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Radiation Safety Design for SSRL Bend Beamline BL2

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Introduction

This technical note describes the shielding design for SSRL bend beamline BL2 for its 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 BL2 operation and beam parameters is given in the note by Bart Johnson [2]. Further information used in this analysis was obtained from a SLAC drawing [3], ray trace drawings [4], and emails from T. Rabedeau [5,6,7]. In this note, the SR shielding is given for 500 mA, while the local shielding for GB is prescribed for both 100 mA and 500 mA.

Operational Mode and Beam Parameters

BL2 has a white-light transport hutch (BL2-0), a filtered-mono experimental hutch (BL2-1), a white-light experimental hutch (BL2-2) and an unfiltered-mono experimental hutch (BL2-3). All three experimental hutches may be operated simultaneously, and any can be entered while the others are operating. The layout of BL2 is shown in Figure 1. There is an in-alcove mirror (the BL2-1 M0 mirror) which deflects part of the SR fan into BL2-1. The other key components, in order of increasing distance from the source, are: Pb collimators within the ratchet-wall opening, Pb allocation mask / hutch shutter assembly (located in BL2-0, and containing the hutch shutters for BL2-1, BL2-2 and BL2-3), BL2-1 and BL2-3 beam stops (in BL2-0), BL2-2 transport pipe (in BL2-3), BL2-1 transport pipe (in BL2-2 and BL2-3, and external to the hutches), BL2-3 beam stop (in BL2-3), BL2-2 beam stop (in BL2-2), and BL2-1 monochromator (external to the hutches).

The BL2 source is a bend magnet with a SR critical energy Ec of 7.8 keV (1.3-T magnetic field) and a power density of 74 W/mradH at 500 mA. The BL2-1 M0 mirror has a cutoff energy of 23 keV. For GB hazard evaluation, the effective length of the bend is taken to be 15 cm, and air pressure is 1 ntorr (equivalent to 0.95 μW of GB power).

Unless otherwise stated, the design requirements are given for 3 GeV and 500 mA. Tables 1-4 show the SR design requirements for BL2-0 through BL2-3, respectively. Table 5 shows the SR requirements for the BL2-1 and BL2-2 transport pipes. Table 6 shows the SR requirements for the BL2-1 monochromator and its entrance slits, located external to the hutches. Table 7 shows the design requirements for the safety components, and Table 8 shows the requirements for scattered GB.

Design Requirements for SR

<u>BL2-0 White Transport Hutch</u>

The SR source is 11.2 mradH white light plus 3.7 mradH pink light, which is intercepted by the Pb allocation mask and hutch shutter assembly. The proposed shielding of 4.76 mm Pb for the side wall and roof is sufficient to meet the design requirements (0.05 mrem/h for side wall and 0.5 mrem/h for roof). The proposed shielding of 9.5 mm Pb for $0° \leq \theta < 20°$ and 6.35 mm

Pb for $\theta \geq 20°$ on the downstream wall is sufficient to meet the design requirement (0.05 mrem/h). Details are shown in Table 1.

BL2-1 Filtered Mono Experimental Hutch

The SR source is 3.7 mradH filtered mono light from white light hitting the BL2-1 M0 mirror (in alcove, Pt-coated mirror, angle of incidence = 0.344°) followed by the BL2-1 monochromator (Si(111)). The target is an experimental sample. The proposed shielding thickness of 3.43 mm Fe is more than sufficient to meet the design requirements of 0.05 mrem/h on the walls and 0.5 mrem/h on the roof. Details are given in Table 2.

BL2-2 White Light Experimental Hutch

The SR source is 6.0 mradH white light. The target is an experimental sample. The existing shielding of 3.5 mm Pb is insufficient to meet the 100-mA requirements. The proposed shielding (described in Table 3) would meet the 500 mA requirements. Until such time as the proposed shielding is installed, the hutch shutters for BL2-2 must be locked closed.

BL2-3 Unfiltered Mono Experimental Hutch

Compton scatter from 1.7 mradH white light incident on the BL2-3 mono (in BL2-0) enters the BL2-3 hutch, along with the intended beam of 1.0 mradH monochromatic light. The compton-scattered white light reaches the hutch walls directly. The target for the monochromatic beam is an experimental sample. The proposed shielding thickness of 3.5 mm Pb is sufficient to meet the design requirements for the side walls and roof. For the downstream wall, the compton-scattered white light necessitates a thickness of 7 mm Pb in a small region corresponding to scattering angles $\leq 5.7°$. Outside this region, 3.5 mm Pb is sufficient. Details are shown in Table 4, which presents separately the shielding requirements for scattered white and scattered monochromatic SR.

BL2-1 and BL2-2 Transport Pipes

The SR source is compton scatter from 4.6 mradH white light hitting the BL2-1 M0 mirror. Inside the BL2-3 hutch, the BL2-1 and BL2-2 transport pipes require 2.2 mm Pb and 2.4 mm Pb shielding, respectively. Inside the BL2-2 hutch, and outside the hutches, the BL2-1 transport pipe requires 2.0 mm Pb. Details are shown in Table 5.

Tanks Enclosing the BL2-1 Mono and its Entrance Slits

The SR source is compton scatter and pink light from 3.7 mradH white light hitting the BL2-1 M0 mirror. The targets are the entrance slits and the mono crystals. The calculation assumes that the entrance slits are set to have a maximum aperture of 20 mm by 5 mm. The shielding needed for the entrance slits, 12.2 mm Fe, is dominated by doubly compton scattered white light. The shielding needed for the mono, 1.59 mm Pb, is dominated by pink light. Details are shown in Table 6.

Design Requirements for GB

GB Safety Components

The BL2 bend source is assumed to have a 15 cm air section at 1 ntorr. The GB safety components for BL2 are as follows: the vertical collimator in the ratchet wall, the allocation mask / hutch shutter assembly (containing the BL2-1, BL2-2 and BL2-3 hutch shutters, and located in BL2-0), the BL2-1 and BL2-3 GB beam stops (in BL2-0), the BL2-2 GB beam stops

(in BL2-2), and the (second) BL2-3 GB beam stop (in BL2-3). (There is a GB beam stop at the downstream end of BL2-1, but it is not necessary.) These are all composed of lead.

All safety components except the allocation mask have sufficient thickness and lateral extension for 500 mA operation. The allocation mask has sufficient thickness for 500 mA except in one small region, where it is 4 inches thick while the requirement is 4.3 inches for 100 mA and 5.3 inches for 500 mA. The result is that secondary GB can enter BL2-3 and travel through a narrow region between the BL2-1 and BL2-2 transport pipes. The GB is intercepted at the downstream end of BL2-3 by the BL2-3 beam stop, but represents a hazard should someone place their hand or an object between the two pipes. A suitable solution would be to create an exclusion zone between the pipes. Details are given in Table 7.

Shielding for scattered GB

The only GB-scattering target that requires shielding is the experimental sample in BL2-2. For 100 mA operation, this requires downstream shielding of 2 inches Pb from 0° to 2°, and 1 inch Pb from 2° to 4°. For 500 mA, the requirement is 3 inches Pb from 0° to 2°, 2 inches Pb from 2° to 4°, and 1 inch Pb from 4° to 6°. Details are given in Table 8. The shielding proposed in the Implementation Plan [2] is sufficient to meet the 500-mA requirements.

Table 1. SR design requirements for BL2-0 white hutch [1].

Hutch Wall	Beamline Target	Fan (mradH)	Distance (cm)	Existing Shielding (mm) [2]	Dose Rate [2] (mrem/h)	Shielding Need (mm) [3]
SSRL Side	Pb Allocation Mask, Pb HS and Si Mono	11.2	108	4.76 Pb	0.02	3.6 Pb
Roof (T=0.1)	Same as above	11.2	101	4.76 Pb	0.02	2.5 Pb [4]
d/s (0^o-10^o)	Si Mono	1.0	43	9.5 Pb	0.02	8.6 Pb
d/s (10^o-20^o)				9.5 Pb	0.003	7.0 Pb
d/s (20^o-30°)				9.5 Pb	0.0002	5.8 Pb
d/s (>30^o)				4.76 Pb	0.046	4.76 Pb

1) Source is white light from bend, Ec=7.8 keV (1.3-T field), 74.1 W/mradH at 500 mA.
2) Existing (or proposed) shielding with the corresponding dose rate.
3) Shielding needed to achieve the design limits (0.05 mrem/h for d/s wall and side wall; 0.5 mrem/h for roof).
4) For roof occupancy factor of 1, shielding need is 3.6 mm Pb.
5) Targets are modeled as small perpendicular Cu blocks.
6) The allocation mask / hutch shutter assembly has sufficient thickness and lateral extension that it does not constitute a SR scatterer in the downstream direction.
7) Results were obtained from Figures 4 and 7 in RP-03-08 [8].

Table 2. SR design requirements for BL2-1 filtered-mono experimental hutch [1].

Hutch Wall	Distance (cm)	Existing Shielding (mm) [2]	Dose Rate [2] (mrem/h)	Shielding Need (mm) [3]	Source Harmonics keV / (γ/s) [4]
Side walls (SSRL and SPEAR)	39	3.43 Fe	5.9E-04	0.2 Fe	23 / 5.68E11 68 / 1.53E05 91 / 1.09E03 113 / 5.05E00
Roof (T=0.1) [5]	75	3.43 Fe	1.6E-04	< 0.2 Fe	
d/s (≥ 5.7°)	100	3.43 Fe	1.2E-03	< 0.1 Fe	

1) The source is filtered mono-light harmonics from 3.7-mradH white light (from bend, Ec=7.8 keV) hitting a 0.155° rhodium mirror (23-keV cutoff) followed by a Si(111) double-crystal monochromator. (For purposes of calculation only. In reality, the minimum incidence angle on the mirror is 0.344°, the mirror material is Pt, and the cutoff is lower.) The target is a slanted Si slab.
2) Existing (or proposed) shielding with the corresponding dose rate.
3) Shielding needed to achieve the design limits (0.05 mrem/h for d/s wall and side wall, 0.5 mrem/h for roof). Values were obtained from Figures 6 and 13 in RP-03-20 [9], which assumes a source magnetic field of 2 T, and does not include the filtering effect of the mirror. A photon-intensity scale factor of 0.0575 (obtained from [7], for photon energy 68 keV from an Si(111) mono) was used to convert from the 2-T results to 1.3-T results, and a mirror reflectivity factor of 7.42e-4 (also from [7], for photon energy 68 keV) was applied.
4) The energies and intensities of mono-light harmonics (from a 1.3-Tesla source) per pole per mradH scaled by the reflectivity of a 0.155° rhodium mirror (23-keV cutoff) [7].
5) For an occupancy factor of 1, the shielding need is still below 0.2 mm Fe.

Table 3. SR design requirements for BL2-2 white experimental hutch [1].

Hutch Wall	Beamline Target	Distance (cm)	Existing Shielding (mm) [2]	Dose Rate (mrem/h) [2]	Proposed Shielding (mm) [3]	Shielding Need (mm) [4]
SPEAR side wall	Slanted Si slab	52.6	3.5 Pb	4.4	6.35 Pb	6.0 Pb
SSRL side wall	Slanted Si slab	121	3.5 Pb	0.77	6.35 Pb	4.9 Pb
Roof (T=0.1)	Slanted Si slab	109	3.5 Pb	1.0	4.76 Pb	3.8 Pb
u/s [5]	Slanted Si slab	14	3.5 Pb	2.5	6.35 Pb	6.1 Pb
d/s (0°-20°) d/s (>20°)	Small perp. Cu block	100	3.5 Pb	120 2.7	9.5 Pb 6.35 Pb	8.7 Pb 6.2 Pb

1) Source is 6.0 mradH white light from bend, Ec=7.8 keV (1.3-T field), 74.1 W/mradH at 500 mA.
2) Existing shielding with the corresponding dose rate.
3) Proposed shielding. Installation to be completed after the start of 100 mA operation of BL2. Until installation is complete, the BL2-2 hutch shutters must be locked closed.
4) Shielding needed to achieve the design limits (0.05 mrem/h for d/s and side wall, 0.5 mrem/h for roof).

5) A backscattering calculation was performed with STAC8 to determine the necessary upstream wall thickness.
6) Results (other than that mentioned in footnote 5 above) were obtained from Figures 3 and 7 of RP-03-08 [8].

Table 4. SR design requirements for BL2-3 unfiltered-mono experimental hutch [1].

Hutch Wall	Light & fan width [1] (mradH)	Target [2]	Distance (cm)	Existing Shielding (mm) [3]	Dose Rate [3] (mrem/h)	Shielding Need (mm) [4]	Source Harmonics keV/(γ/s) [5]
Side walls (SSRL and SPEAR)	White light, 1.7	BL2-3 mono	39.5	3.5 Pb	0.05	3.5 Pb	N/A
Side walls (SSRL and SPEAR)	Mono light, 1.0	Exp. sample	39.5	3.5 Pb	6.4E-05	1.0 Pb	23 / 6.76E11 68 / 2.07E08 91 / 7.76E06 113 / 1.53E05
Roof (T=0.1)	ditto	Exp. sample	109	3.5 Pb	8.4E-06	< 1.0 Pb	
d/s (5.7°-11.3°) d/s (11.3°-21.8°) d/s (> 21.8°)	ditto	Exp. sample	100	3.5 Pb 3.5 Pb 3.5 Pb	7E-06 3E-06 4E-07	1.2 Pb 1.0 Pb 0.7 Pb	
d/s (0°-5.7°)	White light, 1.7	BL2-3 mono	207	8.3 Pb	4E-03	7.0 Pb	N/A

1) As noted in the table, the source is either white light (from bend, Ec = 7.8 keV) or mono light from an Si(111) double-crystal monochromator (the BL2-3 monochromator).
2) The BL2-3 mono is modeled as a small perpendicular Cu block, and the experimental sample is modeled as a slanted Si slab.
3) Existing (or proposed) shielding with the corresponding dose rate.
4) Shielding needed to achieve the design limits (0.05 mrem/h for d/s wall and side wall, 0.5 mrem/h for roof). For white light scattered from the BL2-3 mono, values were obtained from Figure 7 of RP-03-08 [8]. For mono light from the BL2-3 mono, values were obtained from Figures 5 and 11 in RP-03-20 [9], which assumes a source magnetic field of 2 T. A photon-intensity scale factor of 0.0575 (obtained from [7], for photon energy 68 keV from an Si(111) mono) was used to convert from the 2-T results to 1.3-T results.
5) The energies and intensities of mono-light harmonics per pole per mradH for a 1.3 Tesla source [7].

Table 5. SR design requirements for BL2-1 and BL2-2 transport pipes[1].

Pipe	Distance (cm)	Shielding Need (mm) [3]
BL2-1 pipe in BL2-3	30	2.2 Pb
BL2-1 in BL2-2, and outside the hutches	30	2.0 Pb
BL2-2 pipe in BL2-3	30	2.4 Pb

1) Source is compton scattered light from the BL2-1 M0 mirror (from 4.6 mrad white light incident on the mirror).
2) Existing shielding and corresponding dose rate.
3) Shielding needed to achieve design limit of 0.05 mrem/h.
4) Results were obtained from Figure 2 of RP-03-11 [10], and assume that only a one-meter length of illuminated pipe contributes to the dose rate.

Table 6. SR design requirements for BL2-1 mono tank and tank surrounding entrance slits for BL2-1 mono (located outside of BL2-2 hutch) [1].

Wall	Distance (cm) [2]	Shielding Need (mm) [3]
Mono tank lateral wall [4]	30	1.59 mm Pb or 10.0 mm Fe or 6.35 mm Fe plus 0.6 mm Pb
Entrance Slit tank lateral wall [5]	30	2.0 mm Pb or 12.2 mm Fe or 6.35 mm Fe plus 1.0 mm Pb

1) Source is pink light from 3.7 mradH white light hitting a 0.344^{o} platinum-coated mirror, and compton-scattered white light from the mirror. (For the entrance slits, linear half-angle = 2.28 mrad. For the mono, linear half-angle = 0.505 mrad.) Target is a slanted Si slab.
2) Distance is measured with respect to beam impact point.
3) Shielding needed to achieve the design limit of 0.05 mrem/h.
4) For the mono, the shielding need is dominated by scattered pink light.
5) For the entrance slits, the shielding need is dominated by doubly compton scattered white light.
6) Results were obtained from Figure 2 of RP-03-11 [10], and from additional STAC8 calculations (for pink light at mirror angle 0.344^{o}, and double compton with Fe shielding).

Table 7. GB design requirements for safety components of BL2 [1].

Safety Component	Location (m) [2]	Size (X/Y/Z) (inches) [3]	Needed Z Thick (in) (100/500 mA) [4]	Existing H. Lat. Ext. (in) [5]	Needed H. Lat. Ext. (in) (100/500 mA)
Vertical Collimator in Ratchet wall	12.7	9.8 / 3.5 / 8 Pb	4.7 / 5.7 Pb	N/A	N/A
Allocation Mask [6]	16.9	mostly12.4/4/≥7 one small spot is 12.4/4/4 Pb	4.3 / 5.3 Pb	0.5	0.5 / 0.5
BL2-1 HS	16.8	2 X 2.5 / 2 / 4 Pb	Total = 4.3 / 5.3 Pb	N/A	N/A
BL2-2 HS	16.8	2 X 5.5 / 2 / 4 Pb	Total = 4.3 / 5.3 Pb	N/A	N/A
BL2-3 HS	16.8	2 X 2.5 / 2 / 4 Pb	Total = 4.3 / 5.3 Pb	N/A	N/A
BL2-1 BS (in BL2-0) [7]	17.3	8 / 4 / 8 Pb	4.3 / 5.3 Pb	3.4	0.5 / 0.5
BL2-3 BS #1 (in BL2-0) [7]	17.3	4 / 8 / 8	4.3 / 5.3	2.7	0.5 / 0.5
BL2-2 BS #1, (in BL2-2) [8]	22.2	4 / 8 / 5 Pb	4.0 / 5.0 Pb	1.4	0.5 / 0.5
BL2-2 BS #2, (in BL2-2)	23.6	10 / 6 / 6 Pb	3.9 / 4.9	1.8	0.5 / 0.5
BL2-3 BS #2 (in BL2-3)	19.9	8 / 6 / 6 Pb	4.1 / 5.1 Pb	1.2	0.5 / 0.5

1) Bend source, 15 cm air section at 1 ntorr (0.95 μW power at 3 GeV and 500 mA).
2) Distance from center of bend magnet to safety component.
3) X/Y/Z dimensions of the safety component.
4) Longitudinal Z thickness needed for safety component to reach the 0° GB dose limit of 0.05 mrem/h. The pair of values is for 100-mA/500-mA operation. Results were obtained from Figure 10 of RP-03-09 [11].
5) Existing horizontal lateral extension of safety component (*i.e.*, extension beyond the physical-aperture-based GB envelope). The pair of values is for 100-mA/500-mA operation. (The vertical lateral extension meets the design requirements in all cases.)
6) The insufficient thickness of the allocation mask is only an issue if the BL2-2 hutch shutters are out. The affected area is in BL2-3: the narrow region between the BL2-2 transport pipe and the BL2-1 transport pipe. The problem can be remedied by creating an exclusion zone between the two pipes.
7) The inner (*i.e.*, toward the beam axis) side of this component is within the GB envelope. The lateral extension value in the Table refers to the outer side.
8) The inner side of this component is within the GB envelope. It extends 1 inch beyond (inward of) the SPEAR side wall where this wall is closest to the beam axis (*i.e.*, between BL2-2 BS #1 and BL2-2 BS #2), preventing GB rays from reaching the side wall in this region. The lateral extension value in the Table refers to the outer side of the component.
9) The beam stop on the d/s wall of BL2-1 is not necessary for blocking GB.
10) For Z thickness calculations, $\lambda = 1.67$ cm for lead (1.16 cm for heavymet).

Table 8. Design requirements for scattered GB [1].

Scatterer	Hutch Wall	Distance (m)	Necessary Shielding Thickness for 500 mA (inches) [2]	Necessary Shielding Thickness for 100 mA (inches) [2]
Experimental Sample in BL2-2	d/s wall of BL2-2	2.58	3 Pb for $0° < \theta < 2°$ 2 Pb for $2° < \theta < 4°$ 1 Pb for $4° < \theta < 6°$	2 Pb for $0° < \theta < 2°$ 1 Pb for $2° < \theta < 4°$
BL2-2 Exit Port Mask	d/s wall of BL2-2	2.12	0	0
BL2-1 M0 mirror	d/s wall of BL2-0	6.24	0	0
Allocation mask	d/s wall of BL2-0	1.41	0	0
Mono in BL2-0	d/s wall of BL2-3	2.07	0	0
BL2-2 pipe in BL2-3	Pipe wall	0.30	0	0
BL2-1 BS (in BL2-0) [3]	d/s wall of BL2-0	0.94	0	0
BL2-3 BS #1 (in BL2-0) [4]	d/s wall of BL2-3	2.58	0	0
BL2-2 BS #1	d/s wall of BL2-2	1.28	0	0

1) Bend source, 15 cm air section at 1 ntorr (0.95 μW power at 3 GeV and 500 mA). Consideration was given for fraction of GB fan intercepted by target.
2) Shielding needed to achieve the design limits (0.05 mrem/h for d/s and side wall, 0.5 mrem/h for roof).
3) This component is struck by primary GB in its center, but only secondary GB near its edges. It is treated as a secondary-GB scatterer.
4) This component constitutes a GB scatterer only when the BL2-3 HS are out. It scatters primary GB.
5) Results were obtained from Figures 3b, 5b and 7b of RP-03-10 [12].

References

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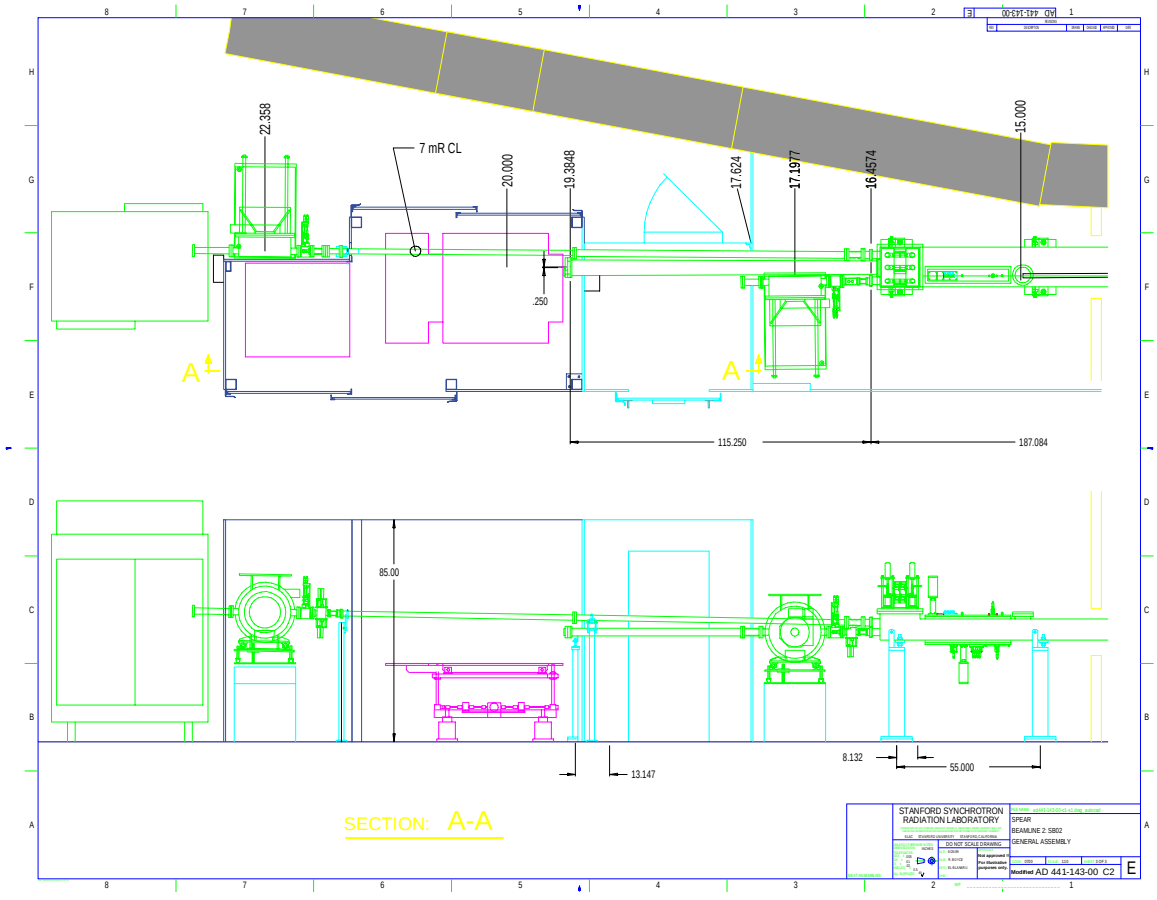

Figure 1. Bend BL2 plan view (top) and elevation view (bottom), showing BL2-0 optics hutch (far right) and three experimental hutches: BL2-1 (filtered mono, left), BL2-2 (white light, middle), and BL2-3 (unfiltered mono, right).