Comparison of Design and Practices
for Radiation Safety among Five Synchrotron Radiation Facilities

James C. Liu and Sayed H. Rokni
Stanford Linear Accelerator Center, MS. 48, P.O. Box 20450, Stanford, CA 94309, USA

Yoshihiro Asano
Synchrotron Radiation Research Center, Japan Atomic Energy Research Institute
SPring-8, Mikazuki, Hyogo 679-5143, Japan

William R. Casey
Brookhaven National Laboratory, P.O. Box 5000, Upton, New York, 11786, USA

Richard J. Donahue
Lawrence Berkeley National Laboratory, MS 2-400, One Cyclotron Rd., Berkeley, CA 94720, USA

P. K. Job
Argonne National Laboratory, Building 401, 9700 South Cass Ave., Argonne, IL 60439, USA

SUMMARY

There are more and more third-generation synchrotron radiation (SR) facilities in the world that utilize low emittance electron (or positron) beam circulating in a storage ring to generate synchrotron light for various types of experiments. A storage ring based SR facility consists of an injector, a storage ring, and many SR beamlines. When compared to other types of accelerator facilities, the design and practices for radiation safety of storage ring and SR beamlines are unique to SR facilities.

Unlike many other accelerator facilities, the storage ring and beamlines of a SR facility are generally above ground with users and workers occupying the experimental floor frequently. The users are generally non-radiation workers and do not wear dosimeters, though basic facility safety training is required. Thus, the shielding design typically aims for an annual dose limit of 100 mrem over 2000 h without the need for administrative control for radiation hazards. On the other hand, for operational and cost considerations, the concrete ring wall (both lateral and ratchet walls) is often desired to be no more than a few feet thick (with an even thinner roof).

Most SR facilities have similar operation modes and beam parameters (both injection and stored) for storage ring and SR beamlines. The facility typically operates almost full year with one-month start-up period, 10-month science program for experiments (with short accelerator physics studies and routine maintenance during the period of science program), and a month-long shutdown period. A typical operational mode for science program consists of long periods of circulating stored beam (which decays with a lifetime in tens of hours), interposed with short injection events (in minutes) to fill the stored current. The stored beam energy ranges

from a few hundreds MeV to 10 GeV with a low injection beam power (generally less than 10 watts). The injection beam energy can be the same as, or lower than, the stored beam energy. However, the stored beam power (product of stored beam current and energy), which is one of the key parameters in determining the production and hazards of gas bremsstrahlung (GB) and SR in beamlines, is quite high (MW to GW levels).

Because of the similar design and dose control goals as well as similar beam parameters and operation modes among SR facilities, it is highly desired and useful for SR accelerator community to have the design and practices for radiation safety of the storage ring and SR beamlines that are professionally sound and consistent. On the other hand, it can be understood that a SR facility may need to have its specific policies and practices, due to its own technical, practical, economical and/or political considerations.

This work compares and summarizes the design and practices for radiation safety among the five SR facilities:
1) Advance Light Source (ALS) of Lawrence Berkeley National Laboratory,
2) Advance Photon Source (APS) of Argonne National Laboratory,
3) National Synchrotron Light Source (NSLS) of Brookhaven National Laboratory,
4) Stanford Synchrotron Radiation Laboratory (SSRL) of Stanford Linear Accelerator Center (SLAC), and
5) SPring8, operated by Synchrotron Radiation Research Center of Japan Atomic Energy Research Institute, RIKEN, and Japan Synchrotron Radiation Research Center.

The goals of this work are to:
1) Provide a framework of radiation safety issues that need to, or may, be considered in the design and operation a SR facility, and
2) Develop sound policies and practices for radiation safety of SR facilities, when it is needed and practical to do so. The consensus of the design policies and practice is not the main goal of the work.

The issues that are addressed in this comparison work are grouped into 6 main sections:
1) Safety interlock systems for ring (injection beam and stored beam) and beamlines,
2) Beam loss scenarios (normal and abnormal) and shielding design for storage ring (lateral wall, ratchet wall, and frontend),
3) Beam loss scenarios and shielding design for SR beamlines. This is divided into two issues: SR and GB. SR issues include white-light hutch, pink-light hutch (and VUV beampipe), and mono-light hutch. Gas bremsstrahlung issues include safety components (stoppers, beam stops, collimators) and shielding for optic components (e.g., mirrors, monochromators, and SR masks). Miscellaneous beamline issues, e.g., occupancy factor, hutch penetration, ground-shine, and ozone hazard, are also discussed.
4) Radiation monitors for ring and beamlines,
5) Safety control issues for top-up operation, and
6) Operational issues.

In the beginning of the report, the definitions are given to facilitate and unify the understanding of the terms used. The material is presented as a series of Question and Answer (Q&A) Tables. Readers should consult the references for more details. In the end, the numerical values for the design and operational parameters for rings and beamlines of the five facilities are summarized in various tables for quick reference and comparison.

The responses to questions are arranged in the order of NSLS, ALS, APS, SPring8 and SSRL, which started the design/operation in about 1980, 1990, 1994, 1995 and 2000, respectively. In addition, NSLS and ALS are low-energy rings, APS and SPring8 are high-energy rings, while SSRL is a medium-energy ring. Therefore, presentation in this order allows an easier and more illustrative comparison between these three groups of light source facilities. Note that SSRL had operated the 2nd-generation SPEAR ring since ~1970 and has just started the 3rd-generation ring operation in 2003. The comparison effort has benefited to many aspects of the safety design and practice for SSRL. The ALS, APS and SPring8 are all 3rd-generation facilities, while NSLS still operates the old storage ring since 1980, which is the reason why the NSLS documentation is not available for some questions.

TERMS AND DEFINITIONS

Allowed Injection Beam Power (Pa)
The beam power that is allowed to be injected into the ring. This can be limited by interlocked devices or administrative control (e.g., operation procedure). In some facilities, the Pa may be the same as the Operation Envelope. The nominal injection beam power Pi can not be more than the Pa. The implication of both the Pi and Pa on the shielding design should be stated.

Beam Loss Monitor
An electronic device (generally coupled with a radiation detector) placed inside the storage ring to detect and terminate abnormal beam losses exceeding a preset level. It may be interlocked through PPS or MPS.

Beamstop (Beam Dump)
A mechanical device, e.g., a lead block, that is fixed in place; generally located in the end of a beamline for beam termination.

Frontend (In Alcove)
The section of a SR beamline between the beamline exit point near the storage ring chamber and the beamline point at the ratchet wall.

Hutch Shutter
A movable, mechanical PPS shutter to be inserted into the SR beamline to block the gas bremsstrahlung and/or synchrotron radiation. It is located upstream of a hutch to which access is permitted. In some cases like optic hutch, this hutch shutter may be the same as the injection stopper. In this work, shutter and stopper are used interchangeably for a mechanical device that can be moved in and out or an electrical device that can be turned on or off.

Injection Stopper
A movable, mechanical PPS stopper to be inserted into the frontend to prevent the missteered injection beam and bremsstrahlung from beam losses in ring from channeling into the SR beamline during the injection period. In the top-up mode, these stoppers may be removed during injection.

Injection Beam Stopper
A movable, mechanical PPS device or an electrical PPS device to remove the injection beam so the ring can be safe for access. This is generally located in the injector-to-ring transport line.

Lateral Wall
The concrete wall that is approximately in parallel to the storage ring vacuum chamber. The lateral wall and ratchet wall, as well as the roof, form the bulk shielding of the ring.

Maximum Credible Injection Beam Power (Pm)
The maximum power of beam that can be injected into the ring, considering reasonable effort of machine tuning and possible failures of all power-related interlocked devices, if any. Pm may be

the same as the Safety Envelope.

MPS (Machine Protection System)
An engineered, interlocked system to protect accelerator or beamline components from radiation damage, but it does not lead to personnel hazards. MPS may not be fail-safe and redundant. Compared to PPS, MPS generally has less rigorous configuration control (e.g., MPS can be controlled by Operation while PPS is controlled by safety professional) and less comprehensive certification and testing program. MPS and PPS may be the same system in some facilities.

Mono-Light Hutch (or Pipe)
The hutch, enclosure, or beampipe that contains the mono-light SR (light that scatters from a monochromator). It is generally located downstream of a monochromator. This can be further divided into two types: filtered-mono light (light scatters from a mirror and then a monochromator) and unfiltered-mono light (light scatters from a monochromator only).

Optic Hutch (Transport Hutch) or Pipe
The hutch (or pipe) that is located immediately downstream of the ratchet wall and contains topic elements like mirrors and/or monochromators. The optic hutch is generally a white light hutch or a pink light hutch (if there is a mirror in the frontend).

Pink-Light Hutch (or Pipe)
The hutch, enclosure, or beampipe that contains the pink-light SR (light that scatters from a mirror). It is generally located downstream of a mirror. It can either be a hard pink light (generally housed in a hutch) or a soft pink light, called VUV, (generally housed in a beampipe).

PPS (Personnel Protection System)
An engineered, interlocked safety system to protect personnel from prompt radiation hazards. PPS shall be fail-safe and redundant. Any PPS change and modification should require configuration control by safety and/or operation personnel. PPS also needs periodic certification, as well as regular operational testing, by qualified personnel.

Ratchet Wall
The concrete wall of the storage ring that is generally made perpendicular to the SR beamline to allow the beampipe to pass into the experimental floor.

Shadow Wall
The shielding placed near the ring chamber and/or the synchrotron radiation beampipes in frontends to block the secondary radiation (coming from beam losses in the ring) from penetrating through the beampipe hole in the ratchet wall.

Stored Beam Stopper
A movable, mechanical PPS device or an electrical PPS device in the ring to remove the stored beam and RF hazards so the ring can be safe for access.

Top-Up Operation

A mode of ring operation that the ring is being injected quasi-continuously to keep the stored beam near its maximum value. The injection stopper in the frontend is open during injection in this mode so SR can delivered continuously to beamlines. Generally, restrictions on operational parameters (e.g., high injection efficiency, high stored current, proper injection energy, etc.) and additional interlocks (radiation detectors near beamlines) are imposed for this mode.

<u>White-Light Hutch (or Pipe)</u>
The hutch, enclosure, or beampipe that contains white light directly from the ring. It is generally located immediately downstream of the ratchet wall and contains SR optic elements, e.g., mirrors and/or monochromators. Some experimental hutches may have white-light.

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Q&A SECTIONS

Section 1: Safety Interlock

Section 1 has a total of 7 questions:
a) What are the interlocked devices to limit the beam energy and current injected into ring?
b) For ring access, what are the interlocked injection beam stoppers to stop injection into ring? What are the design criteria of these stoppers?
c) For ring access, what are the interlocked stored beam stoppers to remove the stored beam hazards?
d) What are the interlocked beam stoppers in a frontend during injection? What are the design criteria of these stoppers?
e) What are the interlocked beam stoppers for a white-light experimental hutch? What are the design criteria of these stoppers?
f) In shielding design, are failure modes of the stoppers considered in the above interlocked safety device?
g) What protection devices are used for the above interlocked beam stoppers?

Question 1a	What are the interlocked devices to limit the beam energy and current injected into the ring? If none, what are used to ensure that there are no hazards when the acceptable injection beam parameters are violated?
NSLS	No interlocked devices. Current relay for ring dipoles is MPS-interlocked. Normal operating conditions are controlled via procedures established for operators. Abnormal operating conditions will be identified through control room instrumentation, including non-interlocked radiation monitors, which are installed in locations outside the ring to detect abnormal beam losses.
ALS	No interlocked devices. Normal operating conditions are controlled via procedures established for operators. Abnormal operating conditions will be identified through control room instrumentation, including non-interlocked radiation monitors, which are installed in locations (inside or outside the ring?) to detect abnormal beam losses.
APS	One current monitor at BTS to monitor injection beam power to 81 W. Many MPS devices, e.g., 13 BPMs and one loss monitor, to monitor and limit mis-steered injection beam in the ring. No interlocked devices for beam energy limitation.
SPring8	DCCTs and dipoles in the Booster-to-ring transport line.
SSRL	The normal injection beam power (P_i) is 4 W. Therefore, there are three average current monitors (ACMs) located in the Booster-to-SPEAR (BTS) transport line to limit the current to the Allowed Injection Beam Power (P_a) of 5 W. The Maximum Credible Injection Beam Power (P_m) is 45 W, which is limited by accelerator physics. No interlocked devices for beam energy limitation.
Note	For SSRL, the implication is that there are shielding design limits associated with abnormal losses of both P_a and P_m at a point in the ring, which is higher than the limit for normal beam losses.
Suggestion	Unless machine is physically incapable of producing higher current, the injection beam current should be monitored and controlled (by electronic means or by administrative process)

Question 1b	For ring access, what are the interlocked injection beam stoppers to stop beam injection into ring? What are the design criteria of the stoppers?
NSLS	1 mechanical 20-cm-Cu stopper in BTS line.
ALS	2 bends and booster kicker in BTS line.
APS	2 bends and 2 tungsten stoppers in BTS line.
SPring8	Bends and 1 mechanical stopper in BTS line.
SSRL	Booster ejection septum and 2 mechanical stoppers in BTS line. The size and location of these stoppers are designed such that the limit of 400 mrem/h for mis-steered beam scenarios and the limit of 25 rem/h for system-failure scenarios (e.g., 1 or 2 stoppers fails) are both met.

Note	No failure analysis is made by most facilities. Redundant devices.

Question 1c	For ring access, what are the interlocked stored beam stoppers to remove the stored beam hazards?
NSLS	Ring RF
ALS	Ring RF
APS	Ring RF
SPring8	Ring RF
SSRL	Ring RF & 2 mechanical stoppers in the ring.
Suggestion	Ring RF (bends are turned off for electrical safety reason)

Question 1d	What are the interlocked beam stoppers in a SR beamline frontend during injection? What are the design criteria of the stoppers?
NSLS	1 safety shutter (20-cm Pb) with a thermal stop. A person standing 1.5-m away from the shutter would not exceed 1 mrem per full stored beam dump at a point. 1/16 of the stored beam energy (3.9×10^{12} e) is converted into bremsstrahlung, which then hits the shutter.
ALS	1 safety shutter (30-cm Pb) and a water-cooled movable mask (MM). Designed to contain gas bremsstrahlung on MM (0.1 mrem/h), abnormal injection beam loss on MM (40 mrem per injection period), and abnormal stored beam loss on MM (40 mrem per event).
APS	For fresh injection, two safety shutters (20-cm W-alloy) with 2 Cu photon stoppers. Each shutter is designed to reduce the gas bremsstrahlung dose rate to 0.25 mrem/h, when the other fails. Top-up injection without shutters is allowed.
SPring8	One Main Beam Shutter (MBS, 40-cm-thick W-alloy). Designed to contain the bremsstrahlung from a normal stored beam loss in the ring chamber (0.6 mrem/h)
SSRL	2 injection stoppers (18-cm Pb or 13-cm W) and a copper MM. Designed to contain gas bremsstrahlung on MM (0.1 mrem/h), mis-steered beam with Pa on MM (400 mrem/h), and system-failure beam with Pa on the 2nd stopper (25 rem/h).

Question 1e	What are the interlocked beam stoppers for a white-light experimental hutch? What are the design criteria of the stopper?
NSLS	A comparable hutch shutter in the beamline to be closed during access to the experimental hutch (and permitting in-alcove safety shutter to remain open). Same design criteria as those of in-alcove safety shutter.
ALS	Same as the safety shutter in-alcove.
APS	White-light experimental hutch has one 18-cm W-alloy hutch shutter and a copper thermal stop for SR protection.
SPring8	Same as MBS in-alcove.
SSRL	White-light experimental hutches have two hutch shutters (HS), designed for GB only because only stored beam exists. Both normal (2 HSs are in) and abnormal (one HS fails) cases are considered. Each hutch shutter is 8.3-cm W-alloy for ID lines (5-cm long for bend lines).

Question 1f	In shielding design, are failure modes of the stoppers considered in the above interlocked safety devices?
NSLS	No
ALS	No
APS	No (except for injection stoppers). All stoppers are redundant.
SPring8	No
SSRL	Yes, e.g., a failure of 2 out of 3 stoppers or a failure of all 3 ACMs.

Question 1g	What protection devices are used for the above interlocked beam stoppers?
NSLS	Water flow of coolant and vacuum are MPS-interlocked for thermal stops.
ALS	Water flow of coolant and vacuum are MPS-interlocked for thermal stops.
APS	Water flow rate and pressure of coolant are PSS-interlocked for thermal stops.
SPring8	Water flow of coolant and vacuum.
SSRL	Water flow of coolant and vacuum are MPS-interlocked for thermal stops. In addition, BTM (burn through monitor) for each mechanical stopper, e.g., injection stoppers, hutch shutters, ring stoppers.

Section 2: Beam Loss Scenarios and Shielding Design for Storage Ring

Tables 1a and 1b summarize the parameters of the injection beam and stored beam that are related to the ring shielding design.

Table 1a: Injection beam parameters.

Parameter	NSLS	ALS	APS	SPring8	SSRL
Energy (GeV)	0.75	1.5	7	8	3
Frequency (Hz)	1	1	2	1	10
Pi (W)	0.5	1.5	20	12	4
Pa (W)	1	6	84	80	5
Pa Limiting Devices	Booster Acceptance	Booster Acceptance	Current Monitor	Booster Acceptance	3 ACMs
Pm (W)	NF	30	308 SE	240	45 Physics
η (%)	NF* / 25-50	75 / ?	95 / 99	10 / 80	75 / 80

1) η is the design/actual injection efficiency.

Table 1b: Stored beam parameters.

Parameter	NSLS	ALS	APS	SPring8	SSRL
Ring Circumference (m)	170	197	1104	1496	234
Beam Energy (GeV)	2.8	1.9	7	8	3
Stored Current (mA)	280	400	100	100	500
# Stored Particles ($\times 10^{12}$)	1	1.6	2.3	3	2.4
Stored Energy (J)	450	500	2578	3840	1200
Stored Power, Ps (MW)	784	760	700	800	1500
Design Lifetime, τ (h)	20	8	54	150 multi 25 single	20

Section 2 has a total of 7 questions:
a) What are the normal beam loss scenarios (including injection and stored beams) and the dose limits in ring shielding design?
b) What are the abnormal beam loss scenarios (mis-steering and system-failure) and the dose limits in ring shielding design?
c) Is the ring shielding design dictated by normal or abnormal beam losses?
d) What are the target geometries and tools (analytic and Monte Carlo) used in ring shielding calculations?
e) What shielding are located in a frontend? What are the beam loss scenarios for their design?
f) What is the shielding used to block the radiation (from beam losses in the ring) from passing through the beamline hole in ratchet wall? What are the design criteria?
g) What is the shielding inside ratchet wall to surround the SR beampipe?

Question 2a	What are the normal beam loss scenarios (including both injection and stored beams) and the dose limits in the storage ring shielding design?
NSLS	For lateral wall, full stored beam (2 GeV, 0.5 A, 567 J) loss over 8 apertures (the QF between 2 bends) over ring in 4-h → 5 mW at a point. Dose limit is 100 mrem for 2000 h → 0.05 mrem/h (0.5 µSv/h) 　Normalized dose limit (NDL) is 10 mrem/h/W for each aperture. (Requires forward and lateral local Pb shields around each aperture).
ALS	For lateral wall, full stored beam (1.9 GeV, 0.8 A, 1000 J) loss on thick targets over 197-m ring in 8-h → 1.05 mW at a point (a line source of 7-m assumed). Dose limit is 200 mrem for 2000 h → 0.1 mrem/h 　NDL is 95 mrem/h/W.
APS	In non-injection regions, 20% of Pa of 84 W loss in each ID → 17 W at a point during injection period. Dose limit is 500 mrem for 2000 h on average → 0.25 mrem/h Injection dose rate limit is 10 times higher, i.e., 2.5 mrem/h 　NDL is 0.15 mrem/h/W. (Requires 15-cm Pb on 88-cm lateral wall. However, because loss is uncertain and conservative, it was decided to measure and then add). In the injection region, 20% of Pse of 308 W loss in septum (with local shield) and 20% of Pse loss at each the first 3 IDs (7 mrem/h outside 1.6 m concrete). 　NDL is 0.14 mrem/h/W.
SPring8	20% of Pi of 12 W loss over 44 apertures (the 44 straights) → 55 mW at a point. Dose limit is 1200 mrem for 2000 h → 0.6 mrem/h. 　NDL is 11 mrem/h/W for each aperture.
SSRL	SSRL physicists provided ring operational conditions, considering 1-month start-up period and 10-month science program (user runs and machine study) → total electrons injected into the ring per year of 3.5×10^{15}. Normal beam loss (high and low) apertures around ring is also identified. Averaged over a year, the normal beam loss (including both injection and stored beam losses) is 2 mW at each of the 28 low-loss apertures. The injection septum has 16 mW and beam abort dump has 50 mW. Dose limit is 100 mrem for 1000 h/y on the floor → 0.1 mrem/h. 　NDL is 50 mrem/h/W for each low-loss aperture.
Note	NDL is a parameter useful for comparison of shielding need. Normal beam loss analysis should include: 1) Total electron injected into ring per year, considering start-up, user runs, and machine studies (with conservative injection efficiency and stored beam lifetime), 2) Total annual doses include both injection beam and stored beam, 3) Instantaneous dose rate during injection, 4) Identification of high loss points (septum, scraper, dump) and low-loss points (ID, QFC). If no apertures are identified, a uniform loss around ring can be

	assumed for low-loss points.

Question 2b	In addition to the normal beam losses in Question 2a, what are the abnormal beam loss scenarios (mis-steering and system-failure) and the dose limits in the ring shielding design?
NSLS	For ratchet wall, full loss of stored beam (2 GeV, 567 J) at a ring aperture and 1/16 of stored energy is converted into bremsstrahlung. Limit is 1 mrem per event NDL = 6 mrem/h/W. (For ratchet wall, requires Pb shield to be added to exit gaps of dipoles and around frontends for secondary rays up to 20º). For beamline, 8"-Pb blocks with L=2" were placed behind mono and/or the end of beamline (may coupled with exclusion zone). Neutron shielding was measured during operation.
ALS	For ratchet wall, full loss of stored beam (1.9 GeV, 1000 J) gives a dose limit of 40 mrem at 0-degree and 10-m from ring to wall NDL is 144 mrem/h/W.
APS	Many Maximum Credible Incident (MCI) scenarios were studied. Worst: a dose limit of 25 rem/h from P_m=308 W loss at a high dispersion point. (Calculated lateral dose to FOE is 10.7 rem/h outside 56-cm heavy concrete). NDL = 81 mrem/h/W.
SPring8	Loss of total stored beam (3840 J) at a ring point. Limit is 10 mrem per event NDL = 9 mrem/h/W.
SSRL	Two types of abnormal beam losses in the ring were considered. 1) A mis-steered injection beam loss of P_a (5 W) at a point. Limit is 400 mrem/h NDL = 80 mrem/h/W. 2) A system-failure case is the 3 interlocked ACMs fail and the beam was injected at the power of P_m (45 W) and lost at a point. Limit is 25 rem/h NDL = 570 mrem/h/W. Normal beam loss scenario (NDL=50) dictates the ring shielding design! For frontend, the injection beam of P_a was assumed to be channeled into beamline and hit the movable mask before the fist injection stopper under mis-steered case or hit the 2nd injection stopper under system-failure case.
Note	Abnormal beam loss analysis should include: 1) Loss of full stored beam at a point with a dose limit 2) Loss of full injection beam at a point with a dose rate limit.

Question 2c	Is the ring shielding design dictated by normal or abnormal beam losses?
NSLS	Abnormal beam loss of a full stored beam at a point.
ALS	Assumed abnormal losses of stored beam at a point.
APS	Both normal and abnormal beam losses.
SPring8	Abnormal beam losses of full stored beam at a point.
SSRL	For beam losses in an aperture of the ring, normal beam loss (50 mrem/h/W) dictates over abnormal beam losses (80 and 570 mrem/h/W). For beam losses in a non-aperture ring location, only mis-steered injection beam loss (80 mrem/h/W) is considered. For beam losses in the frontend, only abnormal beam losses occur and thus mis-steering cases dictate.
Note	1) The NDL values for normal and abnormal beam loss scenarios should not differ too much such that one scenario becomes over-demanding than others.

Table 2 summarizes the ring shielding design comparison, based on Questions 2a to 2c. A few key points are summarized below:

1) The trend of ring wall design is to achieve 0.1 rem/y so that there are minimum control and requirements for users.
2) For a facility, the NDL values for different scenarios should not differ too much (e.g., at SSRL, normal beam loss dictates the ring design),
3) For different facilities, the NDL values can be used to gain insight into consistency of shielding policy (lower is not necessarily better). If a facility has a very small NDL compared to others, then the facility may be too conservative.
4) Based on SPEAR3 design experience, a rule of 2'-3'-4' (i.e., 2' concrete roof, 3' concrete lateral wall, and 4' concrete ratchet wall) is found appropriate for facilities operated with similar parameters. In that case, only high-loss points need local shielding.

Table 2: Ring wall shielding design (based on Questions 2a to 2c).

Parameter	NSLS	ALS	APS	SPring8	SSRL
Normal Loss Dose Limit (mrem/y)	100	200	500	1200	100
Occupancy (h/y)	2000	2000	2000	2000	1000
Normal Loss NDL (mrem/h/W)	10 Stored	95 Stored	0.15? Inject	11 Inject	50 Inj./Stored
Non-injection Region Lateral Wall Concrete (cm)	46 + some Pb	46	88 + 6" Pb?	100	61 + 1" Pb
Abnormal Loss Dose Limits	1 mrem per 567 J	40 mrem per 1000 J	25 rem/h per Pm	10 mrem per 3840 J	0.4 - Pa 25 - Pm (rem/h)
Abnormal Loss NDL (mrem/h/W)	6	144	81	9	80, 570
Skyshine Limit	5	10	10	5	1

	(mrem/7200h)					

| Question 2d	What target geometry and tools (analytic and Monte Carlo codes) were used in the ring shielding calculations?
NSLS	DESY results for thin target from Al chamber. Thick target.
ALS	SHIELD11for thick target. EGS4 for thin target.
APS	IAEA-188 and SHIELD11 for thick target. DESY and EGS4 for thin target.
SPring8	Thick target. IEAE188 and EGS4 were used.
SSRL	Depending on the actual targets, either thick or thin target geometry was used for beam losses in the ring. SHIELD11 for thick target (like shielded apertures) and generic approach using FLUKA for thin target (e.g., not-shielded ring chamber).
Note	The limitations of thick target calculations, e.g., using SHIELD11 analytic code, should be understood (e.g., underestimation of photon dose rates at forward anlges). Similarly, the uncertainty due to geometry simulation using Monte Carlo codes can not be ignored either. In either case, proper safety factors should be applied.
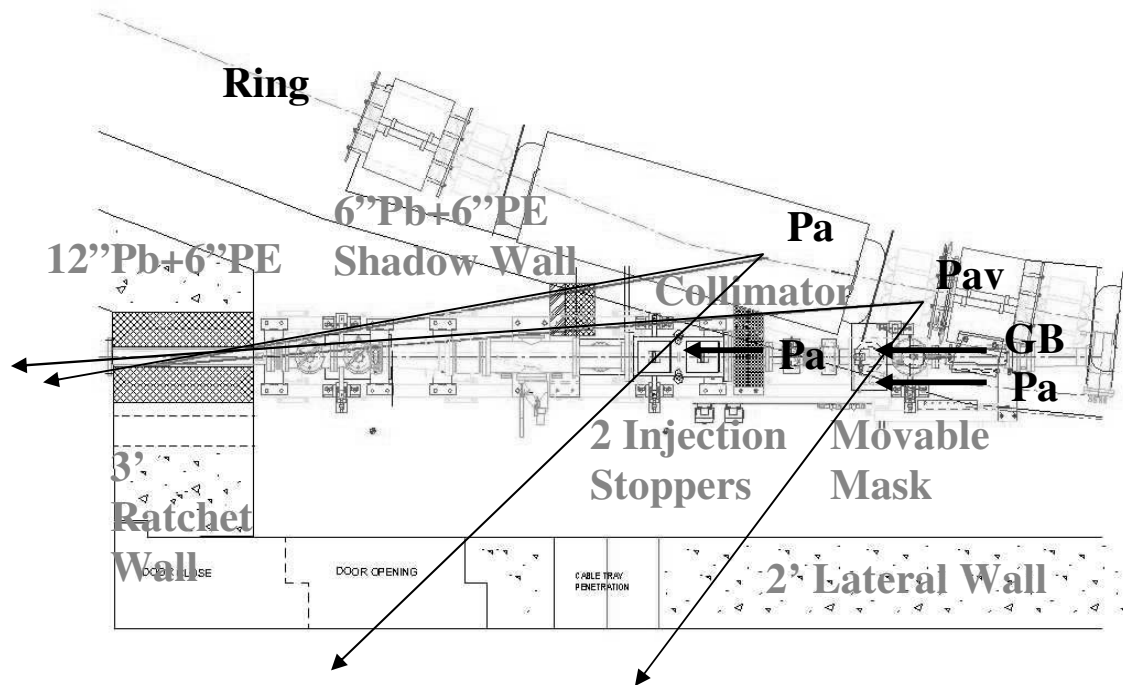
Figure 1. SSRL ring frontend safety design. Beam loss scenarios considered are: 1) GB on MM, 2) abnormal injection loss of Pa at MM or the 2nd stopper, 3) normal average beam loss of Pav = 2 mW in a low-loss aperture, and 4) abnormal injection loss of Pa = 5W at any point. Annual dose for normal beam losses and dose rates for abnormal beam losses are then calculated outside lateral wall and ratchet wall. Colliamtor and shadow walls (6"Pb+6"PE) are used to block the secondary radiation from passing through the beamline hole in ratchet wall. The shielding around the beampipe in the ratchet wall is made of 12"Pb+6"PE. During injection, the movable mask (MM) and 2 injection stoppers are inserted into the frontend.

Question 2e	What shielding are located in a frontend? What are the beam loss scenarios for their design?
NSLS	Collimator, MM, safety shutter (20-cm-Pb), 20-cm-Pb on the ring side of the pipe near ratchet wall (69-cm-concrete) with hole filled with 20-cm-Pb and as much as PE. Abnormal full stored beam loss at a point in ring.
ALS	Collimator (20-cm-Pb) near ring exit flange, movable mask, safety shutter (30-cm-Pb) surrounded by 20-cm-Pb collar near bellyband (12.7-cm-Pb) on ratchet wall (7.6-cm-Pb + 46-cm-concrete) and hole filled with 15-cm Pb + 30-cm PE. GB on shutter, normal stored beam losses in ring, & abnormal injection beam loss and full stored beam loss at a point in ring.
APS	MM, collimator (30-cm-Pb), two safety shutters (20-cm-W), girder shield (20-cm-Pb), ratchet wall (126-cm-concrete) with hole filled with 30-cm-Pb. GB onto shutters, and abnormal injection beam loss at any point in ring.
SPring8	Collimator (10-cm-Pb), MM, Collimator, MBS (40-cm W) & 30-cm-Fe around pipe near ratchet wall (80-cm-concrete) with hole filled with 60-cm Pb + 20-cm concrete. Normal beam losses in ring aperture; Abnormal full stored beam loss at a point in ring; GB on MBS.
SSRL	MM, collimator (15-cm Pb + 15-cm PE), 2 injection stoppers (18-cm-Pb), shadow walls (15-cm Pb + 15-cm PE) near ring chamber, ratchet wall (91-cm-concrete or 60-cm-concrete + 1" Pb) with hole filled with 30-cm Pb + 15-cm PE. In frontends, GB on MM, abnormal injection loss of Pa at MM or 2nd stopper, In ring, normal beam loss of 2 mW in an aperture, and abnormal injection loss of Pa=5W at any point.
Note	Frontend is the connection between ring and beamline. Frontend safety design is related to the ratchet wall design. Typical examples are that a collimator near the beamline exit flange of ring or discrete shield near the ring chamber can supplement the ratchet wall thickness for the forward-peaked secondary bremsstrahlung. Ray trace study is recommended.

Question 2f	What is the shielding used to block the radiation (from beam losses in the ring) from passing through the SR beamline hole in the ratchet wall? What are the design criteria?
NSLS	Collimator. Discrete 20-cm-Pb block on the ring side of the pipe near ratchet wall.
ALS	Collimator (20-cm-Pb) near ring exit flange (for GB cone and rays < 15° to hole from normal stored beam loss in ring chamber). 20-cm-Pb collar near lead bellyband on ratchet wall (for injection loss and point stored beam loss in any ring chamber point).
APS	Collimator, discrete girder shield next to ring chamber, and side shield next to pipe near ratchet wall.
SPring8	30-cm Fe around the pipe near the hole (downstream of MBS).
SSRL	Shadow walls (15-cm Pb + 15-cm PE) near ring chamber. (Consider normal loss of 2 mW at a ring aperture and mis-steered beam loss of 5-W at any point in the ring chamber).
Note	Need ray trace study.

Question 2g	What is the shielding inside ratchet wall hole to surround the SR beampipe?
NSLS	20 cm Pb + PE
ALS	15-cm Pb + 30-cm PE
APS	30 cm Pb (used to be 15-cm Pb + 15-cm PE + 15-cm Pb)
SPring8	60-cm Pb + 20-cm PE
SSRL	30-cm Pb + 15-cm PE

Section 3: Beam Loss Scenarios and Shielding Design for SR Beamlines

Section 3 is divided into three sections: 1)general issues, 2) SR design (further grouped into White, Pink, Mono and VUV), 3) GB design, and 4) miscellaneous issues.

There are 3 questions in the section of general issues:

1) What are the beam loss scenarios in beamline shielding design?
2) What are radiological controls for experimental floor and dose monitoring (personnel and area) requirements?
3) What are the dose limits in beamline shielding design? Is this part of the ring shielding design limit?

In the section of SR design, there are 2 questions each for White, Pink, Mono and VUV:

1) What is the methodology of designing the sizes of white-light hutch stoppers, collimators, and beamstops?
2) What is the methodology of calculating the white light hutch wall thickness (side walls and back walls)?

In the section of GB design, there are two questions:

1) What are the requirements and design calculations for GB safety components, e.g., collimators, hutch shutters, and beam stops?
2) What are the shielding requirements and design calculations for GB scattered from an optic element, like mirrors, monochromators, or masks?

In the section of miscellaneous issues, there are five questions:

1) What are the safety factors used in hutch shielding design?
2) Is the hutch roof occupancy factor considered and what are the rationales?
3) How is the hutch penetration hazard evaluated?
4) How is the ground-shine hazard evaluated?
5) How is the ozone hazard evaluated?

Tables 3a and 3b summarize the parameters related to the beamline safety design.

Table 3a: GB parameters related to beamline safety design.

Parameter	NSLS	ALS	APS	SPring8	SSRL
Pi / Pa (W)	0.5 / 1	1.5 / 6	20 /84	12 /80	4 / 5
Stored Energy (J)	450	500	2578	3840	1200
Stored Beam Energy (GeV)	2.8	1.9	7	8	3
Stored Current (mA)	280	400	100	100	500
Stored Power (MW)	784	760	700	800	1500
Typical Straight Section (m)	5	6	15	19	6
GB Power (mW)	16	19	46	64	38
Dose Limit (mrem/h)	0.05	0.1	0.25	0.6	0.1

1) 1-ntorr was assumed to obtain GB power, using very-thin-target bremsstrahlung formula.
2) The SHIELD11 code gives Hp = 0.075 mrem/h at 1 m at 90-deg from 50-mW GB on 2"-radius Fe target.
3) If the target is a Si mirror (which has less self-attenuation), Hp is then ~0.2 mrem/h (2 mSv/h)   Need 1" Pb shield lateral to Si mirror at SSRL.
4) The forward-angle bremsstrahlung from beam losses in the ring aperture (e.g., an ID), which channels into beamline, can add to the GB dose rate. This is particularly important for top-up operation, where the injection stoppers in frontends are withdrawn during injection.
5) A medium-energy facility tends to have wiggler beamlines than the low- or high- energy facilities. The wigglers have large deflection parameter, K, and have more branch lines. This tends to create an optic hutch with a beamline layout crowded with optic elements, which may be hard to install local GB shielding.

Table 3b: SR parameters related to beamline safety design.

Parameter	NSLS	ALS	APS	SPring8	SSRL
Wiggler ID Field (T)	5	2.1	1	1	2
E_c (keV) = 0.665 B E^2	26	5	33	43	12
Power = 4.22 B E^3 I N (kW/mradH)	0.3	1	8	16	3

General Issues

Question 3a	What are the beam loss scenarios in the SR beamline shielding design?

NSLS	GB and SR under normal stored beam condition.
	
	However, the thickness of safety shutters, lead collimators, and beam stops in the beamlines are designed for "Maximum Credible Radiation Accident", which had two scenarios:
	  1) Bremsstrahlung from a designed stored beam loss in a 1-m, 1-atm air section inside the ring chamber hitting the device,
	  2) Loss of designed stored beam (3.9×10^{12}, 2 GeV, 1248 J) at an aperture in ring and 1/16 of stored beam energy channeling into BL hitting the device (use Bathow's curve).
	
	The limit is 1 mrem per beam loss.
	The 2nd scenario dictates the shielding: 8"-long Pb blocks (L=2" from extreme rays)
	Chamber's source size for ray trace purpose: H 4 to -5 cm & V ±2.1 cm.

ALS	GB and SR under normal stored beam conditions.
APS	GB and SR under normal stored beam conditions (Safety Envelope parameters).
SPring8	GB and SR under normal stored beam conditions.
SSRL	GB and SR under normal stored beam conditions.
Note	

Question 3b	What are the radiological controls for experimental floor and dose monitoring (personal and area) requirements?
NSLS	GERT (CBT 1-h) required to enter floor. Dosimeter required for all regular staff, but not users who stay < 2-3 months. Area TLDs (Li-6/Li-7 on phantom) exchanged every 3 months.
ALS	GERT required to enter floor. Dosimeter required for certain workers, but not users even with full occupancy. Area TLDs monitored for 3 months.
APS	GERT required to enter floor. Dosimeter required if occupancy > 500 h/y. Area TLDs (bare Li-6/Li-7) exchanged every 3 months.
SPring8	Radiation training and dosimeter required to enter the floor. Area GLDs exchanged every month.
SSRL	GERT trained to enter floor. No dosimeter required for users. Area TLDs (moderated Panasonic or Luxel+CR-39) exchanged every 6 months.
Note	1) GERT is a basic radiation safety training for individuals at DOE facilities expected to receive < 0.1 rem/y. 2) Ring shielding design should consider the monitoring and training requirements for user access to experimental floor.

Question 3c	What are the dose limits in the SR beamline shielding design? Is this part of the ring shielding design limit?
NSLS	0.05 mrem/y for 2000 h/y for non-radiation worker like users. Shielding added to achieve reference value of 0.05 mrem/h, whenever possible.
ALS	0.1 mrem/hr for 2000 h/y for either SR or GB. Accident 100 mrem per event. Treated separately from ring because different occupied areas.
APS	0.25 mrem/h for 2000 h/y (0.125 for photon and 0.125 for neutron, as neutron was not calculated but was estimated to be equal to the photo dose rate). Treated separately from ring.
SPring8	0.6 mrem/h for 2000 h/y. Treated separately from ring because, in general, an area will not be exposed to the maximum radiation from ring and that from beamline.
SSRL	0.1 mrem/h for 1000 h/y (0.05 mrem/h for GB and 0.05 mrem/h for SR). Together with the ring limit of 0.1 mrem/h, the total is 200 mrem per 1000-h.

White-Light Hutch Issues

Question 3d	What is the methodology of designing the thickness of white-light hutch stoppers, collimator, and beam stop?
ALS	Both SR and GB are considered (GB dictates). Tromba's NIM analytic method for GB (1 ntorr, 1.9-GeV, 800-mA, r = 20 m). 30-cm Pb with L = 5 cm (or 18-cm W with L = 3.5 cm)
APS	Two PSS redundant stoppers are used. Both SR and GB are considered (GB dictates). Use Frank (LURE) formula to estimate 0-degree unshielded dose rate. Use EGS4 to sample 1/k spectrum and a pencil beam (normalized to LURE dose) hitting device and get dose over 1x1x1 cm cube tissue behind device. 30-cm Pb with L = 4.5 cm (or 18-cm W with L = 3.5 cm)
NSLS	Hutch stopper is the same as injection stoppers in most cases. 8"-thick collimators and beam stops are designed for bremsstrahlung from full stored beam loss in an aperture of the ring.
SSRL	Both GB and SR were considered, but GB dictates over the SR. 1) Tromba and Ferrari NIM methods, r = 10 m, L = 6 m for ID (15 cm for bend), 1 ntorr, 3-GeV, 500-mA. Ferrari source term and Tromba attenuation length were used. 2) The thickness is such that, when GB hits the first stopper, the 0-degree dose rate (scored over a circle of 1" radius) behind the 2nd stopper is < 0.1 mrem/h. When GB hits the 2nd stopper (when the 1st stopper fails), the 0-degree dose rate behind the 2nd stopper is < 25 rem/h. 3) The dose is calculated using FLUKA. 25-cm Pb with L = 5 cm (PGB) or 2.5 cm (SGB) & O=1/4" Pb.
SPring8	Both SR and GB are considered (GB dictates). For GB, EGS4 code and analytic method from Ban are used.
Suggestion	

Question 3e	What is the methodology of calculating the white light hutch wall thickness (side wall and downstream wall)?
NSLS	Actual beamline target materials and geometry in the PHOTON code. NICK command for downstream wall with no sample in experimental hutch. Standard wall thicknesses specified for typical beam lines. Detailed calculations are not routinely performed for normal beam lines. For example, the X17 superconducting wiggler (2.5 GeV, 5-T, 20.8 keV, K=81) 6"-W safety shutter in alcove; double mono, a W safety shutter, and then a 8" Pb (L=2") collimator in optic hutch; Use Si mono as target in PHOTON. Hutch wall is ¼"Pb + ¼" Fe.
ALS	Si target (3-cm radius, 3-cm thick) at 1 m (or beampipe at 30 cm) in PHOTON. Local center area of downstream wall is shielded for no sample case with a full coverage of ±2 degrees from the beginning of hutch. NICK command with a beam size of 1x1 cm^2 (with analytic build-up included) is used.
APS	Both SR and GB are considered (SR dictates side wall and GB dictates back wall). A perpendicular Al target (0.5-cm thick, 0.5-cm radius) in PHOTON and STAC8 (no polarization, with build-up). Many beamlines with actual distances were calculated, and the maximum results are then used for all beamlines. For GB, target is 4x4x3 cm Cu (if first optic element is mask or mono) or 1°-inclined Si target (if first element is mirror). The method is Frank/EGS4. ID hutch side wall is 1.6-cm Pb. Downstream wall is 5 cm Pb and extra 5-cm Pb over center 1 m^2 area (for GB). For white-light pipe, if there is target like slit or filter inside pipe, use Al target for SR and Cu target for GB. If no targets, use 30-cm-long and 1 atm air as target. Method is STAC8 for SR and Frank/EGS4 for GB. Dose limit is 2.5 mrem/h on contact of pipe.
SPring8	A perpendicular Cu (1-cm radius, 1-cm thick) in STAC8 (build-up, no polarization except for the roof). Individual beamline parameters are used for each beamline. There is a 30x30x30 cm^3 Pb gamma stop within 1 m from the first optic element that intercepts the GB. The downstream wall that is not intercepted by the gamma stop is shielded by scattered SR.
SSRL	Scattered SR from a 0.2^o-inclined Si and a perpendicular Cu (0.5-cm-radius and 0.5-cm-thick) in STAC8 (build-up, no polarization). The dose calculated using STAC8 was benchmarked with FLUKA. Actual distances to side walls are used, but 100-cm for downstream wall and 30-cm for beamipe. Local center area of downstream wall is shielded for no target case with a full coverage of solid angle from SR ray trace.

Note	

Pink-Light Hutch Issues

Question 3f	What is the methodology of designing the thickness of pink-light hutch stoppers?
ALS	Specular-reflected SR was considered. PHOTON code used. For SuperBend lines, two fixed aperatures/masks required to go from white to pink shielding. GB is not considered.
APS	Specular-reflected SR from the mirror hits the stopper. STAC8 code used. GB is not considered.
NSLS	Same as for white light beam lines.
SSRL	The worst-case SR scattered from a mirror hits the beam shutter perpendicularly. Both specular-reflected SR and the Compton-scattered SR are considered. Scattered SR dictates over the scattered GB. STAC8 code used.
SPring8	SR scattered from the mirror hits the beam shutter perpendicularly. Both specular-reflected SR and the Compton-scattered SR are considered. STAC8 code used.
Suggestion	

Question 3g	What is the methodology of calculating the pink-light hutch wall thickness (side and back walls)?
ALS	Specular-reflected SR hits a perpendicular Cu target inside the hutch or beampipe. PHOTON code used.
APS	Specular-reflected SR hits air target (30-cm-long, 1 atm) inside hutch. STAC8 code used.
NSLS	Same as for white light beam lines.
SSRL	Mirror-scattered SR hits a 0.2-deg inclined Si target. Both Compton-scattered and specular-reflected SR are considered. Local area of back wall near beam center is shielded for no target case with a full coverage of solid angle. The dose is calculated using STAC8 (benchmarked with FLUKA).
SPring8	Specular-reflected SR hits the standard Cu target. STAC8 code used.
Suggestion	

VUV Beampipe Issues

Question 3h	What is the methodology of calculating the VUV beampipe wall thickness?
ALS	Specular-reflected SR hits a perpendicular Cu target (PHOTON code). SR collimator with ray traces to ensure scattered SR cannot hit beampipe.
APS	
NSLS	
SSRL	The inclined Si mirror of the beamline is used. Both Compton-scattered SR and specular-reflected SR are considered. The dose is calculated using STAC8 (benchmarked with FLUKA). SR collimator may be used to block SR, so that scattered SR does not hit beampipe.
SPring8	Both Compton-scattered SR and specular-reflected SR hitting an inclined beampipe. Doses are calculated with the coupling of STAC8 and G33-CGGP2.
Suggestion	

Mono-Light Hutch Issues

Question 3i	What is the methodology of designing the thickness of mono-light hutch stoppers?
ALS	Only required on one beamline. Mono beam (assume 1 cm2 area) hits back wall. Can hit anywhere ± 2 degrees from hutch entrance.
APS	All harmonics (with 0.1%BW) from mono hits the stopper. Use the aperture area.
NSLS	Standard hutches are prescribed.
SSRL	The worst-case SR scattered from a mono hits the beam shutter perpendicularly. Both mono lights and the Compton-scattered SR are considered.
SPring8	
Suggestion	

Question 3j	What is the methodology of calculating the mono-light hutch wall thickness (side and back walls)?
ALS	The mono light hits a perpendicular Cu target with the hutch wall at 100 cm. PHOTON code is used. See Question 3i.
APS	All harmonics (with 0.1%BW) from mono hits a Cu target?. For a transport pipe, all harmonics (with 0.1%BW) from mono hits a vacuum loss section or potential solid scatters.
NSLS	Standard hutches are prescribed.
SSRL	Mono-scattered SR hits a 0.2-deg-inclined Si target. Both mono-light and the Compton-scattered SR are considered. Local area of back wall near beam center is shielded for no target case with a full coverage of solid angle. The dose is calculated using STAC8 (benchmarked with FLUKA).
SPring8	Mono light hitting the standard Cu target (3rd harmonics is most important). Local area of back wall near beam center is shielded for no target case. The dose is calculated using STAC8.
Suggestion	

Gas Bremsstrahlung Issues

Question 3k	What are the requirements and design calculations for GB safety components, e.g., collimators, hutch shutters, and beam stops?
NSLS	One hutch shutter is used. GB was not considered. Instead, the device thickness was determined based on the Maximum Credible Radiation Accident: loss of designed stored beam at an aperture in ring and 1/16 of stored beam energy channeling into BL hitting the device (use Bathow's curve). Limit is 1 mrem per stored beam loss. 20-cm Pb (or 15-cm-thick W-alloy) with L = 5 cm using the actual ring chamber size.
ALS	One hutch shutter is used. GB from Tromba's NIM analytic method (1.9-GeV, 800-mA, 1 ntorr, r from ID end to device = 20 m). Limit is 0.1 mrem/h. Contiguous 30-cm Pb with L = 5cm (or 18-cm W-alloy with L = 3.5 cm). Use the same results on all beamlines – ID's and BM's.
APS	One hutch shutter is used. 0-degree unshielded GB dose rate from Frank (LURE 1988) formula (7-GeV, 300-mA, 1 ntorr, 15 m straight, r =26 m 2.2 Sv/h) Then use EGS4 to sample 1/k spectrum and a pencil beam (normalized to LURE dose) hitting device and get dose over a 1x1x1 cm^3 region in a 30-cm cube tissue phantom surrounding the device. The photon limit is 0.125 mrem/h with 2000 h/y (note there are no beamstops or hutch shutters outside hutch at APS). 30-cm Pb with L = 5 cm (or 20-cm W-alloy with L = 3.5 cm) Use the same results for IDs and bends. Other GB safety items in a beamline are: 1) Collimators for white-light transport. 2) For beamstop, shutter and collimator, L=5 cm from extreme rays. 3) Combination of W mono aperture & beam stop (vertical offset ≥ 0.8 cm)
SPring8	One safety shutter (MBS) is used. Cu target is used to simulate the first optic element, mono or mirror, hit by GB. GB is calculated using EGS4 and Ban's analytic method. a Pb gamma stop (30x30x30 cm^3) within 1 m from the end of the mono in ID lines, and mirror in bend lines.
SSRL	Two redundant hutch shutters are used. For 0-degree GB dose rate, the maximum dose rate source term from Ferrari and the realistic attenuation length from Tromba in NIM articles are used. (3-GeV, 500-mA, 6-m-long ID (15 cm for bend), 1 ntorr, r = 10 m). The thickness is such that, when GB hits the device, the 0-degree dose rate (scored over a circle of 1" radius) behind the device is ≤ 0.1 mrem/h. When GB hits the 2nd shutter (if the first shutter fails), the 0-degree GB dose rate behind

	the 2nd shutter is ≤ 25 rem/h.
	25-cm Pb with L = 5 cm (PGB) or 2.5 cm (SGB) & O=1/4" Pb.
	The requirements are applied to hutch shutters, GB collimator, and beam stop. The requirements on L and O values are based on FLUKA calculations. Ray trace is based on Physical Envelope.
Note	1) In addition to the Z thickness, the safety device also needs to have a XY size, that has an extra edge from the extreme rays (called L), which can be determined with a GB source size in ring chamber. 2) Two near-by safety components also need to have overlap (called O).

Question 3l	What are the shielding requirements and design calculations for GB scattered from an optic element, like mirrors, monochromators, or masks?
NSLS	Not calculated - Measure and improve during commissioning.
ALS	Forward-scattered GB doses were estimated and measured not to be a problem. Analytic estimation for lateral photon dose ≤ 10 mrem/h (neutron not estimated). However, 1"-2" lead was placed on first optic element of a few ID lines only based on measurements.
APS	A perpendicular 4x4x3 cm^3 Cu target (if first optic element is mask or mono) or 1°-inclined Si target (if first element is mirror) placed at the beginning of hutch hit by GB and the scattered photon dose rates calculated using Frank/EGS4. ID hutch downstream wall is 5-cm Pb and extra 5-cm Pb over the central 1x1 m^2 area. If mirror is the first target, a W-alloy block is also added behind mirror. No lateral shield is needed from calculation. However, neutron measurements indicated non-GB component during top-up injection requires the addition of 15-cm PE laterally for the first optic element in two ID beamlines, which have only 5 mm gap.
SPring8	Inclined Si mono hit by GB using EGS4/MCPHOTO/PICA. 30x30x30 cm^3 Pb within 1 m behind the first optic element. No lateral shielding needed.
SSRL	Sacttaed dose rates as a function of angle for GB hitting three types of targets (0.2-deg-inclined Si target for mirror, perpendicular 1"-cube Cu for mono or slits, and 1"x1"x6" Cu for thick masks) were calculated using FLUKA. Local lateral and forward Pb shield may be needed, e.g., 1" lead beside a small thick optic element, as well as 4" Pb downstream, that intercept primary GB is required.
Note	

Miscellaneous Beamline Issues

Question 3m	What are the safety factors used in hutch shielding design?
NSLS	Standard design from earlier successful hutches is used for new hutches.
ALS	Ring: 800 vs. 400 mA (ring injection at 1.5 GeV and stored beam can be 1.5 or 1.9 GeV) Shield rounded up to the next 1/16". Use 800 mA in design calculation (vs. 400 mA). Does not consider lateral dose attenuation from steel tank and pipe and only 1/8" Fe is considered. Forward-scattered dose can consider self-shielding, if verified by ray trace.
APS	Use 300-mA/7-GeV for GB and 200-mA/7.5-GeV for SR (vs. 100-mA/7-GeV). One TVL added for the final SR shielding thickness. Does not consider attenuation from steel tank and pipe (as every beamline could be different).
SPring8	Conservative factors in STAC8
SSRL	STAC8 (P=0) Does not consider attenuation from steel tank and pipe (as every beamline could be different).

Question 3n	Is hutch roof occupancy factor considered and what are the rationales?
NSLS	Roof is thinner (administratively control for no access to roof).
ALS	100% for roof.
APS	10% for roof (ring roof is 100%).
SPring8	100% for roof (ring roof is 100%).
SSRL	10% for roof (ring roof is 10%).

Question 3o	How is the hutch penetration hazard evaluated?
NSLS	≥ 1 bounce required.
ALS	> 2 bounces required
APS	Empirical rules of 1-5 and 2 bounces
SPring8	> 2 bounces required. Use STAC8 and G33-CGGP2.
SSRL	≥ 2 bounces required.

Question 3p	How is the groundshine hazard evaluated?
NSLS	Empirical rule of grove. Additional shield after measurements.
ALS	Estimated ??? and measured to not be a problem.
APS	Empirical rule of grove and 2"-4" L-shape Pb plate
SPring8	Use STAC8 and G33-CGGP2.
SSRL	Empirical rule of grove. Additional shield after measurements.

Question 3q	How is the ozone hazard evaluated?
NSLS	Air exposure to white light eliminated where possible. Sensed ozone from white ID light in air and mitigated with activated charcoal

	when needed.
ALS	Generic curves provided using PHOTON in air, white beam, typical hutch volume and ventilation rates.
APS	No white light in air, while mono or pink lights in air is not an issue.
SPring8	EGS4 & G value
SSRL	Worst case of white-light evaluated using NCRP yield.

Section 4: Radiation Monitors for Ring and Beamlines

Section 4 has a total of 3 questions:
1) What are the radiation monitors around the outer storage ring wall? Dose the detector have keep-alive source? What are the thresholds of the warning and trip points, if interlocked?
2) What are the beam loss monitors inside the ring? What are the thresholds of the warning and trip points, if interlocked?
3) What are the radiation monitors around the SR beamlines? What are the thresholds of the warning and trip points, if interlocked?

Question 4a	What are the radiation monitors around the outer storage ring wall? Dose the detector have keep-alive source? What are the thresholds of the warning and trip points, if interlocked?
NSLS (170 m)	24 BNL-made "Chipmunks" tissue equivalent ion chambers (each with a gamma source). Warning at 2.5 mrem/h. No trip point.
ALS (197 m)	12 pairs of HPI model 2080/2010 neutron/gamma detectors (use natural background radiation as keep-alive source). Warning at 5 and and trip at 10 mrem/h.
APS (1104 m)	27 pairs of NRC model ADM-610 & neutron NP-100/IP-100 neutron/gamma detectors (each pair with Cm-248 neutron and Cs-137 gamma sources). Trip at 3 mrem/h for neutrons and 10 mrem/h for gammas. No warning point.
SPring8 (1496 m)	5 pairs of Fuji moderated He-3 neutron and ion chamber gamma detectors; one per quadrant and extra one in injection area (no keep-alive sources). Warning at 5 mrem/h, but no trip point (except the one in injection area).
SSRL (234 m)	17 SLAC-made tissue equivalent ion chambers (each with a Cs source). Warning at 5 and trip at 10 mrem/h.
Note	

Question 4b	What are the beam loss monitors inside the ring? What are the thresholds of the warning and trip points, if interlocked?
NSLS	None
ALS	None
APS	None (Fission detectors and Cherenkov detectors, not interlocked)
SPring8	None
SSRL	Plan to use interlocked LIONs, one in each ring quadrant.

Question 4c	What are the radiation monitors around the SR beamlines? What are the thresholds of the warning and trip points, if interlocked?
NSLS	One "Chpimunk" next to the first optical element of an ID beamline.
ALS	One HPI 6031 pulsed-mode photon ion chamber on top of the first optic element

	of all white-light beamlines (ID or bend). Warning at 5 mrem/h.
APS	Same as those around outer lateral wall, but around the first optic element of every ID.
SPring8	None
SSRL	None. Plan to use GM or ion chamber on the first optic element for top-up mode?

Section 5: Top-Up Mode Operation

Section 5 has a total of 2 questions:
1) What is the top-up mode of operation (with injection stoppers in frontends open)?
2) What are the safety controls to allow the top-up mode of operation (injection stoppers in frontends open)?

Question 5a	What is the top-up mode of operation (with injection stoppers in frontends open)?
NSLS	Not allowed.
ALS	Envisioned one pulse every 32 seconds.
APS	Limited to 1.5 nC per pulse in 120 s.
SPring8	One pulse per 1-5 minutes. Total amount of injection and total beam loss at top-up mode are limited. With stopper open, the 0-degree bremsstrahlung from injection beam loss in the SR source point increases the neutron dose by a factor of 2 of natural background level.
SSRL	To be studied in 2006?
Note	The hazards are: 1) Lifetime is less and more electrons are injected into ring, 2) Bremsstrahlung photons from normal injection beam losses channels into beamlines, 3) Injection beam mis-steered into a beamline.

Question 5b	What are the safety controls to allow the top-up operation?
NSLS	Not allowed yet.
ALS	Envisioned controls: 1) Stored current > 10 mA, 2) dEi/Ei < 10%.
APS	1) 1.5 nC per pulse in 120 s. 2) $6 \leq$ Ei (GeV) 3) Stored current $\geq$ 50 mA
SPring8	1) Injection current monitored and limited by toroid interlock. 2) Injection efficiency $\geq$ 80% (with beam loss integrator by BTS-BCM and ring-DCCT and radiation detectors). 3) The BTS and ring dipole magnets are powered on in series. The BTS deflection is upward 9 m. Thus, when the ring dipoles lose magnetic field, the beam can not be injected into ring and, thus, any frontend.
SSRL	Not allowed yet.
Note	

Section 6: Operational Issues

Section 6 has a total of 3 questions:
1) What is the frequency of certifying the safety interlock systems (e.g., PPS) for the ring and beamlines?
2) Do you use one gate or 2 gates for each interlocked access into the ring? What interlocks do you have for each gate?
3) Induced activity issues in ring and SR beamline.

Question 6a	What is the frequency of certifying the safety interlock systems (e.g., PPS) for the ring and beamlines?
NSLS	Once per half-year. Relay + PLC.
ALS	Once per half-year. Relay + PLC
APS	Once per year.
SPring8	Once after each long down (summer and winter)
SSRL	Once per year (additional 6-month validation test on critical elements)
Suggestion	Regulation asks minimum once per year.

Question 6b	Do you use one gate or 2 gates for each interlocked access into the ring? What interlocks do you have for each gate?
NSLS	1 gate with 2 microswitches
ALS	1 gate with 2 microwitches
APS	1 gate with 2 microswitches
SPring8	1 gate with 2 microwitches
SSRL	2 gates, each with 2 microswitches

Question 6c	Induced activity issues in ring and SR beamline
NSLS	Only issue is DOE moratorium on potentially induced metals. Rarely detected.
ALS	Only issue is DOE moratorium on potentially induced metals. None detected.
APS	
SPring8	
SSRL	2 mW at each aperture around the ring (other than injection septum, stored beam dump, and ring stopper) and 0.04 mW of gas bremsstrahlung power. Should be no issues (will do estimation here).
Note	

Table 1. Operating parameters of injection beam.

Parameter	ALS	APS	NSLS	SSRL	SPring8	Note
			X-ray Ring			
Particle Type	Electron	Electron	Electron	Electron	Electron	
Beam Energy (GeV)	1.5	7	0.75	3.0	8.0	
Frequency (Hz)	1	2	1	10	1	
Injection Beam Power, P_i (W)	1.5	20	0.5	4	12	Normal
Allowed Injection Beam Power (AIBP), P_a (W)	6.0 ?	84 (6 nC per pulse)	1 (admin)	5	80	Interlock or physics
Pa Limiting Devices Q1a	Booster acceptance	BOSCOM	None	3 ACMs at BTS	Booster acceptance	
Maximum Credible Injection Beam Power, P_m (W)	30	154 (OE) 308 (SE)	None	45 Physics	240	
Injection Beam Stopper Q1b, Q1f (Failure Analysis)	2 BTS bends, BTS kicker (no)	2 bends, 2 stoppers (no)	1 stopper (no)	BTS septum, 2 stoppers (Yes)	BTS bends, 1 stopper (no)	Stop injection for ring access
Fresh Injection (F), Top-up Injection (T) per day	Design 3F Real 6F (IS Closed)	2F or T (T: IS Open)	2F	2F (1F/3T) (IS Closed)	2F T (1p per 1-5 min)	
Injection Efficiency, η (%)	75	95, 99	75, 25	75, 80	10, 80	Design, Real

Table 2. Operating parameters of stored beam.

Parameter	ALS	APS	NSLS	SSRL	SPring8	Note
			X-ray Ring			
Ring Circumference (m)	197	1104	170	234	1496	
Stored Beam Energy, Es (GeV)	1.9	7	2.8	3.0	8.0	
Stored Beam Current, Is (mA)	400	100	280	500	100	
Number of Stored Particles, N	1.64×10^{12}	2.3×10^{12}	1×10^{12}	2.43×10^{12}	3×10^{12}	
Stored Energy (J) =1.6E-10 N Es	500	2578	450	1200	3840	
Stored Power Ps = Es Is (MW)	760	700	784	1500	800	For GB
Stored Beam Life Time (h)	8	54	20	20	Multi 150 Single 25	
RF Frequency (MHz)	500	352	53	476	509	
Stored Beam Stopper **Q1c**	RF	RF	RF	RF & 2 Al stoppers	RF	Kill stored beam for ring access

Table 3. Safety and shielding design criteria for storage ring.

Parameter	ALS	APS	NSLS	SSRL	SPring8	Note
Stored Beam Power Loss over Ring, Ps	35 mW over 197 m	60 mW over 1104 m	10 mW over 170 m	28 mW over 234 m	3840J/10h, 107 mW over 1453 m	Note 1
Total Loss over Ring, Pr (mW/m)	0.24	0.06	0.08	0.16	0.08	Note 1
Normal						
Total e⁻/y into Ring (mW/m)	---	---	---	$3.5x10^{15}$ (0.3 mW/m)	$3.1x10^{15}$ over 3 month (0.35 mW/m)	Analysis (Note 2)
Normal Beam Loss Analyzed	No	No	No	Yes 25 aper.	Yes 44 aper.	e-/y Apertures
Normal Beam Loss, Pn (mW) **Q2a**	25% of Pi over ring ? (1.9 mW/m)	5% of Pi over ring ? (0.9 mW/m)		2 mW at each of 25 apertures	12x0.2/44 =55 mW?	Averaged over a year
Normal Shielding Limit in mrem/y	200	500	100	100	1200	
Design Occupancy (h/y)	2000	2000	2000	1000	2000	
Normalized Normal Limit (mrem/h/W)	0.1/0.013 = 8 ?	0.25/0.006 = 42	0.05/0.0006 = 83	0.1/0.002 =50	0.6/0.055 =11?	
Skyshine Limit (mrem/y)	10	10	Public 5 Worker 25	Public 1 Worker 10	Public 5	7200 h/y Public
Abnormal						
Abnormal Limits **Q2b, Q2c**	40 mrem for 500 J	308W / 4m 2 pulses D=10.7 rem/h	16 mrem for 493 J	Pa - 0.4 rem/h Pm - 25 rem/h	10 mrem for 3840 J	Abnormal 50 mrem per event
Normalized Abnormal Limit (mrem/h/W)	288	10700/308*3 = 100	117	80 for Pa & 570 for Pm	10?	
Calculation Method						
Target for Beam Loss in Ring **Q2d**	Thick	Thick/Thin	Thick	Thick/Thin	Thick	Shielding calculation
Analytic Tools **Q2d**	SHIELD11	IAEA188 DESY - thin		SHIELD11	IAEA188	
Monte Carlo Tools **Q2d**	EGS4	EGS4		FLUKA Thin target	EGS4	

1) The parameter Pr (averaged power of uniform beam loss around ring) allows the initial estimation of ring shielding thickness. Ps=SxFx1000/(24x3600), Pr=Ps/(ηxR), where S is stored energy in J, F is number of fresh injection per day, η is the design injection efficiency, and R is ring circumference in m. The values of S, F, η and R are given in Tables 1 and 2. For example, SSRL has a loss of $2.43x10^{12}$, 3-GeV stored electrons (i.e., S = 1200 J) around the ring (R = 234 m) over the 12-hour storage period (i.e., F = 2) with a η = 0.75.

2) Analyzed by SSRL physicists. The equivalent loss of 0.3 mW/m is higher than that in Note 1, because it includes 1-month start-up and machine physics programs, in addition to science program.

Table 4. Parameters for storage ring shielding.

Parameter	ALS	APS	NSLS	SSRL	SPring8	Note
Chamber Wall	Al	Al, Cu		0.7-cm Cu	Al	
Bend Magnet Opening Direction	C-shape User Side	C-shape Inner Side	C-shape User Side	C-shape User Side	C-shape User Side	
Local Shield near Ring Chamber	Note 2	None	Local shielding provided as needed	2" Fe beside Apertures	None	
Lateral Wall Thickness (cm)	46 (Note 2)	56x3.7/2.35 = 88 (Note 3)	46	61 (Note 4)	100 (Note 5)	Concrete 2.35 g/cm^3
Distance from Ring to Wall (cm)	100	100	100	100	100	
Roof Thickness (cm)	30	100	30	30	100	Concrete
Distance from Ring to Roof (cm)	100	150	100	100	200	
Ratchet Wall Thickness (cm)	46 cm Conc. + 7.6 cm Pb	80x3.7/2.35 =126	69	91 or 61 + 1" Pb	80	Concrete
Shadow Walls **Q2e**	20 cm Pb around pipe near hole	20 cm Pb Girder Shield	20 cm Pb	15 cm Pb + 15 cm PE	30 cm Fe around pipe near hole	Note 6
Design Criteria	Same as Ring	Same as ring		Same as ring	Same as ring	Note 6
Beamline Hole in Ratchet Wall	15 cm Pb + 30 cm PE	30 cm Pb	20 cm Pb	30 cm Pb + 15 cm PE	60 cm Pb + 20 cm PE	

1) The lateral wall is the outer lateral wall on the user side, unless otherwise stated.
2) For ALS, the first 1/3 section of the ring (injection section) has 5-cm Pb and 60-cm concrete for lateral wall, 10-cm Pb and 60-cm concrete for ratchet wall, and 45-cm concrete roof. For the other 2/3 section of ring, the 46-cm-thick ratchet wall has 7.6-cm Pb wall, and no lead on 46-cm-thick lateral wall. In addition, there is a lead belt (7.6 cm thick and 23 cm high) on every ratchet wall at the beam height around the whole ring for 0-degree bremsstrahlung. For thin target bremsstrahlung, no self-shielding credit is taken for beamline components. The shadow wall is placed near the hole to provide 20-cm Pb attenuation.
3) For APS, high density concrete (HDC) with a density of 3.7 g/cm^3 was used and the equivalent thickness of normal concrete was shown in the table. The lateral wall is 160 cm in injection section (20% injection loss) and decreases to 110 cm concrete for the first 3 IDs, which have high losses.
4) For SSRL, injection septum, stored beam dump, and ring stoppers are high normal beam loss points (which have thick local metal shields). The injection section (kicker region) has 122-cm-thick outer lateral wall and 61-cm roof.
5) For SPring8, in 200-m injection section, the lateral wall is 165 cm thick, ratchet wall is 80 cm, roof is 165 cm. 10-cm Pb collimator placed in beginning of frontend to cover the solid angle of ratchet wall.
6) Purpose of shadow wall (a term used at SSRL) is mainly to block radiation (from beam losses in the ring and frontend) from passing through the beampipe hole in ratchet wall.

Table 5. Parameters for experimental floor outside storage ring.

Parameter	ALS	APS	NSLS	SSRL	SPring8	Note
Area Classification	RCA	None	None	None	RCA	
User Control	GERT no TLD	GERT no TLD	Gert No TLD	None	GERT GLD	On floor
Roof Access Control	Fenced off No lock	GERT TLD	GERT - posted	Fenced off With lock	None	
Area TLD	Month/ring Quarterly& Annual/Wall		Quarterly	Half-year	Monthly	

Table 6. Safety design criteria for SR beamline frontends.

	ALS	APS	NSLS	SSRL	SPring8	Note
Injection Beam Loss in Frontend	Yes	No		Yes (Note 2)	No	A credible event?
Stored Beam Loss in Frontend	No	No	No	No	No	Not a credible event
Injection Stopper (IS) **Q1d**	1 (18 cm W)	2 SS (each 20 cm W)	1 (20 cm Pb)	2 (each 18 cm Pb or 12 cm W)	MBS (40 cm W)	In fronend Closed for Injection
Design Criteria For IS (Dose Limit)	GB on MM (0.1 mrem/h) Pi on MM (40 mrem per injection period)	GB on 2nd SS (0.25 mrem/h)	Brems. (from a **full** stored beam loss in ring) hitting stopper (1 mrem)	GB on MM (0.1 mrem/h) Pa on MM (0.4 rem/h) Pa on 2nd IS (25 rem/h)	Brems. (from **normal** stored beam loss in ring) hitting stopper (0.6 mrem/h)	MM: Movable Mask for SR protection of IS
IS Failure Analysis **Q1f**	No (not credible)	Yes (1st IS fails)	No	Yes (1st IS fails)	No	Note 1
Microswitches	2 In / 2 Out	2 In / 2 Out	2 In	2 In / 2 Out	2 In / 2 Out	Per device

1) Failure analysis means that the abnormal case when one of the interlocked devices (like IS) fails has been considered in the estimation of required device size and location.
2) At SSRL, the injection beam loss in frontend is considered credible but with a lower probability than beam loss in ring. Thus, mis-steered beam loss in frontend has a higher limit at 1200 mrem/h.

Table 7. Safety design criteria for SR beamlines (the worst cases).

	ALS	APS	NSLS	SSRL	SPring8	Note
Hutch Shutter (HS)						
ID White Line **Q1e**	1 (same as IS)	2 (18 cm W or 30 cm Pb each)	1 20 cm lead	Two (total 10" Pb or 7" W)	MBS	User control
ID Mono Line **Q1e**		6 cm W mono/pink	BSS – Xray 1 (for VUV monochro. lines only)		10-cm Pb (30x30 cm)	User control
Bend White Line **Q1e**	1 (same as IS)	Same as ID	BSS – Xray 1 (for VUV monochro. lines only)	Two (total 7" Pb or 5" W)	10-cm Pb (30x30 cm)	
Bend Mono Line **Q1e**		2.1 cm W mono/pink				
VUV Line	1	None	None	2 SS Valves	1	
Failure Analysis **Q1f**	Not credible	No	No	Yes	No	
Design Criteria for HS						
Design Limit (mrem/h) **Q3c**		0.25 contact		0.05 for GB 0.05 for SR	0.6	
Occupancy	2000 h/y	2000 h/y		1000 h/y	2000	
X-ray HS **Q1e, Q3c**	GB/SR	GB/SR	GB on HS SR on HS	GB on HS SR on HS	SR	GB dictates
VUV HS	SR	Reflected SR		Mirror-scattered SR	SR	SR dictates
Beamline Protection Devices						
White Light Beam Stop & BTM **Q1g**	Yes No BTM	Cooled Cu and 18 cm W	Yes No BTM	Yes BTM	Cooled Cu & 10-cm Pb	BTM: Burn Through Monitor

Table 8. Shielding design for SR beamlines (SR aspects)

Stored Beam	ALS	APS	NSLS	SSRL	SPring8	Note
Energy, E(GeV)	1.9	7	2.8	3.0	8.0	
Current, I (A)	0.8	0.1	0.28	0.5	0.1	
Bend White-Light Hutch or Beampipe						
Magnetic Field, B (T)	1.35 Super - 5.0	0.6	1.36	1.3	0.68	
Bend Length (m)		3.06	2.7	1.45		
Bend Radius (m)	4.69 Super – 1.27	39	6.86	7.7	39.27	
Critical Energy $= 0.665\ B\ E^2$ (keV)	3.25 Super - 12	19.5	7.1	7.8	28.9	
SR Power $= 4.22\ B\ E^3\ I$ (W/mradH)	31 Super. - 116	87	35	74	147	Note 1
Fan (mradH)	3?		30	20	1.6	
Distance to Side Wall	30 cm	150 cm	100 cm	100 cm	60 cm	
White Light Hutch Side Wall Shield	2 mm SS (3 mm SS + 5 mm Pb)	S 8 mm Pb R 6 mm Pb	3 mm SS + 3 mm Pb	5 mm SS + 4.5 mm Pb	10 mm Pb, 3 mm Pb around 1st optic element	
Calculation Condition **Q3e**	PHOTON SR on Si	SR dictates Al (0.5 cm Z 0.5 cm R) STAC8	PHOTON SR on Al	SR from 0.2-deg Inclined Si mirror (or perp. Cu)	SR hits Cu 1-cm Z 1-cm R Perpend.	Worst case
Distance to Back Wall				200 cm	175 cm	
White Light Hutch Back Wall Shield		9 (24) mm Pb		8.5 mm Pb	40 mm Pb, 10 mm Pb around 1st optic element	
Calculation Condition **Q3e**		GB dictates Cu (4x4x3 cm) Frank/EGS4	SR from Al plate	SR from 0.2-deg Inclined Si mirror (or perp. Cu)	SR hits Cu 1-cm radius 1-cm thick Perp.	Worst case

1) B is peak magnetic field in Tesla, E is energy in GeV, I is current in Amp, N is number of pole.
2) ALS uses 800 mA, instead of 400 mA, for calculations related to GB and SR.
3) S: side wall, R: roof, B: back wall. Number inside parenthesis is the shield covering a local area over the back wall on beam axis.

	ALS	APS	NSLS	SSRL	SPring8	Note
Wiggler ID White-Light Hutch or Beampipe (highest critical energy and power)						
Magnetic Field, B (T)	2.1	1	5	2	1.0	
# of Pole, N	38	56		26	74	
Critical Energy = 0.665 B E^2 (keV)	5.0	32.6	26 (Operation limited to 22 keV)	12	42.6	
SR Power = 4.22 B E^3 I N (W/mradH)	1850	8100	322	2962	15989	
Fan (mradH)	5		41	5	1.1	
Distance to Side Wall	30 cm?			100 cm	235 cm	
White Light Hutch Side Wall Shield	Mono only 3mm SS??	S 16 mm Pb R 12 mm Pb	6 mm SS + 6 mm Pb	5 mm SS + 7.5 mm Pb	15 mm Pb, 15 mm Pb around 1st optic element	Note 3
Calculation Condition **Q3e**	PHOTON SR on Si	SR dictates Al (0.5 cm Z 0.5 cm R) STAC8	SR from Al plate	SR from 0.2-deg Inclined Si mirror (or perp. Cu)	SR hits Cu 1-cm radius 1-cm thick Perp.	Worst case
Distance to Back Wall				800 cm	400 cm	
White Light Hutch Back Wall Shield		50 (100) mm Pb		13 mm Pb	40 mm Pb, 45 mm Pb around 1st optic element	
Calculation Condition **Q3e**		GB dictates Cu (4x4x3 cm) Frank/EGS4		SR from 0.2-deg Inclined Si mirror (or perp. Cu)	SR hits Cu 1-cm radius 1-cm thick Perp.	

	ALS	APS	NSLS	SSRL	SPring8	Note
Wiggler Pink-Light Hutch or Beampipe (highest critical energy and power)						
Distance to Wall	30 cm?			100 cm		
Pink Light Hutch Wall Shield	Mono only 3mm SS??	S 10 mm Pb R 6 mm Pb B 12 mm Pb		S 4.8 mm Pb R B d = 1 m		Note 3
Calculation Condition **Q3e**	PHOTON SR on Si	Specular Reflected SR Al (0.5 cm Z 0.5 cm R)		SR from Inclined Si mirror	Specular Reflected SR	Worst case
Wiggler Mono-light Hutch or Beampipe						
Mono Hutch Wall Shield	3mm SS	S 10 mm Pb R 6 mm Pb B 12 mm Pb Same as pink	3 mm SS	S 4.8 mm Pb R xx B xx		Note 3
Calculation Condition **Q3f**	PHOTON SR on Si	Mono SR Al (0.5 cm Z 0.5 cm R)		Scattered SR	Mono light 3rd harmonic	
VUV Beampipe						
Beam Shutter						
Calculation Condition		Specular Reflected SR Al (0.5 cm Z 0.5 cm R)		Scattered SR	Scattered SR	
VUV Beampipe Shield				Beampipe or Collimator	Beampipe or Collimator	
Calculation Condition **Q3g**				Scattered SR	Compton & Specular SR from STAC8 & G33-CG	
Design and Calculation Methods						
Which Dictates Hutch Side Wall	SR	SR	SR	SR	SR	SR or GB
Analytic Code Used	PHOTON STAC8	STAC8	PHOTON	STAC8 PHOTON	STAC8 G33-CG	
MC Code Used	None	None		FLUKA	EGS4	
Ray Trace	Yes			Yes		

Table 9. Shielding design for SR beamlines (GB aspects for ID beamlines)

	ALS	APS	NSLS	SSRL	SPring8	Note
Longest Straight Section, L(m)	6	15	5	6	19 m 40 (max)	For GB dose cal.
Vacuum Pressure Design, Pv (ntorr)	1	1	1	1	1	
Vacuum Pressure Actual (ntorr)	0.5	1	3	0.5	0.1	
GB Power (mW) $P_{GB} = P_s f$	0.039	0.046	0.016	0.039	0.064	1 µPa = 7.52 ntorr
Ray Trace Study	Yes	Yes	Yes	Yes	Yes	
0-degree GB (Q3c)						
Unshielded Photon Dose Rate (rem/h)		Frank		338 (Ferrari)		HS & GB beamdump calculation
Dose Scoring Region		1x1x1 cm tissue		Maximum	Maximum	
Tools	NIM A292 (1990) 700-705	4x4x3 cm Cu Frank/EGS4		Tromba Ferrari FLUKA	EGS4 Analytic Ban	
GB Beamstop	25 cm Pb, 2" overlap	18 cm W or 30 cm Pb	20 cm Pb	25 cm Pb, 2" overlap	30x30x30 cm Pb	End of BL 0-degree
Forward-scattered GB (Q3d)						
Dose Rate at 1 m Photon (mrem/h) Neutron (mrem/h)	Not calculated			70 0.01		
Target		4x4x3 cm Cu or inclined Si		0.2-deg. Inclined Si, (Thick Cu)		
Tools		Frank/EGS4		FLUKA		
Shield		If Cu, 2" Pb (4" Pb center)		4" Pb		
Lateral-scattered GB (Q3e)						
Dose Rate at 1 m Photon (mrem/h) Neutron (mrem/h)	10 no estimate		---	0.03 < 0.01	0.12	
Target	Cu	4x4x3 cm Cu or inclined Si	---	0.2-deg. Inclined Si, (Thick Cu)	Cu 1-cm R&Z	Worst case
Tools	Analytic ?	Frank/EGS4	---	FLUKA	EGS4 PICA	
Local shield	Exclusion Zone	15 cm PE	---	2" Pb	None	Beside Target
Target Shielded	ID first optic by measu.	By measu.	---	Mask, Not mirror	---	

1) f is the ratio of air path of straight section (LPv) to air's radiation length (36.818 g/cm^2), which is equal to the fraction of stored beam power, Ps, transfers to the gas bremsstrahlung.
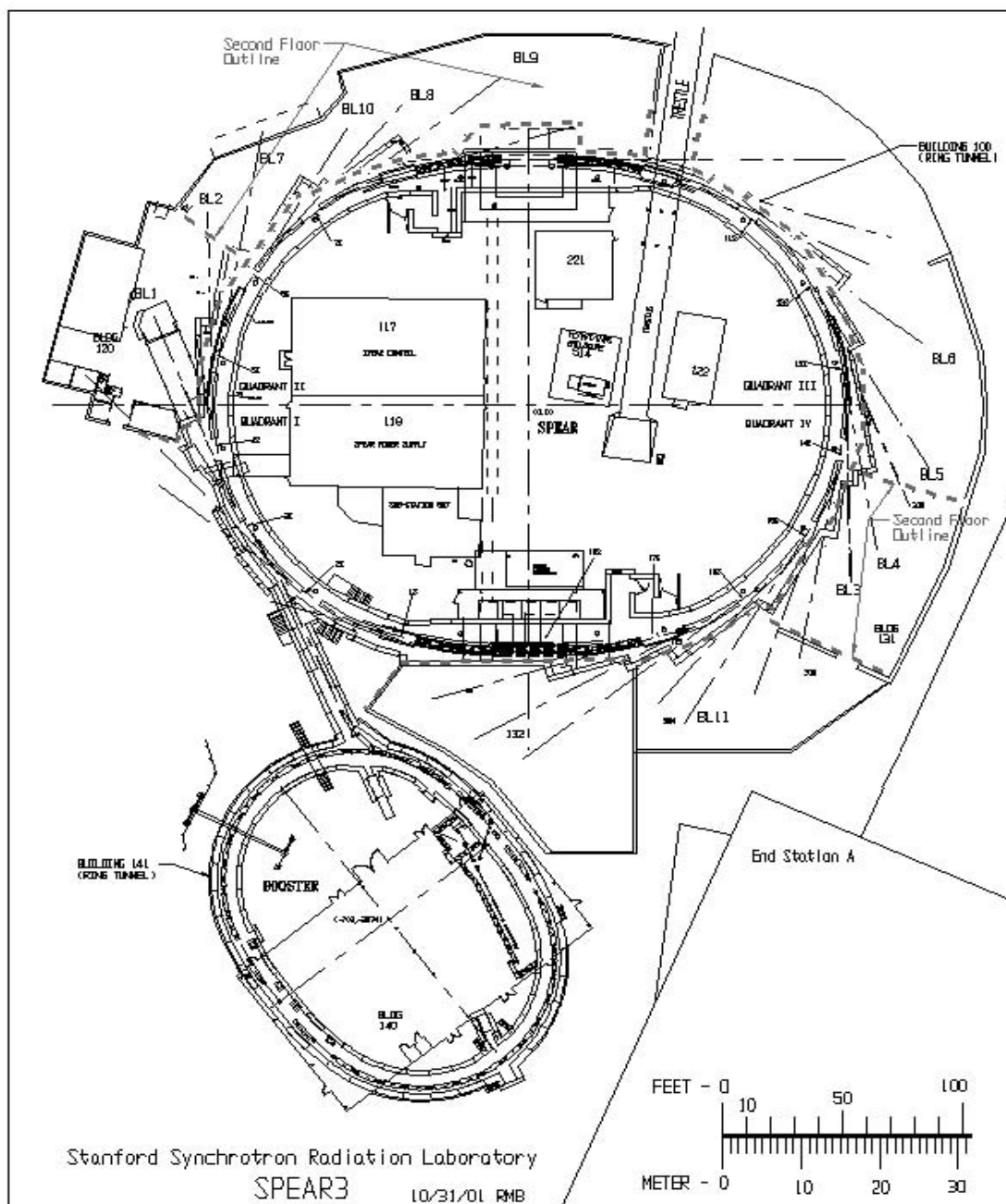
2) ALS uses 800 mA, instead of 400 mA, for calculations related to GB and SR.

Table 10. Radiation monitors around storage ring and SR beamlines.

	ALS	APS	NSLS	SSRL	SPring8	Note
Radiation Monitor						
Radiation Monitor Outside Ring, **Q4a**	HPI 12 n/γ	NRC610 24 n/γ 1 per 46 m	NSLS IC 24 n/γ 1 per 7 m	SLAC TEIC 17 n/γ 1 per 14 m	Fuji 5 n/γ 1 per quadrant, 1 for injection	
Warn/Trip Points (mrem/h)	5/10	5/10	2.5/20	5/10	0.6/none	
Keep-alive Source	None	n/γ sources	γ source	γ source	None	
Beam Loss Monitor inside Ring **Q4b**	None	None	None	LIONs	None	
Warn/Trip Points (mrem/h)	---	---	---	< 5	5/none	
Radiation Monitor at Beamlines **Q4c**	IC on first optical element	None	IC on ID first optical element (alarms at 2 and 20 mrem/h)	None	None	

Table 11. Measured dose rates around storage ring and SR beamlines.

	ALS	APS	NSLS	SSRL	SPring8	Note
Dose Rate outside Wall during Injection (mrem/h)	< 0.1		< 1 (isolated spots < 5 mrem/hr)	<1	< 0.1	
Dose Rate on Roof during Injection (mrem/h)	5-10		< 1, (isolated spots < 5)	<5	< 0.1	
Stored Beam Dose Rate around SR Beamline (mrem/h)	< 0.1		< 0.1	< 0.05	< 0.1	
Annual Area TLD Dose (mrem/2000 h)	< 100		< 100	<30		

Figure 1a. The SSRL layout, showing the injector (10-Hz, 150-MeV Linac and 3-GeV Booster), 234-m-circumference, 3-GeV SPEAR3 ring, and synchrotron radiation beamlines, as well as the building contour around the outer rim of the ring and the SSRL 2nd floor offices (red dashed line).

SPEAR Annual Normal Beam Loss Channels
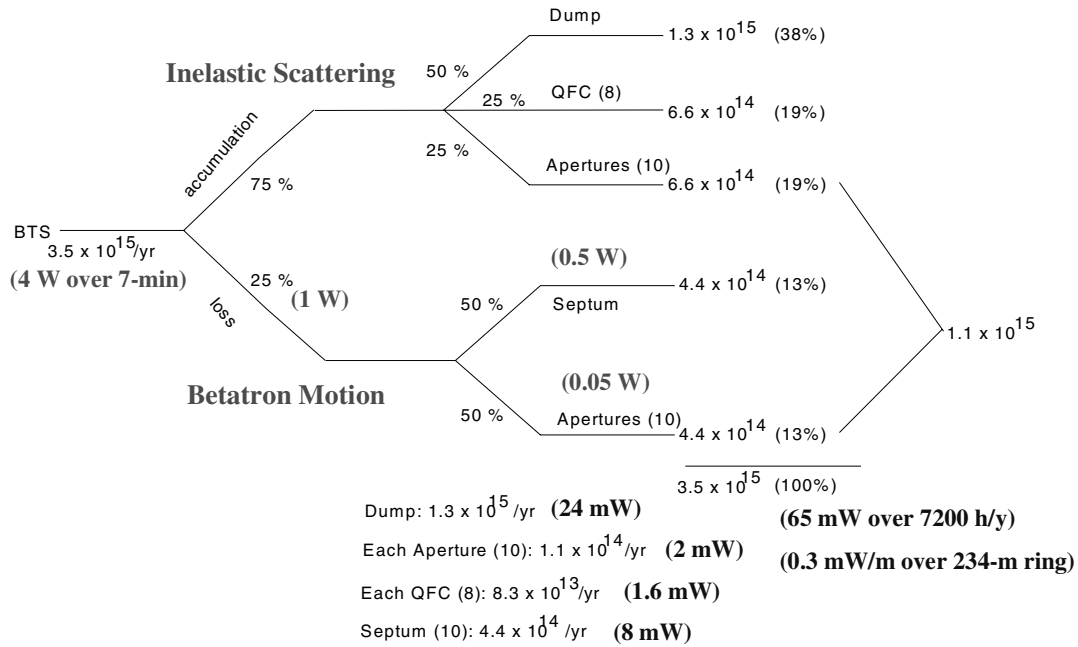
Figure 1b. Annual normal beam loss estimates for SPEAR3 storage ring operation including a 1-month start-up prior to a 10-month scientific program. The 3-GeV electron beam is injected into the ring at 8.3×10^9 s^{-1} (1.33 nA, 10 Hz, 4 W). Total electron injected into the ring is 3.5×10^{15} e/y. At an injection efficiency of 75%, 25% of the injected beam (*i.e.*, 1 W) is lost during the injection period and the remaining 75% is stored (but this is slowly lost within a day). 50% of the electrons lost during injection (*i.e.*, 0.5 W) will hit injection septum, while the remaining 50% loss is equally lost across ten limiting apertures (each 0.05 W). 50% of the stored beam loss is at the stored beam dump, 25% at the eight focusing quadrupole (QFC), and 25% at the above-mentioned ten limiting apertures. Averaged over a year (1.7×10^6 J over 7200 h), the power loss rate is 24 mW at stored beam dump, 11 mW at injection septum, and 2 mW at each of remaining 16 limiting apertures. If the limiting apertures were not identified and the loss was assumed to be uniform over the 234-m ring circumference, the average loss rate would then be 0.3 mW/m.
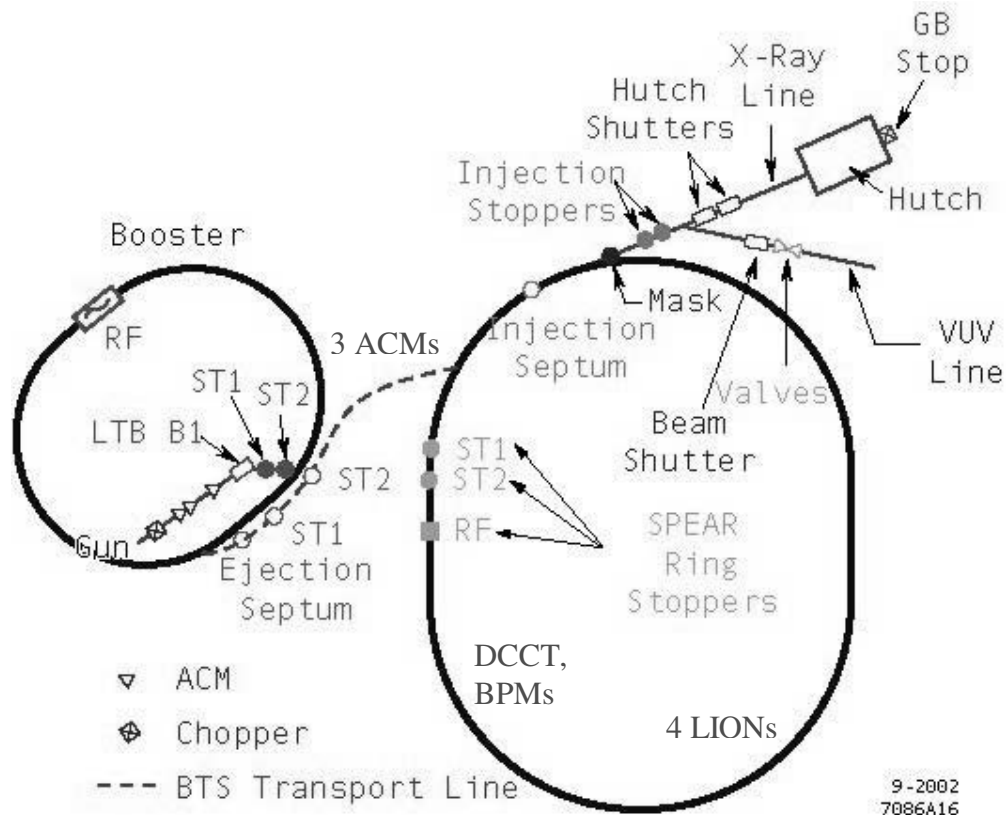
Figure 1c. Three average current monitors (ACM) in Linac to limit beam current to allowed beam power (Pa). Beam stopper systems at SSRL to keep the downstream area safe. For example, there are ejection septum and 2 mechanical stoppers (ST1 and ST2) in Booster-to-SPEAR transport line to stop injection into ring. There are 18ST1, 18ST2, and ring RF to kill stored beam. There are 1 movable mask and 2 injection stoppers inserted in the SR beamline frontend during ring injection. There are 2 hutch shutters before a hutch to block gas bremsstrahlung and SR.
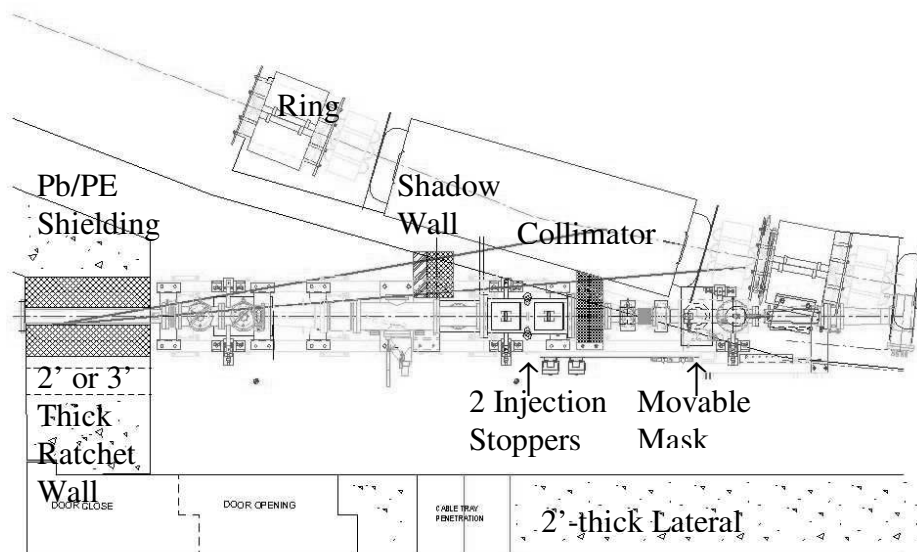
Figure 1d. Typical frontend for a SSRL synchrotron radiation beamline, showing five radiation safety items, in addition to the 2'-thick lateral concrete wall and 2'-3' ratchet concrete wall.

General Double Hutch HPS Schematic
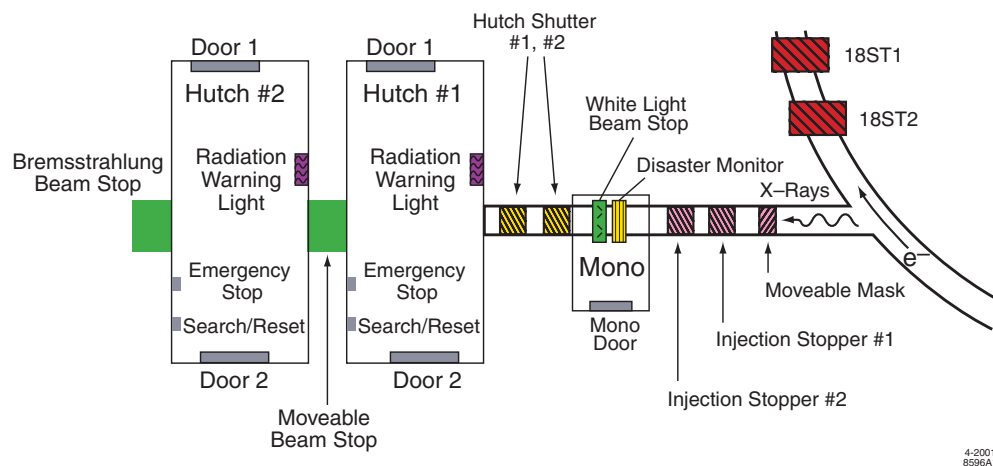
Figure 1e. Main radiation safety items in a SSRL x-ray beamline.
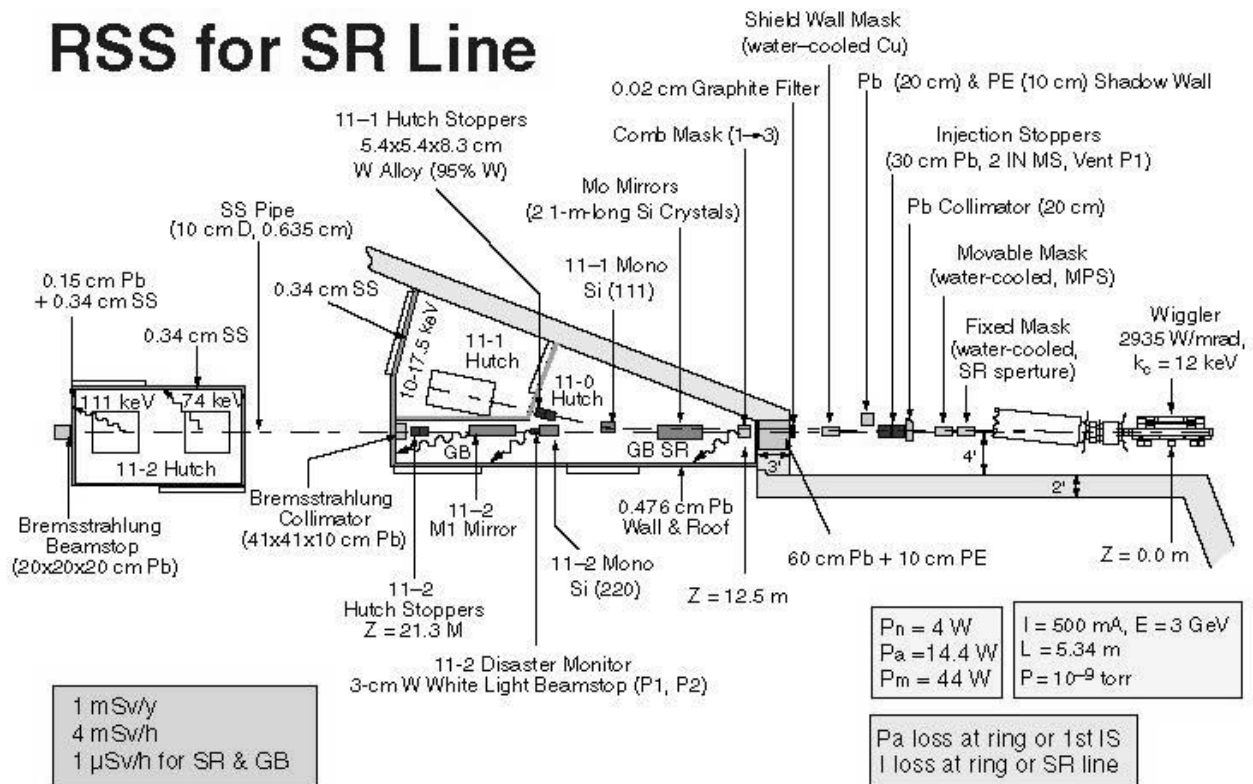
Figure 1f. Radiation safety considerations and safety items for a SR wiggler beamline at SSRL.
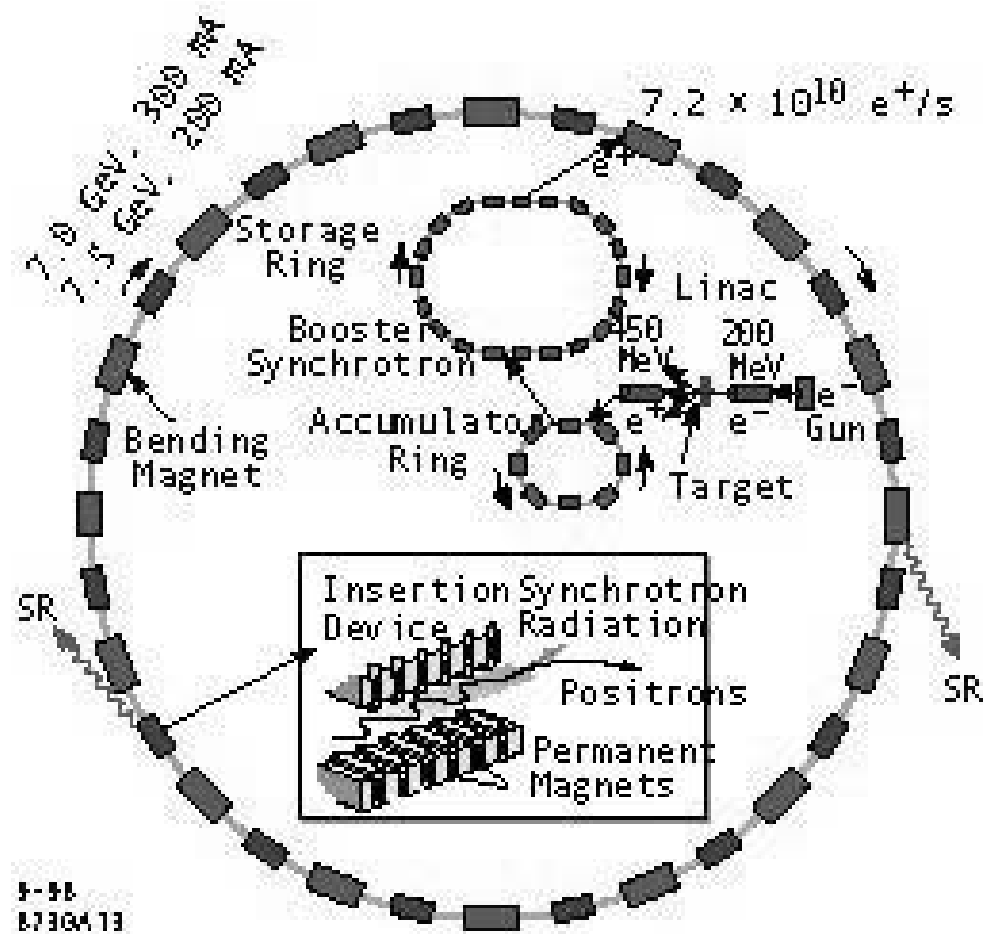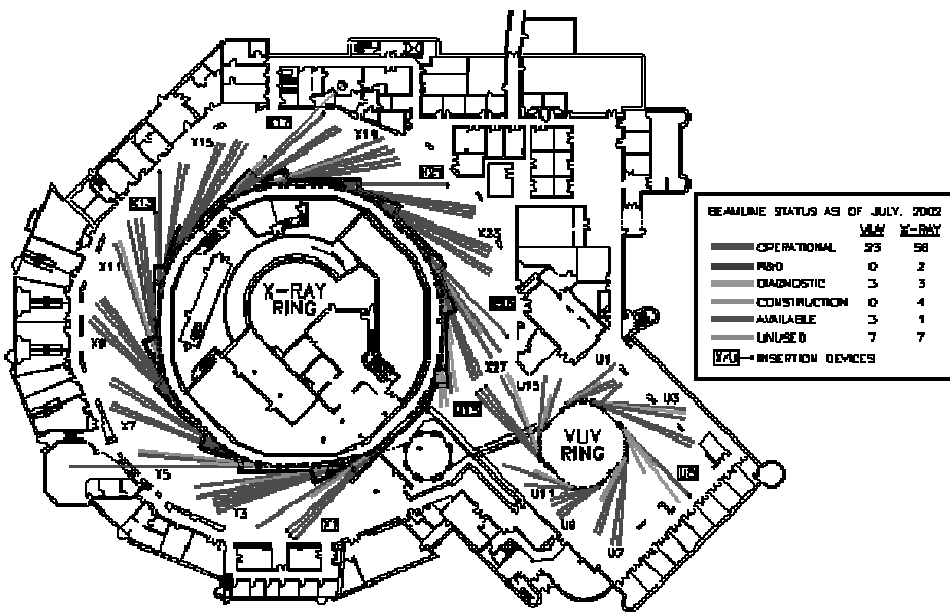
Figure 2a. APS facility.
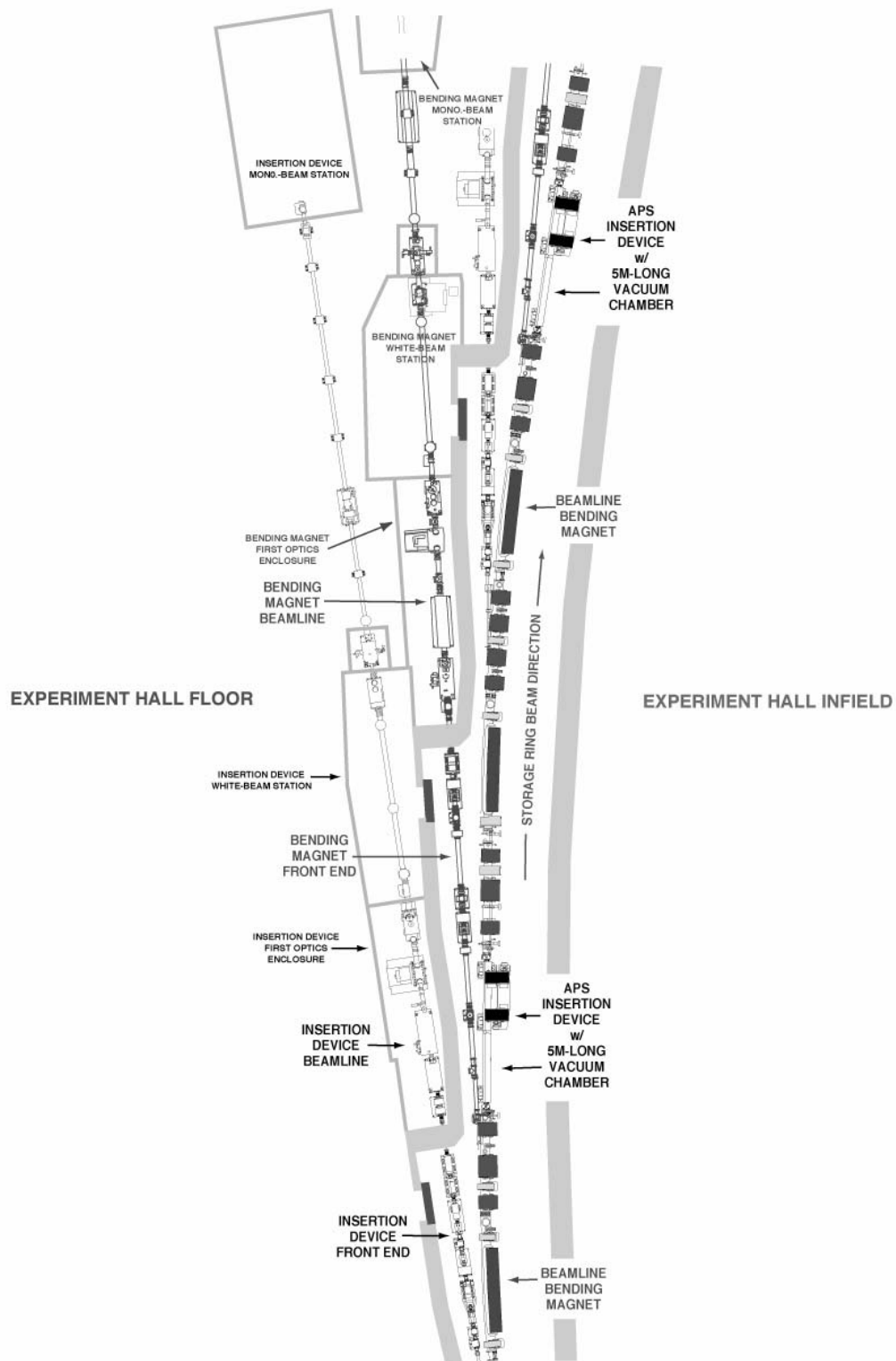
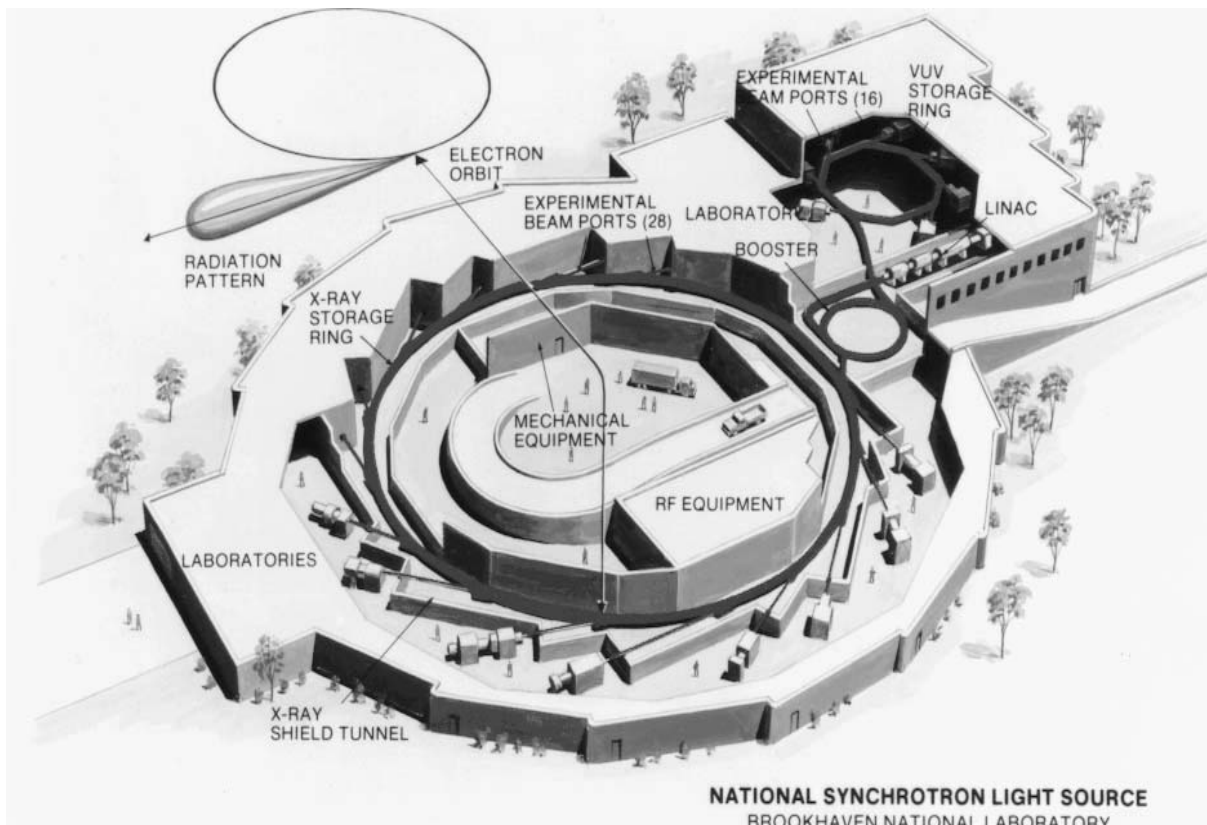Figure 2b. APS ring sections and frontends.

APS Insertion Device Front End Components
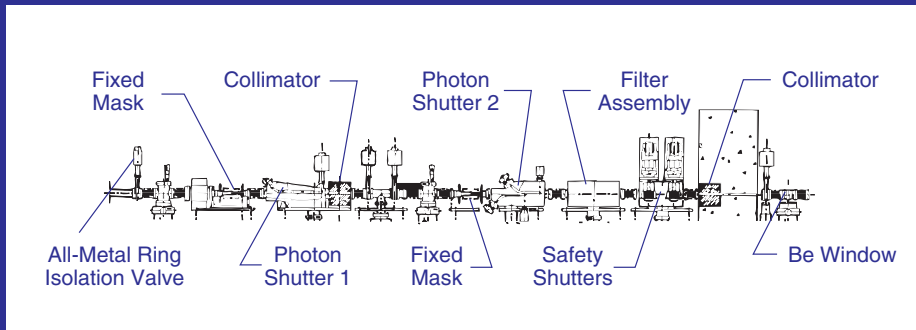
Figure 2c. APS frontend components.

Error!

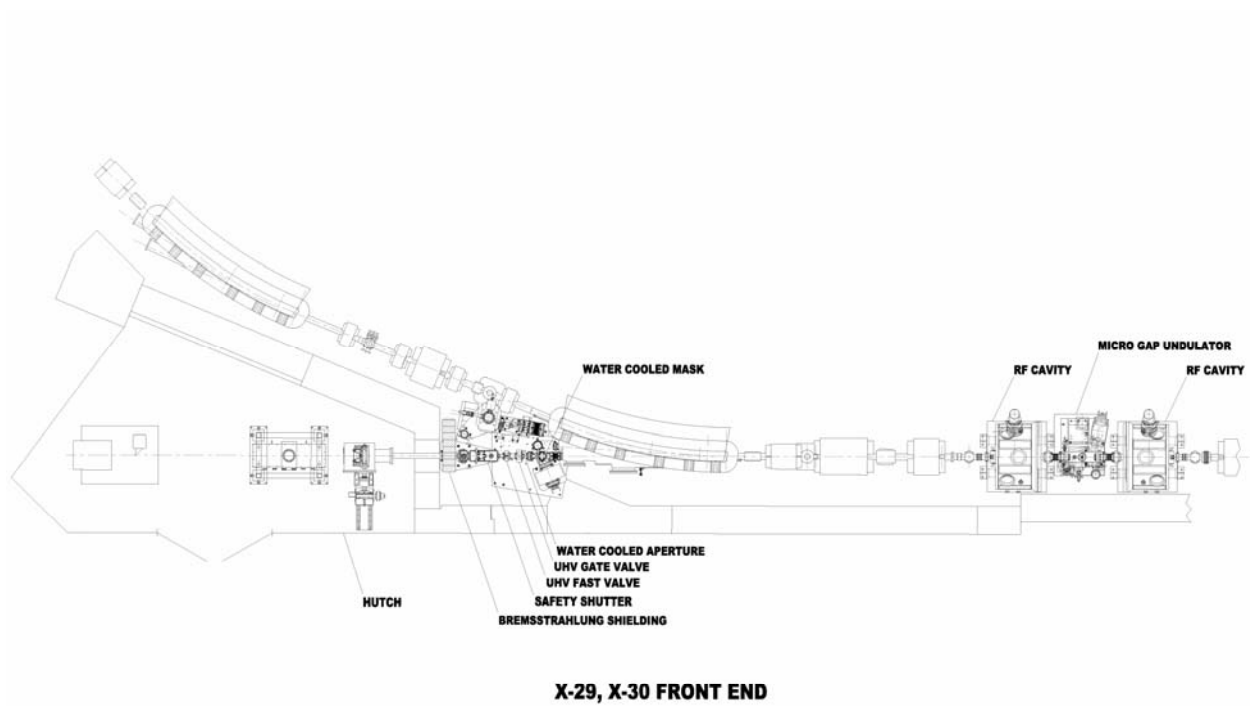NATIONAL SYNCHROTRON LIGHT SOURCE
BROOKHAVEN NATIONAL LABORATORY
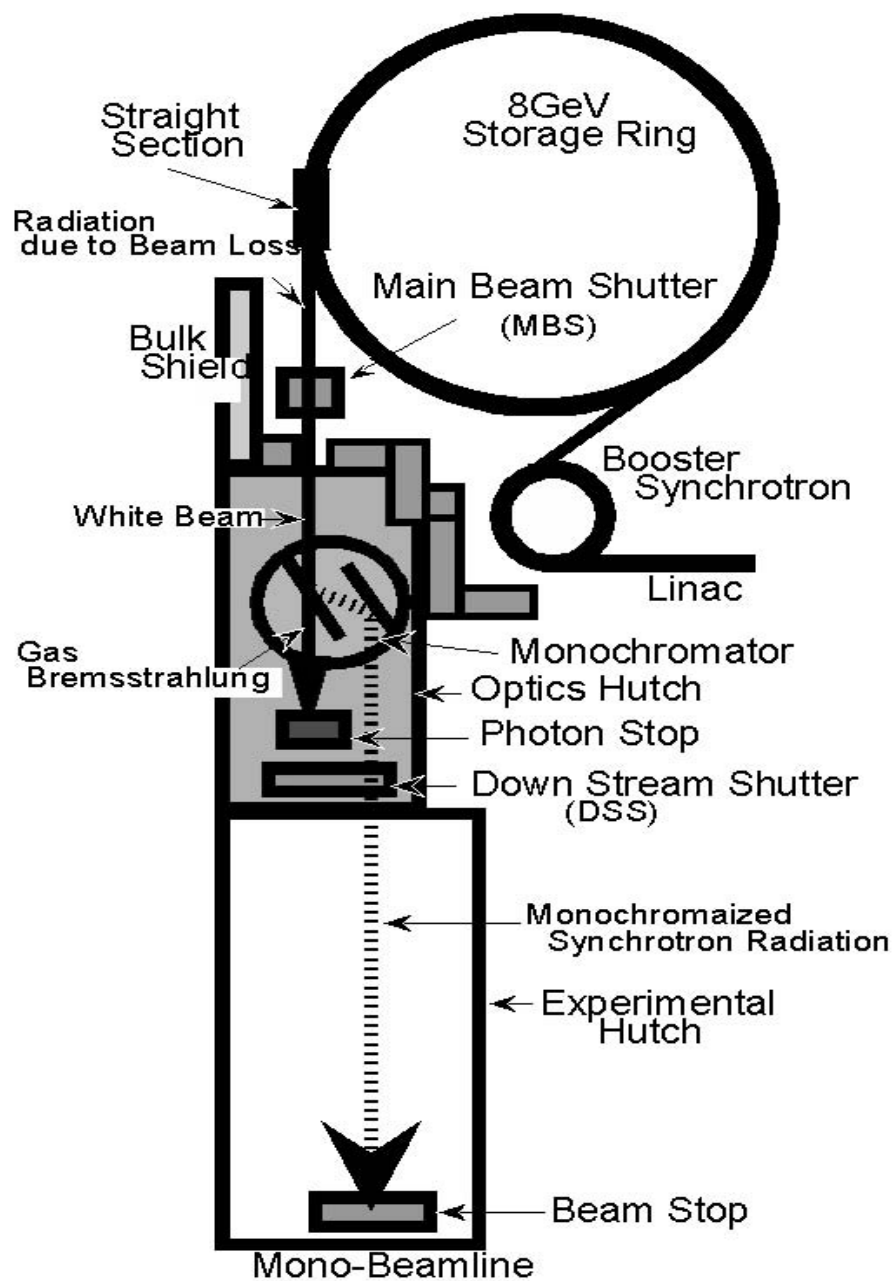
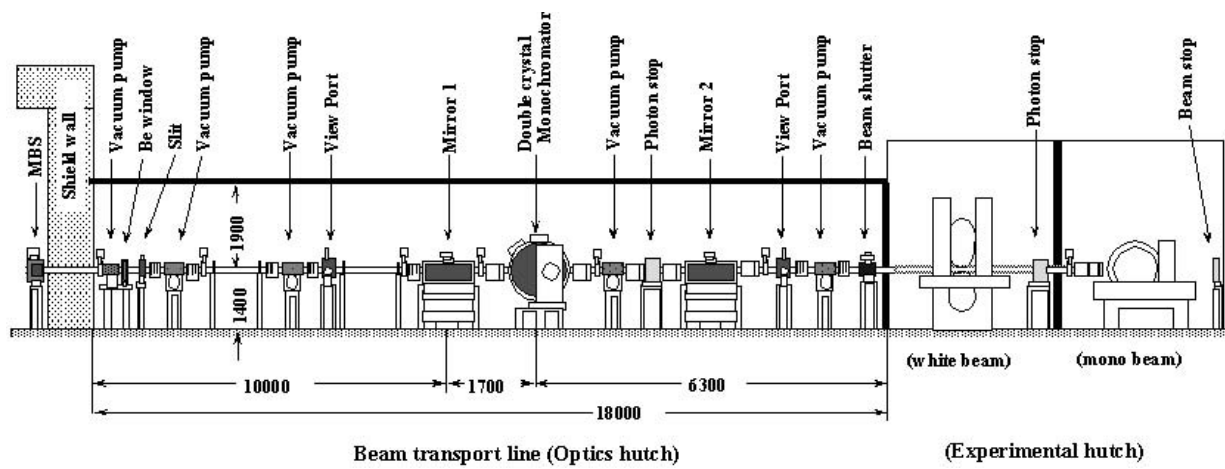Figure 4b. NSLS frontend and beamline.

Figure 5a. SPring8 accelerator facility and beamline.

Figure 5b. Spring8 beamline.