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Monte Carlo simulation study to calculate radiation dose under beam-loss scenarios in *Top-up* operation mode for HXMA beamline at Canadian Light Source

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HIGHLIGHTS

- Monte Carlo method was used to calculate radiation dose for a beamline at Canadian Light Source.
- Three possible beam loss scenarios were studied.
- The predicted worst dose was found below the regulatory dose limit.

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ABSTRACT

This study was conducted to analyze the radiological impact in the experimental area of the Hard X-Ray beamline at Canadian Light Source under beam loss scenario during *Top-up* injection. The radiation doses were calculated using Monte Carlo code: *FLUKA*. The physical size, location, and material of the beamline components were adopted from the technical drawings and were incorporated in the *FLUKA* model. Three (03) beam loss scenarios were simulated: (i) Beam was miss-steered in the storage ring (ii) Beam hit misaligned components inside the ring and (iii) Beam was lost inside the primary optical enclosure (*POE*). Total ambient dose was calculated at several *observation points* for each scenario considering the injected beam as the primary source. The results and impacts were discussed.

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1. Introduction

The Canadian Light Source Inc. (*CLS*) consists of a 250 MeV electron linac, a booster to ramp the beam to 2.9 GeV, and the main storage ring which is designed to operate at an energy of 2.9 GeV at beam currents up to 500 mA. In the storage ring (*SR*), the beam current continuously decays due to a number of beam loss mechanisms Nishimura and Bailey 2009. In the conventional mode of operation (called *decay mode*), the user beam time is interrupted at least two times a day to inject electrons into the storage ring. Alternatively, *Top-up* injection mode is adopted in many synchrotron facilities where small charge of electrons are frequently (e.g. every minute) injected to the storage ring [Joseph et al., 2007; Wang et al., 2007; Job and Casey 2011; Nishimura and Bailey 2009].

There is a qualitative difference between two modes of operation. In *decay mode*, the safety shutters for each beamline remain closed during the injection process. This safety feature ensures that the injected beam or any secondary radiation can not exit the shielded wall that may cause unacceptable radiological hazard in the experimental area. In contrast to decay mode of operation, the *Top-up* mode of operation, which requires the safety shutters to remain open, must include additional safety and control measures to ensure adequate protection to workers and users on the experimental floor [Nishimura and Bailey 2009].

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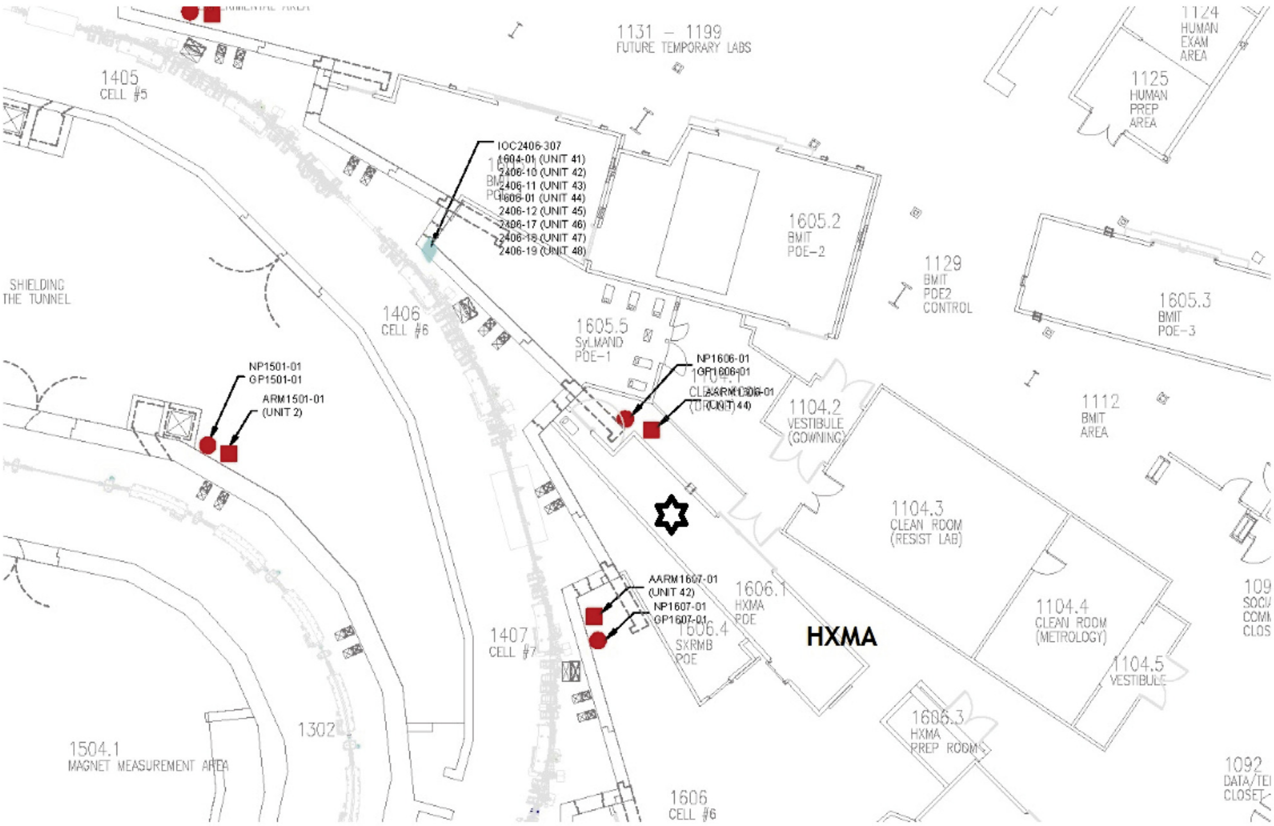

Fig. 1. CAD view of HXMA beamline and surrounding area.

2. Safety considerations and radiological impacts to implement *Top-up* at *CLS*

CLS plans to implement *Top-up* mode of operation with a single shot of electrons in every few minutes. *Top-up* hazard and risk analyses were performed at *CLS* to identify the potential hazards and risks relating to this operation and recommendations were provided to mitigate the hazards. To enhance the overall safety of the proposed operation, *CLS* considered several safeguards to be in place prior to implement the *Top-up* mode of operation. Some of the safety features were as follows:

(i) *Stored current monitor*: This system ensures that *Top-up* injection only proceeds if there is a minimum amount of stored beam already present in the storage ring thereby the dipole and quadrupole magnets are operating at their nominal values.
(ii) *Efficiency monitor*: This system monitors the amount of charge successfully extracted from the booster to the storage ring during each injection. This safety feature can be used to terminate injection if low injection efficiency persists.
(iii) *Electron beam Energy Control*: This control system monitors the power supply currents for the *BTS* (booster to storage) transfer line and the storage ring. This system ensures an energy match between the stored and injected beam.

In addition to above safeguards, the bad orbit protection system prevents miss-aligned stored beam, that can cause a damage to the vacuum chamber by producing errant synchrotron radiation. The Active Area Radiation Monitoring stations (*AARMs*) are used at *CLS* to monitor the radiation dose level in the user area of each beam line. To enhance the safety for *Top-up* operation, additional *AARMs* will be in place for each beamline to monitor the dose levels in the experimental area.

Particle tracking simulation-studies were conducted at *CLS* and other facilities, e.g. NSLS-II, ALS [NSLS 2010; Nishimura and Bailey 2009]. All these studies established that miss-steered or errant injected electron beam can be stopped by the narrow aperture of a mask or a collimator at the beamline front end. However, the loss of an injected electron-beam in the front end of the beamline causes a shower which may result elevated radiation level in the experimental area when the front end safety shutter is open.

The study conducted at NSLS-II indicated that the errant injected electron beam can be confined to the front end inside the storage ring only by an appropriate interlocking of the storage ring magnetic lattice [Job and Casey 2011]. A failure of the storage ring magnet could lead to an unsafe injection of electrons. In an unlikely event, the injected beam may be conveyed down to the primary optical enclosure (*POE*) due to redundant interlock failure [Job and Casey 2011]. The *CLS* review committee identified this event as *improbable* in the report prepared on *Top-up* hazard and risk analysis.

Considering the hazard of possible beam loss during *Top-up* injection with safety shutter open, a Monte Carlo study was performed to calculate the radiation dose in the user area. Hard X-ray Microanalysis (HXMA) beamline was modeled for particle transport calculation and radiation dose was calculated at several *observation points* outside of the *POE* under 3 beam loss scenarios (see details in section 4.3). This paper reports the results obtained from this study.

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