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# Radiological considerations for POE-1 photon shutters, collimators and beam stops of the Biomedical Imaging and Therapy beamline at the Canadian Light Source

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**Abstract**

A study of radiation levels due to primary and secondary gas bremsstrahlung is carried out for the BioMedical Imaging and Therapy (BMIT) beamline at the Canadian Light Source (CLS). The BMIT beamline, being built at present, is a major research and diagnostic tool for X-ray imaging and X-ray radiation therapy for animals and humans. For the BMIT beamline to be as flexible as possible, a movable tungsten collimator is designed. This can move vertically and assumes two positions; up and down. The BMIT beamline is, thus, able to perform two modes of operation: one white beam, the other monochromatic. Gas bremsstrahlung produced in the vacuum chamber propagates with synchrotron radiation and may enter the imaging or therapy hutch. In this study, the dose behind the collimator is investigated in each mode by assessing the energy deposition in a water phantom that surrounds the entire copper shutter-tungsten collimator unit. When estimating the dose, particular attention is given to the opening area of the collimator, since this passage leads to the imaging or therapy hutch. Also examined are the doses when a tungsten safety shutter is closed.


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## 1. Introduction

The Canadian Light Source (CLS) is a 2.9 GeV, 500 mA, third generation synchrotron facility. The CLS is equipped with seven Phase I beamlines, which are actively engaged in experiments or beamline commissioning with a reduced current, typically up to 250 mA. Six more beamlines are being built at present; one of these Phase II beamlines is the BioMedical Imaging and Therapy (BMIT) beamline [1,2], which utilizes a super-conducting insertion device (ID). The BMIT beamline is anticipated to provide a major research and diagnostic tool for X-ray imaging and X-ray radiation therapy for animals and humans.

High-intensity and very forward-peaked gas bremsstrahlung is generated by interaction of circulating electrons with the residual molecules in the ring vacuum chamber. This primary gas bremsstrahlung is produced all around the storage ring, but it presents a particular problem for the IDs. Gas bremsstrahlung produced in the ID straight section propagates with synchrotron radiation (white beam) into the Primary Optical Enclosure (POE-1), where each optical component, such as windows, slits, monochromators and stops, poses a potential scatterer of the primary gas bremsstrahlung. Radiation from these components are referred to as secondary gas bremsstrahlung in this study.

It is imperative to know the radiation levels due to gas bremsstrahlung, both primary and secondary, when passing through a photon shutter followed by an in-vacuum tungsten collimator unit employed in the BMIT

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beamline. When the collimator is in the down-position, it allows the monochromatic beam (hereafter abbreviated mono beam) to pass through, and stops the white beam. When in the up-position, the collimator stops the mono beam and only the white beam is guided into the experimental hutch, which we define as either the imaging or therapy hutch. When both beams are to be blocked, a tungsten safety shutter is actuated and placed between the photon shutter and the in-vacuum collimator. All these components are installed in the POE-1. This shutter–collimator unit is viewed as the first of its kind designed specifically for the use for animals and humans.

In this work, radiation due to primary and secondary gas bremsstrahlung behind the tungsten collimator placed in the BMIT beamline is investigated by Monte Carlo simulations. Based upon the various objectives of the BMIT beamline, the dose and dose rate are assessed under various conditions, such as the mono beam with or without a photon shutter, or the white beam with or without a photon shutter. By these assessments, our aim is to provide some reference dose and dose rate due to gas bremsstrahlung in the operation of the imaging and therapy beamline. These calculations of dose contributions from radiation sources other than synchrotron radiation will be most likely required as plans are developed for human research. There are plans for the use of both monochromatic beam and filtered white beam studies in animal systems that may translate to human studies. Earlier studies of the gas bremsstrahlung drove the design of the shutter and collimator arrangement to minimize contributions to the dose and dose rate from this source of radiation.

In Section 2, the gas bremsstrahlung production rate, the NOFPs/h (the number of photons per hour) employed for the ID beamlines is discussed. In Section 3, the geometry used in the Monte Carlo, EGS4 [3] simulations is stated. Section 4 gives the results of the simulations for the mono beam and Section 5 is for the white beam. Section 6 discusses a case where a tungsten safety shutter is activated. Sections 4–6 deal with the dose at the back of the collimator unit. Section 7 discusses the dose through the sides. Conclusions are given in Section 8.

## 2. Gas bremsstrahlung production rate

The gas bremsstrahlung production rate, NOFPs/h, is proportional to the electron path length. At the CLS, the length of the ID straight section, $L_{\mathrm{ID}}$, from the exit of the dipole to the entrance of the next dipole is approximately 8 m. To evaluate the dose rate (Sv/h), the NOFPs/h of the gas bremsstrahlung produced in the straight section must be calculated. The pertinent parameters used to obtain NOFPs/h are as follows:

- circulating electron energy: 2.9 GeV;
- stored current in the storage ring: 500 mA;
- gas pressure: 0.133 μPa ($= 10^{-9}$ torr);
- length of ID straight section: 8 m;
- the minimum photon energy considered (EMIN): 0.01 MeV;
- effective charge of gas molecules in vacuum chamber: 8.1.

With these constants, NOFPs/h above EMIN is found to be $3.71 \times 10^{9}$/h for the ID beamlines. A detailed account of obtaining NOFPs/h may be found elsewhere [4].

## 3. Geometry and regions of interest for dose estimates

The layout of the photon shutter and in-vacuum collimator in the BMIT beamline is as follows. The direction of the primary gas bremsstrahlung is assumed to define the $Z$-axis. The upstream edge of the photon shutter, which is a 15 cm thick copper piece, is taken to be the coordinate origin. Our preliminary analysis finds that a thin tungsten plate attached to the back of the photon shutter is a very effective radiation moderator. Hence, a copper photon shutter backed by a thin tungsten plate is considered as one unit in this article. Let W($A * B * C$) denote a tungsten plate, A cm wide (along $X$-axis), B cm in height (along $Y$-axis) and C cm thick (along $Z$-axis). The same notation is used for different materials. In our dose estimates, a copper photon shutter Cu(0.6 ∗ 0.6 ∗ 15.0) with a tungsten backing W(0.6 ∗ 0.6 ∗ 3.0) are used. These components are separated by 1 mm in vacuum. At 176 cm downstream from the origin, an in-vacuum collimator unit, consisting of a copper cooling element, Cu(11.6 ∗ 7.0 ∗ 2.4) followed by a tungsten collimator, W(11.6 ∗ 7.0 ∗ 20.0), is placed. The collimator unit is movable downward for the passage of the mono beam, and upward to allow the white beam through. Finally extra protection is provided by a lead collimator, Pb(29.0 ∗ 16.5 ∗ 22.0) placed downstream of the tungsten collimator unit in case of radiation propagating far from the $Z$-axis, as the width and the height of the lead collimator are more than twice that of the in-vacuum tungsten collimator.

The locations of these elements are shown in Fig. 1. In the figure, the 1st bin is for the photon shutter and the 3rd bin is for the tungsten backing. The 5th bin is reserved for the tungsten safety shutter, W(11.0 ∗ 6.0 ∗ 18.0), which is in closed position when no beam is required in the experimental hutch. The copper cooling element occupies the 7th bin and the tungsten collimator is in 9th bin followed by a lead collimator in the 11th bin. A water phantom, in which an energy deposition is calculated by the EGS4 code, occupies the 13th to the 20th bins. Although the entire structure from the 1st bin to the 12th bin is encompassed by the water phantom, for clarity, Fig. 1 does not show the water phantom for the upper and lower surfaces, and side of the structure. See Fig. 2 for comparison. The thickness of the water phantom is denoted by $\Delta H_2O$. If $\Delta H_2O = 2$ cm, the variation of the dose as a function of the depth up to 16 cm can be obtained. All other empty spaces are considered as vacuum.