Preliminary Supplemental Shielding Calculation of BMIT SOE-1 at the Canadian Light Source

Bassey Bassey[1,*], Abdallah Abueidda[2], Grant Cubbon[3], Darin Street[3], Asm Sabbir Ahmed[3], Tomasz Wysokinski[3], George Belev[3], Dean Chapman[4]
[1]Department of Physics & Engineering Physics, University of Saskatchewan, Saskatoon, SK, Canada
[2]Division of Biomedical Engineering, University of Saskatchewan, Saskatoon, SK, Canada
[3]Canadian Light Source, Saskatoon, SK, Canada
[4]Department of Anatomy & Cell Biology, University of Saskatchewan, Saskatoon, SK, Canada
* Corresponding author. Email address: bassey.bassey@usask.ca

Abstract

High field superconducting wiggler beamlines present shielding challenges due to the high critical energy of the synchrotron spectrum. Recently, an unexpected, but predictable, weakness in the secondary optical enclosure (SOE-1) was discovered on the BioMedical Imaging and Therapy (BMIT) insertion device (ID) beamline 05ID-2 at the Canadian Light Source (CLS). SOE-1, a monochromatic beam hutch, is the fourth and last hutch on the BMIT beamline 05ID-2. The monochromatic beam in SOE-1 is supplied by three monochromators housed in an upstream primary optical enclosure (POE-3), the third hutch on BMIT 05ID-2 beamline. The monochromators are a computed tomography (CT) monochromator, diffraction enhanced imaging (DEI) monochromator and the K-Edge subtraction (KES) monochromator. The present shielding of SOE-1 is based on a shielding calculation against: scattered monochromatic beam (fundamental and harmonics) from the CT or KES monochromator; direct CT beam; and KES beam on the downstream wall of the SOE-1. Radiation levels above the expected were measured recently at the downstream end of SOE-1. This increment in radiation levels is attributed to scattered white beam by the KES monochromator (a single crystal monochromator) in POE-3 into SOE-1, and hence the reason for this supplemental shielding calculation. Though this is peculiar to the BMIT beamline 05ID-2, it may not be uncommon for beamlines that use single crystal monochromators.

Preliminary calculations of the level of expected leakage due to the scattered white beam arriving on the downstream wall of the SOE-1 will be presented and compared with recent measurements of the same as well as the supplemental shielding that will reduce the leakage to less than 1microSv/hr as required at the CLS.

Keywords: Shielding, Monochromator, Secondary optical enclosure

1. Introduction

The BioMedical Imaging and Therapy (BMIT) facility at the Canadian Light Source (CLS) is a world class facility that has unique synchrotron-specific imaging and therapy capabilities [1]. There are two beamlines at the BMIT facility, and are grouped under Phase II beamlines at the CLS [2]: the bend magnet (BM) beamline 05B1-1, which became operational in 2011 [1], and the insertion device (ID) beamline 05ID-2, under commissioning. At the BMIT facility, two hutches, the primary optical enclosure (POE-2) and secondary optical enclosure (SOE-1), are designated for experiments. The BM beamline shares POE-2 with the ID beamline for experiments when the ID beamline is in therapy mode but has exclusive use of POE-2 when the ID beamline is in imaging mode in SOE-1[3] . The ID is a multi-pole superconducting wiggler; its specifications are as given in Table 1[1].

As part of the commissioning process of the ID beamline, a radiation survey of the ID beamline was undertaken over the period of August to October, 2013. The results of the survey showed an unexpected, but predictable, weakness in SOE-1; radiation levels above the expected were measured at the downstream end (Back Wall) of SOE-1. The SOE-1, a monochromatic beam experimental hutch, is the fourth and last hutch on the ID beamline (Fig. 1). The monochromatic beam in SOE-1 is supplied by three monochromators housed in an upstream primary optical enclosure (POE-3), the third

hutch on BMIT ID beamline[4]. The monochromators are a computed tomography (CT) monochromator, diffraction enhanced imaging (DEI) monochromator and the K-Edge subtraction (KES) monochromator. The length, width and height of SOE-1 are 10.53 m, 6 m, and 5 m respectively. The present shielding of SOE-1 is based on a shielding calculation against:

- scattered monochromatic beam (fundamental and harmonics) from the CT or KES monochromator;
- direct CT beam;
- KES beam on the downstream wall of the SOE-1.

The increment in radiation levels at the Back Wall of SOE-1is attributed to scattered white beam by the KES monochromator (a single crystal monochromator) in POE-3 into SOE-1, and hence the reason for this supplemental shielding calculation. Though this is peculiar to the BMIT ID beamline, it may not be uncommon for beamlines that use single crystal monochromators.

We present preliminary calculations of the level of expected leakage due to the scattered white beam arriving on the Back Wall of the SOE-1 as well as the supplemental shielding that will reduce the leakage to less than 1microSv/hr as required at the CLS. Also presented is a comparison of the calculations with measurements that were made.

Table 1 Wiggler Specifications

Parameter	Value	Unit
Magnetic Field, B_0 (max)	4.3	T
Critical Energy, E_C (max)	24	keV
Period Length, λ_0	4.8	cm
Deflection Parameter, K (max)	19.3	K/γ ~3.4 mrad
Photon Range	0.1-0.6	Å
Energy Range	20-100+	keV
N (full + half field)	25 + 2	poles
Peak Power Density [a]	40.1	W/mm^2

[a] @ 26.5 meters (500 mA, 2.9 GeV)

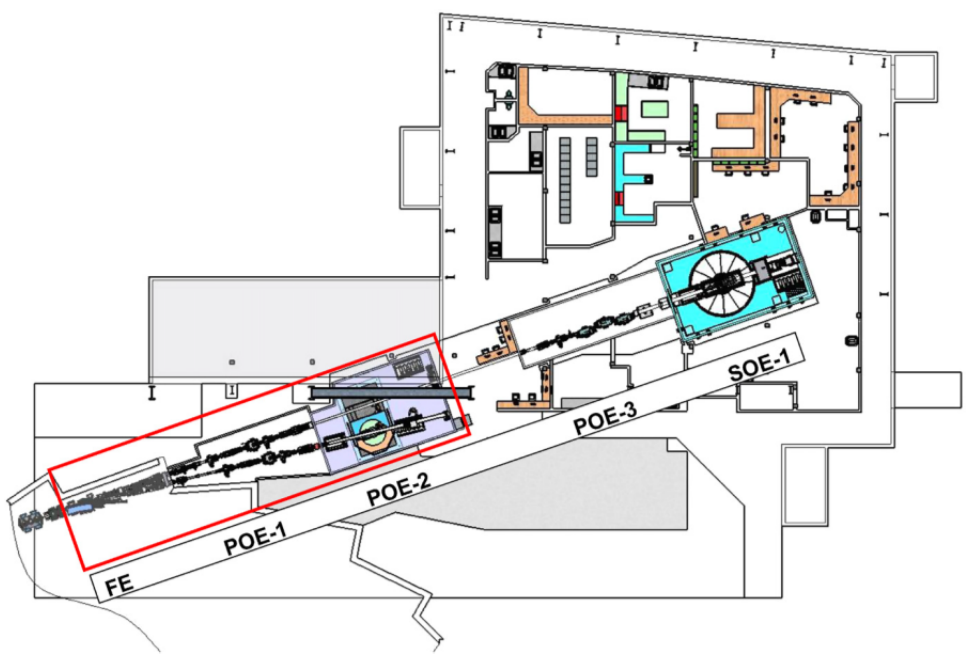

Fig.1. View of BMIT Facility and hutches

2. SOE-1 shielding at time of radiation survey

As previously stated, the shielding of SOE-1 was done against scattered and direct monochromatic beams from the CT, DEI and KES monochromators housed in POE-3. The shielding of SOE-1 at the time of the radiation survey is as given in Table 2.

Table 2. SOE-1 Shielding

Side Wall Thickness		Roof Wall Thickness		Back Wall Thickness	
Fe (mm)	Pb (mm)	Fe (mm)	Pb (mm)	Fe (mm)	Pb (mm)
6.35	8.00	6.35	8.00	6.35	8.00

The Back Wall of SOE-1 has an additional local shielding to stop the direct monochromatic beams from the CT and KES monochromators [5]: 35mm thick Pb at beam height ± 0.25 m above and below with a lateral width of 0.75 m centered on the ID beamline center; 30mm thick Pb at beam height ± 1 m above and below with a lateral (horizontal) width of 0.75 high 0.75m wide strip centered on the ID beamline centerline; 15mm thick of the same lateral width extending to the floor and above the 30 mm thick Pb to a height of 3.9 m from experimental floor.

3. Measurements and Calculations

3.1 Measurements

Radiation testing for the BMIT SOE shielding was completed using the KES monochromator. Since the KES monochromator is a single crystal monochromator, fewer photons are lost and the photon flux delivered to the SOE is greater than that from a double crystal monochromator. The tests were completed at different energies. The vertical range for the KES Mono is shown in Fig. 2. No radiation above normal background radiation was found on the SOE side walls or in the area above the SOE-1.

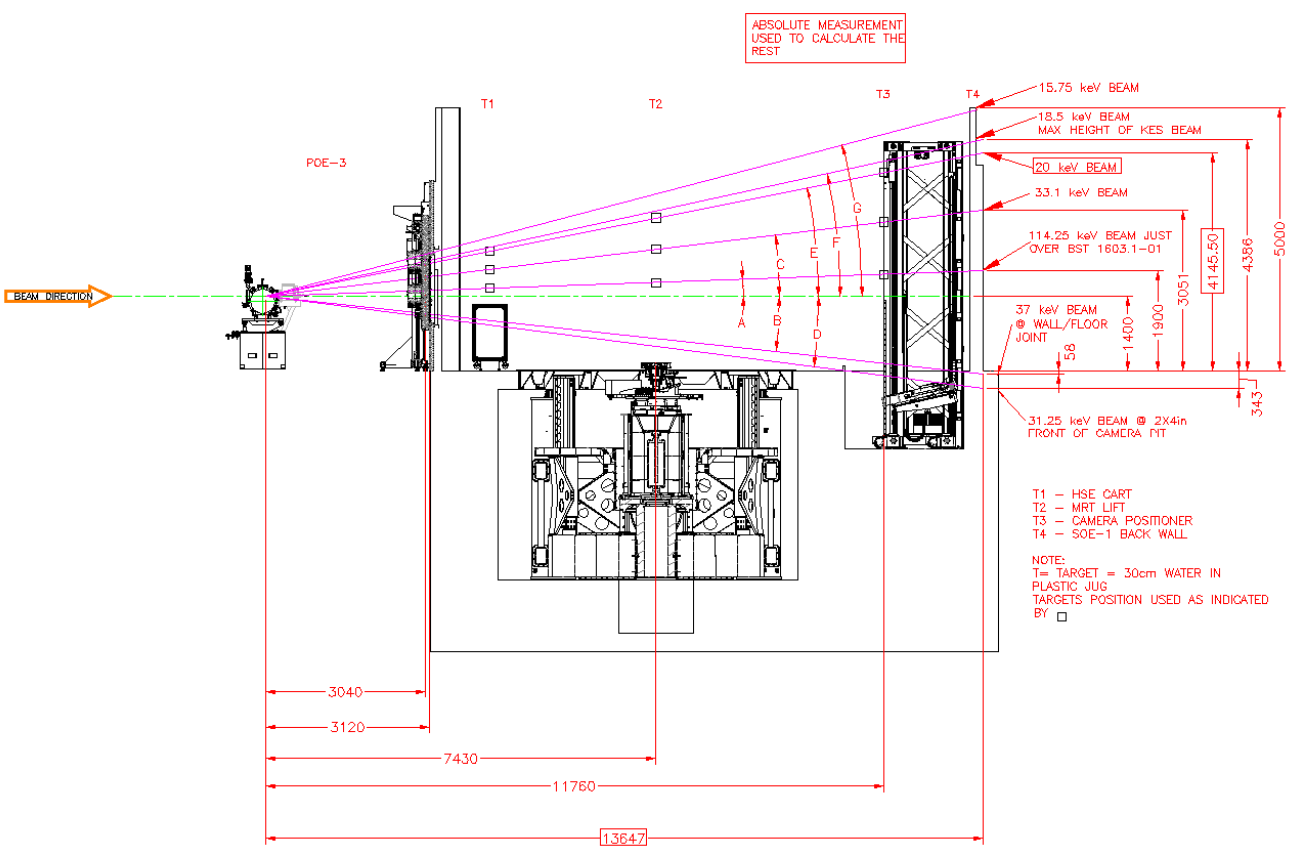

Fig. 2. Vertical range for various KES Monochromator Energies.

As the angle of the beam from the KES monochromator was changed, radiation was detected outside the SOE-1 Back Wall shielding between the edge of the local lead shielding and the support beam of the camera positioner, and also above the extra vertical shielding. The maximum angle of the beam attainable did not allow the beam to directly strike the ceiling of the enclosure. The ring current and the wiggler filed at the time of the radiation testing were 4.1 T and 0.250 A, respectively. The maximum radiation level measured was 1.46 μSv/hr. The results of the radiation testing are as shown in Table 3.

Table 3. Radiation Measurements at BMIT SOE-1 Back Wall

Beam Energy (keV)	Vertical Position Above the Floor (m)	Dose Rate (μSv/hr)
20	4.00 (i.e., 2.6 above beam)	1.46 ± 20%
33	3.15 (i.e., 1.75 above beam)	0.40 ± 20%
112	1.90 (i.e., 0.5 above beam)	0.66 ± 20%

3.2 Calculations

The program used for calculation of the radiation dose and required shielding is written in Interactive Data Language (IDL), and is similar to other programs such as STACK 8-partly derived from the program PHOTON. The written program can also be used to calculate the radiation dose to a subject within the hutch during experiments. In the calculations, the following approximations are made:

- only Compton scattering is responsible for beam scattering;
- the incident beam is assumed to be scattered from point source rather than an extended source;
- only single scattering is considered- dose contribution from re-scattering is not considered (i.e. build-up effect is ignored).

We calculated the level of expected leakage due to the scattered white beam arriving on the SOE-1 Back Wall -1 at the same conditions (wiggler field of 4.1 T and ring current of 0.250 A) and positions the measurements were made. The scatter material used was Si with a scatter length of 0.2 cm. A comparison of the calculated and measured values is as shown in Table 4.

Table 4. A comparison of measured and calculated dose rate values at BMIT SOE-1 Back Wall

Beam Energy (keV)	Vertical Position Above the Floor (m)	Dose Rate (μSv/hr)	Dose Rate (μSv/hr)
20	4.00 (i.e., 2.6 above beam)	1.46 ± 20%	1.36
33	3.15 (i.e., 1.75 above beam)	0.40 ± 20%	0.62
112	1.90 (i.e., 0.5 above beam)	0.66 ± 20%	0.68

The calculations for the supplemental shielding required to reduce the leakage to less than 1micro Sv/hr as required at the CLS were done using the following input parameters: scatter material (Si), scatter length (0.50cm), Wiggler field (4.3 T), Ring current (0.500 A), and 0.635 cm of Fe. The results of these calculations are as shown in Table 5.

Table 5. Results of calculations for supplemental shielding of SOE-1 Back Wall

Lead Thickness (cm)	Maximum Dose Rate (μSv/hr)
0.8	14.38
1.0	4.93
1.2	1.90
1.4	0.79
1.6	0.36

The SOE-1 Back Wall, aside the local shielding, is shielded with 0.635 cm thick Fe and 0.8 cm thick Pb. Based on this shielding, the expected leakage due to the scattered white beam arriving on the SOE-1 Back Wall is 14.38 μSv/hr as shown in Table 5. By using a Si material of scatter length 0.5cm in our calculations, we were being very conservative.

4. Conclusion and Recommendation

Based on our calculations, a lead thickness of 1.4 cm reduced the dose rate at BMIT SOE-1 Back Wall to the target value of less than 1μSv/hr. Since there is currently 0.8 cm of lead at the SOE-1 Back Wall, we recommend an additional 0.8 cm of lead to be added to it. This will completely stopped the leakage of the white beam, through the SOE 1 back wall, scattered into SOE-1by the KES monochromator in POE-3.

Acknowledgements

We acknowledge the support from the National Sciences and Engineering Research Council of Canada, the Social Sciences and Humanities Research Council of Canada, the Canadian Institute of Health Research Training grant in Health Research Using Synchrotron Techniques, the University of Saskatchewan, and the Akwa Ibom State University.

References

[1] T W Wysokinski DC, G Adams, M Renier, P Suortti, and W Thomlinson (2013). Beamlines of the Biomedical Imaging and Therapy Facility at the Canadian Light Source - Part 2. *Journal of Physics: Conference Series. 425 Part 7.*

[2] Asai J, Wysokinski TW, Smith S, Chapman D (2008). Radiological considerations for POE-1 photon shutters, collimators and beam stops of the Biomedical Imaging and Therapy beamline at the Canadian Light Source. *Nuclear Instruments and Methods in Physics Research A, 585, 1-11.*

[3] Wysokinski TW, Chapman D, Adams G, Renier M, Suortti P, Thomlinson W (2007), Beamlines of the biomedical imaging and therapy facility at the Canadian light source-Part 1. *Nuclear Instruments and Methods in Physics Research A, 582, 73-6.*

[4] Asai J, Wysokinski TW, Chapman D, Mullin C (2011). Radiation shielding study against gas bremsstrahlung for the BMIT POE3 at the Canadian light source. *Radiation Physics and Chemistry, 80, 716-722.*

[5] Chapman Dean (2007). CLSI Document No. 26.2.35.1- Rev. 0