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Radiation safety design for SSRL storage ring

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Abstract

In 2003, the Stanford Synchrotron Radiation Laboratory (SSRL) has upgraded its storage ring to a 3rd generation storage ring (SPEAR3). SPEAR3 is deigned to operate at 500 mA stored beam current and 3 GeV energy. The 234-meter circumference SPEAR3 ring utilizes 60-cm-thick concrete lateral walls, 30-cm-thick concrete roof, as well as 60-cm or 90-cm-thick concrete ratchet walls. A total of 3.5×10^{15} e^-/y will be injected into the ring with an injection power of 4 W and an injection efficiency of 75%. Normal beam losses occur due to both injection and stored beam operations in the total of 20 low loss as well as 3 high loss limiting apertures. During the 6-minutes injection period, an instantaneous power loss of 0.05 W occurs at each low loss aperture. When averaged over the operational year, the loss of both the injection and stored beams is equivalent to an average loss of 2 mW at each low loss aperture. On the other hand, the average losses in the high loss apertures are 16 mW for the injection septum, 47 mW for the beam abort dump, and 13 mW for the ring stoppers. The shielding requirements for losses in the new ring were based on a generic approach that used both FLUKA Monte Carlo particle generation and transport code and empirical computer codes and formulae.

Keywords: SPEAR3; synchrotron radiation; storage ring design

1. Introduction

In 2003, SSRL (Stanford Synchrotron Radiation Laboratory) upgraded its storage ring to SPEAR3 (3 GeV and 500 mA), a 3rd generation storage ring. SSRL is a division of SLAC (Stanford Linear Accelerator Center) and, thus, the SLAC safety policies and practices apply to SPEAR3 design. The 234-m-circumference SPEAR3 ring

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inherited the existing SPEAR2 concrete ring walls and roof (60-cm-thick lateral wall, 30-cm-thick roof, as well as 60-cm or 90-cm-thick ratchet wall; at the injection section, the outer lateral wall is 120-cm-thick and the roof is 60-cm-thick). Currently there are 16 ratchet walls with 11 operating main beamlines around the outer ring wall.

SPEAR3 has a thin copper antechamber vacuum chamber design and 36 C-shaped gradient dipoles (opening toward the outer lateral wall), instead of the H-shaped bends for SPEAR2 (3 GeV and 100 mA). There are three normal high loss apertures (septum, stored beam abort dump and ring stoppers) and 20 low loss apertures (8-high dispersion quadrupoles, 7 insertion devices, 2 synchrotron masks, and 3 injection kickers) around the ring. It is expected that these apertures will have local shielding to accommodate the increase of stored current. During SPEAR3 operation, the stored beam current will be increased from 100 mA (SPEAR2) to 500 mA. This significant increase in the stored beam current requires reexamining the shielding of all normal beam loss points in the SPEAR3 ring. Radiation shielding calculations were performed to identify the amount of shielding required under the assumption of SPEAR3 beam loss conditions. The radiation dose limits for the different beam loss conditions are listed in Table 1. The normal beam loss is based on available information regarding future SPEAR3 operation (Corbett, J. et al., 2001). During mis-steering conditions, the maximum injected beam power allowed by the Average Current Monitors (ACMs) in the Booster To SPEAR (BTS) line is 5 W. On the other hand, during a system failure (failure of the ACMs), the maximum credible beam power is 45 W. As shown in Table 1, normal beam losses dictate the shield design.

In this paper, the following radiation safety design and requirements for the SPEAR3 ring are presented:

1) Beam loss scenarios which includes: a) annual normal beam losses of both the injected and stored beam in all identified apertures in the ring, and b) Mis-steered loss of the Allowed Injection Beam Power of 5 W (P_a) at any point in the ring chamber and frontend components.
2) Shielding design limits at SLAC and the design criteria used for SPEAR3 ring.
3) Shielding requirements for the lateral wall and roof.
4) Generic shielding methodology and requirements for the ratchet wall.

2. Beam loss scenarios

The beam loss scenarios considered in this analysis are summarized as follows:

1) Normal beam losses around the ring during both the injection and stored beam operations (Corbett, J., 2001a). A total of 23 limiting apertures (8 QFCs, 7 insertion devices, 1 SR masks near West Pit, 3 injection kickers, injection septum, stored beam abort dump, and ring stoppers) around the ring were identified as normal beam loss points. Figure 1 shows all limiting apertures in the SPEAR3 ring. The septum, beam abort dump and ring stoppers (used to kill the stored beam) are the three high loss points, while the remaining 20 apertures are low loss points. A total of 3.5×10^{15} e^-/y will be injected into the ring with an injection power of 4 W (3 GeV, 10 Hz) and an estimated injection efficiency of 75%. During the 6-min injection period, an instantaneous power loss of 0.05 W (with an added safety factor of two) occurs at each low loss aperture, as well as at the beam abort dump. On the other hand, injections loss in the septum is 0.5 W and there is no injection loss in the ring stoppers (they remain open during injection). When averaged over a period of 7200 h/y, the annual loss of both the injection and stored beams is equivalent to an average loss of 2 mW at each low loss aperture. The average loss is 47 mW at the beam abort dump, 16 mW (with an added safety factor of 2 to account for uncertainty in the estimated injection efficiency) at the septum, and 13 mW at the ring stoppers.
2) Mis-steered loss of the Allowed Injection Beam Power of 5 W (P_a) at any point in the ring antechamber at a maximum horizontal angle of 1^o (Corbett, J., 2002).
3) Mis-steered loss of power P_a at any point in the frontend section.
4) Loss of the power P_a at a point in the frontend during system failure conditions, e.g., movable mask or an injection stopper fails to be inserted into the beamline during injection.

Figure 2 shows the radiation safety items located in a frontend, consisting of a copper movable mask (MM), a lead/polyethylene (15-cm Pb and 15-cm PE) collimator, two beamline injection stoppers (lead or heavimet) interlocked to be inserted into the beamline with MM during injection, a lead/polyethylene (30-cm Pb and 15-cm PE) shielding in the ratchet wall hole, and the 15-cm Pb and 15-cm PE shadow walls placed at strategic locations near the ring chamber. The shadow walls are primarily used to intercept the secondary radiation generated from beam losses in the ring chamber that may otherwise pass through the beampipe hole in the ratchet wall.

3. Shielding design limits at SLAC and criteria used for SPEAR3 ring

The shielding design limits at SLAC are shown in Table 2. The shielding design limit for normal beam losses is generally 10 mSv/y for Radiologically Controlled areas (RCA) and 1 mSv/y for non-RCA (an occupancy of 2000 h/y is generally assumed). For abnormal beam losses, the limit is 4 mSv/h for mis-steered beam and 0.25 Sv/h for system failure cases. Active devices should be present to detect and terminate abnormal beam losses (except stored beam losses). Based on the SLAC limits and practical considerations for SSRL, the criteria used for SPEAR3 ring shielding design under three types of beam loss scenarios are given in Table 3. The shielding design criterion for normal beam losses is set at 1 mSv per 1000 h, based on a maximum occupancy of 700 h/y for SSRL users on the floor. The shielding design value outside the outer ring wall for a normal beam loss of 2 mW at a low loss aperture is 1 μSv/h. This is equivalent to a Normalized Dose Limit (NDL) of 0.5 mSv/W.h. The corresponding shielding design value outside the inner ring wall (which is occupied infrequently) is 8 mSv per 2000 h (i.e., 4 μSv/h). The design value on top of roof is 30 mSv per 2000 h (average 15 μSv/h). The roof is fenced off and administratively controlled for no access.

For mis-steered beam losses, the limit is raised to 12 mSv/h outside the ring wall (equivalent to a NDL of 2.4 mSv/W.h for 5 W loss at any point in the ring), because of the use of active Beam Containment System (BCS) devices around the ring (e.g., 18 interlocked radiation detectors called Beam Shut Off Ion Chambers (BSOICs) outside the outer ring wall and four Long Ion Chambers (LIONs) inside the ring). Since the roof is to be fenced off, the mis-steered criterion for the roof was set at 30 mSv/h. For the system failure beam losses, the SPEAR3 ring design criterion is 0.25 Sv/h. The Maximum Credible Injection Beam Power (P_m) is 45 W (a system failure of all six ACMs in Linac and the BTS lines). This is equivalent to a NDL of 5.55 mSv/W.h. Therefore, normal beam losses dictate the shielding design.

Currently, there are no SLAC limits for the instantaneous dose rates during the short injection periods. However, the maximum dose rates experienced during SPEAR2 injection periods are less than 10 μSv/h outside the outer lateral wall, 50 μSv/h outside the inner wall, and 150 μSv/h on the roof. The same dose rates were adopted as SPEAR3 design goals during injection. Note that the ratio between injection beam loss and average beam loss at a low loss aperture is 25 (0.05 W over 0.002 W). Thus, when the normal loss design criterion is 1 μSv/h, it is expected that the dose rate during injection outside the outer lateral wall could be ~ 25 μSv/h. In any case, the radiation level during the injection period should be less than 50 μSv/h. Otherwise, Radiation Area (RA) control would be needed.

4. Shielding and safety requirements

The dose calculations were performed using the analytical SHIELD11 code (Nelson, W. and Jenkins, T., 2005) for thick target cases and the FLUKA Monte Carlo code (Fasso, A. et al., 2001) for thin target cases. Since the thin target results could be significantly affected by any change in the estimated low beam loss (2 mW) or the incident beam angle on the thin target (change in the effective thickness of the target (Mao, X. et al., 2000)), a safety factor of three was added to the FLUKA results.

4.1 Shielding of Lateral Wall and Roof

4.1.1 Normal and Abnormal Beam Losses in Ring Chamber

The shielding requirements (Khater, H. et al., 2003), for lateral wall and roof from normal and abnormal beam losses in the ring chamber are summarized in Table 4 (shielding requirements) and Table 5 (dose rates). For example, Table 4 shows that the injection septum is 160-cm, 75-cm, and 100-cm from the inner surface of the 120-cm-thick outer wall, 60-cm-thick inner wall, and 60-cm-thick roof, respectively. The shielding required is 0-cm, 10-cm Fe, and 10-cm Fe on the side of outer wall, inner wall, and roof, respectively. The length of shield should cover 45^o backward of the first beam loss point and 45^o forward of the last beam loss point inside the septum. Table 5 shows that the resulting doses (for 16 mW loss) are 0.4 mSv over 1000 h/y, as well as 2.1 mSv and 4.8 mSv over 2000 h/y, outside the outer wall, inner wall, and roof, respectively. The corresponding mis-steered dose rates (for 5 W loss) at the outer wall, inner wall and roof are 0.12, 0.33, and 0.73 mSv/h, respectively.

Similar to the injection septum, the other two high normal beam loss points (stored beam abort dump and ring stoppers) also need additional shielding. The-highest inner ring dose is due to the beam abort dump (7.95 mSv/2000h). For 2 mW loss at a low loss aperture, Tables 4 and 5 show that 5-cm-thick Fe or 2.5-cm-thick Pb local shield is needed. Based on FLUKA simulations (Khater H. et al., 2004), the length of the local shielding is 30-cm upstream and 60-cm downstream of beam loss point (mid point of a QFC or the beginning and/or the end of an ID).

The height should cover a vertical angle of ± 30^o to the outer lateral wall. Section G4 of the ring is located immediately downstream of the septum. According to experience from SPEAR2 and other SR facilities, this section tends to have more normal beam losses than other ring sections. Therefore, it was assumed that Section G4 has an average normal beam loss of 4 mW.

In addition to normal beam losses in apertures, abnormal beam loss of 5 W could occur at any point in the ring chamber. The worst case is that the 3 GeV injection beam is mis-steered to hit the thin 0.7-cm Cu antechamber wall with a maximum horizontal angle of 1^o (Corbett, J., 2002). Table 5 shows that the mis-steered loss of 5 W resulted in dose rates of 5, 2.85, and 28.5 mSv/h outside the outer wall, inner wall, and roof, respectively. Therefore, no shield for lateral wall and roof is needed for mis-steered beam loss in the ring.

4.1.2 Mis-steered Injection Beam Loss in the Frontend

FLUKA simulations (Liu, J. et al., 2003) with frontend geometries for both bend and ID beamlines (similar to Figure 2) were used to calculate the dose rates outside the lateral wall, ratchet wall, and roof. Table 6 shows that, for 3 GeV electron beam hitting the 2^o-tilted Cu movable mask in an ID beamline, the roof has a maximum dose rate of 55.5 mSv/h at 5 W, which is higher than the limit of 30 mSv/h. The higher than normal dose rate limit was justified by the following 3 arguments: a) the roof is fenced off, b) mis-steered injection beam losses in a frontend are not likely (Corbett, J., 2003), and c) credit for use of active radiation detectors. The corresponding dose rate outside the lateral wall is 10.8 mSv/h.

4.2 Shielding of Ratchet Wall

The radiation of concern outside the ratchet wall is the forward peaked photons and neutrons from beam losses in ring chamber or a frontend component. Generic approach for ratchet wall shielding calculation and requirement has been developed. Implementation of safety requirements is reviewed for every ratchet wall via comprehensive ray trace study.

4.2.1 Normal and Abnormal Beam Losses in Ring Chamber

FLUKA simulation (Liu, J. et al., 2002) of 3 GeV electron hitting a 0.7-cm Cu antechamber wall at 1^o has been performed. The source terms (normalized photon and neutron dose rates in mSv/W.h at 1 m), as well as the associated attenuation lengths in concrete, lead, and polyethylene have been calculated as a function of angle relative to the beam direction. With these pre-calculated data, the dose at any angle and shield thickness can be calculated using the information obtained from the ray trace study. The generic shielding requirements for ratchet wall were developed by studying the two worst geometry cases for 60-cm and 90-cm ratchet walls (i.e., for shortest distance between the ratchet wall and ring source point).

Ray trace studies were performed (Rabedeau, T., 2003) for 16 source points (SA to SK) and 5 dose points outside ratchet walls for the worst in-alcove geometries (OF to OJ). Two heights at a dose point were studied; the ray at median plane (to examine the thickness and width of shadow walls, as well as their locations) and the ray that just skims over the 30-cm-tall shadow wall (to examine the need of lead skirt on top and below every shadow wall). Data sheets using the Excel program (which incorporates the FLUKA calculated source terms and attenuation lengths) were developed to calculate the corresponding dose rates. As an example, Table 7 shows the calculated dose rates outside a 60-cm-thick concrete ratchet wall with 2.5-cm Pb on its inner surface. Note that the source points ID, SE, and SL are normal beam loss points, while the others are mis-steered beam loss points. Some normal loss points generate doses outside ratchet wall that are higher than the limit (NDL = 0.5 mSv/W.h). The 5-cm-thick and 90-cm-long Fe local shielding alongside the aperture, required for normal beam losses, was not considered in these calculations. The actual doses from normal beam losses are acceptable, after the local shield is added (Khater, H. et al., 2003). The mis-steered limit of 2.4 mSv/W.h is met in all cases. Similar analysis was performed for the most critical 90-cm-thick concrete ratchet wall. The ray trace study also showed that there are some self-shielding of ring components, particularly when the ray is off the median plane. Since the self-shielding was not considered in the calculations, the safety factor of 3 for the FLUKA results was not applied in this case.

The ratchet wall shielding requirements are summarized in Table 8. The 90-cm-thick concrete ratchet wall effectively shield against beam losses from the ring. The 60-cm-thick ratchet wall needs an additional 2.5-cm-thick Pb shield. The collimator and shadow walls need to be at least 15-cm Pb and 15-cm-thick PE and 30-cm-tall and their locations should be placed such that all rays from ring chamber to the hole in the ratchet wall are intercepted.

4.2.2 Mis-steered Injection Beam Loss in the Frontend

The FLUKA simulations with frontend geometries of 60-cm and 90-cm ratchet walls (similar to Figure 2), as well as SHIELD11 for-thick target cases, were used to calculate dose rates outside the ratchet wall. Some key dose results are shown in Table 6. Compared with beam losses of 5 W in ring chamber, the beam losses of 5 W in frontend would have demanded an additional 2.5-cm-thick lead wall on the ratchet wall, if the argument of low probability of 5 W loss in frontends was not accepted.

4.2.3 Generic Safety Requirements for Frontend Components

The generic safety requirements for the different frontend components are summarized as follow (Liu, J. et al., 2003):

1) For a minimum distance of 2 m between the front face of an injector stopper and the outer surface of ratchet wall, a stopper-thickness of 12.7-cm heavimet or 17.8-cm lead is needed for 0^o dose.
2) The minimum distance D1 between the first stopper and the 60-cm ratchet wall outer surface is 6.2 m and the minimum distance D2 between the front face of the 2nd injector stopper and the outer surface of 60-cm ratchet wall is 3.1 m. For the 90-cm ratchet wall, the minimum D1 and D2 distances are 3.1 m and 1.8 m, respectively. This assumed no lead wall on the inner surface of ratchet wall.
3) 30-cm Pb and 15-cm PE filling the hole around the beampipe in the ratchet wall is acceptable.
4) Collimator should be at least 15-cm Pb and 15-cm PE and 30-cm-high, same as the shadow wall requirements.

Note that there are five ratchet walls that do not have SR beamlines yet and these beamlines, as well as the unused beam exit points need to be terminated with 10-cm-thick lead (20-cm-wide and 10-cm-high) shielding immediately downstream of the beamline exit point. This is to prevent the beam from hitting and creating a shower in the concrete wall.

Summary

SSRL implemented the required shielding according to the two phases of operation. Prior to the 1.5 W/100 mA operation, all normal high loss apertures (septum, beam abort dump and ring stoppers) shielding are implemented, except the 5-cm-Fe shielding alongside the low loss apertures (e.g., QFC, IDs, SR masks, and kickers), which will be implemented prior to the 5 W/500 mA operation. The maximum annual dose outside the outer lateral wall at locations frequently occupied by users from normal beam losses at any aperture is 0.5 mSv over

1000 hours. This is to be considered together with the doses from beamline operation, which also has a design criterion of 1 mSv per 1000 h. Finally, the dose rate on the experimental floor during normal injection is 10 μSv/h.

Acknowledgements

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Figure Captions

Figure 1. Location of physical limiting apertures (loss points) in SPEAR3 ring.

Figure 2. A typical frontend for a SSRL synchrotron radiation beamline, showing five radiation safety items (movable mask, 2 injection stoppers, collimator, lead/polyethylene shadow wall, and lead/polyethylene shielding in the hole of the ratchet wall), in addition to the 60-cm-thick concrete lateral wall and concrete ratchet wall (90-cm-thick or 60-cm and 2.5-cm Pb).

Table 1. Dose Rate Limits for Different Beam loss Scenarios.

Operation condition	Dose rate limit	Beam loss scenario	Normalized dose rate limit
Normal	1 μSv/h	2 mW	0.5 mSv/Wh
Mis-steering	4 mSv/h	5 W	0.8 mSv/Wh
System Failure	0.25 Sv/h	45 W	5.56 mSv/Wh

Table 2. Shielding Design Limits at SLAC.

Conditions	Normal	Mis-steering	System Failure
Radiological Control Area (RCA)	10 mSv/y	4 mSv/h	0.25 Sv/h
Non-RCA	1 mSv/y	4 mSv/h	0.25 Sv/h

* An individual entering a RCA needs to wear a dosimeter.

Table 3. Shielding Design Criteria for SPEAR3 Ring at 5 W/500 mA.

Area	Normal Beam Loss	Mis-steering Loss at 5 W	Normal Injection [3]
Outer Ring Wall (User Side)	1 mSv / 1000 h (1 μSv/h) [1]	12 mSv/h [2]	10 μSv/h
Inner Ring Wall (Less Occupied)	8 mSv / 2000 h (4 μSv/h)	12 mSv/h [2]	50 μSv/h
Roof (Fenced and No Access)	30 mSv / 2000 h (15 μSv/h)	30 mSv/h	150 μSv/h

1) The criterion of 1 mSv per 1000 h is set based on a maximum occupancy of 700 h/y for SSRL users on experimental floor.

2) In SPEAR3 shielding implementation, the mis-steered limit was raised from 4 to 12 mSv/h. SSRL justified this via the extensive use of BSOICs/LIONs in the ring.

3) The criteria for normal injection are set based on the maximum dose rates experienced during SPEAR2 operation. In SPEAR3 shielding implementation, the dose rates may be up to a factor of 2-3-higher than the SPEAR2 values.

Table 4. Shielding Requirements for Lateral Walls and Roof for Beam Losses in the Ring Chamber.

Element	Outer Ring Side	Inner Ring Side	Top	Length and Height Requirements
Injection Septum (120-cm@160-cm, 60-cm@75-cm, 60-cm@100-cm)	0	10-cm Fe or 5-cm Pb	10-cm Fe or 5-cm Pb	1) Height should cover ± 30° vertical angles. 2) For septum and ring stoppers, the length requirement is 45° backward of the first and 45° forward of the last beam loss points in a device. 3) For beam abort dump, low loss apertures, and G4 section, the length requirement is 30-cm upstream and 60-cm downstream of the beam loss point.
Stored Beam Abort Dump (120-cm@198-cm, 60-cm@198-cm, 60-cm@100-cm)	0	7.6-cm Fe or 7.6-cm Pb	7.6-cm Fe or 7.6-cm Pb	
Ring Stoppers (60-cm@150-cm, 60-cm@150-cm, 60-cm@100-cm)	15-cm Fe or 7.6-cm Pb	5-cm Fe or 2.5-cm Pb	0	
Low Loss Apertures (60-cm@420-cm, 60-cm@75-cm, 30-cm@100-cm)	5-cm Fe or 2.5-cm Pb	0	0	
G4 (Downstream of Septum) (60-cm@420-cm, 60-cm@198-cm, 60-cm@100-cm)	5-cm Fe or 2.5-cm Pb	0	0	

Table 5. Dose Rates outside SPEAR3 Lateral Walls and Roof from Beam Losses in the Ring Chamber.[a]

Location	Normal [b] (e/7200h)	Outer	Inner	Roof	Mis-steering	Outer	Inner	Roof
Injection Septum	8.8×10^{14} (16 mW)	0.4	2.1	4.8	5 W	0.12	0.33	0.73
Beam Abort Dump	2.6×10^{15} (47 mW)	0.95	7.95	20	5 W	0.1	0.41	1
PPS Ring Stoppers	7.0×10^{14} (13 mW)	0.7	5	25	N/A			
Low Loss Aperture	1.1×10^{14} (2 mW)	0.5	2.3	2.3	5 W	1.25	2.85	28.5
Section G4	2.2×10^{14} (4 mW)	1	4.6	11	5 W	1.25	2.85	6.5
Straight [c] (0.7-cm Cu target)	N/A				5 W	5	2.85	28.5
Dose Limit		1 mSv / 1000 h	8 mSv / 2000 h	30 mSv / 2000 h		12 mSv/h	12 mSv/h	30 mSv/h

a. Shielding required for these dose rates are shown in Table 4.

b. Annual electron normal loss at each location (5 W allowed injection beam power and 500 mA operation).

c. Straight sections include the beampipes in bare ID straights and the gap between any two components (like dipoles and quads).

Table 6. Dose Rates from Abnormal Beam Losses of 5 W at a Thin Target in SPEAR3 Ring.

Dose Location	Beam Loss Location	Maximum Dose Rate (mSv/h at 5 W)	Shielding to Meet the Limit
Lateral Wall	Frontend	10.8	None
Roof	Frontend	55.5	None
Ratchet Wall	Ring Chamber*	9 (60-cm ratchet wall)	2.5-cm Pb wall
		11 (90-cm ratchet wall)	None
	Frontend	18 (60-cm ratchet wall)	2.5-cm Pb wall
		18 (90-cm ratchet wall)	None

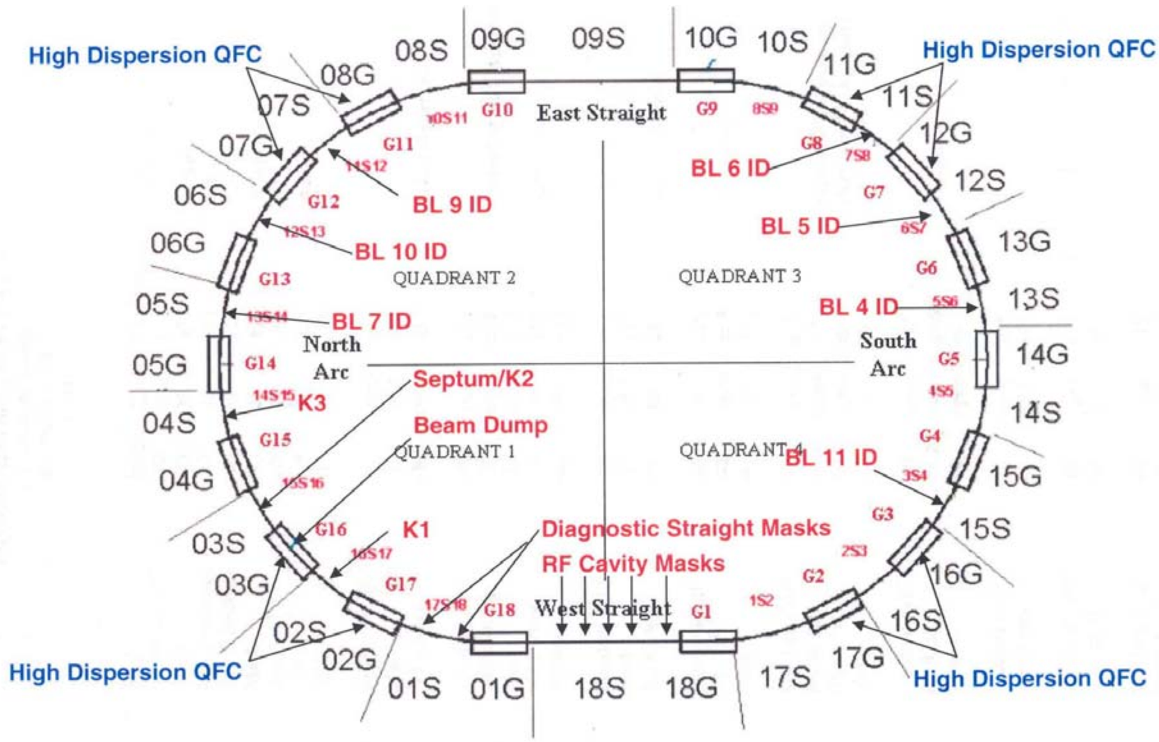
* The safety factor of 3 was not applied to the FLUKA calculated doses outside ratchet wall from beam losses in ring chamber, due to the credit of self-shielding from ring components was not considered in ray trace study.

Table 7. Dose Rates outside 60-cm-thick Ratchet Wall with 2.5-cm-thick Pb on the Wall.

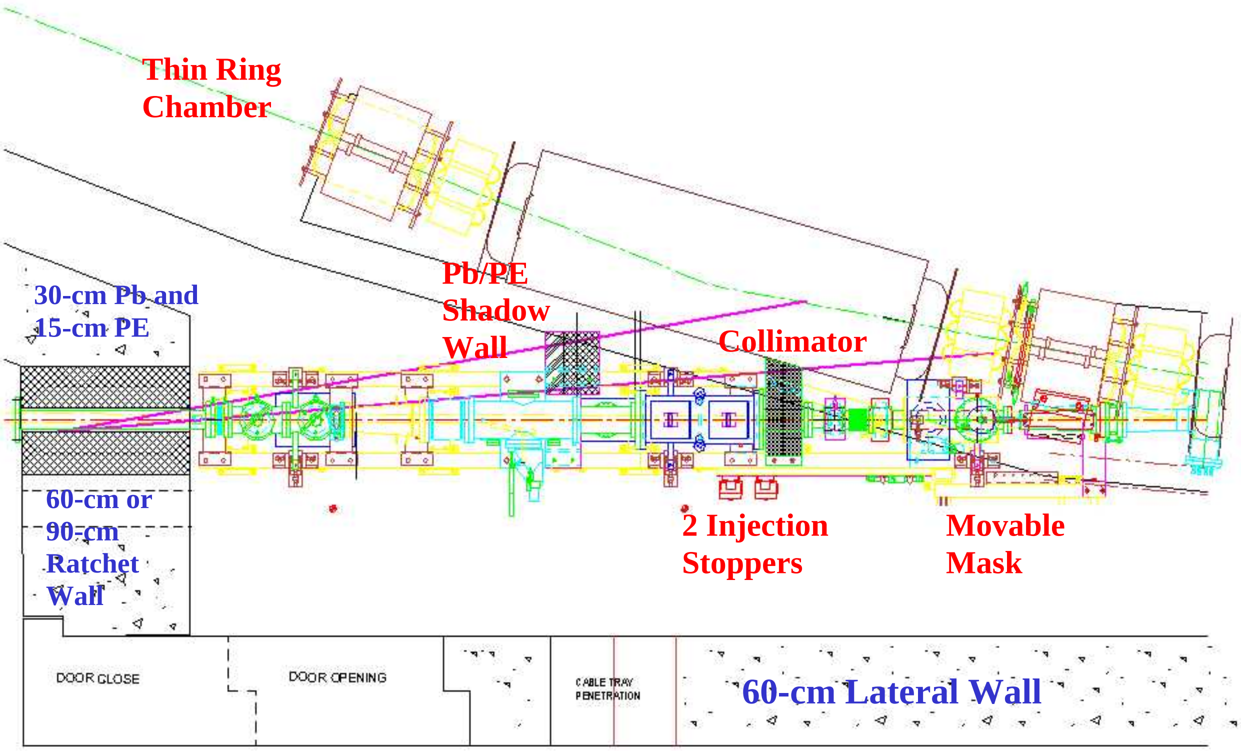
Dose Point	Source Point	Scatter Angle (^{o}) (Angle with respect to Beam direction)	Normalized Dose (mSv/W.h)
OF median plane	ID	5	0.7
OF over shadow wall	ID	5	0.7
OG median plane	SL	57	0.005
OG over shadow wall	ID	2	0.55
OH median plane	SL	54	0.14
OH above shadow wall	ID	2	0.55
OI median plane	SL	49	0.05
OI above shadow wall	ID	2	0.55
OJ median plane	SL	36	0.2
OJ above shadow wall	SE	6	1.4
OF median plane	SA	6	0.8
OF over shadow wall	SA	6	0.8
OG median plane	SL	57	0.005
OG over shadow wall	SA	2	0.8
OH median plane	SA	<2	0.34
OH above shadow wall	SB	6	0.9
OI median plane	SK	35	0.14
OI above shadow wall	SB	4.5	1
OJ median plane	SK	25	0.3
OJ above shadow wall	SH	7.5	1.8

Table 8. Shielding for Concrete Ratchet Wall from Beam Losses in Ring Chamber.

Component	Shielding Requirement
Lead Wall added to Ratchet wall	No lead needed for 90-cm-thick concrete wall. 2.5-cm-thick Pb needed for 60-cm-thick concrete wall.
Collimator	15-cm Pb and 15-cm PE-thick, 30-cm -tall, 30-cm -wide to cover the beampipe hole in ratchet wall.
Shadow Walls	15-cm Pb and 15-cm PE-thick, 30-cm-tall to cover the beampipe hole for all rays.
Hole Shielding	30-cm Pb and 15-cm PE around the beampipe in the ratchet wall.



black = SPEAR 3 sector numbering
red = SPEAR 2 sector numbering
RED BOLD: Limiting Aperture
BLUE BOLD: High non-linear dispersion QFC Location



Thin Ring Chamber
30-cm Pb and 15-cm PE
Pb/PE Shadow Wall
Collimator
60-cm or 90-cm Ratchet Wall
2 Injection Stoppers
Movable Mask
DOOR CLOSE
DOOR OPENING
CABLE TRAY PENETRATION
60-cm Lateral Wall