Radiological Consequences of Beam Loss at Beamline Front End during Top-off Injection into the Storage Ring

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Abstract

NSLS-II (National Synchrotron Light Source II) is a new state-of-the-art 3rd generation synchrotron that will produce x-rays of unprecedented and world-leading brightness, which will advance experimental capabilities to serve a wide range of scientific disciplines. 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. In this paper the Top Off radiological calculations are performed on the base of the tracking results from the accelerator group.

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. 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.

The first group of NSLS-II beamlines which comes in operation is PROJECT beamlines. The radiological calculation in this paper was based on the as-built parameters of SRX, which has the largest apertures among PROJECT beamlines. The dose rate during top off operation was calculated for different scenarios. Based on the FLUKA results, with the control group interlocking the injection rate at 30 nC/min, the dose rate with the worst scenario during top off is ~ 100 mrem/h, which is far under PS shielding policy limit with the implementation of area radiation monitors (ARM) around storage ring (SR) ratchet wall area.

1. Introduction

NSLS-II plans to run the top-off mode operation at the end of year 2015. 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 (C2) was selected as the safe point (i.e. electron beam can't travel further beyond the safe point).

Particle tracking simulations showed that no errant particle beam can strike C2 within 5mm of the aperture edge [1]. FLUKA Monte Carlo simulations were performed to validate the radiation levels in the occupied regions due to the injected electron beam incident at or before the new safe point (5mm from C2 aperture edge).

2. FLUKA Calculation

The photon shutter collimators (C2) have the same aperture dimensions for all PROJECT beamlines, which are listed in Table 1.

Table 1 Photon shutter collimator (C2) aperture size

	Dimensions X (cm)	Dimensions Y (cm)
Safety end point: C2	7.92	2.84

The ratchet wall aperture dimensions are listed in Table 2. As seen in Table 2, SRX (5-ID beamline) has the largest ratchet wall aperture, which is applied in the FLUKA geometry. 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.

Table 2 Ratchet wall aperture dimensions for 6 project beamlines

Beamlines	Dimensions X (mm)	Dimensions Y (mm)
SRX	**78.44**	**21.80**
IXS	28.03	21.47
HXN	27	20.8
CHX	26.95	20.82
CSX	27.2	27.28
XPD	44.74	17.03

2.1 Beam transport to FOE

Figure 1 shows the dose rate when the full injected electron beam of 15 nC/s incident on the fixed mask inside the First Optics Enclosure (FOE) [2]. Note this scenario is not credible based on the particle tracking simulation. The dose analysis is included in this note for completeness and demonstrating the dose level if electron beam travels further than safe point.

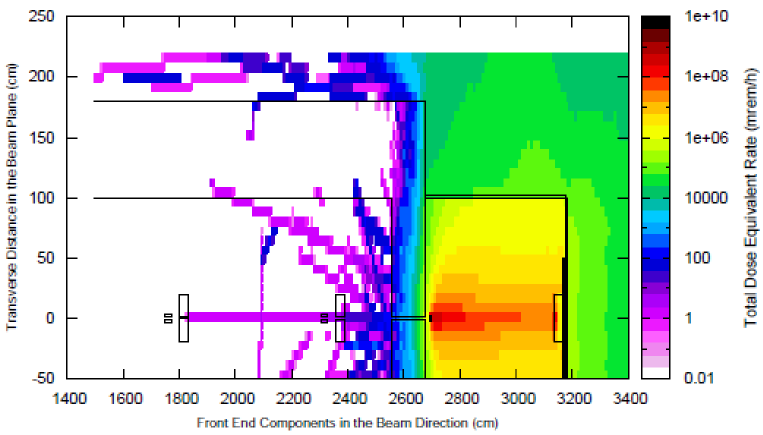

Figure 1. 3 GeV, 15 nC/s electron beam entering the First Optics Enclosure (FOE)[2]

As shown in Figure 1, the maximum total ambient dose equivalent rate outside of FOE is ~ 100 rem/h due to the full top-off injection beam loss in the FOE. This corresponds to 30 mrem per pulse of the injected beam.

2.2 Beam impact > 5 mm from the edge of C2 aperture

A detailed FLUKA simulation was performed for electrons lost on or before the safe point (5 mm from the C2 aperture edge), which may be a credible scenario. The main parameters in FLUKA model are summarized in Table 3. Figure 2 shows the FLUKA geometry. Note in FOE FLUKA model only takes credit of the gas bremsstrahlung (GB) stop and 2 mm iron (Fe) pipe around beam.

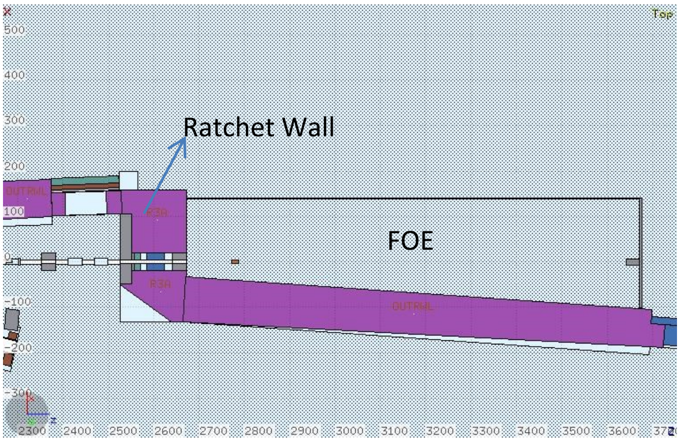

Figure 2. FLUKA geometry

Table 3 FLUKA simulation parameters

Photon shutter collimator 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 / lateral wall distance in Table 3 are from 5-ID SRX beamline, which has the largest ratchet wall aperture among project beamlines*.

In FLUKA simulation, the beam is lost in Front end, including at safe point (5 mm of the aperture edge), or before safe point (scraping upstream beam pipes); FLUKA simulations included the following injected beam mis-steering scenarios:

Scenario1: Beam lost at 5 mm outboard side from the photon shutter collimator aperture edge.
Scenario2: Beam lost at 5 mm inboard side from the photon shutter collimator aperture edge.
Scenario3: Beam scraping outboard beam pipe 40 cm upstream of photon shutter collimator.
Scenario4: Beam scraping inboard beam pipe 40 cm upstream of photon shutter collimator.

The dose rates from the above four mis-steering cases are summarized in Table 4 and in typical FLUKA dose plots of scenario 4 shown in Figure 4.

Table 4 Dose rates from different mis-steering cases (injected beam lost in front end)

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Injection rate 15 nC/s	FOE downstream wall	500	1000	700	2000
	FOE lateral wall	40	50	100	100
	SR @ corner	800	800	2500	1800

- *Note: in reality, the dose rate on FOE downstream wall will be much lower than Table 5 due to the collimators and secondary gas bremsstrahlung (SGB) shields in FOE, which are not included in FLUKA model for top off calculation.*

As shown in Table 4, scenario 4 gives the largest dose rates around FOE. Figure 5 shows FLUKA dose rate distribution: beam scraping inboard beam pipe 40 cm upstream of C2.

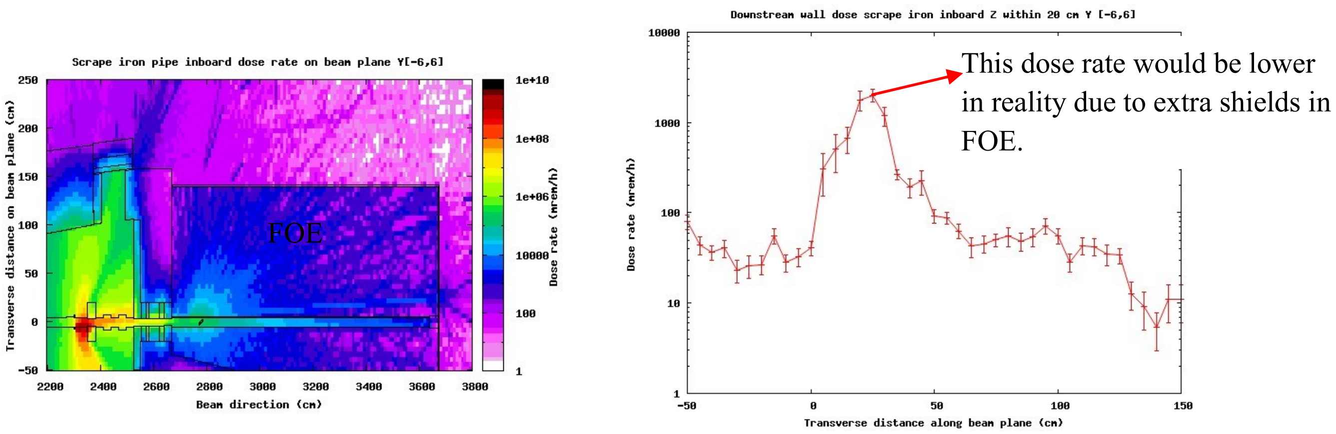

Figure 3. Dose rate on beam plane when electron beam scrapes iron pipe 40 cm upstream of photon shutter collimator at 15 nC/s

Note the above calculation doesn't take credit of GB collimators and SGB shields in FOE, which will reduce the dose rate significantly in reality.

3. Conclusions

The dose rates were studied for 3 GeV, 15 nC/s electron beam mis-steered at different locations during top off operation. The dose rates in all occupied areas are less than 2000 mrem/h for possible mis-steering scenarios (i.e. electron beam track > 5 mm of C2 aperture edge), except at the door seam of storage ring ratchet wall (2500 mrem/h). Considering the injection rate interlocked to lower than 45 nC/min during top-off operation, the maximum dose rate in the occupied areas is ~ 100 mrem/h.

Acknowledgements

Thank Steve Kramer for sharing his Storage Ring FLUKA model, which is used as a geometry base for this top off FLUKA calculation. This manuscript has been authored by employees of Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy. The

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