Specification for Beam Line Radiation Shielding and Components at the Diamond Light Source

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This is general guidance for beam line shielding. For more specific and recent information, refer to individual beam line documents on Sharepoint.

Document Change Record

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1.0	20th November 2003	Published on share point
2.0	9th December 2003	Figures for steel walls added.
3.0	16th December 2003	Figures for steel and lead combination added
4.0	5th March 2004	Addition of dipole beam line. Reorganised tables.
5.0	5th March 2004	Minor correction
6.0	27th April 2004	Modification for dipoles and free access to hutch roofs
		Hutch wall vacuum for calculation 8×10^{-9}mbar
7.0	10th February 2005	Modification for final gap field strengths and dipoles
8.0	28th July 2008	Added shielding figures for TAM3950

1. Radiation Safety Policy.

The annual dose to people working around the Diamond accelerators and beam lines will be restricted to be As Low As Reasonably Practicable (ALARP). It is expected that the annual dose of prompt radiation to any person working on the Diamond site will be less than 1mSv. Health Physics personnel will perform routine regular area surveys or whenever new beam lines and facilities are commissioned. The dose rates around the accelerators and beam lines will be restricted and recorded by a system of installed radiation monitors. An extensive system of passive monitors will integrate the annual dose in the various areas. The results will be analysed for trends of increased doses and the shielding in those areas will be evaluated and improved as appropriate.

It is expected that the annual doses of prompt radiation will be so low that the provision of personnel dosimetry for work in the experimental areas is not necessary.

2. Specification of radiation safety beam line components and hutches.

The beam lines will be subjected to the X-rays of the synchrotron radiation and also bremsstrahlung resulting from the particles in the electron beam interacting with the residual gas molecules in the storage ring. The X-ray radiation will be of extremely high dose rate but relatively low in energy and hence not very penetrating. The bremsstrahlung radiation will be of much lower dose rate but having an energy up to that of the primary electron energy, 3GeV, it will be extremely penetrating. The hutch shielding and dimensions of shutters etc will be determined by which of the synchrotron radiation X-rays or bremsstrahlung radiation dominates at that point along the beam line.

The dose rate and penetration of the synchrotron radiation X-rays depends on the type and field of the source i.e. insertion device or bending magnet and the electron beam current. It will reduce in dose rate and change spectrum after slits, mirrors and monochromators. For a fixed electron energy, the dose rate of the bremsstrahlung will depend on the residual gas pressure and composition and the electron beam current. Initially the accelerator was intended to produce a beam current of 300mA. It is now intended to increase the number of RF cavities to three which will allow a stored beam of 500mA which will produce more X-rays and bremsstrahlung.

It is expected that the base pressure in the storage ring will be around 1.0×10^{-10}mbar. The residual gas will compose of hydrogen and carbon-monoxide and -dioxide. Methane will also be present in vacuum vessels pumped by a NEG coating. The dynamic pressure in the ring will depend on the outgassing from the vacuum surfaces. When the beam falls on unconditioned surfaces, the pressure will deteriorate from the base pressure due to photo stimulated desorption, even from well prepared surfaces. This photo stimulated desorption will reduce significantly as the surfaces condition. It is expected that the dynamic pressure will reduce to approximately 1.0×10^{-9}mbar after about 100Ah of beaming.

It is expected that a beam will not be injected into the storage ring at a vacuum of worse than 1.0×10^{-7}mbar. It is assumed that beam line staff will want to open their line shutters when a vacuum of 8.0×10^{-9}mbar is achieved.

2.1. Hutches

All optics hutches will be subjected to bremsstrahlung radiation, which will usually dominate the shielding requirement on insertion device beam lines. Any other hutches which can accept white beam will be subject to the same shielding requirement. For all beam lines where the bremsstrahlung is stopped in the optics hutch (or other upstream hutch), downstream hutches need shielding for the synchrotron radiation only. For VUV or soft X-ray beam lines, it is possible that the fabric of the experiment hutch wall or the beam tube itself will be sufficient to shield the beam line. This must be confirmed for each such beam line by the RPA.

The specified roof shielding allows free access to the roofs. It is assumed that the roof is at least 2 metres above the beam height – if this is not the case for any hutch, then these figures will not provide adequate shielding.

Shielding figures have been calculated for 300mA and 500mA operation at 3GeV, 8.0×10^{-9}mbar and are presented separately. Tables 1 to 3 give shielding requirements for various components at 300mA. Tables 4 to 6 give the specifications for the same components at 500mA. It should be noted that as the vacuum improves towards 1.0×10^{-9}mbar, the lower 300mA specification bremsstrahlung shielding may be adequate for 500mA operation. Please refer to TDI-HP-BL-REP-0004. Note, however, that the intensity of synchrotron radiation generated is independent of vacuum. If non bremsstrahlung hutches are shielded to 300mA specification initially, an upgrade would be required for 500mA operation. Tables 1 and 4 summarise the shielding specifications for the hutches at DLS. These specifications cover the original seven phase 1 insertion device beam lines and a generic bending magnet beam line, for comparison purposes. For further information on the shielding specification for subsequent beam lines, contact Health Physics.

2.2 Beam Transport pipes.

Generally, white beam transport should be avoided, particularly if there are potential scattering components along the transport. Any components such as mirrors, slits or monochromators should be contained within hutches. Ray tracing must be performed to ensure that the X-ray and bremsstrahlung beams cannot strike the transport pipe under any circumstances. The minimum distance between the edge of the radiation beam and the inside wall of the transport must be 10mm.
Tables 2 and 5 summarise shielding specifications for beam transport at the DLS.

2.3 Shutters and Stops.

Shutters are remotely controlled devices which be can moved into the beam to provide access into a downstream hutch. Stops are non movable devices which permanently prevent radiation passing downstream.

The nominal operating vacuum of the storage ring is 1×10^{-9}mbar, however, it is possible that the machine will operate at worse levels of vacuum. It has been assumed that beam lines will still take beam at vacuums as poor as 8.0×10^{-9}mbar. Hence, all shutters and stops downstream of the front end are specified for 8.0×10^{-9}mbar.

There will be times, such as machine commissioning, when the machine will have stored beam at worse vacuums than this, as poor as 1×10^{-7}mbar. The front end shutter must always be an effective radiation shield at any machine condition when there is beam in the machine, so front end shutters are specified for 1×10^{-7} mbar.
The current design plan shows that there are possibly two shutters in the front end. An operating philosophy for these shutters has been proposed in document TDI-PSS-MIN-0004, Operation of Beam Line Shutters. Tables 3 and 6 show the required shutter thicknesses.
The transverse dimensions of the shutters / stops in both horizontal and vertical planes are determined from the primary bremsstrahlung ray tracing. The extremal ray should not be closer than 35mm from the lateral edge of a tungsten alloy block, or 45mm from the edge of a lead block (in either plane). In addition to this, the lateral dimensions of shutters must satisfy the criteria set in section 8 of the shutter design guidance document (TDI-HP-GEN-REP-0001).

If it is intended to remove the bremsstrahlung component from the beam within the optics hutch, then the X-ray beam needs to be offset from the bremsstrahlung which is then stopped in a suitable beam stop. The offset between the centre of the bremsstrahlung beam and the X-ray beam needs to be a minimum of 8mm. If any smaller offset is used, then the bremsstrahlung cannot be considered to have been removed, and downstream components and hutches will need to be shielded for bremsstrahlung.

For beam lines where the bremsstrahlung component has been removed in the optics hutch, the thickness of downstream shutters and stops will be determined by the synchrotron radiation. Tables 3 and 6 show the required shutter thicknesses.

3. Lead or Steel

The tables show that large quantities of lead are needed for the bulk shielding. At energies of a few MeV and above, steel would be approximately half as effective as lead as a radiation shield. Hence, although double the thickness of steel may be required, it does present several advantages - steel would be easier and less hazardous to work with and the raw material is cheaper. However, there are no existing designs for steel hutches of the required thickness, so a new design would be required. Cable ducts and doors may pose particular engineering problems. Required shielding thicknesses for steel are also presented in the tables where appropriate.

There is a special case. The enhanced spectrum produced on beam line I15 would cause the synchrotron radiation to dominate the shielding case if steel is to replace lead as the shielding material. Excess steel would be required to replace lead on this beam line. Figures are quoted for this beam line where appropriate. It has been assumed that beam line I15 will take full bremsstrahlung beam at all hutches.

Table1: Shielding Specification for Hutches at 300mA. (figures quoted are mm in lead or steel)

Hutch Type	Upstream Wall	Lateral Wall	Roof	Downstream Wall, Lead	Downstream Wall, Steel
ID White Beam, 300 mA	30 lead or 65 steel	30 lead, or 65 steel	10 lead or 50 steel	50, (100 locally)	100, (200 locally)
ID Mono / Pink Beam – **No Bremsstrahlung.**	7 lead or 65 steel	7 lead or 65 steel	7 lead or 50 steel	8	95
BLI15, all hutches	30 lead or 165 steel or 6 lead + 60 steel	30 lead or 165 steel or 6 lead + 60 steel	12 lead or 150 steel or 10 lead + 15 steel	50, (100 locally)	185 (200 locally)
BM, all hutches	8 lead	8 lead	8 lead	8	N/A

Table 2: Shielding Specification for Beam Transport pipes, 300mA

Beam Type (Air Scatterer)	Lead thickness, mm	Steel thickness, mm
Minimum edge of beam to inner wall separation	10 mm (air)	10 mm (air)
ID White Beam	50	100 (For BLI15, 240 mm steel OR 100 mm steel + 8 mm lead)
ID Mono / Pink Beam	10	100
BM, all beams	12	N/A

Table 3: Specification for Shutter and Stop Thicknesses, 300mA

Beam Type	Mallory 1000, mm	TAM3950, mm	Lead, mm
ID White Beam, front end	300	285	420
ID White Beam, other	260	245	370
ID Mono / Pink Beam	12	Not calculated	15
BM White beam, front end	170	155	240
BM White beam, other	140	125	190
BM Mono / Pink Beam	12	Not calculated	15

Annex 1 - Parameters used throughout these calculations:

Derived Working Limit,	$0.5\mu Svh^{-1}$.
Beam Energy	3.0GeV
Length of ID straight	18.75m
Vacuum for port shutters:	1×10^{-7}mbar.
Vacuum for other shutters:	8.0×10^{-9}mbar.
Mallory 1000 composition:	Tungsten-Nickel-Copper (90/6/4%)
Mallory 1000 density:	$16.9gm\cdot cm^{-3}$
TAM3950 composition:	Tungsten-Nickel-Iron (95/3/2%)
TAM3950 density:	$18.1gm\cdot cm^{-3}$

Table 4: Shielding Specification for Hutches, 500mA. (figures quoted are mm in lead or steel)

Hutch Type	Upstream Wall	Lateral Wall	Roof	Downstream Wall, Lead	Downstream Wall, Steel
ID White Beam	50 lead or 100 steel	50 lead or 100 steel	25 lead or 50 steel	75, (125 locally)	150, (250 locally)
ID Mono / Pink Beam – **No Bremsstrahlung.**	7 lead or 65 steel	7 lead or 65 steel	7 lead or 50 steel	8	95
BLI15, all hutches	50 lead or 180 steel or 5 lead + 100 steel	50 lead or 180 steel or 5 lead + 100 steel	25 lead or 155 steel or 6 lead + 50 steel	75, (125 locally)	195, (250 locally)
BM, all hutches	8 lead	8 lead	8 lead	8	N/A

Table 5: Shielding Specification for Beam Transport pipes, 500mA.

Beam Type (Air Scatterer)	Lead thickness, mm	Steel thickness, mm
Minimum edge of beam to inner wall separation	10 mm (air)	10 mm (air)
ID White Beam	50	100 (For BLI15, 240 mm steel OR 100 mm steel + 8 mm lead)
ID Mono / Pink Beam	10	100
BM, all beams	12	N/A

Table 6: Specification for Shutter and Stop Thicknesses, 500mA.

Beam Type	Mallory 1000, mm	TAM3950, mm	Lead, mm
ID White Beam, front end	310	295	440
ID White Beam, other	270	255	390
ID Mono / Pink Beam	12	Not calculated	15
BM White beam, front end	180	165	250
BM White beam, other	140	130	200
BM Mono / Pink Beam	12	Not calculated	15

Annex 2 - Parameters used throughout these calculations:

Derived Working Limit,	0.5µSvh^{-1}.
Beam Energy	3.0GeV
Length of ID straight	18.75m
Vacuum for port shutters:	1×10^{-7}mbar.
Vacuum for other shutters:	8.0×10^{-9}mbar.
Mallory 1000 composition:	Tungsten-Nickel-Copper (90/6/4%)
Mallory 1000 density:	16.9gm·cm^{-3}
TAM3950 composition:	Tungsten-Nickel-Iron (95/3/2%)
TAM3950 density:	18.1gm·cm^{-3}