RP Note 04-12 (May 14, 2004)

Radiation Safety Design for SSRL Wiggler Beamline BL4 (SPEAR3 100 mA Operation)

H. Y. Khater, J. C. Liu and A. A. Prinz

Radiation Protection Department, Stanford Linear Accelerator Center
2575 Sand Hill Road, M/S 48, Menlo Park, CA 94025

Introduction

This technical note describes the shielding design for SSRL wiggler beamline BL4. The shielding design controls the synchrotron radiation (SR) and gas bremsstrahlung (GB) hazards. The criteria, methodology and rules for the design follow the RP summary note RP-03-21 [1] and its references. Information regarding BL4 operation and beam parameters is given in the note by T. Rabedeau [2]. Further information used in this analysis was obtained from ray trace drawings [3], and email from T. Rabedeau [4]. In this note, the SR and GB shieldings are given for 100 mA operation of SPEAR3.

Operational Modes

Proposed SPEAR3 Mode

BL4 is a wiggler source, which has a SR critical energy (E_c) of 4.25 keV (at 0.7-T magnetic field), 20 effective poles, and a power density of 160 W/mradH at 100 mA. The total synchrotron horizontal fan width coming out of the wiggler is 5.2 mrad. As shown in Fig. 1, the SR passes thru the comb mask into BL4-0 transport tunnel and then to various branch lines. Only 2 mradH (wiggler SR) is allowed into the BL4-0 "Back" pink light hutch (BL4-2 mono hutch), which is followed by the BL4-2 pink light hutch. The BL4-1 and BL4-3 branch lines are not used and their hutch shutters (located in-alcove) will remain locked in place at all times. In addition, the BL4-1 and BL4-3 hutches as well as the two BL4-0 "Front" hutches (BL4-1 and BL4-3 mono hutches) are locked at all times.

For GB hazard evaluation, the straight section length in the ring is assumed to be 6 m long (the actual straight section length is 5.3 m) and the air pressure is 1 ntorr (equivalent to 7.6 μW of GB power). The beamline utilizes an in-alcove M0 mirror. The mirror, which is always in place, reflects the SR into the BL4-0 "Back" hutch. The BL4-0 "Back" hutch is considered a pink light hutch and is followed by the BL4-2 filtered-mono experimental hutch.

Previous SPEAR2 Mode

In comparison, during the SPEAR2 operation, white light was allowed inside the BL4-2 filtered-mono experimental hutch. In addition, the two in-alcove 3”-thick copper hutch shutters were the only barriers between GB from BL4 wiggler and personnel in the experimental hutch. An analysis to determine the level of dose rates due to un-scattered gas bremsstrahlung (PGB) radiation from BL4 wiggler inside the BL4-2 experimental hutch was performed [5].

The analysis showed the dose rate at the location of the hutch shutters (unshielded) is 57.8 rem/h. Using conservative values of $\lambda^{-1}_{c.m.}$ = 3.68 cm for copper attenuation, the 6”-copper shutters reduce the dose rate behind the hutch shutters (at about 1’) to 920 mrem/h. Since the closest access point to the beam line inside BL4-2 hutch is at a distance of about 45’ from the hutch shutters, the resulting dose rate inside the hutch is estimated to be 0.45 mrem/h (reduction is due to inverse square law for distance). This value is about an order of magnitude higher than our current design limit. These results highlighted the importance of installing the M0 mirror in-alcove and the necessity of performing detailed ray tracing of PGB and SGB in BL4.

Design Requirements for Synchrotron Radiation

BL4-0 “Front” Pink Light Transport Tunnel

Since the M0 mirror in alcove is always kept in place [2], for SR shielding design, the BL4-0 “Front” tunnel is a pink transport tunnel. The M0 mirror in alcove provides pink light at a small vertical angle of 14.2 mrad. In this case the entire beamline is elevated above the electron beam level in order to transport the reflected beam.

Two SR sources can enter the BL4-0 “Front” transport tunnel. The pink light and Compton light resulting from 2 mradH wiggler white light (160 W/mradH) hitting the 7.1 mrad inclined mirror in-alcove. In the BL4-0 “Front” transport tunnel, the pink light as well as Compton light (with a linear half-angle of 4.4 mrad) hits the beampipe. Generic pink-light and double Compton shielding results [6] were used in the design of BL4-0 “Front” transport tunnel. A 1 meter long section of the beampipe was simulated as an inclined Si target for the shielding design purpose. As shown in Table I, the current tunnel walls, with 3.4 mm of Pb, provides more than adequate shielding for personnel outside the tunnel.

BL4-2 Pink Light Transport Pipe

Pink and Compton lights scattered from the mirror hit the BL4-2 transport beampipe between the BL4-0 “Front” (on SSRL side) and BL4-3 hutches. A one meter long section of the beampipe was simulated as an inclined Si target for the shielding design purpose. As shown in Table II, since the beampipe is surrounded with 6.35 mm of Pb, the current Pb shield surrounding the beampipe between the BL4-0 "Front" and BL4-3 hutches provides adequate shielding for personnel in the vicinity of the pipe.

BL4-0 "Back" Pink Light Transport Tunnel

As mentioned before, the M0 mirror in alcove provides pink light at a small vertical angle of 14.2 mrad. Pink light from the in-alcove M0 mirror hits the 4-2 multilayer monochromator. In the meantime, Compton light scattered from the mirror (with a linear half-angle of 1.5 mrad) hits the adjustable slit (before the monochromator). The 4-2 mono and the adjustable slit were simulated as inclined Si targets for the shielding design purpose. As shown in Table III, the current transport walls, with 3.4 mm of Pb, provides more than adequate shielding for personnel outside the BL4-0 "Back" transport tunnel.

BL4-2 Filtered-Mono Hutch

The SR source entering the BL4-2 hutch consists of filtered mono-light harmonics from 2 mradH white light hitting the M0 mirror in-alcove and then the multilayer monochromator Si(111) in the BL4-0 "Back" transport tunnel. Dose rates were estimated using the source terms and half-value layers reported for a 500 mA, 2-T field [8]. Results were normalized for a horizontal fan width of 2 mrad and 20-pole 0.7-T field. To adjust for the magnetic field, the intensities of mono-light harmonics per pole per mradH in a 2-T field [1] were scaled down by the ratio of the photon intensities of the 68.1-keV harmonic light for 1-T and 2-T. The flux intensity was conservatively increased by a factor of 100 because the 4-2 mono is a multilayer mono. In addition, filtering of the mono light was accounted for by multiplying the results by the mirror reflectivity at 68.1-keV. As shown in Table IV, the current hutch wall (including the door) thickness of 3.4 mm Pb meets the design requirement of 0.05 mrem/h.

Design Requirements for Gas Bremsstrahlung (GB)

GB Design Requirements for Safety Components

The BL4 wiggler source is assumed to be a 6-m long air section at 10^{-9} torr. The BL4-1 and BL4-3 branch lines are terminated by two Pb beamstops (located inside the BL4-0 "Front" transport tunnel). The beamstops intercept the PGB from the straight section. The locations of these safety components from the center of ID device and their X/Y/Z dimensions are shown in Table V. The generic safety component shielding results described in [1,8] were used in this analysis. The longitudinal Z thickness of the beamstops are sufficient to satisfy the 0-degree GB dose limit.

The BL4-2 experimental hutch is protected by a Pb collimator (located inside BL4-0 "Front" transport tunnel) as well as a Pb beamstop (located inside BL4-0 "Back" transport tunnel). The locations of these safety components from the center of ID device and their X/Y/Z dimensions are also shown in Table V. Because of the copper comb mask, the Physical Envelope ray trace shows that only Secondary GB (SGB) can hit the collimator. In addition, the beamstop only intercepts SGB passing through the movable mask and M0 mirror. The longitudinal Z thicknesses of the collimator and beamstop are sufficient to satisfy the 0-degree GB dose limit.

GB Design Requirements for Optic Components

The generic optic component shielding results described in [1,9] were used in this analysis. The Physical Envelope ray trace shows that primary GB rays hit the in-alcove M0 mirror, the Cu comb mask and the BL4-2 transport pipe. Due to the fact that the distance between the comb mask and BL4-0 "Front" transport tunnel could be as short as only 24 cm, additional shielding along the sides of the comb mask is needed. As shown in Table VI, 2" Pb are needed on the SPEAR side (at 90°). On the other hand, a shield that varies in thickness from 2-3" Pb (varies based on angle) is also needed on the SSRL side to cover the space between the comb mask and BL4-3 beamstop (at 25° with respect to beamline). If the shielding is not installed, a barrier (an exclusion zone) must be erected along each of the BL4-0 "Front" transport tunnel side walls. The barrier must be located at a distance of 1 m from the axis of the beampipe.

Finally, PGB hitting the BL4-2 transport pipe (between BL4-0 "Front" hutch and BL4-3 hutch) will result in high dose rates outside the pipe. As shown in the table, using results for GB hitting a mirror to simulate the GB hitting the beampipe, indicate the need for placing an additional 1" Pb along the side of the beampipe on the SSRL and SPEAR sides. If the shielding is not installed, a barrier (an exclusion zone) must be erected along each of the BL4-2 transport tunnel side walls. The barrier must be located at a distance of 1 m from the axis of the beampipe and extend from the SPEAR wall to the BL4-0 "Front" hutch on the SPEAR side and from the BL4-0 "Front" hutch to the BL4-3 hutch on the SSRL side.

Summary

The safety and shielding requirements for BL4 are:

1. The in-alcove mirror has to be in place during beamline operation at all times.
2. The 3.4-mm Pb walls of the BL4-0 "Front" pink light transport hutch are sufficient.
3. The 3.4-mm Pb walls of the BL4-0 "Back" pink light transport hutch are sufficient.
4. The 6.35-mm Pb lateral shield along the BL4-2 pink light transport pipe is sufficient.
5. The 3.4-mm Pb walls of the BL4-0 "Front" hutch are sufficient.
6. The 3.4-mm Pb walls of the BL4-0 "Back" hutch are sufficient.
7. The 3.2-mm Pb walls of the BL4-1 hutch are sufficient.
8. The 3.2-mm Pb walls of the BL4-3 hutch are sufficient.
9. The 3.4-mm Pb walls of the BL4-2 filtered mono light experimental hutch are sufficient.

10. The GB safety components inside BL4-0 “Front” transport tunnel are; BL4-1 and BL4-3 Pb GB beamstops and a collimator. The sizes and locations of safety components are acceptable for the GB requirements for 100-mA operation.
11. The only GB safety component inside BL4-0 “Back” transport tunnel is the BL4-2 Pb GB beamstop. Size and thickness of the beamstop is acceptable for the GB requirements for 100-mA operation.
12. The only GB optic element inside BL4-0 “Front” transport tunnel is the Cu comb mask. An additional 2” Pb (on SPEAR Side) and 2-3” Pb (varies based on angle) (on SSRL side) are needed to shield the comb mask. If the shielding is not installed, a barrier (an exclusion zone) must be erected along each of the BL4-0 “Front” transport tunnel side walls. The barrier must be located at a distance of 1 m from the axis of the beampipe.
13. The BL4-2 transport pipe is considered a GB optic element. An additional 1” Pb lateral shield is needed on the SPEAR and SSRL sides of the pipe. If the shielding is not installed, a barrier (an exclusion zone) must be erected along each of the BL4-2 transport tunnel side walls. The barrier must be located at a distance of 1 m from the axis of the beampipe and extend from the SPEAR wall to the BL4-0 “Front” hutch on SPEAR side and from the BL4-0 “Front” hutch to the BL4-3 hutch on the SSRL side.
14. The two BL4-0 “Front” hutches must be kept locked at all times.
15. The BL4-1 and BL4-3 hutches must be kept locked at all times.
16. The BL4-0 “Front” tunnel must be B-locked.
17. The BL4-0 “Back” tunnel must be Rad-locked.

References

1. James Liu, Alberto Fassò, Hesham Khater, Alyssa Prinz and Sayed Rokni, “Generic shielding design for SSRL beamlines,” RP note RP-03-21, Nov 14, 2003.
2. Thomas Rabedeau, “BL4 SPEAR3-100 mA Shielding Implementation,” SSRL Engineering Note M481, Rev. 2, May 14, 2004.
3. BL4 Ray Trace Drawing GP 441-017-70-c0, Sheets 1-3, 3/15/04.
4. Thomas Rabedeau, “Excel file “sp3_bl_upgrade1.xls,” email to James Liu, August 21, 2003.
5. H. Y. Khater, “Analysis of the Hutch Shutters Used in SPEAR2 for BL4 and BL7,” Memo to Sayed Rokni, January 14, 2004.
6. A. A. Prinz, J. C. Liu and H. Y. Khater, “Generic Synchrotron Radiation Shielding Design for SPEAR3 Pink-Light Hutches and VUV Vacuum Chambers,” RP-03-11, 11/12/03.
7. Alberto Fassò and J. C. Liu, “Attenuation of Scattered Monochromatic Synchrotron Radiation in Iron and Lead,” RP Note 03-20, 11/12/03.
8. H. Khater, et al., “Primary Gas Bremsstrahlung Shielding Requirements for SPEAR3 Beam Lines,” RP-03-09 Rev. 1, 11/10/03.
9. A. A. Prinz, et al., “Shielding for Scattered Gas Bremsstrahlung for SPEAR3 Beam Lines,” RP-03-10, Rev. 1, 2/13/04.

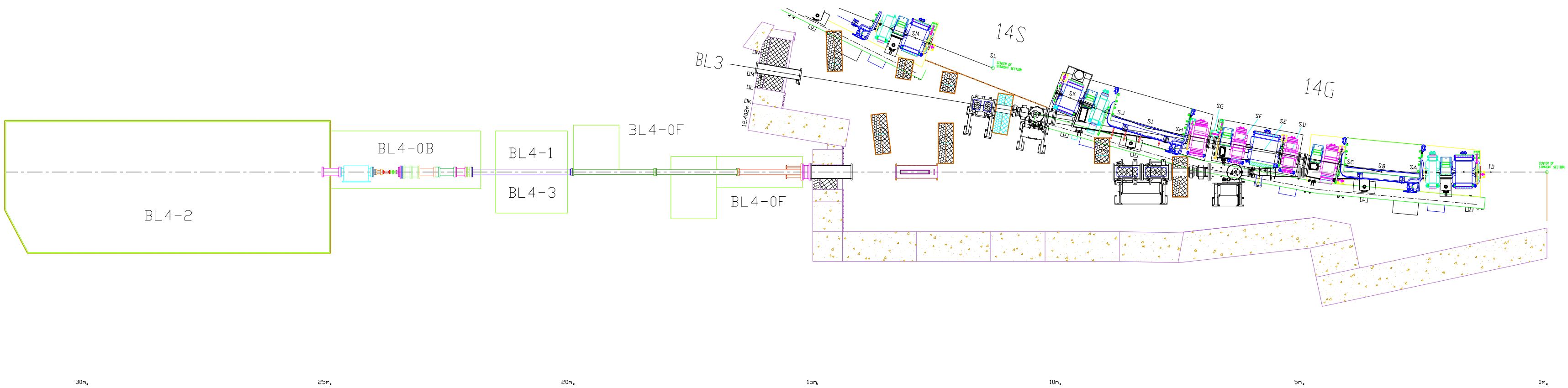

Figure 1. BL4 Plan View.

Table I. SR Design Requirements for BL4-0 “Front” Pink Light Transport Tunnel[1]

Hutch Wall	Beamline Target	Distance (cm)	Dose Rate (mrem/h)	Existing Shielding (mm)	Required Additional Shielding (mm)[2]
Hutch Wall (SPEAR side)	Beam Pipe[3]	24	<1e-4	3.4 Pb	None
Hutch Wall (SSRL side)	Beam Pipe	24	<1e-4	3.4 Pb	None
Downstream Wall	Beam Pipe	50[4]	<1e-4	3.4 Pb	None
Roof	Beam Pipe	100	<1e-4	3.4 Pb	None

[1] Source is 2 mradH white light from ID, E_c = 4.3 keV, 20 poles, 160 W/mradH for 100 mA.
[2] Amount of additional shielding needed to reduce the dose rate to ≤ 0.05 mrem/h.
[3] Compton light scattered from the mirror (with a linear half-angle of 4.4 mrad) hits the beam pipe. One meter of the beam pipe simulated as an inclined Si target for the shielding design purpose.
[4] Distance to BL4-0 “Front” hutch on SSRL side.

Table II. SR Design Requirements for BL4-2 Pink Light Transport Pipe[1]

Hutch Wall	Beamline Target	Distance (cm)	Dose Rate (mrem/h)	Existing Shielding (mm)	Required Additional Shielding (mm)[2]
Hutch Wall (SPEAR side)	Beam Pipe[4]	24	<1e-4	9.75 Pb[3]	None
Hutch Wall (SSRL side)	Beam Pipe	2.4	<1e-4	6.35 Pb	None
Roof	Beam Pipe	100	0.05	1 Pb	None

[1] Source is 2 mradH white light from ID, E_c = 4.3 keV, 20 poles, 160 W/mradH for 100 mA.
[2] Amount of additional shielding needed to reduce the dose rate to ≤ 0.05 mrem/h.
[3] The transport pipe is 6.35 mm thick and the BL4-0 “Front” tunnel and BL4-0 “Front” hutch are 3.4 mm thick each.
[4] Compton light scattered from the mirror hits the beampipe between the two BL4-0 “Front” and BL4-3 hutches. Compton light scattered from the mirror (with a linear half-angle of 2.6 mrad) hits the beampipe. One meter of the beampipe simulated as an inclined Si target for the shielding design purpose.

Table III. SR Design Requirements for BL4-0 "Back" Pink Light Transport Tunnel[1]

Hutch Wall	Beamline Target	Distance (cm)	Dose Rate (mrem/h)	Existing Shielding (mm)	Required Additional Shielding (mm)[2]
Hutch Wall (SPEAR side)	4-2 Mono/ Adjustable Slit[3]	75	<1e-4	3.4 Pb	None
Hutch Wall (SSRL side)	4-2 Mono/ Adjustable Slit	40	<1e-4	3.4 Pb	None
Downstream Wall	4-2 Mono/ Adjustable Slit	40[4]	<1e-4	3.4 Pb	None
Roof	4-2 Mono/ Adjustable Slit	100	<1e-4	3.4 Pb	None

[1] Source is 2 mradH white light from ID, E_c = 4.3 keV, 20 poles, 160 W/mradH for 100 mA.
[2] Amount of additional shielding needed to reduce the dose rate to ≤ 0.05 mrem/h.
[3] Pink light from the in-alcove M0 mirror hits the 4-2 mono. Compton light scattered from the mirror (with a linear half-angle of 1.5 mrad) hits the adjustable slit. The 4-2 multilayer monochromator and the adjustable slit were simulated as inclined Si targets for the shielding design purpose.
[4] Distance to BL4-2 hutch.

Table IV. SR Design Requirements for BL4-2 Filtered Mono Light Hutch[1]

Hutch Wall	Distance (cm)	Dose Rate (mrem/h)	Existing Shielding (mm)	Required Additional Shielding (mm)[2]
Hutch Wall (SPEAR side)	100	8e-10	3.4 Pb	None
Hutch Wall (SSRL side)	160	3e-10	3.4 Pb	None
Downstream Wall	100	2e-7[3]	4.77 Pb	None
Roof	100	8e-10	3.4 Pb	None

[1] Source is 2 mradH white light from ID. Si(111) Crystal with 0.7-T field. The intensities of mono-light harmonics were scaled down by ratio of the photon intensities of the 68.1-keV harmonic light for 1-T and 2-T. Filtering of the mono light was accounted for by multiplying the results by the reflectivity of 68.1-keV cut-off-mirror. The flux intensity was increased by a factor of 100 because the 4-2 mono is a multilayer mono.
[2] Amount of additional shielding needed to reduce the dose rate to ≤ 0.05 mrem/h.
[3] If the mono-light hits the back wall (misses the target), the dose rate outside the wall is two orders of magnitude higher.

Table V. Gas Bremsstrahlung Design Requirements for BL4 Safety Components

Safety Components	Location (m)	Size X/Y/Z (in)	Required Z Thickness (inch)	Existing Lateral Extension (in)		Required Lateral Extension (in)	SSRL Action
				Horiz.	Vert.		
BL4-1 and BL4-3 Hutches							
Beamstops (BL 4-0 "Front" Transport Tunnel) [1]	15.6	Two 6x8x10 Pb	7.8	2.8	2.8	0.5	
BL4-2 Hutch							
Collimator (BL4-0 "Front" Transport Tunnel) [2]	16.3	8x2x10 Pb	7.7	1.6	0.8	0.5	
Beamstop (BL4-0 "Back" Transport Tunnel) [3]	23.7	12x8x10 Pb	7.2	1.7	1.5	0.5	

[1] PGB is intercepted by BL4-1 and BL4-3 hutch shutters, only SGB may interact with the beam stops.
[2] Due to the presence of the Cu comb mask (before the collimators), only SGB may interact with the collimators.
[3] The beamstop intercepts SGB passing through the movable mask and M0 mirror.

Table VI. Gas Bremsstrahlung Design Requirements for BL4 Optic Components

Optic Components	Location (m)	Distance (m)	Dose Rate (mrem/h)	Angle	Existing Shielding	Required Additional Shielding[1]	SSRL Action
BL4-0 Transport Tunnel							
Comb Mask[2,3]	15.2 (SPEAR side)	0.24	0.5	90°	None	**2" Pb**	**A**
Comb Mask[2,3]	15.2 (SSRL side)	0.6	0.56	25°	None	**3" Pb**	**A**
Comb Mask[2,3]	15.2 (SSRL side)	0.24	0.5	90°	None	**2" Pb**	**A**
Comb Mask[2]	15.2 (Roof)	1	0.03	90°	None	None	
BL4-2 Transport Pipe							
Beam Pipe[3,4]	18 (SPEAR side)	0.24	0.1	90°	None	**1" Pb**	**B**
Beam Pipe[3,4]	18 (SSRL side)	0.3	0.07	90°	None	**1" Pb**	**B**
Beam Pipe[4]	18 (Roof)	1	0.006	90°	None	None	

[1] Amount of additional shielding needed to reduce the dose rate to ≤ 0.05 mrem/h.
[2] Results for PGB scattering of a long (6x1x1 inch) Cu target were used.
[3] If the shielding is not installed, a barrier (an exclusion zone) must be erected along BL4-0 transport tunnel side wall. The barrier must be located at a distance of 1 m from the axis of the beampipe.
[4] Using results for GB hitting a mirror to simulate GB hitting the beampipe.
[A] **Installation of two fences that run the length of BL4-0 transport tunnel. Both fences are spaced 1 m away from the axis of the beampipe.**
[B] **Installation of two fences that run along the BL4-2 transport tunnel side walls. Both fences are located at a distance of 1 m from the axis of the beampipe and extend from the SPEAR wall to the BL4-0 "Front" hutch on SPEAR side and from the BL4-0 "Front" hutch to the BL4-3 hutch on the SSRL side.**