

Dose rate considerations for the BMIT POE3 at the Canadian Light Source

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Abstract

A dose rate study is undertaken when gas bremsstrahlung strikes a monochromator, a copper absorber and a tungsten beam stop in the third primary optical enclosure (POE3) of the BioMedical Imaging and Therapy (BMIT) insertion device (ID) beamline. In the POE3, computed tomography, diffraction enhanced imaging and K-Edge subtraction monochromators are housed to conduct various diagnostic and therapeutic studies. The safety features of this beamline must be examined with great care, as this multipurpose beamline is intended for use on animals and humans.

In the POE3 a tungsten beam stop, two safety shutters, and a lead movable wall are placed for the safe operation of the BMIT beamline. However, for one particular usage of the monochromator, bremsstrahlung and X-rays propagate closely together until the former is stopped by the tungsten beam stop while the safety shutters remain open to allow the passage of the latter to the experimental area. It is thus imperative to know the anticipated dose rate around the POE3, especially behind the back wall. The dose rate estimates are presented based on a realistic model of the POE3 with its safety features.

1. Introduction

The Canadian Light Source (CLS) is a 2.9 GeV, 500 mA, third-generation synchrotron facility. High-energy electrons interacting with residual molecules in the vacuum chamber generate the gas bremsstrahlung. When produced in the ID straight section, highly forward-peaked bremsstrahlung may travel with synchrotron radiation to the experimental area. The purpose of this report is to assess the radiation levels when bremsstrahlung strikes a beam stop placed in the POE3 of the BMIT ID beamline.

The BMIT-ID beamline [1] is one of the Phase II beamlines being built at present. The POE3 houses three monochromators, listed in order of the location from upstream: the computed tomography (CT) monochromator, the diffraction enhanced imaging (DEI) monochromator and the K-Edge subtraction (KES) monochromator. The bremsstrahlung beam stop is placed outside the KES monochromator. This beam stop must be small enough vertically for the KES beam to be deflected above or below and for the CT and DEI beam to pass over the top of the beam stop. However, the beam stop must be thick enough to stop the bremsstrahlung. At present the vertical distance between the CT and the bremsstrahlung is 1.5 cm.

The beam from the monochromator propagates toward the 13 cm-thick lead movable wall to which two safety shutters are attached. There are two holes on the movable wall for the higher and the lower energy X rays of the KES. When the DEI or CT is in operation, the movable wall is shifted upward or downward so that the KES X-rays are prohibited from entering the experimental hall as shown in Fig.1. It is noted that in this situation two safety shutters are open.

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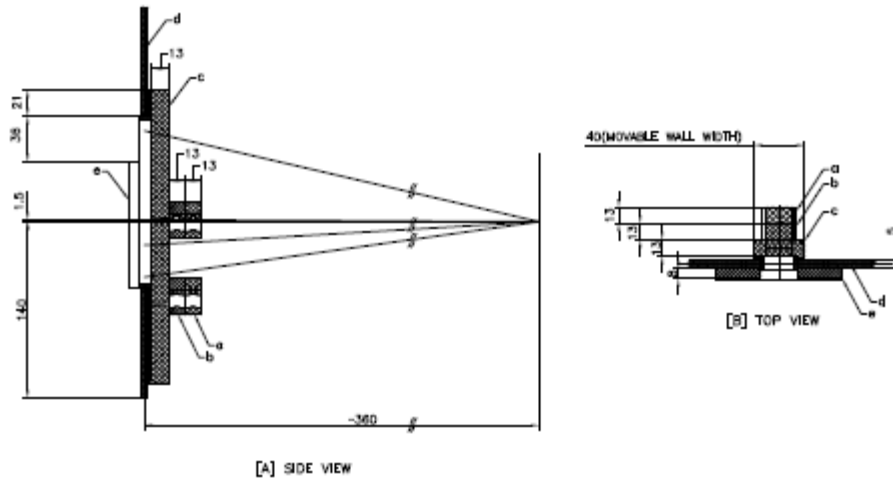


Fig.1 - Shielding setting for the CT operation. Safety shutters are in open position.

a) safety shutter SS1, b) safety shutter SS2, c) lead movable wall, d) lead back wall and e) lead centre reinforcement.
 Note the small opening on the lead movable wall. The length is in units of cm.

If various possible settings are considered, the worst case scenario might be that the CT rays are passing over the bremsstrahlung stop which is only 1.5 cm above the top surface. These X-rays propagate through the movable wall to the experimental area, whereas the bremsstrahlung is stopped by the beam stop. This bremsstrahlung stop consists of a copper absorber followed by a tungsten beam stop. The dimension of the tungsten stop is (X(width), Y(height), Z(thickness))=(21.4, 1.8, 18.0) in units of cm. The hole of the movable wall has a dimension (X, Y)=(21.4, 3.0). Hence there exists an open area (X, Y)=(21.4, 0.6) over the top surface of the beam stop when the CT rays are in use. The radiation originates from the copper absorber tungsten unit and could travel through the opening to the experimental floor.

Although the optical elements and the movable lead wall in the POE3 are yet to be installed, the aim of this paper is to estimate the expected dose rates behind the back wall of the POE3. These assessments will allow for safe operation of the BMIT beamline, as this multipurpose beamline is intended for use on animals and humans.

In Section 2, the model of the POE3 structure and the beam stops are constructed as close as possible to the planned construction of the POE3. Section 3 gives the dose rates estimate behind the back wall. Section 4 gives the conclusion.

2. Model and parameters used for dose rate estimates

The inside width, height and length of the POE3 are taken as 224 cm, 360 cm and 360 cm, respectively. The elements considered from upstream in the POE3 include a silicon crystal, a copper absorber followed by a tungsten stop. There are two lead safety shutters (SS1 and SS2) which are attached to the lead movable wall. The back wall is a 5 cm-thick lead wall reinforced by an 8 cm-thick lead centre piece. The side is a 3 cm-thick lead wall and the roof is constructed by lead 1 cm-thick. The lead wall thicknesses have been determined by our previous investigations [2, 3]. A schematic view of the POE3 and elements considered in it are given in Fig.2. The bremsstrahlung direction defines the Z axis which is 140 cm up from the floor. The bremsstrahlung entrance to the POE3 is taken as the coordinate origin (X, Y, Z)=(0, 0, 0) where the silicon crystal is placed. The number of photons (NOFPs) produced is found to be 3.71×10^9 /h. A more detailed account is found in our previous report [2].

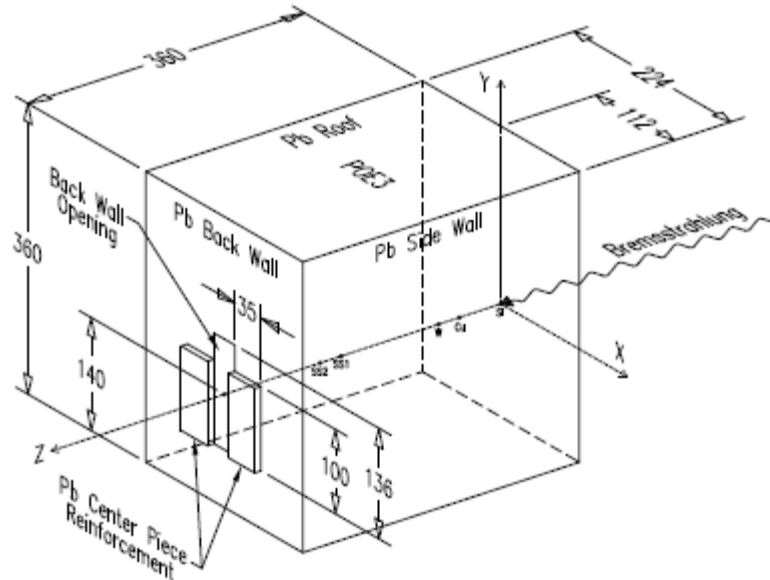


Fig.2 - Schematic view of POE3 and its elements considered in simulations. The movable lead wall placed inside the back wall is not shown for clarity. All units are in cm but not to scale.

The bremsstrahlung produced in the ID straight section propagates with the synchrotron radiation and strikes the thin silicon crystal and the copper absorber-tungsten beam stop, which are 1 cm, 3 cm and 18 cm in thickness, respectively. In the following, the dimensions (X, Y, Z) of all elements and the upstream position (in Z) of each element are summarized. We are only interested in the case where the lead safety shutters (SS1 and SS2) are open. Hence, the closest distances from the beam axis to the safety shutter (in Y) are also given. The negative sign indicates the Y position is below the beam axis. Units are in cm:

- Silicon crystal: (16.0, 2.0, 1.0) located at Z=0.0
- Copper absorber: (21.4, 1.60, 3.0) located at Z=37.0
- Tungsten beam stop: (21.4, 1.80, 18.0) located at Z=40.0
- Lead upper safety shutter 1: (21.4, 15.0, 13.0) located at Z=321 and Y=2.50
- Lead lower safety shutter 1: (21.4, 4.7, 13.0) located at Z=321 and Y=-7.80
- Lead safety shutter 2: same as the safety shutter 1 but located at Z=334.0
- Lead Movable wall: (40.0, 204.0, 13.0) located at Z=347.0
- Lead back wall: (224.0, 360.0, 5.0) located at Z=360.0
- Lead centre piece for the reinforcement: (100.0, 35.0, 8.0) located at Z=365.0 for each side on the X axis.

A schematic view of the movable wall and back wall seen from upstream is given in Fig. 3. A square cornered by 5, 6, 7 and 8 is the outer edge of the movable wall (M) and the area inside the square delineated by 1, 2, 3 and 4 is a hole in the movable wall. Similarly, a square cornered by 13, 14, 15 and 16 is the outer edge of the back wall (B) and a square formed by 9, 10, 11 and 12 is a hole in the back wall. The shaded area indicates the shadow image of the tungsten stop placed near the origin. Scales on the right and the bottom are in units of cm. The beam is 140 cm high from the floor. As shown, the movable wall has a hole (X, Y)=(21.4, 3.0) centred at the beam axis and the back wall has a similar hole of size (X, Y)=(30.0, 136.0). The last element, the lead centre piece is installed for additional shielding, covering from X=15 to 50 cm and -15 to -50 cm. (See also Fig.1). The back wall, side wall and the roof of the POE3 are enclosed by a water phantom in which the energy deposition per unit mass is estimated by the EGS4 code [4]. The thickness of the water phantom is assumed to be 1 cm throughout this article, unless otherwise specified.

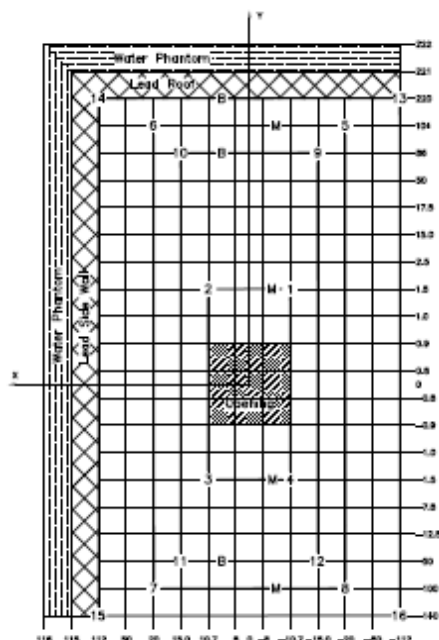


Fig.3 - Schematic view of the movable wall (M) and the back wall (B) seen from upstream. The shaded area indicates the shadow of the tungsten stop placed near the origin. The X and Y coordinates are in units of cm but not to scale.

3. Dose rate distribution immediately behind the back wall

The bremsstrahlung striking the thin silicon crystal (1.0 cm) most likely penetrates through it to hit the copper and tungsten unit causing the cascade showers. The tungsten thickness is 18 cm and the length of the top surface from the beam axis is only 0.9 cm, which is the height necessary for the CT beam clearance.

Looking through the components from upstream, there is an unobstructed area that is open continuously to the experimental area. Hence, it is possible that the radiation higher than the regulatory limit of $5\mu\text{Sv/h}$ will be present behind the back wall of the POE3. Specifically, the area exposed is that which is lined by a top surface of the tungsten stop ($Y=0.9$) and the movable wall opening upper edge ($Y=1.5$) over the entire movable wall opening area in the X direction ($X=-10.7$ to $+10.7$) as shown in Fig. 4. In Fig.4, the centre of Region 1 is the beam axis (through the paper), and after passing through the tungsten beam stop (X, Y, Z)=(21.4, 1.8, 18.0), this area is unshielded. Region 3 is also treated in the same way. As mentioned earlier these two Regions are shadowed by the tungsten stop. Regions 2, 4 are not covered by any shielding materials. Regions 5, 6, 7, 8 and 9 are shielded by the 13 cm-thick lead movable wall. Because of the symmetrical geometry with respect to the Z axis, Regions considered above may suffice to map out the dose rates of interest.

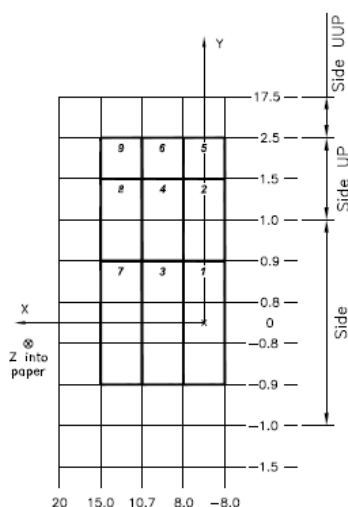


Fig.4 - Regions of interest in water phantom for dose estimates behind the back wall when looking through the POE3 from upstream. Region 1 and 3 are shadowed by the tungsten stop, which is placed near the origin. Region 2 and 4 are not covered by any shield. Regions 5, 6, 7, 8 and 9 are shielded by the movable wall. Coordinates are in cm but not to scale.

Our main objective in this section is to assess the dose rate for Regions 2 and 4 as well as for Regions 1 and 3. These Regions are exposed to radiation since no shield is placed to cover these areas. To estimate the dose rate, a 5 cm-thick water phantom is set immediately behind the lead centre reinforcement. The dose rate is calculated in a 1 cm interval in the water phantom to see how it varies with the water depth.

The maximum dose rate is found in Region 1 and the results are shown in Fig.5 as a function of the water depth. The maximum takes the value $0.505 \pm 0.040 \mu\text{Sv/h}$ between 1 and 2 cm in the water phantom. Hence, the dose rate behind the back wall is well under the regulatory limit of $5 \mu\text{Sv/h}$.

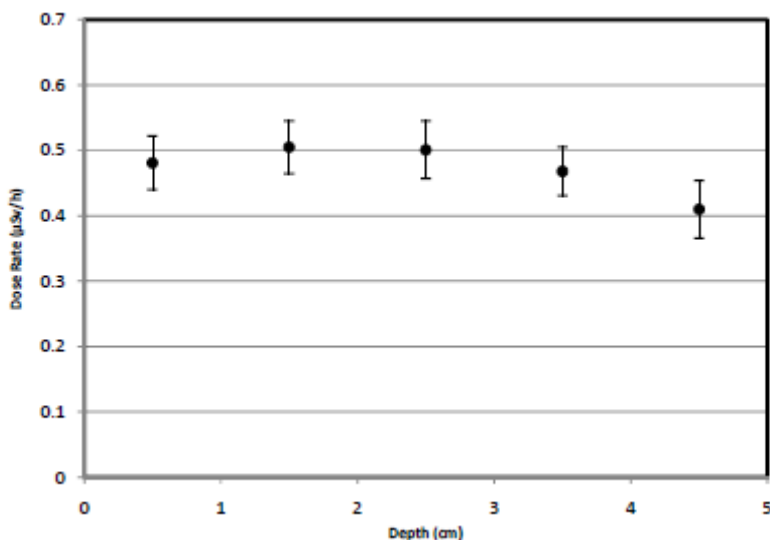


Fig.5 - Dose rate in Region 1 as a function of depth behind the back wall.

4. Conclusion

Radiation dose studies are conducted for the POE3 of the BMIT ID beamline. The POE houses three monochromators for CT, DEI and KES studies. Since this multi-purpose beamline is intended for animals and humans, the safety against radiation must be considered thoroughly. In the POE3 various safety features such as a tungsten beam stop, two safety shutters, a lead movable wall and a lead centre reinforcement are incorporated. However, when the CT or DEI are in use, two safety shutters must remain open, prompting concern regarding radiation exposure and a subsequent examination of the dose rate around the POE..

When bremsstrahlung strikes the copper/tungsten unit, the dose rate behind the back wall of the POE3 is found to be well below the regulatory limit of $5 \mu\text{Sv/h}$. The tungsten beam stop, W(21.4, 1.8, 18.0) is capable of containing the radiation in the POE3 as far as the back wall is concerned.

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