LCLS-II Technical Note

Long Beam Loss Monitors: Installation details and trip threshold analysis

LCLS-II TN-21-08

9/1/2021

Christine Clarke

Contents

1 Introduction

This note presents a summary of the studies from Radiation Physics and the implications for trip thresholds for the Long Beam Loss Monitors (LBLMs) that are a part of BCS. The information contained within, when not from a referenced document, is, with gratitude, from conversations with Radiation Physics (RP) members.

This document could be considered to be an independent review of the RP requirements (RP-17-05-R2[1]) which also draws together all the information in one place for ease of reference. On occasion, the opinions of the author are given.

LCLS-II requirements for the LBLMs are given in a Physics Requirements Documents (LCLSII-2.7-PR-0079) and the trip thresholds are stated in terms of beam loss which is a rough approximation of the maximum beam loss allowed in specific conditions before exceeding regulatory requirements.

This note describes the applicable regulatory requirements and describes how those may map to beam loss scenarios, based on RP studies.

Table 1 summarizes the dose rates necessary to meet regulations. This summary aims to be in agreement with information given in RP documents and in conversation with RP members.

Details on the beam loss scenarios are subsequently described in this note area by area with reference to relevant RP simulations and studies when available. This is to provide a connection between the requirements for radiation safety and beam loss scenarios that could be replicated to validate the studies and to inform when there may be constraints for operation. Table 4 captures the results of these simulations and the conclusions of this note.

Note that simulation results are considered guidance only. It is expected that they are accurate to a factor of two, at best.

It is assumed that MPS alarm and trip thresholds are set below BCS trip thresholds (in accordance with LCLSII-2.7-PR-0078) to further mitigate beam loss (ALARA) and that operators actively work to keep beam loss to the "normal" levels (as given in LCLSII-2.7-PR-0079). However the BCS thresholds must ensure a safe operating environment independent of this.

Table 1: Summary of dose rates necessary to meet regulations by area.

Area	Start (m)	End (m)	Driving Requirement for Radiation dose rate trip threshold (mrem/h)	Notes
Linac	From CID maze (upstream of gun) -22.03	Wooden door at BSY – 3050.51	5 mrem/h at 30 cm	Also expected to meet general area dose rate requirements for the gallery
BSY (minus BTHW)	Wooden door – 3050.51	Muon shield wall – 3207.26	5 mrem/h at 30 cm	Also expected to meet general area dose rate requirements for the gallery
BTHW	Muon shield wall – 3207.26	2 m inside BTHW hill – 3331.00	None	

[1] These RP trip thresholds were reviewed and approved by the Radiation Safety Committee in June 2017.

HH, BTH	2 m inside BTHW hill – 3331.00	2 m inside Undulator hill – 3560.49	0.05 mrem/h at 12 ft, 0.5 mrem/h at fence, 5 mrem in 1 hour 30 cm from fence, 5 mrem/y at public locations	
TDUND/TDUNDB	Right inside undulator hill – 3558.49	5 m downstream of TDUND/TDUNDB – 3568.79	5 mrem/h at 30 cm	Historically, trip thresholds met 0.5 mrem/h in this area and it is required by RP to meet this lower historical trip threshold at least initially unless it interferes with operations.
Undulator Hall	2 m inside Undulator hill - 3560.49	5 m upstream of first penetration in B921- 3674.50	None	
Below 921	5 m upstream of first penetration - 3674.50	5 m downstream of last penetration - 3710.78	5 mrem/h at 30 cm	
Undulator Hall	5 m downstream of last penetration in B921 - 3710.78	Wall between Undulator Hall and Dumpline Hall - 3732.71	None	
Dumpline Hall	Wall between UH and dumpline hall – 3732.71	Wall between dumpline hall and FEE – 3769.92	0.05 mrem/h in NEH	
Along SXR/HXR BYD	Start of BYD1 – 3735.95	End of BYD3 – 3739.35	0.05 mrem/h in NEH	

2 Linac

2.1 Requirements

2.1.1 Area Classification

The building above the accelerator housing (the Klystron or Linac Gallery) is classified as a Radiologically Controlled Area (RCA). The building currently has Radiation Areas posted around klystrons that feed the copper Linacs.

To remain a RCA and avoid Radiation Area postings, the BCS is required to limit radiation in the gallery such that there is below 5 mrem dose in one hour as measured 30 cm from shielding.

Peak dose rates may exceed 5 mrem/h if they are terminated fast enough such that 5 mrem accumulated dose in one hour is not exceeded.

From sector 11 onwards, two accelerators run concurrently: LCLS-II and FACET-II in sectors 10 through to 20 and LCLS-II and LCLS-Cu in sectors 21 onwards.

The BCS for LCLS-II is required to be independent from FACET-II (LCLSII-1.1-IC-0493) and so the LBLMs in sectors 10-20 for LCLS-II need to be calibrated to LCLS-II loss only. It is also planned to retain the LCLS-Cu BCS and therefore the LBLMs in sectors 21-30 likewise need to be calibrated to LCLS-II loss only. For the purposes of setting requirements on LCLS-II beam loss, we can assume no beam loss above "normal" from the other beamline[2]. "Normal" loss is defined to be 0.5 mrem/h or below in the Klystron Gallery.

Therefore LCLS-II BCS trip limits must be set to limit dose rates to 5 mrem/h or below for sectors 0 -10 and 4.5 mrem/h for sectors 11-30 as measured in the Klystron/Linac gallery 30 cm from shielding.

2.1.2 Dose to SLAC personnel

SLAC personnel that could accrue more than 100 mrem in one year in the Klystron/Linac gallery must be Radiation Workers. This is administratively controlled.

Radiation Workers can accrue up to 360 mrem in one year according to the SLAC ALARA limit, 500 mrem in one year according to the SLAC administrative control limit or 5000 mrem in one year per the DOE limit (ref: Radiological Worker I Study Guide).

In these cases, localised dose rates are not considered and general area dose rates for the gallery are considered. Occupancy for a worker in the gallery is assumed at 200 hours in one year (10% full occupancy).

Therefore BCS trip limits should be ~1 mrem/h or below as measured "general area" in the Klystron/Linac gallery.

This will be coupled with monitoring of normal (persistent) radiation levels in the gallery by Radiation Physics group and awareness of work activities to ensure individual workers do not accrue unnecessary dose. Additional shielding may be added to penetrations, or "hot spot" signage established if hot-spots are found that could contribute to SLAC personnel dose.

2.1.3 Dose to general public

Dose to general public is not considered for the Linac. Members of the general public are not allowed to enter the Klystron/Linac gallery. This is controlled through postings.

[2] We consider it unlikely that both beamlines would have heavy losses simultaneously. There are some design points where the Linacs would wish to purposefully lose the beam (collimators, dumps) and could cause high dose rates in the gallery. In these cases, administrative controls will be in place for example posting the penetration as a Radiation Area, if it isn't already posted thus due to the proximity of a klystron.

Shielding is sufficient such that the Linac does not contribute in a measurable way to skyshine.

2.2 Case Studies of Beam Loss

Further information on the studies presented below can be found in the following documents:

LCLSII-1.2-PR-0472

RP-15-09

RP-RPG-160308-MEM-01-R1

The Klystron/Linac Gallery has thick earth shielding (~25 ft) between it and the accelerator housing except for the locations of service penetrations where the shielding is much thinner due to the necessity to bring cables, waveguides and other items out.

There are multiple shielding designs for the penetrations. Each one is presented here.

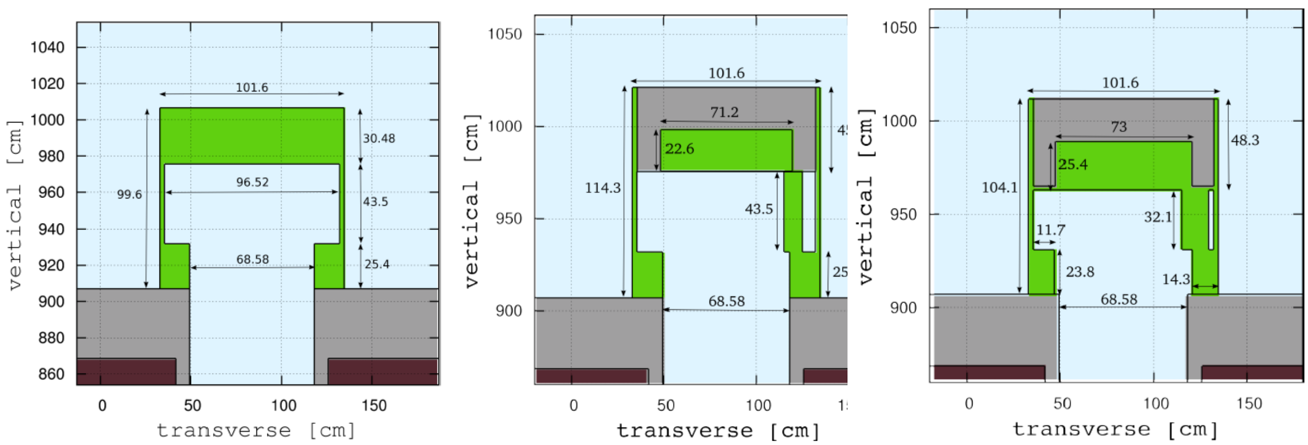

Figure 1: Service penetration shielding designs. Three designs are shown.

2.2.1 Service penetrations

Service penetrations are capped with three designs as shown in Figure 1.

The radiation dose maps for each design is shown in Figure 2. These are for shallow angle beam mis-steers in the housing with 2 MW beams. Normal operational beams are expected to be 250 kW.

These studies show that 5 mrem/h dose rates will be present 30 cm from the shielding with beams of the order 1 kW assuming the 30 cm is measured transversely (that is, SLAC personnel are not permitted to be seated on the penetration shielding). Depending on the actual shielding installation, this beam power may vary and this is a guide only.

It is highly recommended that SLAC personnel are not only trained not to sit on shielding but also prevented from sitting on shielding through an engineered method such as pigeon spikes. This is not part of the LCLS-II project however should be implemented for beam operations else beam operations should set conservatively low trip thresholds below requirements.

General area near a service penetration is about 1 rem/h for the 2 MW case and therefore about 0.5 mrem/h with 1 kW beam loss. Depending on the actual shielding installation, this beam power may vary and this is a guide only.

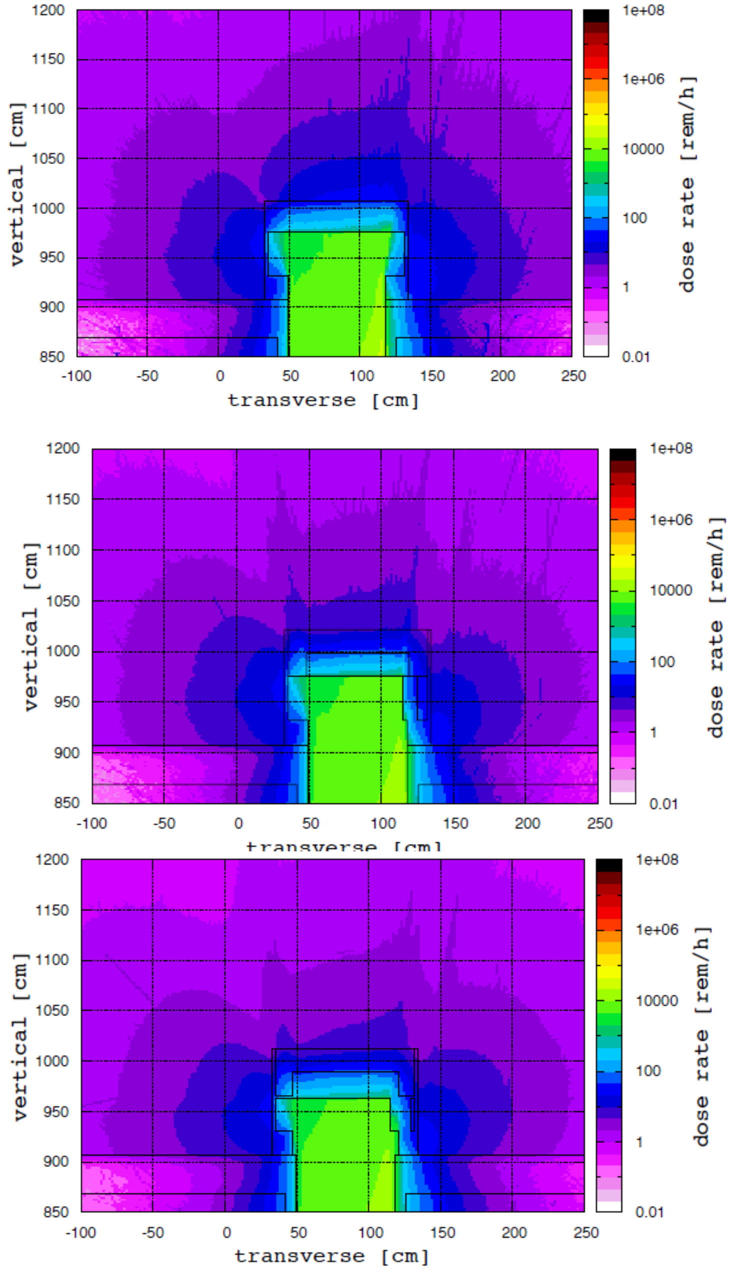

Figure 2: Dose rate maps for service penetrations with a shallow angle mis-steer beam loss below the penetration of a 2MW beam.

2.2.2 ODH Penetrations

There is only one design for capping ODH penetrations. This is shown in Figure 3 alongside dose rate calculations for different levels of beam loss. Note that there is no significant difference between a mis-steer loss (labeled MS) and a so-called "in beampipe" loss (labeled Norm)[3].

These studies show that 5 mrem/h dose rates will be present 30 cm from the housing with beams of the order 1 kW assuming the 30 cm is measured transversely (in the case of ODH penetrations, this is enforced

[3] "In-beampipe" loss covers items in the beampipe, scraping on apertures etc. and unlike mis-steer losses, are compatible with delivery of beam and less likely to be noticed and corrected.

through the ODH duct that extends above the shielding to the roof). Depending on the actual shielding installation, this beam power may vary and this is a guide only.

General area near a service penetration is about 1 mrem/h with 1 kW beam loss. Depending on the actual shielding installation, this beam power may vary and this is a guide only.

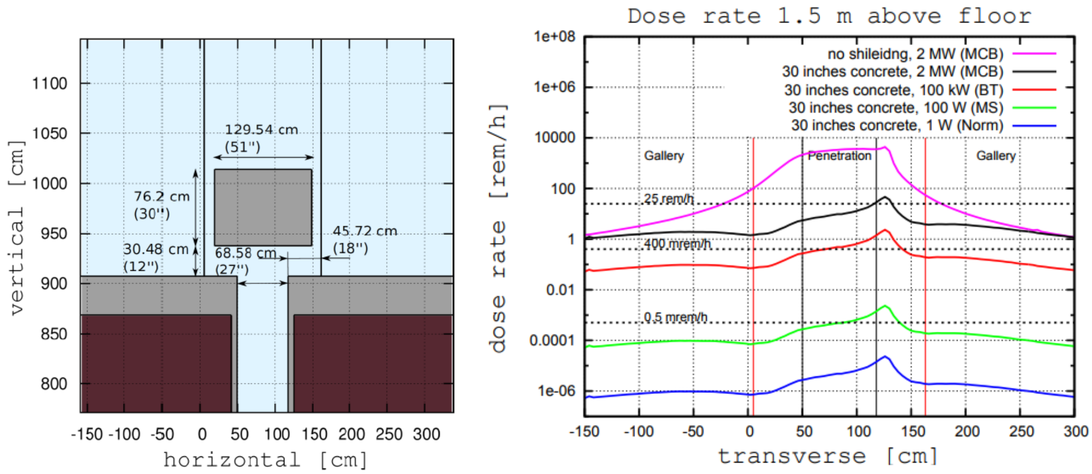

Figure 3: Left: Design for penetration shielding for an ODH penetration. Right: Dose rate maps for various loss scenarios below the penetration.

2.2.3 Helium Supply Line Penetrations

There is only one design for shielding the helium supply line penetrations. This is shown in Figure 4. Dose rate maps are produced for 2 MW beam mis-steer case below the penetration and the results are shown in Figure 5.

These studies show that 5 mrem/h dose rates will be present 30 cm from the housing with beams of the order 1 kW assuming the 30 cm is measured transversely (this is reasonable as the shielding extends higher than 2 m from the floor of the gallery). Depending on the actual shielding installation, this beam power may vary and this is a guide only.

General area near a service penetration is about 1 rem/h for the 2 MW case and therefore about 0.5 mrem/h with 1 kW beam loss. Depending on the actual shielding installation, this beam power may vary and this is a guide only.

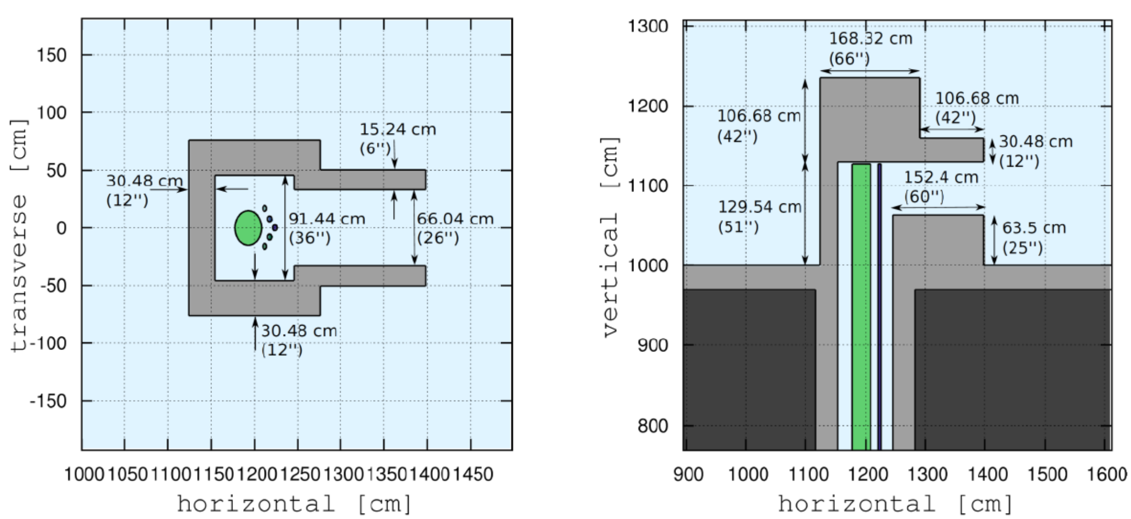

Figure 4: Design for penetration shielding for helium supply line penetrations.

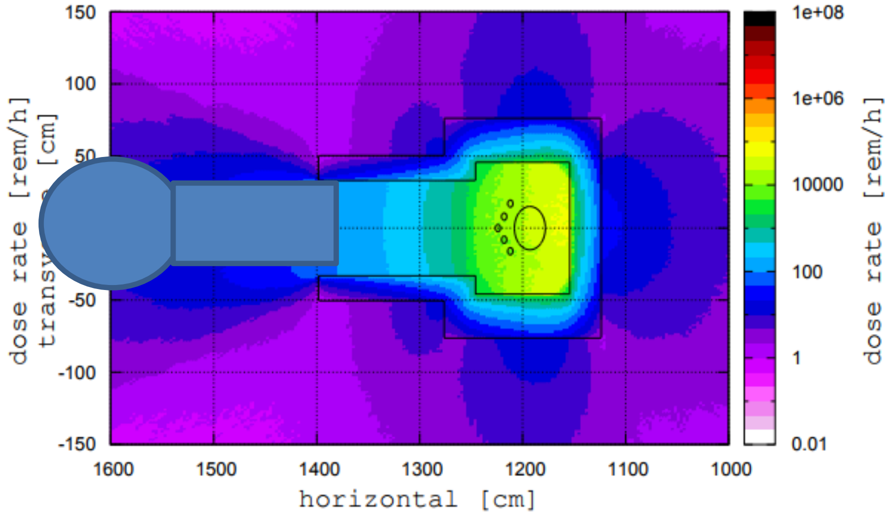

Figure 5: Dose rate map for a 2 MW beam mis-steer below a penetration for helium supply line. Note that the helium piping effectively forms an exclusion zone for people and shapes have been added to the map to indicate where people cannot be due to this equipment

2.2.4 Closed Penetrations

There is only one design for entirely closing penetrations. This is shown in Figure 6 alongside dose rate calculations for different levels of beam loss. Note that there is no significant difference between a mis-steer loss (labeled MS) and a so-called "in beampipe" loss (labeled Norm).

These studies show that 5 mrem/h dose rates will be present 30 cm from the housing with beams of the order 5 kW assuming the 30 cm is measured transversely (that is, SLAC personnel are not permitted to be seated on the penetration shielding). Depending on the actual shielding installation, this beam power may vary and this is a guide only.

It is highly recommended that SLAC personnel are not only trained not to sit on shielding but also *prevented* from sitting on shielding through an engineered method such as pigeon spikes. This is not part of the LCLS-II project however should be implemented for beam operations in the opinion of this author.

General area near a service penetration is about 0.5 mrem/h with 5 kW beam loss. Depending on the actual shielding installation, this beam power may vary and this is a guide only.

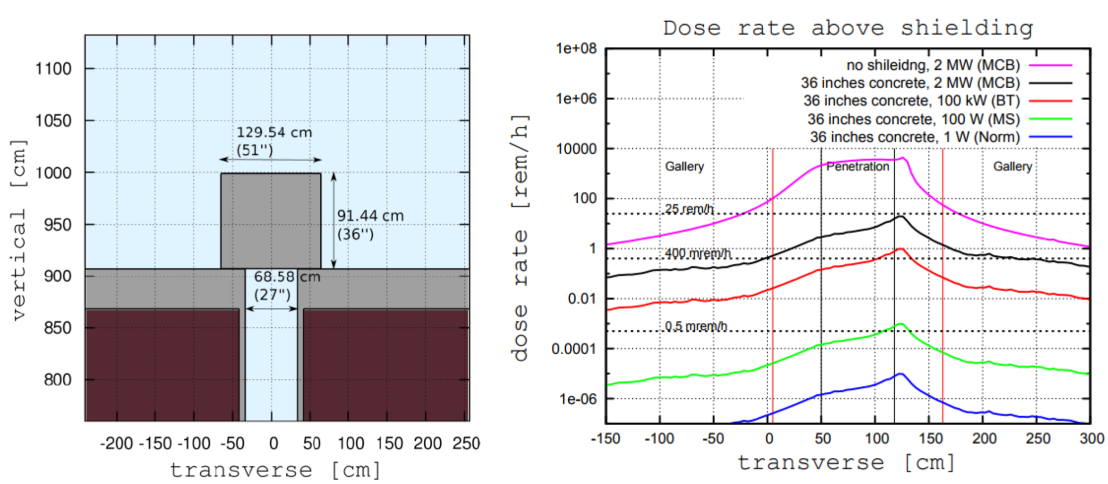

Figure 6: Left: Penetration cap design for closed penetrations. Right: Dose rates for various beam loss scenarios.

2.2.5 Borax-filled Penetrations

After the dog-leg, the LCLS-II beam travels in a "bypass line" that is roughly centred in the accelerator housing and is not, unlike the LCLS-II beamline prior to the dog-leg, directly below the north-side penetrations. In these areas, there are no plans to add concrete shielding and instead the penetrations will be filled with bags or borax. This is as is already the case for FACET and LCLS copper Linacs.

A photograph of such a penetration is shown in Figure 7 alongside dose rate calculations for different levels of beam loss. Note that there is no significant difference between a mis-steer loss (labeled MS) and a so-called "in beampipe" loss (labeled Norm). Note: "in-beampipe" loss covers items in the beampipe, scraping on apertures etc. and unlike mis-steer losses, are compatible with delivery of beam and less likely to be noticed and corrected.

These studies show that 4.5 mrem/h dose rates will be present 30 cm from the housing with beams of the order 4.5 kW assuming the 30 cm is measured transversely (that is, SLAC personnel are not permitted to be be above a penetration). Depending on the actual shielding installation, this beam power may vary and this is a guide only.

General area near a service penetration is about 0.5 mrem/h with 4.5 kW beam loss. Depending on the actual shielding installation, this beam power may vary and this is a guide only.

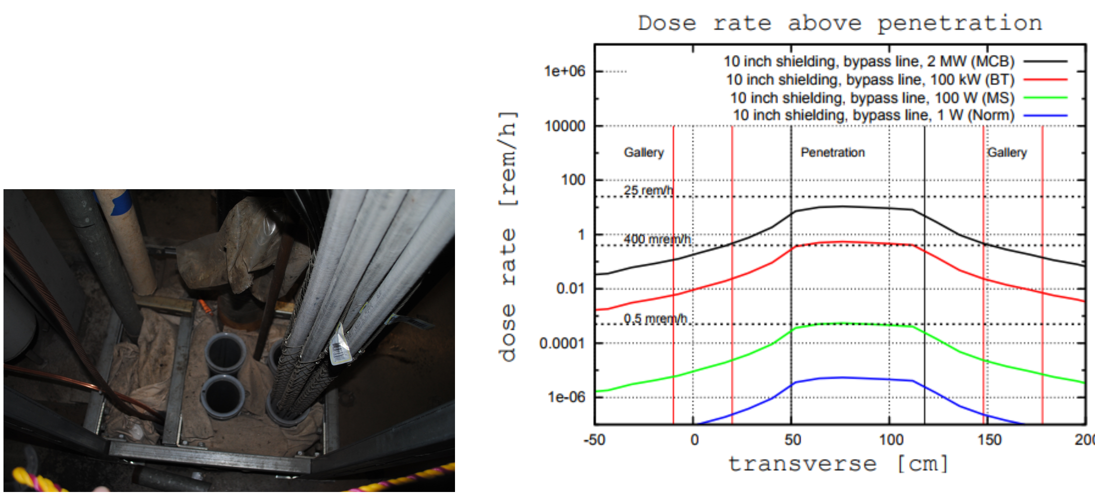

Figure 7: Left: Photograph of an existing penetration filled with borax. Right: Dose rate maps for various mis-steer scenarios.

2.3 Conclusion for Linac BCS Trip Thresholds

LBLMs are required to have BCS trip thresholds that satisfy both:

- Dose not to exceed 5 mrem in one hour (measured 30 cm from shielding) for sectors 0 – 10 or dose not to exceed 4.5 mrem in one hour (measured 30 cm from shielding) for sectors 11 – 30 and
- Personnel dose not to exceed 360 mrem annual ALARA limit (500 mrem SLAC Administrative limit and 5000 mrem DOE radiological worker limit), effectively a limit of ~1 mrem/h general area

RP simulations indicate that the trip threshold suitable throughout the Linac is approximately 1 kW of beam loss through a mis-steering or in-beampipe event (e.g. obstruction in the pipe or close aperture) though it can vary depending on the shielding that is built.

Personnel dose is further monitored and controlled administratively and this may result in the identification of persistent hot-spots with potential postings or spot-shielding.

3 Beam Switch Yard

3.1 Requirements

3.1.1 Area Classification

There are multiple buildings above the beam switch yard: B136 and pump house stations. These buildings include in them penetrations. B136 is an RCA. The pump house stations are accessible to SLAC personnel that only have course ESH 219 (i.e. they do not have GERT or Radiation Worker training). SLAC personnel may not wear dosimeters in the pump house stations.

To avoid Radiation Area postings, the BCS is required to limit radiation in these buildings such that there is below 5 mrem dose in one hour as measured 30 cm from shielding.

Peak dose rates may exceed 5 mrem/h if they are terminated fast enough such that 5 mrem accumulated dose in one hour is not exceeded.

Therefore BCS trip limits must not be above 5 mrem/h as measured in B136, etc, from penetration shielding.

3.1.2 Dose to SLAC personnel

SLAC personnel that could accrue more than 100 mrem in one year in RCAs such as B136 must be Radiation Workers. This is administratively controlled.

Radiation Workers can accrue up to 360 mrem in one year according to the SLAC ALARA limit, 500 mrem in one year according to the SLAC administrative control limit or 5000 mrem in one year per the DOE limit (ref: Radiological Worker I Study Guide).

In these cases, localised dose rates are not considered and general area dose rates for the buildings are considered. Occupancy for a worker in the gallery is assumed at 200 hours in one year (10% full occupancy).

Therefore BCS trip limits should be ~ 1 mrem/h or below as measured "general area" in building B136.

SLAC personnel that only have course ESH 219 may be present in the pump house stations (i.e. they do not have GERT or Radiation Worker training) and SLAC personnel may not wear dosimeters. Therefore, annual limits of 100 mrem in one year must be met. Occupancy in the pump station buildings is not considered to be full occupancy. Assuming 10% occupancy (200 hours), general area dose rates in these buildings must be limited to 0.5 mrem/h to limit dose to SLAC personnel.

This will be coupled with monitoring of normal (persistent) radiation levels in the buildings by Radiation Physics group and awareness of work activities to ensure individual workers do not accrue unnecessary dose. Additional shielding may be added to penetrations, or "hot spot" signage established if hot-spots are found that could contribute to SLAC personnel dose.

3.1.3 Dose to general public

Dose to general public is not considered for the BSY. Members of the general public are not allowed to enter the buildings above the BSY. This is controlled through postings.

Shielding is sufficient such that the BSY does not contribute in a measurable way to skyshine.

3.2 Case Studies of Beam Loss

Case studies have yet to be completed and published.

3.3 Conclusion for BSY BCS Trip Thresholds

LBLMs are required to have BCS trip thresholds that satisfy all:

- Dose not to exceed 5 mrem in one hour (measured 30 cm from shielding) and
- Radiation Worker Personnel dose not to exceed 360 mrem annual ALARA limit (500 mrem SLAC Administrative limit and 5000 mrem DOE radiological worker limit), effectively a limit of ~1 mrem/h general area in B136
- Non-Radiation Worker Personnel dose not to exceed 100 mrem in one year, a limit of 0.5 mrem/h general area in the pump house station buildings

RP simulations have not been published that indicate the approximate trip threshold in terms of beam power.

It can be extrapolated from previous experience that beam loss equivalent to 10 kW mis-steer in the BSY is expected to meet the requirements. For consistency with Linac trip thresholds, LCLS-II will require 1 kW for the BSY.

Personnel dose is further monitored and controlled administratively and this may result in the identification of persistent hot-spots with potential postings or spot-shielding.

4 BTHW

4.1 Requirements

4.1.1 Area Classification

There are multiple buildings above BTHW (Beam Transport Hall West). These buildings include in them penetrations. The buildings are accessible to SLAC personnel that only have course ESH 219 (i.e. they do not have GERT or Radiation Worker training).

To avoid Radiation Area postings, the BCS is required to limit radiation in these buildings such that there is below 5 mrem dose in one hour as measured 30 cm from shielding.

Peak dose rates may exceed 5 mrem/h if they are terminated fast enough such that 5 mrem accumulated dose in one hour is not exceeded.

Therefore BCS trip limits must not be above 5 mrem/h as measured from penetration shielding.

4.1.2 Dose to SLAC personnel

SLAC personnel that only have course ESH 219 may be present in the buildings (i.e. they do not have GERT or Radiation Worker training) and SLAC personnel may not wear dosimeters. Therefore, annual limits of 100 mrem in one year must be met. Occupancy in the buildings is not considered to be full occupancy. Assuming 10% occupancy (200 hours), general area dose rates in these buildings must be limited to 0.5 mrem/h to limit dose to SLAC personnel.

This will be coupled with monitoring of normal (persistent) radiation levels in the buildings by Radiation Physics group and awareness of work activities to ensure individual workers do not accrue unnecessary dose. Additional shielding may be added to penetrations, or “hot spot” signage established if hot-spots are found that could contribute to SLAC personnel dose.

4.1.3 Dose to general public

Dose to general public is not considered for the BTHW. Members of the general public are not allowed to enter the buildings above the BTHW. This is controlled through postings.

Shielding is sufficient such that the BTHW does not contribute in a measurable way to skyshine.

4.2 Case Studies of Beam Loss

Case studies have yet to be completed and published.

4.3 Conclusion for BSY BCS Trip Thresholds

LBLMs are required to have BCS trip thresholds that satisfy both:

- Dose not to exceed 5 mrem in one hour (measured 30 cm from shielding) and
- Non-Radiation Worker Personnel dose not to exceed 100 mrem in one year, a limit of 0.5 mrem/h general area in the pump house station buildings

RP simulations have not been published that indicate the approximate trip threshold in terms of beam power.

It can be extrapolated from previous experience that full beam loss can occur and requirements are met. Therefore no LBLMs are required by RP for this area for BCS functions. For consistency with Linac trip thresholds, LCLS-II will require 1 kW for the BSY.

Personnel dose is further monitored and controlled administratively and this may result in the identification of persistent hot-spots with potential postings or spot-shielding.

5 Head-house and Beam Transport Hall

5.1 Requirements

5.1.1 Area Classification

The area around the HH and BTH is the Research Yard. Buildings exist in the research yard that are office spaces. These are not posted as Radiologically Controlled Areas (RCAs). In order to avoid posting as an RCA, dose rates in these buildings need to be below 0.05 mrem/h. Buildings are located as close as 12 ft from fence.

The areas outside of the buildings, e.g. immediately at the PPS fence located 18ft from the concrete shielding of the BTH, must avoid Radiation Area postings and therefore the BCS is required to limit radiation at the fence to below 5 mrem dose in one hour as measured 30 cm from the fence (which marks the edge of the shielding which in this case is air).

Peak dose rates may exceed 5 mrem/h if they are terminated fast enough such that 5 mrem accumulated dose in one hour is not exceeded.

Therefore BCS trip limits must not be above 5 mrem/h as measured 30 cm from the fence/shielding or 0.05 mrem/h as measured in the office spaces.

5.1.2 Dose to SLAC personnel

SLAC personnel that only have course ESH 219 may be present (i.e. they do not have GERT or Radiation Worker training) and SLAC personnel may not wear dosimeters. Therefore, annual limits of 100 mrem in one year must be met. Occupancy at the fence is not considered to be full occupancy. Assuming 10% occupancy (200 hours), dose rates at the fence must be limited to 0.5 mrem/h to limit dose to SLAC personnel. Here we do not take a "general area" approach and instead take the value at the fence as the length of the BTH is 225 m and the dose could accrue at any location along that length.

5.1.3 Dose to general public

Dose to general public is not considered for the Research Yard. Members of the general public are not expected to be present in the research yard.

Shielding of the BTH is not sufficient for high-energy neutron shielding and high-energy neutrons penetrating the 1.2-1.8 metre thick BTH concrete roofs are expected to contribute measurably to skyshine.

The skyshine requirement is to be below 5 mrem/y (per facility) as measured in locations where the public may be, for example the Stanford Guest House, Rosewood Hotel, Sharon Heights etc.

5.2 Case Studies of Beam Loss

LCLSII-1.2-PR-0263 presents a study of distributed beam loss over the length of the BTH that is exposed in the Research Yard. The study finds that 75 W beam loss distributed evenly along the 225 m length of the BTH produces 0.05 mrem/h 12 ft from the fence (location of office buildings). This is shown in Figure 8.

Note that this 75 W also met 0.5 mrem/h limitation at the fence.

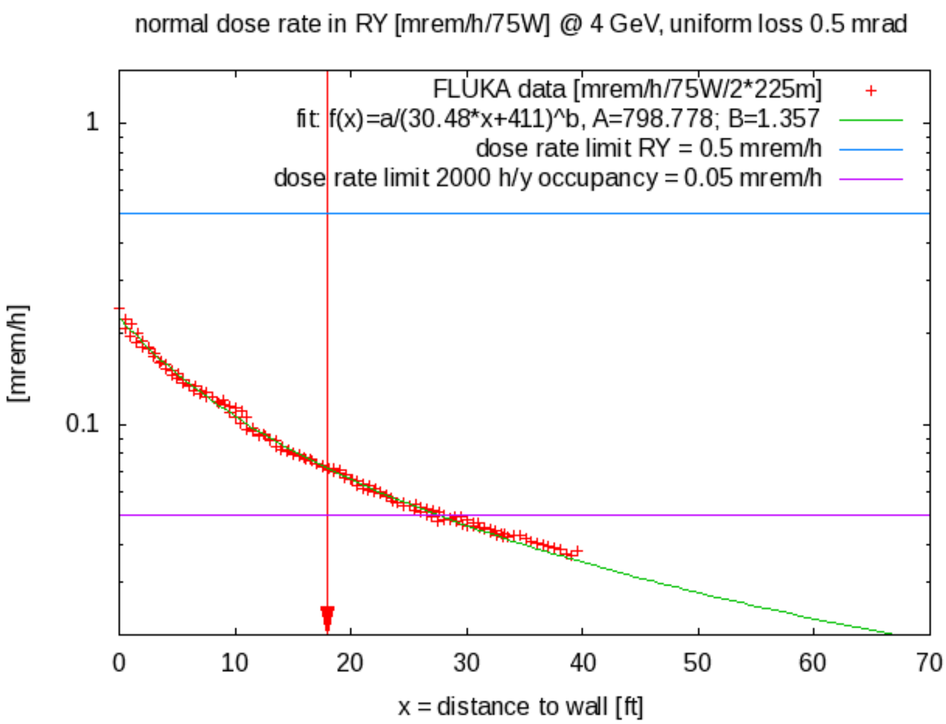

Figure 8: Dose rates from the BTH wall from a 75 W beam loss (shallow angle mis-steer) evenly distributed across the BTH. The fence is at 18 ft from the wall. The buildings are at 30 ft from the wall.

Besides such distributed loss, there can be localised beam loss from either in-beamline or mis-steer events.

LCLSII-1.2-PR-0263 defines the position of the fence such that a 2 MW beam "in beampipe" loss gives 25 rem/h (i.e. beam loss occurs inside the pipe from, for example, an obstruction or aperture). Such "in beampipe" losses don't necessarily prevent delivery of the beam and could continue. Therefore they need to be considered when setting the BCS trip threshold to meet 0.5 mrem/h at the fence for occupancy expectations and regulations of annual dose to personnel. Given that 2 MW "in beampipe" loss gives 25 rem/h at the fence, it can be extrapolated that 40 W would produce 0.5 mrem/h at the fence.

Beam mis-steer events are when the beam fully leaves the beam pipe and could hit the wall of the BTH. The published study RP-RPG-150904-MEM-01 calculates 300 rem/h dose rates from 120 kW mis-steered beam. However this scenario has been excluded as ray-traces do not show it as possible. Mis-steer events are studied through ray traces such that they may be intercepted by protection collimators (also called burn-through monitors) prior to striking the shielding wall and the collimators/burn-through monitors limit the event to 3 rem total or 25 rem/h. If the event in RP-RPG-150904-MEM-01 was credible, it would imply a limitation of 2 W being allowed to strike the protection collimators to meet the 5 mrem/h. The beam power allowed to strike the BTH collimators in LCLS was 5 W and compared to LCLS, the position of the fence for LCLS-II is further from the BTH wall therefore, given the position of the fence, it is assumed that a beam mis-steer of 35 W would need to cause a trip.

RP-RPG-131105-MEM-01 presents a study of skyshine and finds that 48 W loss along exposed parts of

BTH contributes a 0.4 mrem dose to the general public. To meet the 5 mrem requirement for a facility, this implies a 600 W trip threshold for distributed beam loss, ignoring the small contributions that may come from other areas. Since this number is above the requirement needed for area classifications and personnel dose control (75 W) it can be said that this lower limit safety satisfies the skyshine also. 75 W constraint is calculated to contribute 0.625 mrem/y skyshine.

5.3 Conclusion for HH/BTH BCS Trip Thresholds

LBLMs are required to have BCS trip thresholds that satisfy all:

- Dose not to exceed 5 mrem in one hour (measured 30 cm from fence/shielding) and
- Personnel dose not to exceed 100 mrem non-radiological worker limit, effectively a limit of 0.5 mrem/h at the fence
- Classification of office buildings in research yard not to be RCAs, therefore a limit of 0.05 mrem/h 12 ft from fence

RP simulations indicate that all three criteria can be met by:

- Sum of all LBLMs along BTH not to exceed 75 W of distributed loss
- An individual LBLM, where the LBLM is assumed to capture the full signal, not to exceed 35 W of loss at a single point in the beamline

6 Undulator Hall

6.1 Requirements

6.1.1 Area Classification

The Undulator Hall is within a mound of earth that provides shielding. The area above the Undulator Hall must avoid Radiation Area postings and therefore the BCS is required to limit radiation above the Undulator Hall to below 5 mrem dose in one hour as measured 30 cm from the shielding (earth).

Peak dose rates may exceed 5 mrem/h if they are terminated fast enough such that 5 mrem accumulated dose in one hour is not exceeded.

Therefore BCS trip limits must not be above 5 mrem/h as measured 30 cm from the shielding.

6.1.2 Dose to SLAC personnel

SLAC personnel that only have course ESH 219 may be present (i.e. they do not have GERT or Radiation Worker training) and SLAC personnel may not wear dosimeters. Therefore, annual limits of 100 mrem in one year must be met. Occupancy of this area is not considered to be full occupancy. Assuming 10% occupancy (200 hours), dose rates above the hill must be limited to 0.5 mrem/h to limit dose to SLAC personnel. Here we do not take a “general area” approach and instead take the value at any point as the dose could accrue at any location on the hill.

6.1.3 Dose to general public

Dose to general public is not considered for the area above the Undulator Hill. Members of the general public are not expected to be present at this location.

Shielding is sufficient such that the Undulator Hall does not contribute in a measurable way to skyshine.

6.2 Case Studies of Beam Loss

This is an issue only right inside the undulator hill where the earth shielding is the thinnest. After 10 m, there is no concern due to increased earth shielding except for where there are service penetrations under B921 (see section 7). A cut-away is shown in Figure 9 of the west end of the undulator hill.

In the first 10 m, there is an in-beam dump called TDUND that is used for tune-up. It is not for safety purposes therefore, though MPS needs to protect the dump from damage, there are no BCS requirements to protect the dump from damage. TDUND is enclosed in a small bunker with inner layers of borated polyethylene and outer plates of marble. The bunker has a shielding effect on beam loss that occurs within the bunker.

RP-RPG-120829-MEM-01 is a LCLS study with 15 GeV beam which is likely to be similar as for LCLS-II beam therefore the study has not been repeated for the lower beam energy. This study shows that 420 W loss at the location of TDUND results in 0.05 mrem/h on the hill (shown in Figure 10) which meets requirements by a factor 10. The beam losses for LCLS were restricted to 420 W as there was no operational need to raise to 4.2 kW though the higher threshold would also meet the requirement. Given this historical precedence, 420 W is also suggested for LCLS-II however it is noted by this author that raising the trip threshold is also likely to meet regulatory requirements.

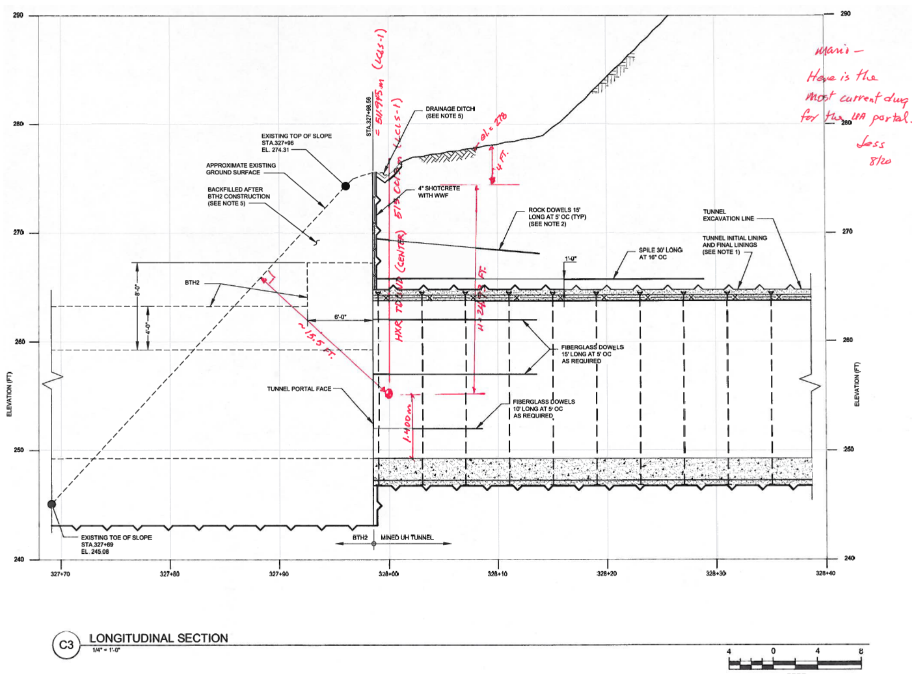

Figure 9: The west end of the undulator hill.

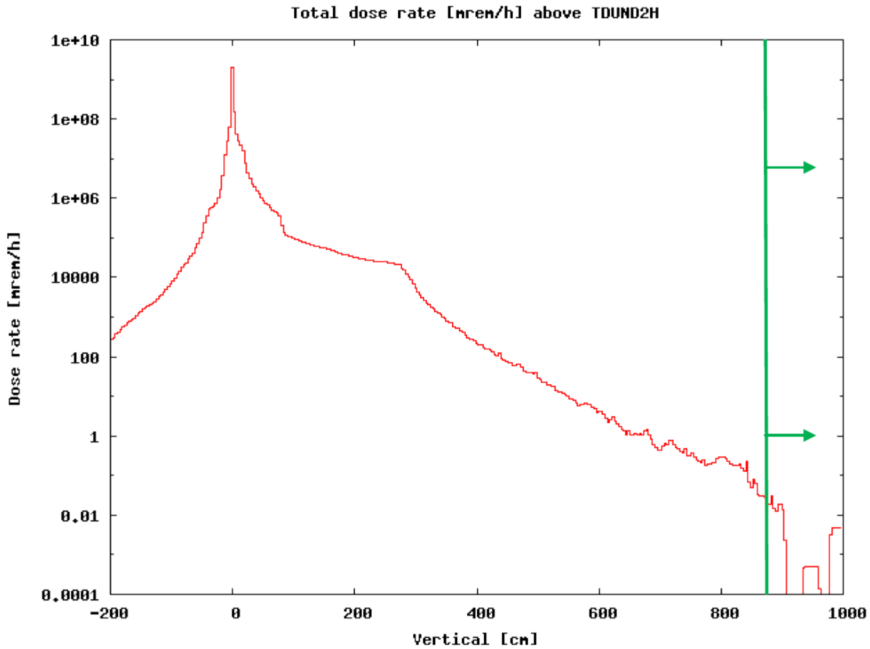

Figure 10: Expected dose rate [mrem/h] at the vertical line for 420 W 15 GeV LCLS beam.

There do not exist studies for beam loss due to mis-steers outside of the TDUND bunker. From a coarse analysis, comparing the dose rate map for beam loss on TDUND2H (Figure 11) to the dose rate map for a beam mis-steer (see RP-RPG-160603-MEM-01), there indication that ~1 kW beam mis-steer would cause 0.5 mrem/h on the hill.

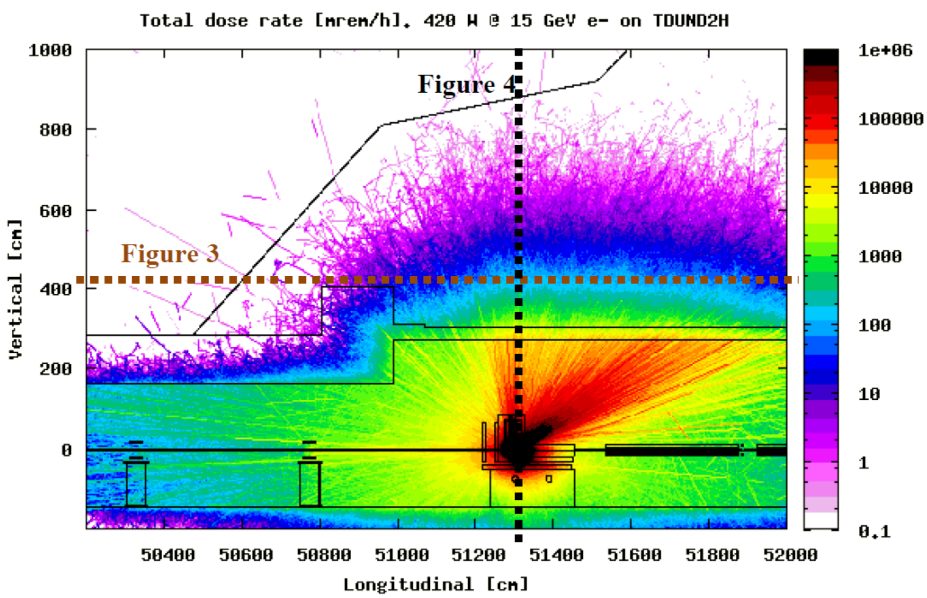

Figure 11: Expected dose rate [mrem/h] elevation map at the HXR beam plane for 420 W - 15 GeV on TDUND2H.

6.3 Conclusion for Undulator Hall BCS Trip Thresholds

LBLMs are required to have BCS trip thresholds that satisfy all:

- Dose not to exceed 5 mrem in one hour (measured 30 cm from shielding) and
- Personnel dose not to exceed 100 mrem non-radiological worker limit, effectively a limit of 0.5 mrem/h above the hill

RP simulations based on LCLS indicate that criteria can be met by LBLMs with a trip threshold equivalent to signal from 4.2 kW on TDUND and suggest conservatively setting the threshold at 420 W to meet with currently implemented trip thresholds and provide assurance that a beam mis-steer case is also satisfied.

7 Undulator Hall - Below 921

7.1 Requirements

7.1.1 Area Classification

Building 921 is above the Undulator Hall. Penetrations exist within B921 that represent weak points in the shielding making this area above the Undulator Hall unique. B921 is classified as a Radiologically Controlled Area.

To remain a Radiologically Classified Area and avoid Radiation Area postings, the BCS is required to limit radiation in B921 such that there is below 5 mrem dose in one hour as measured 30 cm from shielding.

Peak dose rates may exceed 5 mrem/h if they are terminated fast enough such that 5 mrem accumulated dose in one hour is not exceeded.

Therefore BCS trip limits must not be above 5 mrem/h as measured in B921 30 cm from penetration shielding.

7.1.2 Dose to SLAC personnel

SLAC personnel that could accrue more than 100 mrem in one year must be Radiation Workers. This is administratively controlled.

Radiation Workers can accrue up to 360 mrem in one year according to the SLAC ALARA limit, 500 mrem in one year according to the SLAC administrative control limit or 5000 mrem in one year per the DOE limit (ref: Radiological Worker I Study Guide).

In these cases, localised dose rates are not considered and general area dose rates for the building are considered. Occupancy for a worker in B921 is assumed at 200 hours in one year (10% full occupancy).

Therefore BCS trip limits must not be above 1.8 mrem/h as measured “general area” in B921.

This will be coupled with monitoring of normal (persistent) radiation levels in the gallery by Radiation Physics group and awareness of work activities to ensure individual workers do not accrue unnecessary dose. Additional shielding may be added to penetrations, or “hot spot” signage established if hot-spots are found that could contribute to SLAC personnel dose.

7.1.3 Dose to general public

Dose to general public is not considered for B921. Members of the general public are not allowed to enter B921. This is controlled through an engineered access control system (i.e. badge reader).

Shielding is sufficient such that the Undulator Hall below B921 does not contribute in a measurable way to skyshine.

7.2 Case Studies of Beam Loss

Simulations for penetrations were performed and published in RP-RPG-160307-MEM-01. 10 inches of poly were assumed as the existing shielding as for the penetrations. Here a 1 kW beam mis-steer produces approximately 100 mrem/h dose rates (Figure 12) therefore a 50 W beam mis-steer would produce 5 mrem/h dose rates immediately above the penetration shielding.

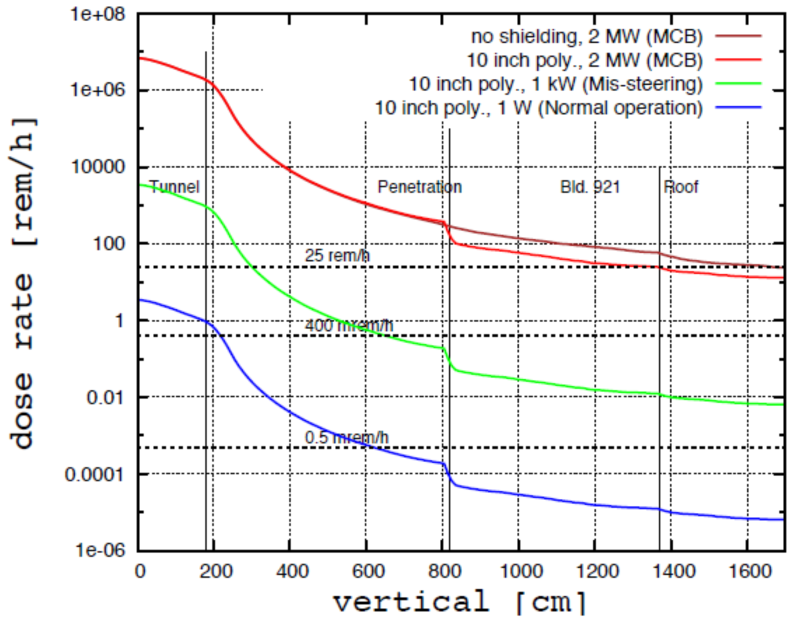

Figure 12: Dose rates above the penetration.

Due to the penetration geometry, the streaming radiation is strongly collimated. These studies found that the dose rate dropped about 3 orders of magnitude within 1-2 feet from the penetration (Figure 13). Therefore, if personnel are discouraged from being directly above the penetration through a barrier or postings, the dose rate measurement measured 30 cm from the shielding transversely (i.e. to the side as opposed to directly above the penetration) is 5 mrem/h with approximately 50 kW beam.

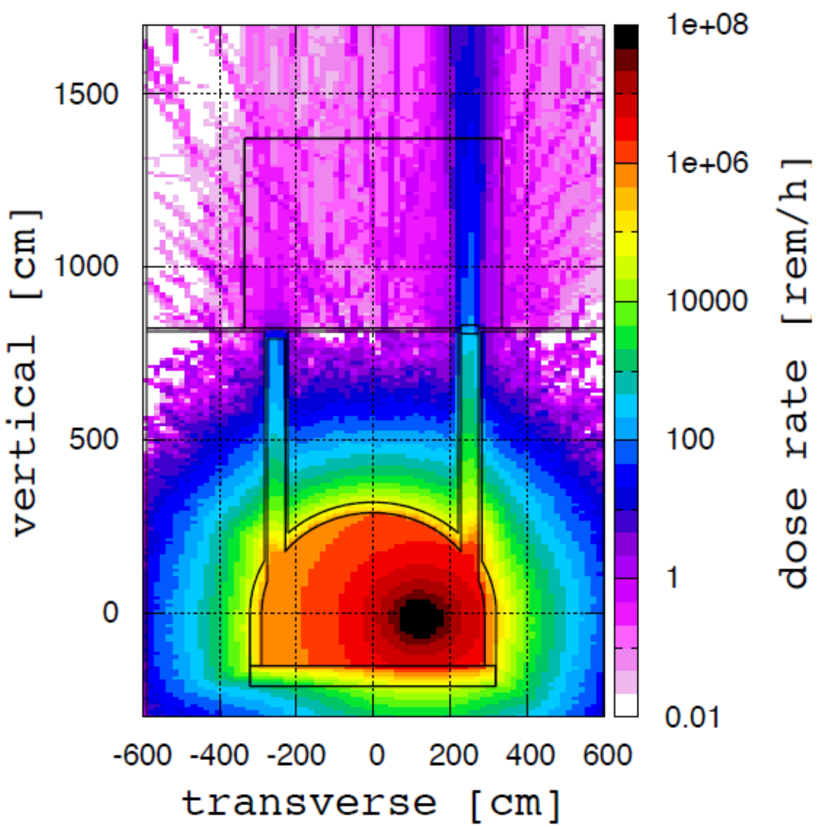

Figure 13: Dose rates transversely from the penetration for 2MW beam loss.

7.3 Conclusion for BCS Trip Thresholds below 921

LBLMs are required to have BCS trip thresholds that satisfy:

- Dose not to exceed 5 mrem in one hour (measured 30 cm from shielding) and
- Personnel dose not to exceed 360 mrem ALARA limit (500 mrem SLAC Administrative limit and 5000 mrem DOE radiological worker limit), effectively a limit of ~1 mrem/h general area

RP simulations based on LCLS indicate that criteria can be met by LBLMs with a trip threshold ~ 35 W[4] – 50kW depending on whether personnel are permitted to be on top of penetration shielding. Establishing a barrier around the penetration is advised by this author but this is not currently assumed to happen therefore the lower threshold of 35 W will be taken by LCLS-II.

8 Dumpline Hall and BYD Magnets

8.1 Requirements

8.1.1 Area Classification

The area beyond the dumpline hall is the Near Experiment Hall (NEH) building. This building is posted as a Controlled Area but not a Radiologically Controlled Area (RCA). It is accessible to personnel that have course ESH 219 and course 115 (GERT) but they do not have Radiation Worker training. Personnel may not wear dosimeters in the NEH.

To avoid Radiation Area postings, the BCS is required to limit radiation in this building such that there is below 5 mrem dose in one hour as measured 30 cm from shielding.

Peak dose rates may exceed 5 mrem/h if they are terminated fast enough such that 5 mrem accumulated dose in one hour is not exceeded.

Therefore BCS trip limits must not be above 5 mrem/h as measured from the FEE/NEH shielding wall.

8.1.2 Dose to SLAC personnel

SLAC personnel that only have course ESH 219 and course GERT 115 may be present (i.e. they do not have Radiation Worker training) and SLAC personnel may not wear dosimeters. Therefore, annual limits of 100 mrem in one year must be met (this is the SLAC administrative limit, the DOE limit is 5000 rem for a GERT-qualified worker [GERT study guide]). Occupancy in the NEH is considered to be full occupancy (2000 hours). Therefore dose rates in the NEH must be limited to 0.05 mrem/h to limit dose to SLAC personnel. Here we do not take a "general area" approach and instead take the value at the FEE/NEH wall as the dose could accrue at any location along that length.

8.1.3 Dose to general public

General public are considered present in the NEH. General public personnel only have course ESH 219 and course GERT 115 (i.e. they do not have Radiation Worker training) and they may not wear dosimeters. Annual limits of 100 mrem in one year must be met (this is both the DOE limit and the SLAC Administrative limit for visitors). Occupancy in the NEH is considered to be full occupancy (2000 hours). Therefore dose rates in the NEH must be limited to 0.05 mrem/h to limit dose to the general public. Here we do not take a "general area" approach and instead take the value at the FEE/NEH wall as the dose could accrue at any location along that region.

[4] Note that the difference between 50 W and 35 W is likely due to the historical fact that a LION is 35 m long and this led to a handy rule of thumb of 1 W/m = 35 W/LION. Given that all simulation results are approximate and numbers can easily varies by ~ factor two, this difference is not a concern. All figures in terms of Watts are estimates good to a factor of 2.

8.2 Case Studies of Beam Loss

This is a unique area of the FEL complex in that secondary particles from beam losses on the "Bending Y Direction Dipoles" (BYDs) and beam dumps generate prompt dose rates in downstream areas where personnel are present, essentially in front of the electron beam. RP-07-16 relates radiation in the FEE to radiation in the NEH and found that 20 W of 17 GeV beam lost in the EBD generated 0.01 mrem/h dose rates in NEH Hutch 1 (Figure 14 and Table 2).

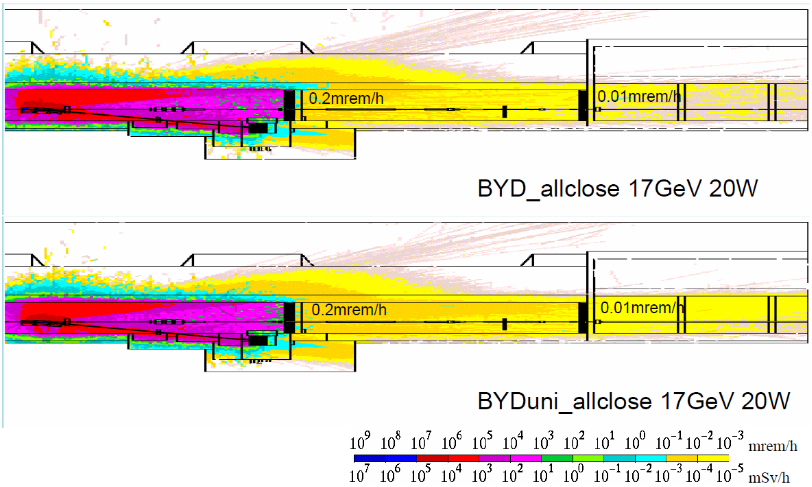

Figure 14: Comparison on dose rate between point loss (above) and uniform loss (below). In this case, the PPS Stopper is closed and entry to NEH Hutch 1 is permitted. Bremsstrahlung power through the wall into the FEE is ~1467 mW for the point loss and 38.8 mW for the uniform loss on BYD (Fluka simulations).

Table 2: Bremsstrahlung power through wall 1 3.75 inch diameter hole for 20 W point and uniform loss on BYD1.

	Fluka Simulation for Brem power	NEH Hutch 1 dose rate in access
20 W point loss on BYD	1467 mW * old geometry	0.01 mrem/h
20 W uniform loss on BYD	38.8 mW	0.01 mrem/h

RP-16-22 updates the studies for LCLS-II relating beam loss in the dumpline to radiation in the FEE for the point loss case (Table 3). Note there is a line that includes new collimators for LCLS-II with an aperture deliberately designed to reduce radiation entering the FEE.

Table 3: Bremsstrahlung power through wall 1 3.75 inch diameter hole for 120 W point loss on BYDs.

	Fluka Simulation for Brem power for SXR	Fluka Simulation for Brem power for HXR	NEH Hutch 1 dose rate in access assuming simultaneous
120 W point loss on BYD assuming electron collimators not present	3876 mW	3207 mW	0.048 mrem/h
120 W point loss on BYD crediting electron collimators	0.19 mW	0.18 mW	~ 1 nrem/h

8.3 Conclusion for Dumpline and BYD BCS Trip Thresholds

LBLMs are required to have BCS trip thresholds that satisfy:

- Dose not to exceed 5 mrem in one hour (measured 30 cm from shielding) and
- SLAC Personnel dose not to exceed 100 mrem SLAC Administrative limit (5000 mrem DOE limit), effectively a limit of 0.05 mrem/h at FEE/NEH wall
- General public dose not to exceed 100 mrem DOE limit, effectively a limit of 0.05 mrem/h at FEE/NEH wall

RP simulations indicate that criteria can be met even with full beam loss **if** the collimators are present (PCPM1 & PCPM3) and perform exactly as designed. Without the collimators, criteria can be met by LBLMs with a trip threshold of 120 W[5].

9 Conclusion

Requirements for controlling beam loss are given in terms of dose rates by area in Table 1. Table 4 summarises the range of trip thresholds in terms of beam power lost that may be possible for BCS. The "simulation maximum" is based on RP simulations as described previously in this document. The RP maximum combines RP studies with experience and gives the limits as documented in RP-17-05-R2. The minimum is based on the normal operations analysis presented in LCLSII-2.7-PR-0079. The BCS threshold should be placed high enough not to limit operations but below the maximally allowed RP trip threshold which is likely to breach requirements.

Note that estimates of beam loss based on simulations are considered good to a factor of 2 at best.

Note that simulations are missing for the following and so "simulation maximum" numbers do not exist:

- BSY penetrations
- Mis-steer in BTH that is allowed by ray trace
- Dose consequence of hitting a collimator in the dumpline

If they are needed for calibration purposes, they should be performed prior to beam and BCS commissioning.

Please note that the author of this document also recommends that personnel are not permitted to rest on top of shielding through engineering methods or administrative postings. In the absence of these controls, the author recommends more conservative thresholds than the RP thresholds.

Table 4: Estimates for ranges for LBLM trip thresholds given in terms of beam power lost.

Area	Start (m)	End (m)	Maximum trip (to meet requirements) according to simulations	Radiation Physics Trip threshold per RP-17-05-R2
Linac	From CID maze (upstream of gun) -22.03	Wooden door at BSY – 3050.51	1 kW[6]	1 kW
BSY (minus BTHW)	Wooden door – 3050.51	Muon shield – 3207.26	Not available	10 kW

[5] It is noted that simulations are considered to be good to a factor 2 only so when given in RP-17-10, this 120 W was rounded to 100 W.

[6] Assuming personnel are not allowed to sit on shielding. Else, 400 W may be required in some places. This would need to be evaluated in a more detailed manner.

BTHW	Muon shield wall 3207.26	2 m inside BTHW hill – 3331.00	Not available	No limit
HH, BTH	2 m inside BTHW hill – 3331.00	2 m inside Undulator hill – 3560.49	40 W at a point, 70 W total	35 W at a point, 70 W total
TDUND /TDUN DB	Right inside undulator hill – 3558.49	5 m downstream of TDUND/TDUN DB – 3568.79	4.2 kW	420 W
Below 921	5 m upstream of first penetration - 3674.50	5 m downstream of last penetration - 3710.78	50 kW if personnel not above penetration else 35 W	35 W
Dumpli ne Hall	Wall between UH and dumpline hall – 3732.71	Wall between dumpline hall and FEE – 3769.92	120 W	100 W
Along SXR/H XR BYD	Start of BYD1 – 3735.95	End of BYD3 – 3739.35	120 W	100 W