17-BM Beamline Shielding Analysis Revisited with the Addition of the XAS Experimental End Station

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1. INTRODUCTION

The purpose of this report is to assess the radiological implications on the 17-BM beamline shielding because of introducing the new X-ray Absorption Spectroscopy (XAS) experimental end station into the First Optics Enclosure (FOE). Figure 1 shows the XAS experimental end station inside the FOE of the 17-BM beamline. The earlier 17-BM beamline radiation shielding analysis for Gas Bremsstrahlung (GB)/Synchrotron Radiation (SR) [1] and top-off analysis [2] show that the dose rates meet the shielding design criteria stated in the NSLS-II Shielding Policy and this report will show that they remain unaffected by the introduction XAS.

Figure 1: The layout of the 17-BM (FOE) enclosure highlighting the XAS experimental end station. Beam travels from right to left in this figure.
2. GB ANALYSIS

The 17-BM beamline has a white beam mirror (WBM) in the front end which deflects the synchrotron beam vertically and passes through a vertically offset ratchet wall collimator. Under normal operation of the beamline, the primary GB will strike the WBM. As discussed in reference [1], the amount of scattered GB that enters the FOE is well collimated by the ratchet wall collimator (RCO) and the scattered radiation by any components, at any position, inside the FOE yield negligible dose rates outside of the FOE, and the forward scattered GB is significantly attenuated by the bremsstrahlung stop (BRS) located outside of the downstream wall of the FOE. Therefore, the additional scatter targets introduced by the XAS experimental end station do not affect the dose rates outside of the FOE calculated in [1].

3. SR ANALYSIS

The synchrotron beam entering the FOE is mirror reflected pink beam. The SR analysis carried in reference 1 showed that for a three-pole wiggler, white beam and an optimum scatter target the dose rates outside the FOE are negligible with the existing FOE shielding.

4. TOP OFF ANALYSIS

The earlier top-off analysis showed that when the injected beam strikes the safe end point as determined by the backward particle tracking, an intense electromagnetic shower develops inside the FE, is scattered by components in the FE, and escapes through the RCO into the FOE. When this intense forward scattered beam enters the FOE, it is further scattered by beamline components inside of the FOE and broadened in the transverse direction. The earlier analysis [2] was performed for a scatter target located approximately within one meter from the upstream face of the FOE to mimic the slits of the XFP experimental end station. The FLUKA simulation for this case showed that this forward scattered radiation is significantly attenuated by the BRS to keep the dose rates below the 100 mrem/h limit established for a fault condition in the NSLS-II Shielding Policy. In the case of the XAS experimental end station, the slits (SLT), Double Crystal Monochromator (DCM) and Diagnostic Absorber (DA), which are located near the downstream end of the FOE, become important scatter targets. It is then prudent to carry out FLUKA simulations and confirm that the dose rates remain below 100 mrem/hr with the introduction of these additional scatter targets.

4.1 DESCRIPTION OF THE FLUKA MODEL

The FLUKA model used for this study is based on the model used previously to analyze beamline shielding and top-off for the 17-BM beamline [2], supplemented by additional beamline components associated with XAS experimental end-station and include the SLT, DCM and DA.
The positions and dimensions of these additional components are given in Appendix 1. Figure 2 shows the updated FLUKA model (Top and Elevation views) of the 17-BM beamline with all components incorporated in the FLUKA simulations. All components are placed symmetrically with respect to the beam centerline in the horizontal plane. For the FLUKA model, the Z-axis represents the white beam direction centerline, the X axis is the horizontal axis normal to the beam direction, the Y axis is the vertical axis and the beam travels from left to right.

Figure 2: Plan and elevation view of the 17-BM FLUKA geometry at the white beam plane.

In all the FLUKA simulations, a pencil beam of 3 GeV electrons is assumed for the injected beam and the results are normalized to a booster to storage ring injection charge rate of 45 nC per minute.

4.2 RESULTS OF THE SIMULATIONS

Based on the backward particle tracking analysis described in [1], the electron beam is assumed lost at the safe endpoint at 2 mm from the downstream aperture edge of fixed mask 2 (FM2) either outboard or inboard. Two scenarios were considered: (i) injected beam striking the taper of FM2 aperture on the outboard side and (ii) injected beam striking the taper of FM2 aperture on the inboard side. All ambient dose equivalent rates are reported in units of mrem/h. Simulations were also performed with the WBM retracted, SLT closed, and DCM retracted out of the beam. All results are given for the top-off mode of operation where the FE safety shutters remain open during injection into the storage ring.

Figure 3 shows the total ambient dose rates distribution inside and outside the FE and FOE when the electron beam strikes the taper of FM2 aperture on the outboard side, with the SLT open and
WBM/DCM at their nominal positions (inserted). The stream of radiation that exits in the FE through the ratchet wall collimator into the FOE is further scattered by the SLT and DCM as seen in Figure 3 (Elevation View). The total ambient dose rates are well below 100 mrem/hr everywhere outside the FE and FOE walls and roof, except at a localized area on the exterior of the downstream wall of the FOE.

**Figure 3:** The total dose distributions (mrem/hr) in the front end and FOE for the case where the electron beam strikes near the tapered surface of FM2 on the outboard side, with WBM/DCM inserted. The top figure shows a plan view (y=8.73 cm) and the bottom shows the elevation view at the beam centerline.

The Bremsstrahlung Stop (BRS) located on the exterior of the downstream wall of the FOE largely attenuates the forward peaked radiation. Figure 4 shows that the total ambient dose rates outside the BRS are below 100 mrem/h and the highest dose rates are in the forward direction on contact with the BRS as seen from Figure 4(b). The estimated maximum total ambient dose rate outside the front face of the BRS were approximately 70 mrem/h.
Figure 4: The total ambient dose distributions (mrem/h) at the exterior of downstream wall of the FOE (a) on contact and (b) away from the wall (along beam direction) for the case where the electron beam strikes near the tapered surface of FM2 on the outboard side, with SLT open and WBM/DCM inserted into the beam. The purple rectangle is the outline of the BRS. The results are similar when the electron beam strikes the taper of FM2 aperture on the inboard side and the total ambient dose are shown in Figure 5. The main difference is the profile of the shower development downstream from FM2, which is more enhanced on the outboard side as illustrated in Figure 5 (plan view). The total ambient dose rates outside the FE and FOE walls and roof and BRS are below 100 mrem/h.

Figure 5: The total dose distributions (mrem/h) in the front end and FOE for the case where the electron beam strikes near the tapered surface of FM2 on the inboard side, with WBM/DCM
inserted. The top figure shows a plan view (y=8.73 cm) and the bottom shows the elevation view at the beam centerline.

In Figure 6, the total ambient dose rates are given when the WBM is retracted, for the case when the electron beam strikes near the tapered surface of FM2 on the outboard side. The results are comparable to previous two cases. Figure 7 shows the total ambient dose rates outside the surface of the BRS are below 100 mrem/h. Other configurations where the DCM is retracted with the slits fully closed were also simulated and the results are comparable to the ones shown above for the configurations with and without the WBM inserted.

**Figure 6:** The total dose distributions (mrem/hr) in the front end and FOE for the case where the electron beam strikes near the tapered surface of FM2 on the outboard side, with WBM retracted, SLT open and DCM at its nominal position. The top figure shows a plan view (y=8.73 cm) and the bottom shows the elevation view at the beam centerline.
Figure 7: The total ambient dose distributions (mrem/h) at the exterior of downstream wall of the FOE (a) on contact and (b) away from the wall (along beam direction) for the case where the electron beam strikes near the tapered surface of FM2 on the outboard side, with WBM retracted, SLT open and DCM at its nominal position. The purple rectangle is the outline of the BRS.

5. SUMMARY AND CONCLUSIONS

The analysis described in Sections 2, 3 and 4 of this report indicates that dose rates meet the shielding design criteria established in the NSLS-II Shielding Policy and confirms that the earlier 17-BM beamline radiation shielding analysis for Gas Bremsstrahlung (GB)/Synchrotron Radiation (SR) [1] and top-off analysis [2] remain unaffected by the introduction of XAS.

6. REFERENCES


The XAS addition to the 17-BM XFP beamline consists of a new monochromator, connected to the rest of the beamline by UHV vacuum pipe, with a typical pressure of 1x10^{-8} Torr. There is a 4-blade set of Oxford Instruments water-cooled pink beam slits located at 31965 mm for vertical blade center and 32100 mm for center of horizontal defining blades that have a design maximum aperture of 50mm x 50mm.

The monochromator contains an upward reflecting channel cut Si (111) channel cut crystal, which will supply monochromatic light to a spectroscopy end-station. Downstream of the channel cut crystal is a pink beam diagnostic absorber located at 32580 mm. A 250 µm thick Be exit window at 32694 mm separates beamline vacuum from atmosphere.

The first crystal of the monochromator, which intercepts synchrotron pink beam reflected from the mirror, is located 32450 mm from the 3PW source. The second crystal is offset 3mm vertically from the first crystal. The expected angular range of the first crystal, used to define the monochromatic energy, is expected to be 7° – 27°. A motorized water-cooled diagnostic absorber, located 130mm downstream of the crystal, fabricated from copper, prevents white (or pink) beam from propagating further down the beamline to the XAS end station.

All other components of the 17-BM XFP beamline, as tabulated and discussed in NSLS-II Technical Note #218 (“17-BM XFP Beamline Radiation Shielding Analysis”) remain unchanged.

<table>
<thead>
<tr>
<th>Component</th>
<th>Dimensions/Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirror</td>
<td>14000 mm</td>
</tr>
<tr>
<td>Oxford slits vertical blade center</td>
<td>z = 31965 mm</td>
</tr>
<tr>
<td>Horizontal blade center</td>
<td>z = 32100 mm</td>
</tr>
<tr>
<td>Maximum designed clear aperture</td>
<td>Horz.36mm x Vert.16mm</td>
</tr>
<tr>
<td>a) Slit blades</td>
<td>tungsten</td>
</tr>
<tr>
<td>b) Slit blade thickness</td>
<td>3mm</td>
</tr>
<tr>
<td>c) Absorber</td>
<td>OFHC copper</td>
</tr>
<tr>
<td>d) Absorber thickness</td>
<td>8mm</td>
</tr>
<tr>
<td>Tungsten Blade</td>
<td>x = 55 mm, y = 50mm, z = 3mm</td>
</tr>
<tr>
<td>Copper block</td>
<td>x = 55mm, y = 50mm, z = 8 mm</td>
</tr>
<tr>
<td>U/S tungsten blade 1 to U/S tungsten blade 2:</td>
<td>20 mm</td>
</tr>
<tr>
<td>Monochromator 1st crystal center</td>
<td>z = 32450 mm</td>
</tr>
<tr>
<td>Diagnostic absorber (DA)</td>
<td>z = 32580 mm (Upstream Edge)</td>
</tr>
<tr>
<td>Copper block</td>
<td>x = 88.9 mm, y = 25.4 mm, z = 19.05 mm</td>
</tr>
</tbody>
</table>