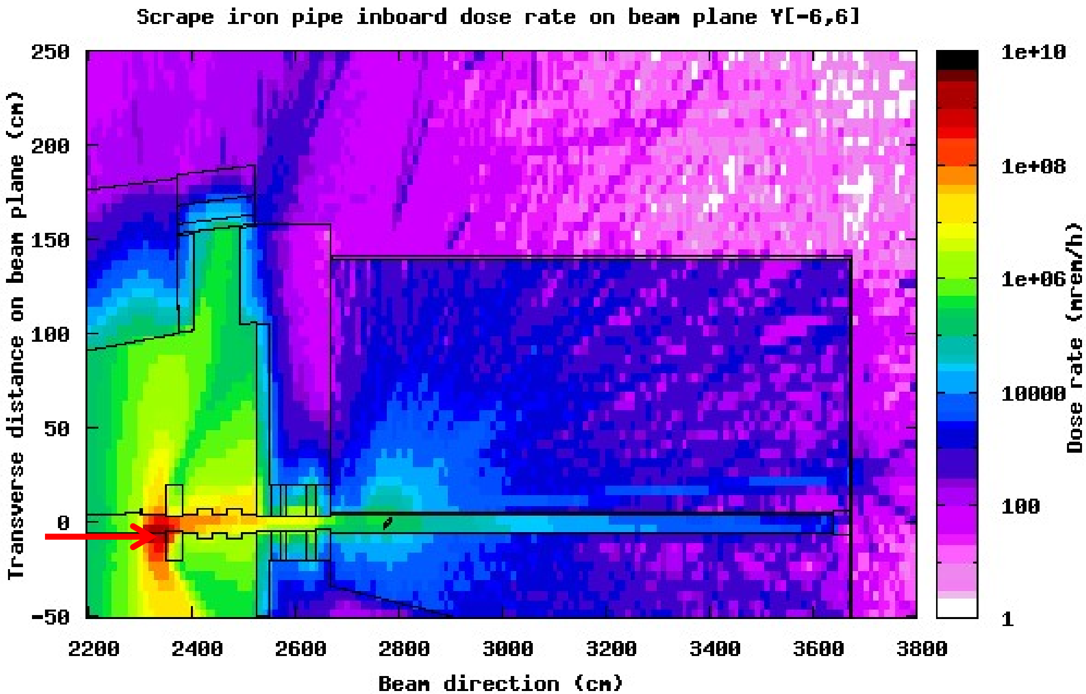
Scenario 4: 3 GeV, 15 nC/s electron scrape iron pipe inboard



Maximum dose rate:

FOE down wall: 2000 mrem/h

FOE lateral wall: 100 mrem/h

SR @ corner: 1800 mrem/h

Dose rate on beam plane (3 GeV, 15 nC/s electron beam scrape iron pipe inboard side 40 cm upstream of C2 at 5 mrad)

3 GeV, 15 nC/s Top off dose rate summary

Injection rate 15 nC/s	5 mm outboard from edge (mrem/h)	5 mm inboard from edge (mrem/h)	Beam scrape pipe out board (mrem/h)	Beam scrape pipe inboard (mrem/h)
FOE downstream wall	500	1000	700	2000
FOE lateral wall	40	50	100	100
SR door seam @ corner	800	800	2500	1800

1. Top-off dose rate summary: 3 GeV, 15 nC/s electron beam gets lost at or before safe point.
2. Note the FOE downstream wall dose rate estimate here is conservative (in reality there are additional shields in FOE, which are not included in FLUKA calculation.

Maximum dose rate (injection rate at 45 nC/min)

Injection rate 45 nC/min	5 mm outboard from edge (mrem/h)	5 mm inboard from edge (mrem/h)	Beam scrape pipe out board (mrem/h)	Beam scrape pipe inboard (mrem/h)
FOE downstream wall	25	50	35	100
FOE lateral wall	2	3	5	5
SR door seam @ corner	40	40	124	90

1. Limiting the injection rate is not causing a burden for operation.
2. ARM in surrounding area, maximum dose rate ~ 100 mrem/h, acceptable.

Conclusions

- NSLS-II limits the injection rate to < 45 nC/min during top off. The maximum dose rate in the occupied areas is ~100 mrem/h when beam is mis-steered before safe point during top-off operation.
- There is going to be an area radiation monitor (ARM) around each Storage Ring (SR) ratchet wall.
- The accumulated dose is < 1 mrem per accident, assuming 3 seconds response time of ARM.

Thank you!