RP Note 04-07 (12-17-04) Rev. 2 (1-05-05)

# Radiation Safety Design for SSRL Bend Beamline BL8

Alberto Fassò, James C. Liu, Alyssa A. Prinz

Radiation Protection Department, Stanford Linear Accelerator Center
MS 48, P.O. Box 4349, Stanford, CA 94309

## Introduction

This technical note gives the shielding design for SSRL bend beamline BL8 for its synchrotron radiation (SR) and gas bremsstrahlung (GB) hazards. The criteria, methodology and rules for the design follow the RP summary note 03-21 [1] and its references. The design requirements are given for 3 GeV and 500 mA, unless otherwise noted.
BL8 includes three branch lines: BL8-PM, BL8-1 and BL8-2.

- BL8-PM is a white light line used for a position monitor. It extends only 1.5 m beyond the SPEAR ratchet wall and it is completely enclosed in a doorless enclosure with lead walls 6.35 mm thick. It takes a synchrotron radiation fan of 0.64 mradH.
- BL8-1 is a VUV filtered monochromatic line reflected by a mirror with a 250 eV energy cutoff located in alcove and rising at a large angle (11.5°) up to the second floor. The horizontal fan hitting the mirror has a width of 8 mradH. The maximum SR power downstream of the mirror is less than 1.5 W.
- BL8-2 is also a VUV filtered monochromatic line, reflected by a mirror with a 1.5 keV energy cutoff located in alcove and raising vertically at a 4.9° angle. It has a horizontal fan width of 4 mradH and the maximum power downstream of the mirror is less than 4 W.

Neither BL8-1 nor BL8-2 are located inside an enclosure.
Information on BL8 operation and beam parameters has been obtained from ray trace drawings [2] and from a comprehensive spreadsheet provided by T. Rabedeau. Details can be found in a SSRL Engineering Note [3].

## Operational mode

BL8 is a bend magnet source (1.286 T field) with a critical energy of 7.78 keV. Its power density at 500 mA is 74.1 W/mradH. Due to the large angle of BL8-1 and BL8-2, gas bremsstrahlung cannot enter either of those two lines. For beamlines BL8-1 and BL8-2 to operate, it is necessary that the corresponding M0 mirrors in alcove not be withdrawn from the beam. However, in case either of those mirrors should be withdrawn, both the synchrotron radiation beam and the gas bremsstrahlung would be fully intercepted by the SPEAR ratchet wall.

No access is possible to the BL8-PM enclosure. Its walls consist of lead panels which are secured in place by a padlock.

# Synchrotron radiation

## Beam line BL8-PM

The BL8-PM line takes 0.64 mradH of white light. Dose rates estimated using the attenuation curves in [4] are reported in Table 1 for 500 mA operation. All dose rates are lower than the 0.05 mrem/h limit.

## Beam lines BL8-1 and BL8-2

Beam lines BL8-1 and BL8-2 are not inside a hutch: therefore the necessary shielding must be provided by the wall of the vacuum chamber itself, and by local shielding around possible targets. Both lines transport low-intensity VUV light reflected by mirrors located inside the SPEAR alcove.

Two SR components have been considered: scattered pink light and white light Compton-scattered by the M0 mirror. The corresponding calculations for 500 mA operation have been made using the curves reported in [5] and are reported in Table 2.

Low-energy pink light (0.25 keV cutoff for BL8-1 and 1.5 keV cutoff for BL8-2, but a 1.5 keV cutoff was conservatively assumed for both cases) can scatter off a few optical elements along the line. The thickness of the vacuum chamber and of the optical elements containers is everywhere at least 1.7 mm, sufficient to attenuate the low-energy scattered radiation to acceptable levels. However, that thickness is not sufficient for Compton-scattered radiation from the M0 mirrors hitting the wall of the vacuum pipe. Therefore, Pb sheets of 1/8″ and 1/16″ thickness will be wrapped around the vacuum chamber from the SPEAR ratchet wall up to the next mirror or monochromator entrance slit.

In addition, where bellows and viewports are present, the effective shielding thickness is reduced. All the bellows and viewports from the ratchet wall to the bellows just downstream of the mono grating need to be shielded with at least 1.1 mm of Pb-equivalent.

Due to the very low energy of the synchrotron radiation all experiments are carried out in vacuum. Beam stoppers exist in each line, but only to protect vacuum valves and other equipment. Therefore the only component protecting against direct irradiation by the SR beam in BL8-1 and BL8-2 is the vacuum chamber itself.

## Safety components

In BL8-1 and BL8-2, the vacuum pipe itself and the mirror/monochromator tanks are safety components from the ratchet wall up to the last location which can be directly irradiated by photons Compton-scattered from the mirrors, namely the location where the pipe inclination changes. This location is 15.0 m from the center of the bending dipole for BL8-1, and 16.5 m for BL8-2. The lead caps (1/16″ thickness) used to cover the viewports located on the side of the BL8-1 M1 mirror tank must also be considered safety items.

## Dose rates from beam in BL8-1 or BL8-2 with the vacuum chamber removed

Downstream of the ratchet wall, the vacuum chambers for BL8-1 and BL8-2 serve a beam containment and radiation shielding function. Dose rates in the event that beam is present with the vacuum chamber open have been estimated for BL8-2. (Values for BL8-1 should be somewhat lower due to greater distance and lower cutoff energy of the M0 mirror). Two cases were investigated: dose rate downstream of the vacuum isolation valve, with the valve closed and the beamline stoppers open, and dose rate with both the valve and the beamline stoppers open. In the latter case, vacuum would not be maintained, and after a certain period of time the beam would be terminated by MPS or (in the event of multiple MPS failures) by air filling the SPEAR ring. The valve-open case is considered much less likely to occur than the valve-closed case, due to the greater number of MPS failures (e.g., the fast valves in alcove) that would be required.

**Case 1. Dose rate with isolation valve closed and beamline stoppers open**:
Radiation arises from pink beam and compton scattered light (from the M0 mirror) hitting the isolation

valve. The valve material is stainless steel, with a minimim thickness of 0.34″. The STAC8 code was used to estimate the dose rate. For 100 mA operation, the dose rate (dominated by the Compton-scattered light) is 1.1 rem/h.

**Case 2. Dose rate with isolation valve open and beamline stoppers open**:
Both the direct pink beam and Compton-scattered light from the M0 mirror contribute to the dose rate. We assume the beamline is completely vented to air (11 m at atmospheric pressure). For 100 mA operation, the dose rate due to Compton-scattered light (estimated using STAC8) is 1.0 rem/s (note units). FLUKA was used to estimate the dose rate from direct pink beam, assuming a beam cross section of 1 mm by 10 mm, and using a mirror-filtered input spectrum generated by STAC8 (see Fig. 2 and 3). At 100 mA, the dose rate from direct pink beam is 34 rem/s. An upper limit of 41 ms can be placed on the survival time of the beam after vacuum is breached, resulting in a total dose of 1.4 rem.

The upper limit on beam survival time is based on degradation of the SPEAR beam by scattering off air in the ring, and assumes complete failure of the in-alcove and ring MPS (which would dump SPEAR RF and terminate the beam in less than 20 ms). It is derived as follows.

We assume the instantaneous appearance of a 1″ diameter hole in the vacuum system (assumed to be a simple 1″ diameter pipe), at a location 11 m downstream of the SPEAR ring. With the initial pressure difference across the opening being more than a factor of 2, conditions for choked flow prevail. Air will move through the opening at the speed of sound, and the initial pressure front will move toward the SPEAR ring at a velocity greater than or equal to the speed of sound, reaching the ring in a maximum time of 32 ms.

The beam lifetime is roughly inversely proportional to the average pressure in the ring. Whether the gas producing this pressure is evenly distributed or not should, to first approximation, make no difference. Extrapolating from an initial value of 28 h at 1.8 nTorr (obtained from the SPEAR CDR), one can estimate the beam lifetime for a given average pressure. Using standard equations for the mass flow rate of a gas under choked flow conditions, one obtains the time necessary for a given mass of air to move through the opening where the BL8 vacuum chamber meets the SPEAR ring. (We assume the opening to be 1″ in diameter, and the volume of the ring to be 2000 liters). Taking the sum of the mass-flow time needed to reach a given average pressure, and three times the lifetime at that pressure, and varying the value of pressure to find a minimum, one obtains 9 ms as the time necessary for air just outside the ring to enter the ring and kill the beam. Adding the time necessary for the air to reach the ring (32 ms), one obtains 41 ms as the time between vacuum breach and termination of the beam.

## Administrative controls

In light of the potential exposure should the BL8-1 or BL8-2 vacuum chamber be open while beam is running, the following administrative controls are necessary. Items 2 and 3 below will be included in the BL8 BLA.

1. In keeping with SSRL policy, opening of the BL8-1 or BL8-2 vacuum chamber between the ratchet wall and the beamline exit valve shall require that the injection stoppers be closed and the beamline disabled with the on/off line key locked in the accelerator operators lock box and tagged **"DO NOT USE — OPEN RSWCF"**.

2. The BL8-1 vacuum chamber must be clearly marked as a radiation safety item (with tape and signs or stickers) between the ratchet wall and a point 15.0 m downstream of the bend magnet source. The RSWCF that must be opened in order to open the vacuum chamber shall specify that the injection stoppers be closed and the beamline disabled with the on/off line key locked in the accelerator operators lock box and tagged **"DO NOT USE — OPEN RSWCF"**.

3. The BL8-2 vacuum chamber must be clearly marked as a radiation safety item (with tape and signs or stickers) between the ratchet wall and a point 16.5 m downstream of the bend magnet source. The RSWCF that must be opened in order to open the vacuum chamber shall specify that the injection stoppers be closed and the beamline disabled with the on/off line key locked in the accelerator operators lock box and tagged **"DO NOT USE — OPEN RSWCF"**.

4. The BL8-1 and BL8-2 vacuum chambers outside the ratchet wall shall be visually inspected prior to each experiment.

5. Operation is authorized only until the end of the present run, after which the issue of beam containment for BL8 is to be re-evaluated.

# Gas Bremsstrahlung

Gas Bremsstrahlung needs to be considered only for what concerns the BL8-PM line. The other two branch lines are completely outside the GB fan.

As specified in [1], shielding against gas bremsstrahlung is considered separately for safety components and for optical components.

The fan width of the BL8-PM steering line is 0.64 mrad. Multiplying by the dipole bending radius (786 cm), one obtains the length of the electron orbit arc to be considered for GB production: 0.47 cm. Scaling with respect to the 600 cm assumed for GB production in a typical ID, the total GB power entering the line is $8 \times 10^{-4}$ times lower, namely only 32 nW at 500 mA.

## Safety components

There is only one safety component in the BL8-PM line: the beam dump located at the end of the line. Its requirements, taken from [1], are dictated by primary GB produced in a bend line and are reported in Table 3.

## Optical components

There are several possible targets inside the BL8-PM enclosure (position monitor screen and assembly, copper end plug, collimator, Be window). The incident gas bremsstrahlung is primary GB, but of very low power. The resulting dose rates from scattered GB, reported in Table 4, are well below the limits.

# Summary

- The shielding of the BL8-PM line is adequate for both scattered SR and GB at 500 mA operation.
- The shielding of lines BL8-1 and BL8-2 is sufficient provided a lead wrap of sufficient thickness is applied around the respective beam pipes, up to the mirror included and up to the entrance slit.
- The vacuum pipe of BL8-1 must be considered a Radiation Safety Device from the ratchet wall up to 15 m from the center of the bending dipole. That of BL8-2 must be a Radiation Safety Device from the ratchet wall up to 16.5 m from the center of the bending dipole. The viewport lead caps in the BL8-1 mirror tank must also be considered as Radiation Safety items. A Radiation Safety Work Control Form must therefore be issued in order to repair, modify or remove any part of those vacuum pipes in the indicated regions or the viewport caps.
- Only BL8-PM needs to be considered concerning GB. The only safety component, the beam dump, satisfies all requirements for primary GB from a bend magnet.

# References

[1] J.C. Liu, A. Fassò, H.Y. Khater, A.A. Prinz and S. Rokni, "Generic Radiation Safety Design for SSRL Synchrotron Radiation Beamlines", RP Note 03–21 (11-14-03) Rev. 2-13-04

[2] Drawing GP 451-028-24 C "SSRL Beam line 8 ray trace" (5 sheets). May 24, 2004

[3] D. Brehmer and T. Rabedeau, "BL8 SPEAR-100mA Shielding Implementation Note", SSRL Engineering Note 2010-M476 Rev. 1 (5/21/2004)

[4] J.C. Liu, H.Y. Khater, A.A. Prinz and S. Rokni, "Synchrotron Radiation Shielding Design for SPEAR3 White Light Hutches", RP Note 03–08 (Rev. 11-10-03)

[5] A. Prinz, J. Liu, and H .Khater, "Generic Synchrotron Shielding Design for SPEAR3 Pink-Light Hutches and VUV Vacuum Chambers", RP-03-11 (11-12-03)

[6] A.A. Prinz, J.C. Liu, H.Y. Khater and S. Rokni, "Shielding for Scattered Gas Bremsstrahlung for SPEAR3 Beam Lines", RP Note 03–10 (6-11-03) (Rev. 2-13-04)

Table 1: SR design requirements for BL8-PM white enclosure[1]

| *Enclosure Wall* | *Beamline Target* | *Distance (cm)* | *Fan width (mrad)* | *Existing Shielding (mm)* | *Dose Rate*[2] *(mrem/h)* | *Shielding Needed (mm)* |
|---|---|---|---|---|---|---|
| SSRL side, Roof[3] | PM screen,<br>Cu end plug,<br>PM Assembly,<br>collimator,<br>Be window | 30 | 0.64 | 6.35 Pb | 0.01 | 5.25 |
| Downstream[4]<br>4°<br>5.5°<br>23° | <br>Side port coll.<br>Be window<br>PM screen | <br>144<br>104<br>24 | 0.64 | 6.35 Pb | <br>0.023<br>0.039<br>0.021 | <br>5.8<br>6.2<br>5.2 |

[1] Bend white light has $E_c = 7.78$ keV (1.286 T field), 74.1 W/mradH at 500 mA
[2] Dose rates referring to an inclined Si target for the side wall and a Cu target for the downstream wall
[3] The actual distance between the beam and the side wall/roof is about 7 cm. However, one foot is assumed to be the typical working distance, as in the case of beam lines without a hutch.
[4] Angles $< 4°$ are covered by the GB beam dump.

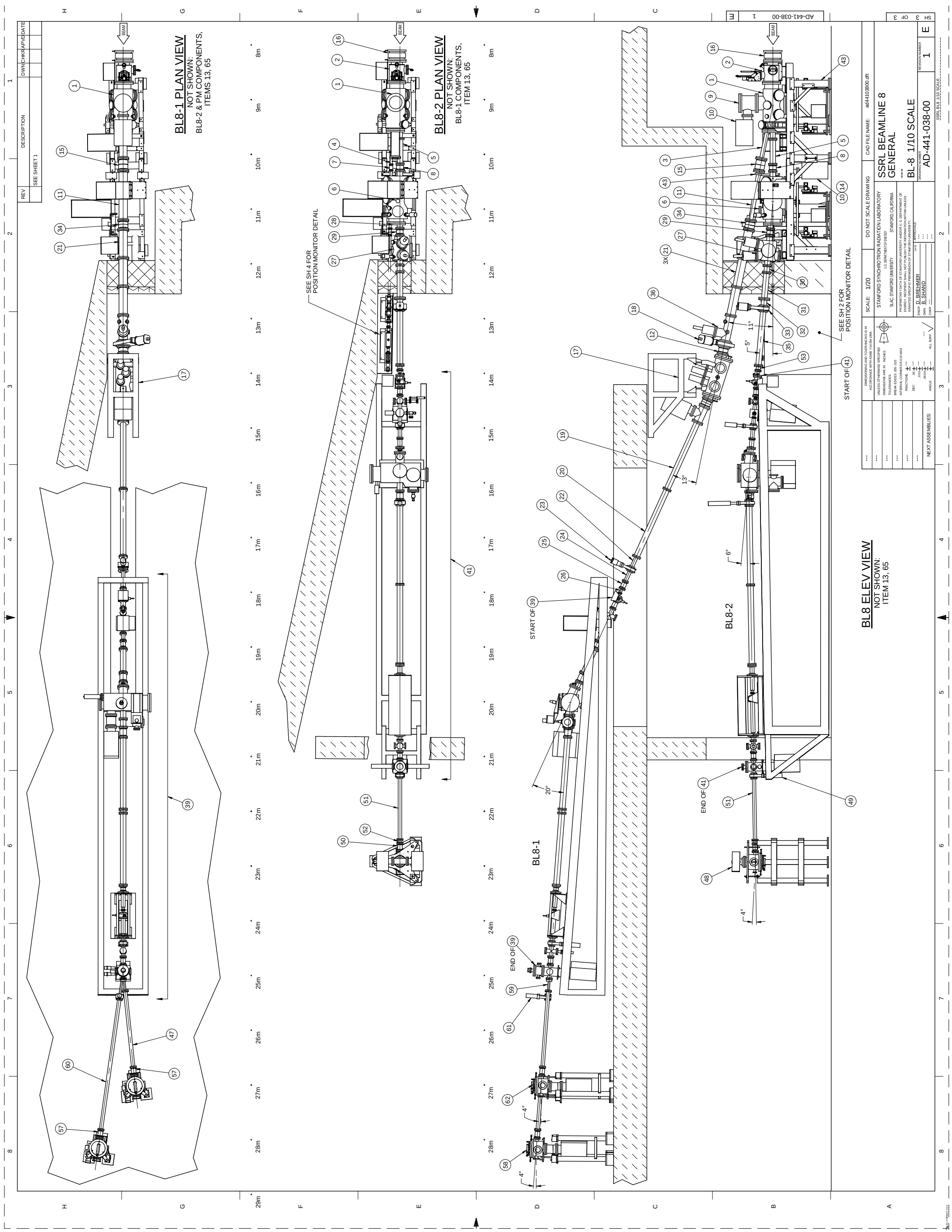




Figure 1: Beam line 8 layout

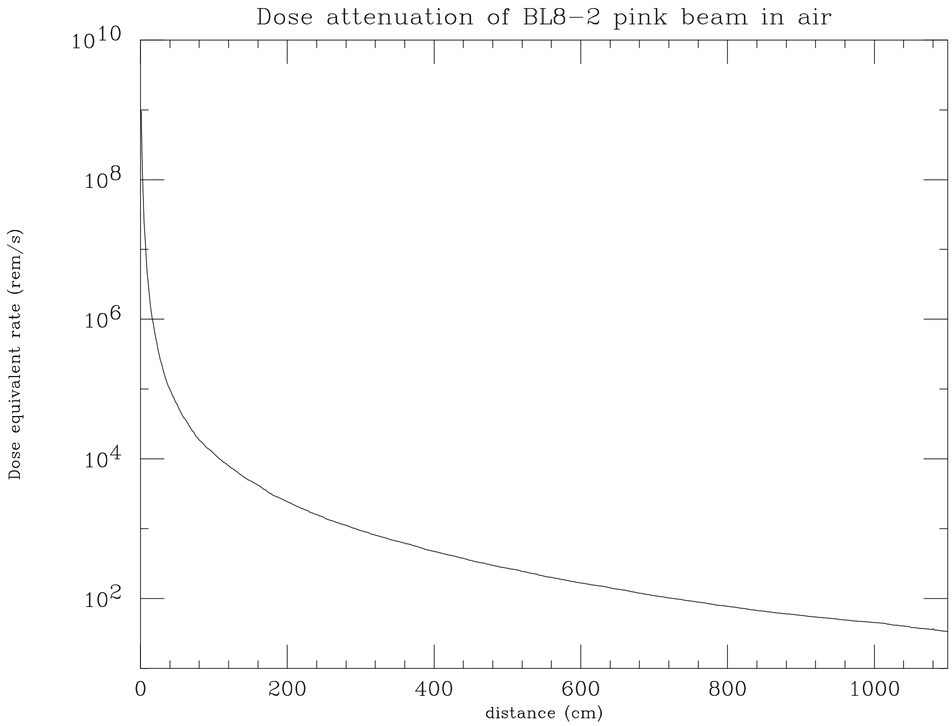


Figure 2: Attenuation in air of BL8-2 filtered synchrotron radiation

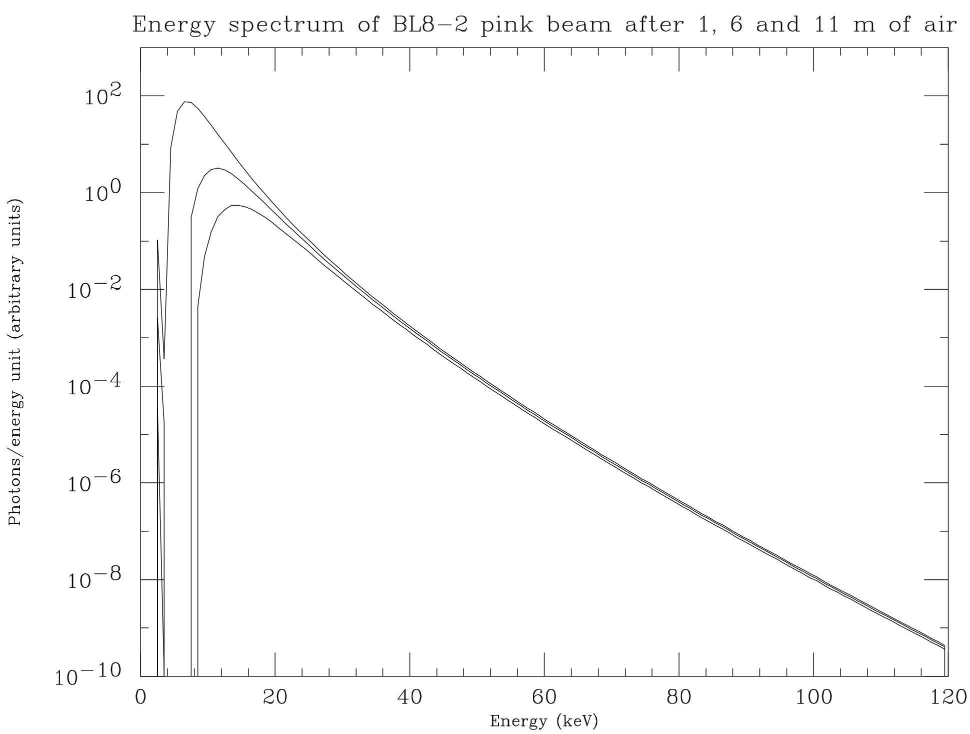


Figure 3: Photon spectra in BL8-2 filtered synchrotron radiation after 1, 6 and 11 meters of air

Table 2: SR design requirements for BL8-1 and BL-8-2 pink lines [1]

| *Beamline Target* | *Distance (cm)* | *Fan width (mrad)* | *Half-angle subtended [2] (mrad)* | *Existing pipe wall or mono tank shielding* | *Dose Rate [3] (mrem/h)* | *Additional shielding needed (provided) [4]* |
|---|---|---|---|---|---|---|
| BL8-1 vacuum pipe | 30 | 8 | 1.9 | $\geq$ 2.8 mm Fe | 5.8 | 1.9 mm Pb (3.2) |
| stopper | | | 1.3 | $\geq$ 2.8 mm Fe | 2.7 | 1.4 mm Pb (1.6) |
| mirror | | | 1.0 | $\geq$ 3.4 mm Fe | 1.2 | 1.1 mm Pb (1.6) [5] |
| BL8-2 vacuum pipe | 30 | 4 | 3.2 | $\geq$ 1.7 mm Fe | 37 | 2.4 mm Pb (3.2) |
| entrance slit | | | 2.9 | $\geq$ 12.7 mm Fe | 0.027 | none |
| bellows, viewports [6] | | | 9.4 | | | 1.1 mm Pb |
| grating | | | 1.3 | $\geq$ 12.7 mm Fe | 0.005 | none |

[1] Bend white light has $E_c = 7.78$ keV (1.286 T field), 74.1 W/mradH at 500 mA.
[2] The angle considered is that subtended by 1 m of pipe
[3] The dose is largely dominated by radiation Compton-scattered from the M0 mirror. The reflected pink light contribution is more than three orders of magnitude lower.
[4] The necessary shielding will be achieved by wrapping the beam pipe from the SPEAR ratchet wall up to the collimator itself or to the mirror/entrance slit with a Pb sheet. The Table reports the thickness required and in parentheses that implemented.
[5] The downstream wall of the mirror tank is thinner than the lateral walls (2.1 mm): therefore, the required additional shielding is 3.0 mm Pb (3.2 have been implemented).
[6] Bellows and viewports downstream of the entrance slits needing to be shielded against pink light scattered from objects inserted in the beam (photo-diode, grating baffles)

Table 3: Gas Bremsstrahlung design requirements for BL8-PM safety components [1]

| *Safety item* | *Distance from SPEAR dipole (cm)* | *Existing lateral and vertical extension $L_H$, $L_V$ (inch Pb)* | *Required lateral and vertical extension $L_H$, $L_V$ (inch Pb)* | *Existing thickness (inch Pb)* | *Required thickness (inch Pb)* |
|---|---|---|---|---|---|
| Beam stop | 1400 | $L_H$,$L_V$ = 2.7 | $L_H$,$L_V$ = 1 | 8 | 7.3 |

[1] Requirements are for primary GB from a bend line. The power, corresponding to a 0.64 mradH fan at 500 mA, is 32 nW.

Table 4: Gas Bremsstrahlung design requirements for the BL8-PM enclosure. Optical components [1]

| *Enclosure Wall* | *Beamline Target* | *Distance (cm)* | *Existing shielding (mm)* | *Dose Rate* [2] *(mrem/h)* | *Shielding Needed (inch)* |
|---|---|---|---|---|---|
| SSRL side, Roof | PM screen, Cu end plug, PM Assembly, collimator, Be window | 30 | 6.35 Pb | $1.4 \times 10^{-4}$ | none |
| downstream[3] | | | | | |
| 4° | Side port coll. | 144 | 6.35 Pb | 0.02 | none |
| 5.5° | Be window | 104 | | 0.02 | none |
| 23° | PM screen | 24 | | 0.02 | none |

[1] Bending magnet source, 0.47 cm long air section at 1 ntorr (32 nW at 3 GeV for a 0.64 mradH fan at 500 mA). The radiation source is primary GB scattered by an optical component (position monitor, window, end plug).
[2] Doses calculated for a short Cu target and a shower fully developed in the shielding wall.
[3] Downstream wall of BL8-PM enclosure. The bremsstrahlung collimator intercepts the whole GB physical envelope (see ray trace [2]) and covers an angle of about 4° with respect to any possible target