BNL-210971-2019-TECH
NSLSII-ESH-TN-137

# IXS 10ID Radiation Shielding Analysis

Z. Xia,

August 2018

Photon Sciences
**Brookhaven National Laboratory**

**U.S. Department of Energy**
USDOE Office of Science (SC), Basic Energy Sciences (BES) (SC-22)

# DISCLAIMER

| NSLS II TECHNICAL NOTE<br>BROOKHAVEN NATIONAL LABORATORY | NUMBER<br>NSLSII-ESH-TN-137 |
|---|---|
| AUTHORS:<br>Z. Xia | DATE<br>8/14/2018 |
| 10-ID IXS Beamline Radiation Shielding Analysis | |

## 1. Introduction:

This note documents the radiation shielding analysis of Inelastic X-ray Scattering (IXS, 10 ID) beamline at 500 mA, including Gas Bremsstrahlung (GB) and Synchrotron Radiation (SR). Figure 1 shows the layout of IXS, which uses an in vacuum undulator (IVU22) source.

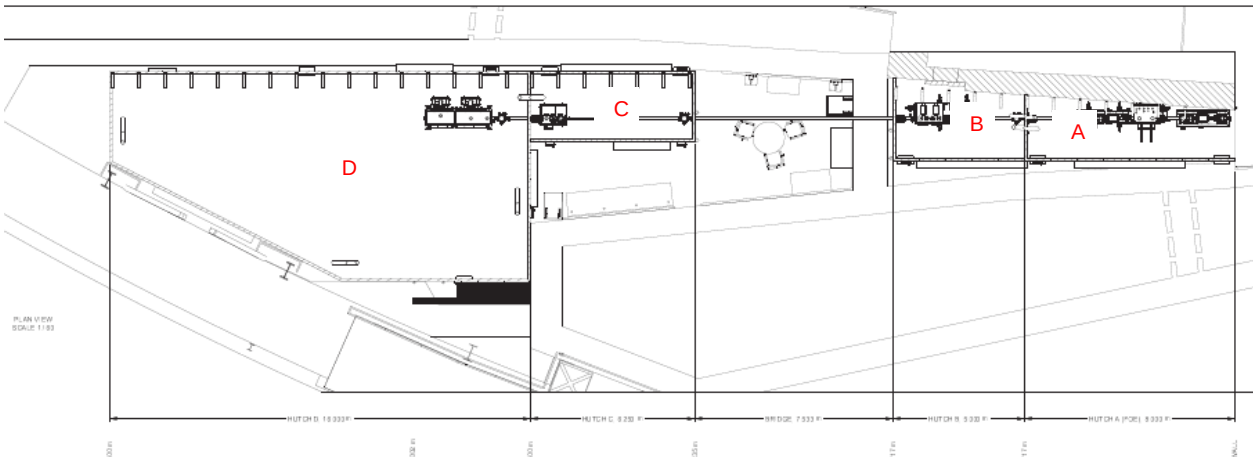


Figure 1 IXS layout

## 2. GB Shielding Calculation

For the evaluation of GB shielding requirements, the undulator source is assumed to have a 15.5-m-long air section at $10^{-9}$ torr. The FLUKA simulation uses a 1/*k* energy spectrum (with *k* denoted as the photon energy) from 10 keV up to 3 GeV [1], and the FLUKA results are normalized to the power of 17 μW, which is the GB source for 3 GeV, 500 mA electron beams at 1 ntorr of Storage Ring Vacuum [2]. The First Optical Enclosure (FOE) shielding is dominated by GB. The FOE lateral panel is made of 18 mm Pb, roof 6 mm Pb and downstream wall 50 mm Pb.

The main scatterers considered in the Scattered Gas Bremsstrahlung (SGB) shielding analysis are: fixed mask, mono crystal and white beam stop. The IXS FLUKA geometry is shown in Figure 2 and main parameters are listed in Table 1.

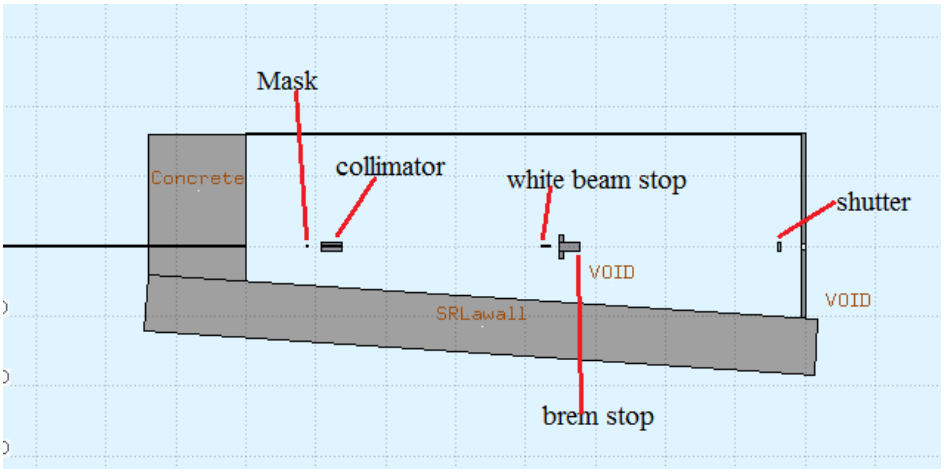


Figure 2 Main scatterers, collimators and shields (mono crystal NOT shown in this layout)

Table 1 Z locations and dimensions of main scatterers and shields

| Scatterers | Upstream Z location (Distance from straight section center) | Dimensions | Material |
|---|---|---|---|
| Fixed mask | 2758.73 cm | 2.54 cm × 2.54 cm × 2.54 cm L (aperture: 0.221 cm × 0.221 cm) | Copper |
| Mono crystal | 2937.61 cm | 3 cm × 3 cm × 10 cm L (rotate 12.5 degree) | Silicon |
| White beam stop | 3093.44 cm | 1.5 cm × 3.252 cm × 13.72 cm L (4.8 degree cut on top) | Copper |
| Shields | Upstream Z location (Distance from straight section center) | Dimensions | |
| Collimator | 2778.7 cm | 12 cm × 11 cm × 30.5 cm L (aperture: 1.2 cm ×1.2 cm) | Lead |
| Bremsstrahlung stop | 3119 cm | 12 cm × 11 cm × 30.5 cm L (aperture: 1.2 cm ×1.2 cm) | Lead |
| Extended lead on bremsstrahlung stop | 3119 cm | 33.6 cm × 26.2 cm × 7.6 cm thick (aperture: 12 cm ×11 cm, surrounding brem stop) | Lead |
| Shutter | 3433.1 cm | 12.5 cm × 15 cm × 3.8 cm thick (4 cm × 2.5 cm) | Tungsten |

### 2.1 Fixed mask as scattering target

The IXS fixed mask has a minimum aperture size of 2.2 mm × 2.2 mm, located immediately upstream of the collimator. The target simulated in FLUKA is a 1” copper cubic with the minimum size (2.2 mm × 2.2 mm) aperture.

The FLUKA simulation was done in a conservative approach for mask scatterer: GB is uniformly spread along Z in a 0.17 mrad cone (in reality GB is peaked around center). Two scenarios were simulated: Shutter closed and shutter open. The dose rate on the lateral wall and roof is < 0.05 mrem/h for all scatterers. Note in this note only the dose rates from white beam stop scatterer are plotted.

### 2.1.1 Shutter A closed, Fixed mask scatterer (with extended Pb around bremsstrahlung stop)

Figure 3 shows the dose rate on beam plane. On the downstream wall of FOE, it is seen the dose rate is < 0.05 mrem/h on contact in most areas expect the center, which is inside the hutch B beam pipe (under configuration control), an unoccupied area.

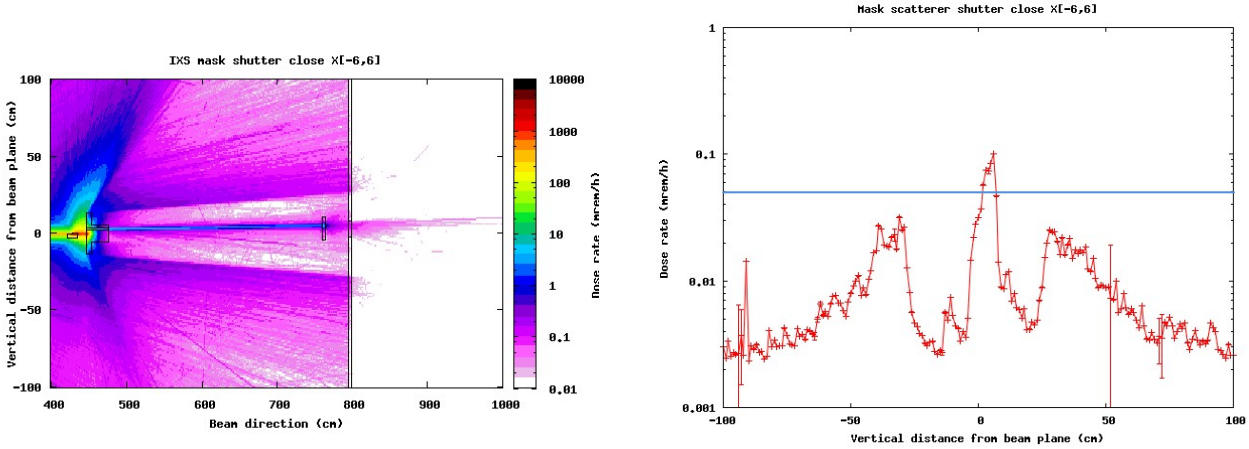


Figure 3 Fixed Mask as scatterer, dose distribution on vertical plane with shutter CLOSED

### 2.1.2 Shutter A open, Fixed mask scatterer (without taking credit of extend Pb around bremsstrahlung stop)

When shutter in hutch A is open, hutch B is unoccupied. The dose rates downstream of FOE (in hutch B) are analyzed. Figure 4 shows the dose rate with “shutter open” scenario (shutter not included in the model and aperture size on FOE downstream wall is 40 mm × 25 mm). On the downstream wall of FOE, it is seen the dose rate is < 0.05 mrem/h at 2 meters away from FOE downstream wall. Note Hutch B is ~ 4 m long, therefore it is safe to occupy downstream of hutch B when hutch A shutter is open.

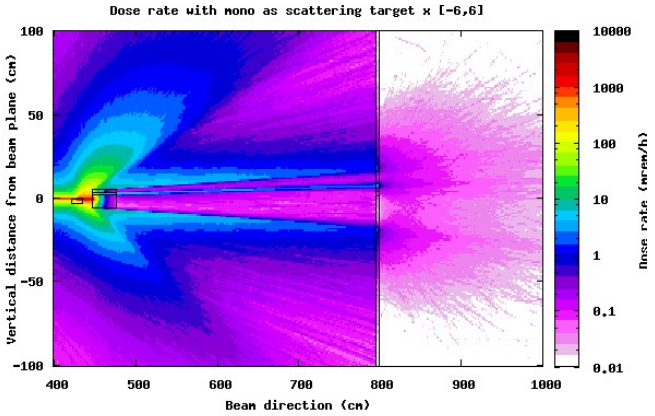


Figure 4 Fixed Mask scatterer, dose distribution on vertital plane with shutter OPEN

### 2.2 Mono crystal as scattering target

IXS has a 3 cm × 3 cm × 10 cm Long (rotated at 12.5 degree) Silicon crystal in FOE, diffracting beam upward. The dose rates on beam plane are plotted for “Shutter Open” and “Shutter Closed” scenarios.

#### 2.2.1 Shutter A closed, Mono scatterer (with extended Pb around bremsstrahlung stop)

Figure 5 shows the dose rate on the vertical plane. On the downstream wall of FOE, it is seen the dose rate is < 0.05 mrem/h on contact downstream of FOE when hutch shutter A is closed.

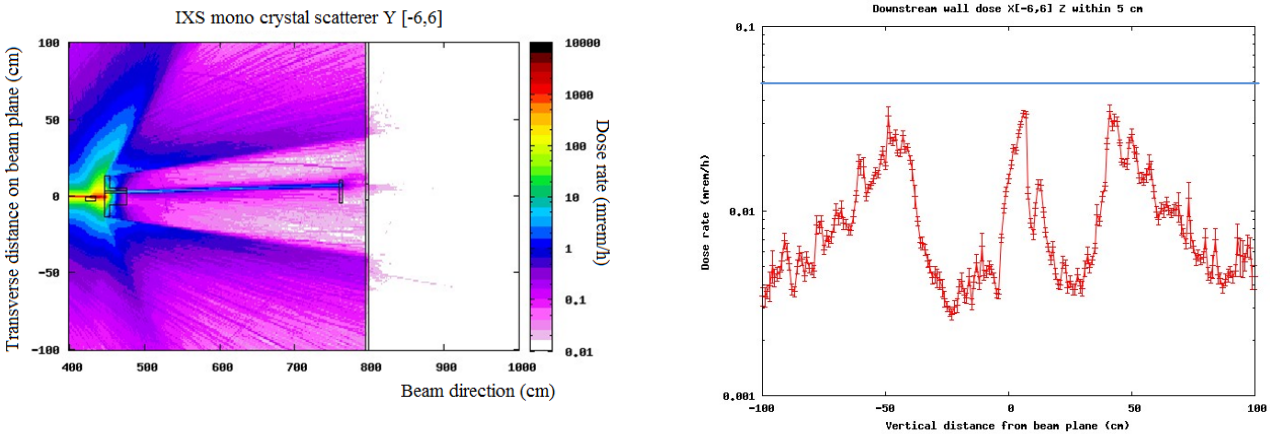


Figure 5 Mirror scatterer, dose distribution on vertical plane with shutter CLOSED

### 2.2.2 Shutter A open, Mono scatterer (without taking credit of extend Pb around bremsstrahlung stop)

Figure 6 shows the dose rate with “shutter open” scenario. On the downstream wall of FOE, it is seen the dose rate is < 0.05 mrem/h at 2 meters away from FOE downstream wall. Hutch B is ~ 4 m long, so it is safe to occupy downstream of hutch B when hutch A shutter is open.

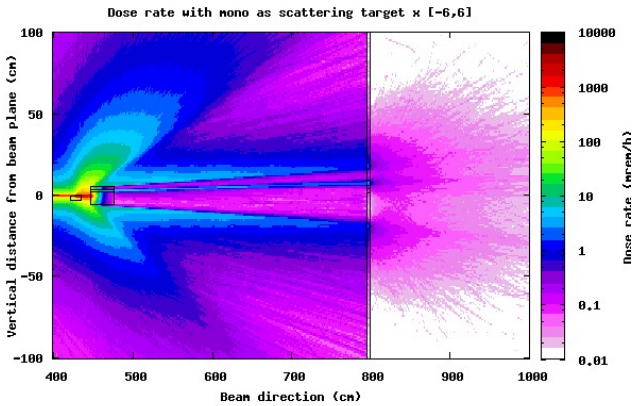


Figure 6 Mono crystal as scatterer, dose rate on the vertical plane with shutter OPEN

## 2.3 White beam stop as scattering target

### 2.3.1 White beam stop scatterer, FOE downstream wall dose

Figure 7 shows the dose rate on the vertical plane from white beam stop scatterer. On the downstream wall of FOE, it is seen the dose rate is negligible on contact (white beam stop is immediately followed by the bremsstrahlung stop). This calculation is done without taking credit of extended Pb and shutter A.

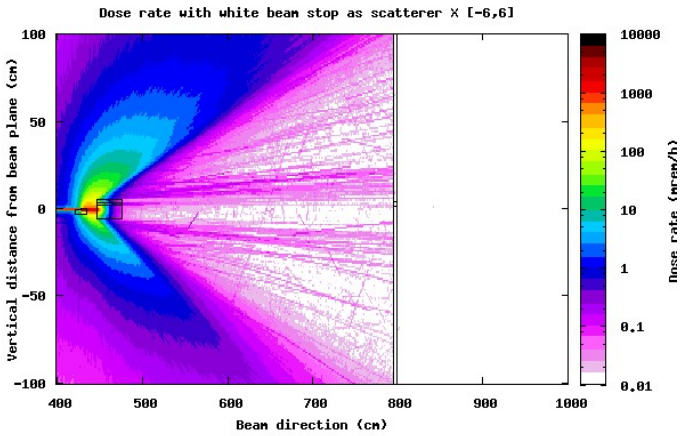


Figure 7 White beam stop as scatterer, dose rate on the vertical plane with shutter OPEN

The white beam stop is immediately followed by the bremsstrahlung stop, so the dose rate on downstream wall is acceptable during “shutter open” and “shutter closed” scenarios.

### 2.3.2 White beam stop scatterer, lateral wall and roof dose rate

Figure 8 shows the dose rate on lateral wall and roof, and the dose rate is < 0.05 mrem/h on contact.

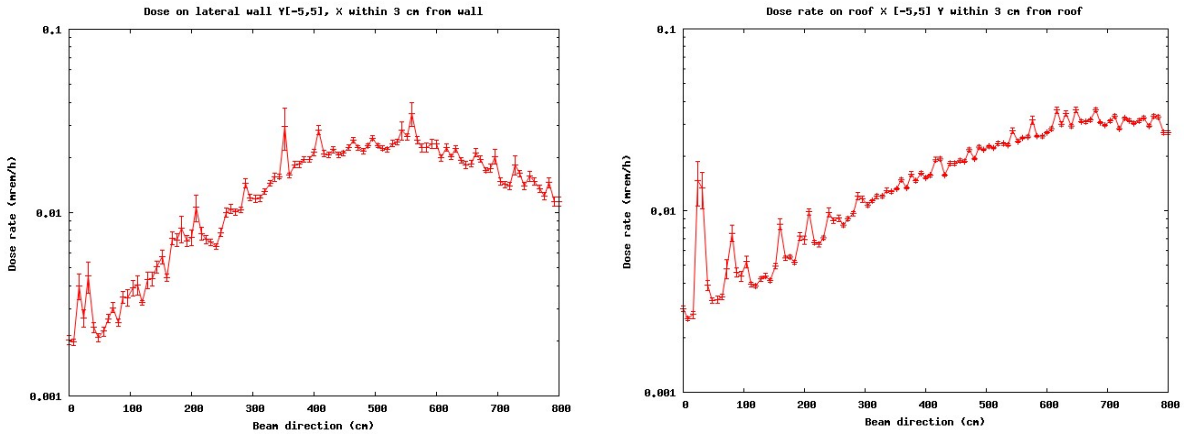


Figure 8 Lateral wall and roof dose rate from white beam stop scatterer

## 3. SR Shielding Calculation

The IXS 10 ID beamline is an IVU 22 source and the parameters are listed in Table 2.

Table 2 Source Parameters for IVU22 [3]

| Source | Max. source opening | No. Of periods | Max. $B_{eff}$ (T) | Period (mm) | $E_c$ (keV) | Total power (kW) |
|---|---|---|---|---|---|---|
| IVU22-6m | 1.0 mrad-H | 272 | 1.12 | 22 | 6.7 | 24.5 |

### 3.1 FOE wall / roof for white beam

The FOE shielding is dominated by GB. The dose rate from SR is negligible on lateral, roof and downstream walls with current FOE shielding.

### 3.2 Transport pipe

The transport pipe is wrapped with 4 mm lead. Assuming beam at 1” to the pipe, the dose rate is calculated conservatively with STAC 8 for a compressed 10 m air target. The dose rate is negligible outside of the pipe (<0.001 mrem/h). The monochromatic beam energies and bandwidths are listed in Table 3.

Table 3 Monochromatic beam energy and bandwidth [3]

| **Energy (keV)** | **Reflection** | **Undulator Harmonic** | **Bandwidth (eV)** |
|---|---|---|---|
| 9.1 | Si(111) | 5 | 1.2 |
| 27.3 | Si(333) | 15 | 0.22 |
| 36.4 | Si(444) | 20 | 0.17 |
| 45.5 | Si(555) | 25 | 0.06 |
| 63.7 | Si(777) | 35 | 0.02 |

### 3.3 Monochromatic hutch

#### 3.3.1 Mono hutch lateral wall and roof

The fixed mask in IXS FOE trims SR fan down to 80 μrad x 80 μrad [3]. The mono hutch shielding calculation was done taking credit of the trimmed SR fan: 0.08 mradH. The SR scattering target is assumed to be a 10 cm radius, 2 cm thick Silicon target tilted at 0.155 degree to incident beam.

Table 4 Dose rate on Mono hutch lateral wall and roof

| | **Max. source opening** | Minimum distance from target to shielding (m) | Dose rate (mrem/h) |
|---|---|---|---|
| Lateral wall | 0.08 mrad-H | 0.9 | <0.001 |
| Roof | | 2 | 0.005 |

#### 3.3.2 Mono hutch downstream wall

A mono beam stop (305 mm × 305 mm × 25 mm thick Pb) is installed around the beam center at the end of hutch D to stop the monochromatic beam upon possible direct hitting the downstream wall. (Similarly in hutch B and hutch C, the lead guillotines shield scattered radiation from SR at small angles). Table 5 lists the dose rate on downstream wall of mono hutches assuming the target is 1 meter away from the shielding.

Table 5 IXS dose rate on mono hutch downstream wall

| | **Max. source opening** | Dose rate (mrem/h) |
|---|---|---|
| Area covered by mono beam stop (< 8.7 degree) | 0.08 mrad-H | <0.001 |
| Area outside of mono beam stop coverage (>8.7 degree) | | 0.05 |

## 4. 50 mA commissioning analysis

The dose rate on FOE downstream wall from IXS mask scatterer (no lead extension on the bremsstrahlung stop) is plotted in Figure 9.

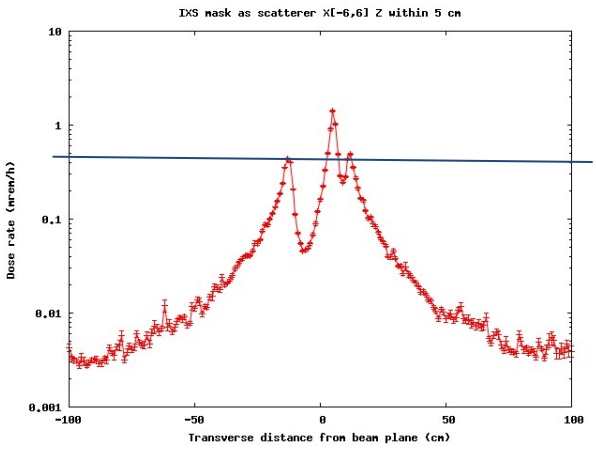


Figure 9 Dose rate on FOE downstream wall from IXS mask scatterer at 500 mA, without Pb extension around the bremsstrahlung stop

The middle leakage is blocked by shutter based on SGB ray trace. The dose rate at 50 mA is < 0.05 mrem/h without extending the Pb bremsstrahlung stop.

## 5. Conclusions:

For 500 mA operation, with the extended Pb around the bremsstrahlung stop in addition to all other shields, the IXS beamline radiation level meets NSLS-II shielding policy.

1) The dose rates in all occupied areas are < 0.05 mrem/h.

*Note IXS is shielded for 50 mA commissioning if Pb extension around the bremsstrahlung stop is not installed. The extended Pb shielding around the bremsstrahlung stop must be installed before the current goes up.*

By comparing the shielding in FLUKA model and ray trace, there are a few differences between them (e.g. the actual bottom lead is shifted more downstream in reality). However, based on review, these differences are trivial and not making a problem since the shielding is blocking the scattered radiation to same angles in reality.

All shielding will need to be verified by radiation survey during commission. If a radiation leakage is observed during the measurement, shielding shall be installed to mitigate the radiation level outside of the enclosure to acceptable level.

**Reference:**

[1] J.Donald Cossairt, Fermilab-TM-1834, Radiation Physics for Personnel and Environmental Protection, Revision 11, November 2011.

[2] P.K. Job, Shielding Guidelines for Secondary Bremsstrahlung at NSLS-II Beamlines with Mirror as the First Optical Element, September 11, 2012.
[3] Emails from Y. Cai to Z. Xia.