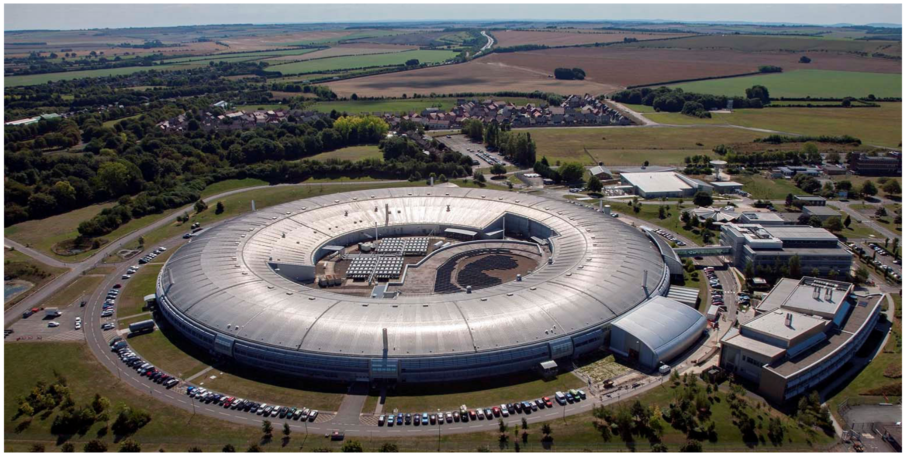


Shielding assessments for Diamond II machine upgrade

Sanjeev Faruk & Richard Doull
Diamond Light Source Ltd.

Diamond II upgrade

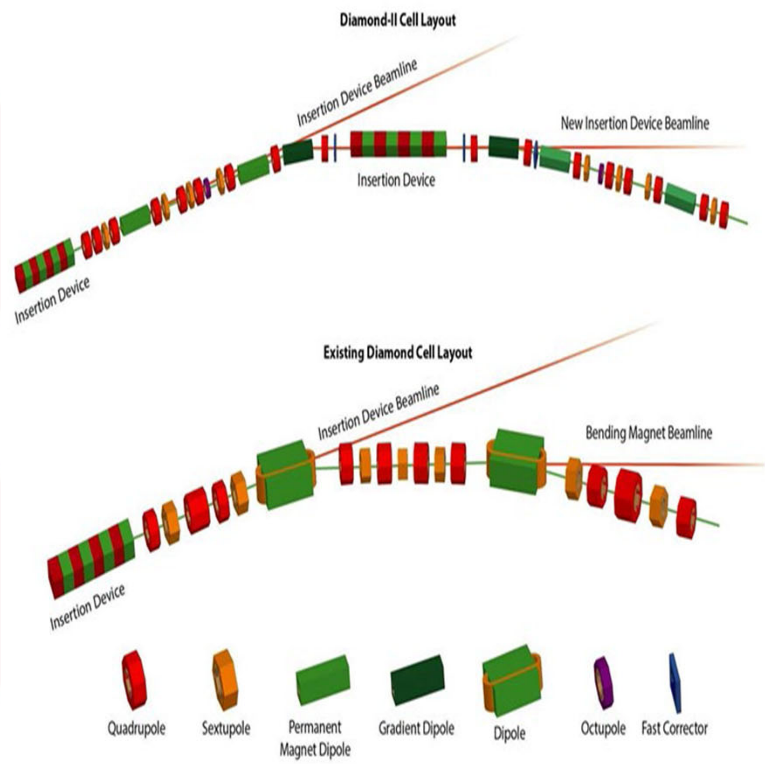
Diamond is currently working on enhancing the storage ring by minimising emittance while boosting brightness and coherence.

Diamond-I

- Energy 3.0 GeV
- Max Current 500 mA, operating at 300 mA
- Straight sections 18.581m and 15.581m
- Insertion device (ID)
- Bending magnet

Diamond-II

- Energy 3.5 GeV
- Max current 300 mA
- Straight sections 3.95m, 6.59m and 9.59m
- D-II Storage Ring will be Double Triple Bend Achromat
- Bending Magnet Beamline will be replaced mid straight Insertion Devices.



RadSynch 2019

In RadSynch 2019, we presented –

- Storage ring and Booster shielding checks using SHIELD11 for Diamond II.
- Gas Bremsstrahlung semi-empirical calculations to determine the Booster to Storage (BTS) shutter and port/optics shutter,
- STAC8 calculation for beamlines hutch shielding checks.

Goal: Is existing shielding adequate?

- Check if all the existing shielding is adequate to comply with the local limit (0.5 μSv/h) outside of
  - Linac bunker (concrete)
  - Booster vault (concrete)
  - Storage ring (Barytes & concrete)
- or do we need additional shielding?
- How to comply with the regulation?

Lack of information!

Ring parameter?

Electron loss rate?

No design!

Ring pressure?

Length of Straight section?

Magnet?

How long will it take?

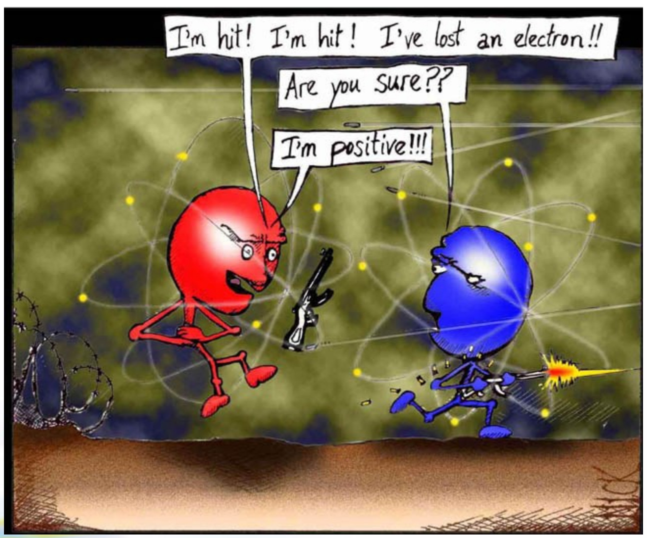
Collimator?

Electron loss - Normal

- **Electron Losses**

  Normal loss:

  Persist over long periods



Courtesy of Humorgeeky.com

Loss location	Losses e^-/s
Linac	$1.6\ 10^8$
LTB1	$2.9\ 10^8$
Booster injection	$4.7\ 10^8$
Booster extraction	$7.3\ 10^7$
Storage ring	$4.2\ 10^8$

Estimated average electron losses at various points in Diamond-II under normal conditions.

Electron loss -Abnormal

Abnormal loss scenarios

Location	Cause of abnormal loss
Linac	Mis-steering occurring due to corrector errors/failures in-between linac sections.
LTB	Linac beam directed into Faraday cup or mis-steered into the collimator.
Booster	Linac beam mis-steered, either hitting the injection septum or where it enters the narrow aperture vessels in the arcs.
Booster	3.5 GeV beam hits extraction septum.
BTS	Booster beam directed into Faraday cup or mis-steered into the collimator.
Storage Ring	Mis-steering of injected beam, hitting a collimator.
	Loss of stored beam through various mechanisms.

<u>Abnormal loss:</u>

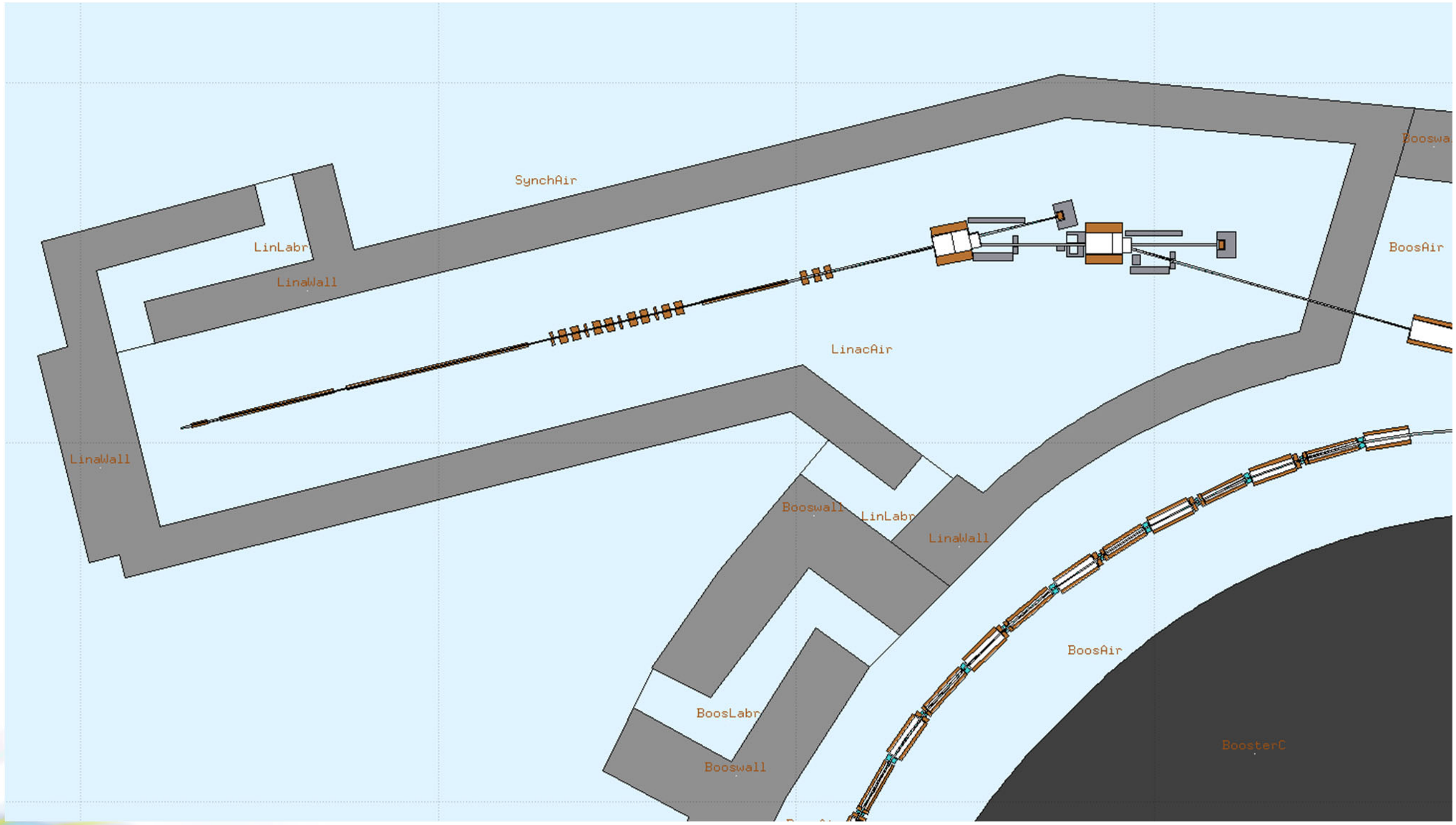
occurs under test or fault conditions – persist for a short time

Loss location	Charge (nC)	Losses e^-/s
Linac	9 nC	$2.8\ 10^{11}$
LTB	9 nC	$2.8\ 10^{11}$
Booster injection	7.2 nC	$2.3\ 10^{11}$
Booster extraction	7.2 nC	$2.3\ 10^{11}$
Storage ring injection	6.5 nC	$2.0\ 10^{11}$

Estimated maximum abnormal electron losses at various points in Diamond-II

In estimating the loss rates, higher transfer efficiencies have been assumed than normal losses to be more pessimistic:
80% Linac end to LTB end, 90% Booster injection, 100% BR acceleration, 100% BR extraction, 100% SR injection.

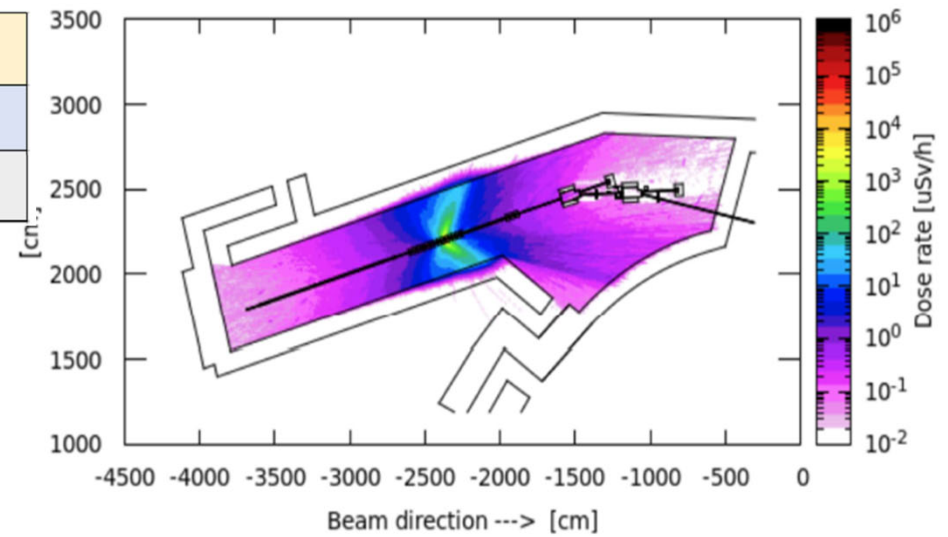
Linac vault


SynchAir
LinLabr
LinaWall
LinacAir
BoosAir
LinaWall
Booswall
LinLabr
LinaWall
BoosAir
BoosLabr
Booswall
BoosterC

Linac – normal loss condition

Loss location	Losses e^-/s	Dose rate outside shielding μSv/h	Comments
Linac	1.6 10^8	< 0.1	Shielding is adequate
LTB dipole	2.9 10^8	90	PSS will restrict access to booster when the Linac is in operation.

- Losses at the first LTB dipole could lead to 90 μSv/h in Booster Zone 1.
- Personnel Safety System (PSS) will be configured so the Linac can only operate when Booster Zone 1 is searched and locked.



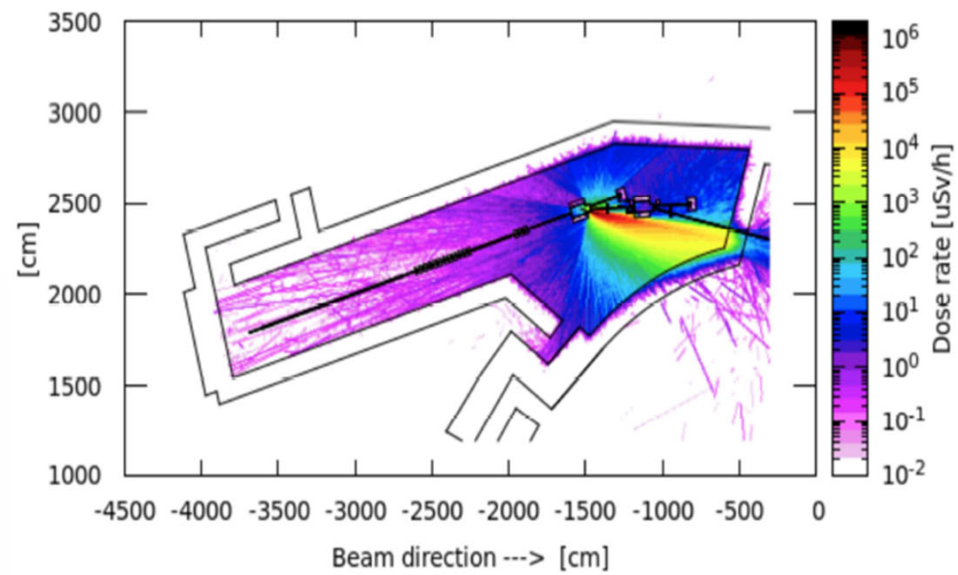
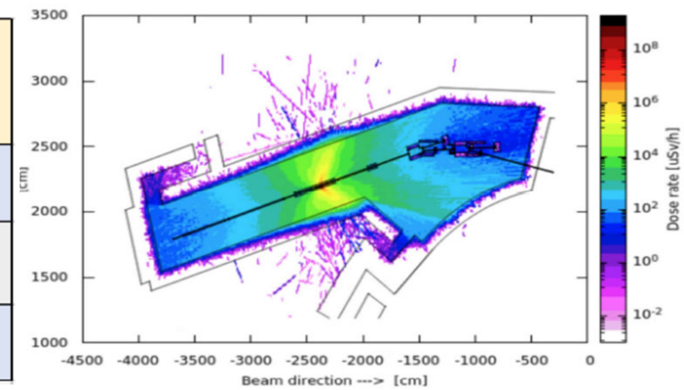
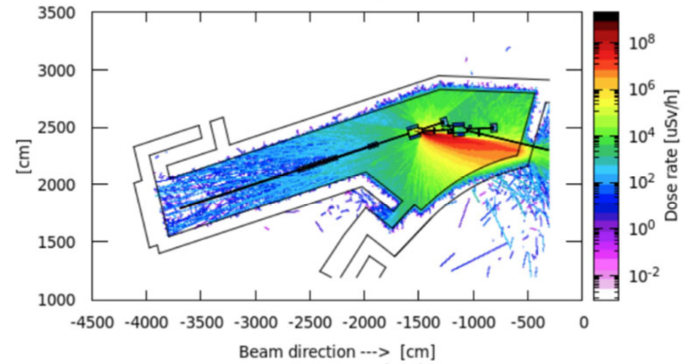


Fig 1: FLUKA models showing dose rate (electrons, neutrons & X-ray) outside the Linac shield wall due to 1.6e+08 electron loss/s along the Linac (upper) and 2.9e+08 electron loss/s at the first LTB dipole magnet (lower)

Linac – abnormal loss condition

Loss location	Losses e⁻/s	Dose rate outside shielding (µSv/h)	Additional lead shielding required to reduce dose rates to 7.5 µSv/h
Linac	$2.8\ 10^{11}$	90 & 30	23 mm & 13 mm
LTB dipole	$2.8\ 10^{11}$	90000	N/A - PSS will restrict access to Booster Zone 1
Faraday cup	$2.8\ 10^{11}$	30	13 mm





Mis-steering of quadrupole corrector magnet-
23 mm of Pb in parallel to magnets on the rear entrance side, and 13 mm Pb installed on the main entrance side.

LTB dipole
Booster zone 1 will be locked by PSS.

Faraday cup
An additional 13 mm Pb shall be installed on the Rear entrance side of the Faraday cup.

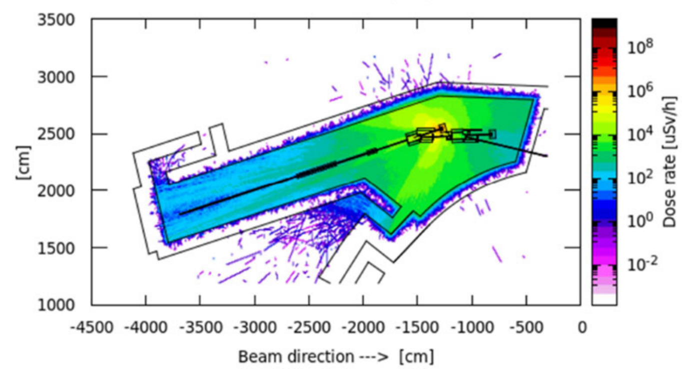
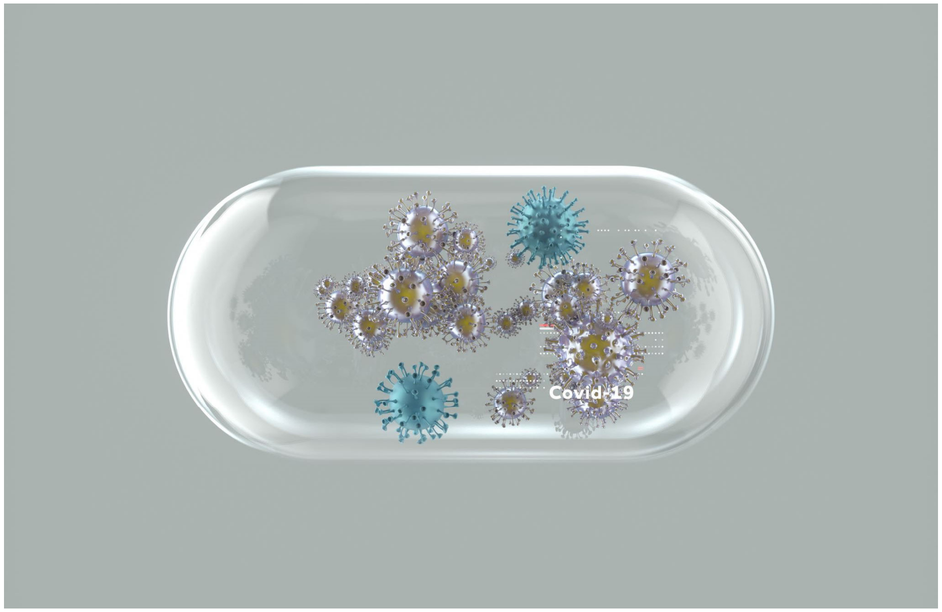
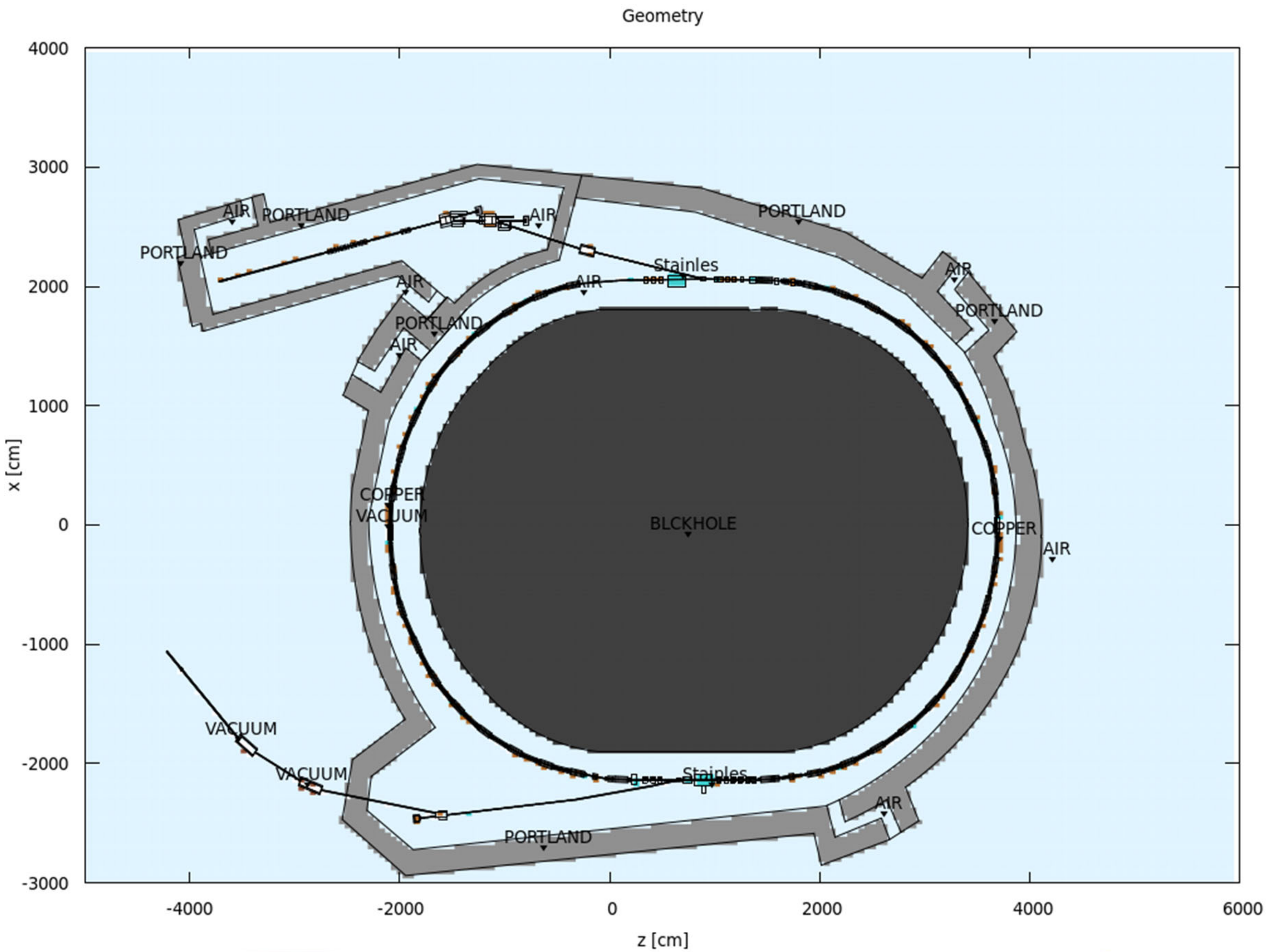


Fig 2: Mis-steering at a quadrupole corrector magnet (upper), at the LTB dipole magnet (centre) and in the Faraday cup (lower)

Booster ?!



Booster vault



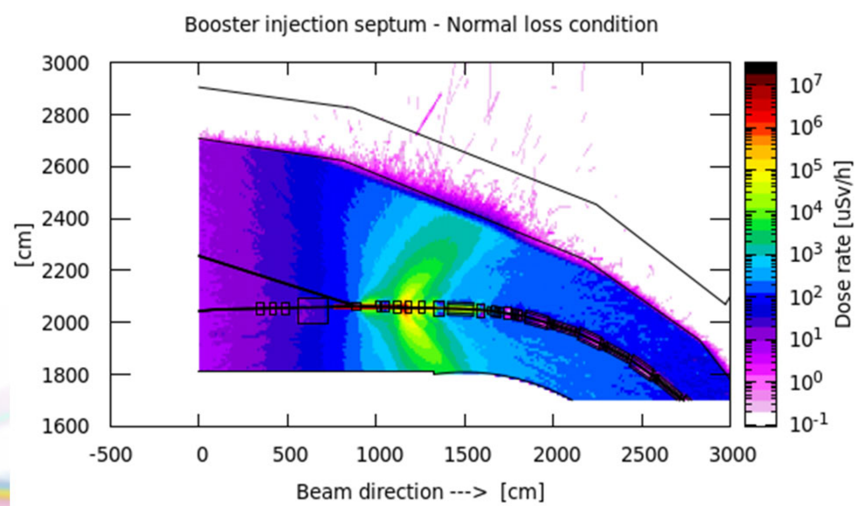
diamond

Booster Injection– normal loss

Loss Location	Losses e⁻/s	Dose rate outside shielding µSv/h	Comments
Injection Septum	4.7 10^8	<1.0 [SW & R]	Less than 1000 hrs per year would be spent by someone in these areas, accessed infrequently, leading to the annual dose being less than 1 mSv/y; hence, no additional controls are necessary for the hall area.

SW = Side wall; R = Roof

Access to the roof will be restricted and only possible under a Permit to Work (PTW) procedure that ensures the Booster is off.



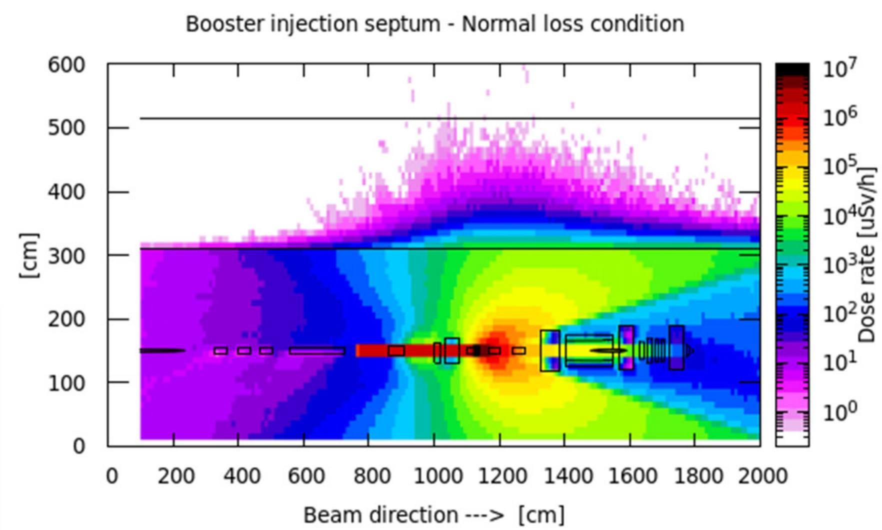


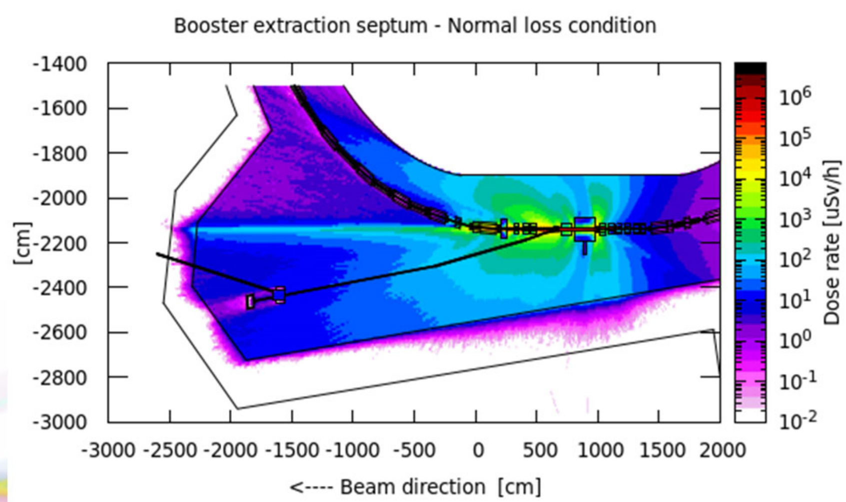
Fig 3: The Booster shield wall (upper) and roof (lower) due to 4.7E+08 electron loss/s at the injection septum magnet.

Booster Extraction– normal loss

Loss Location	Losses e^-/s	Dose rate outside shielding µSv/h	Comments
Extraction Septum	7.3 10^7	<0.5 [SW] <1.0 [R]	This would not require additional controls for the hall area.

SW = Side wall; R = Roof

Access to the roof will be restricted and only possible under a Permit to Work (PTW) procedure that ensures the Booster is off.



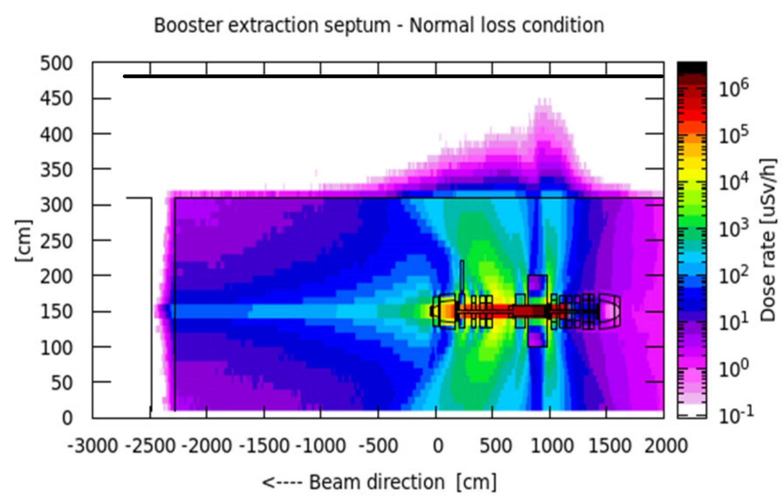


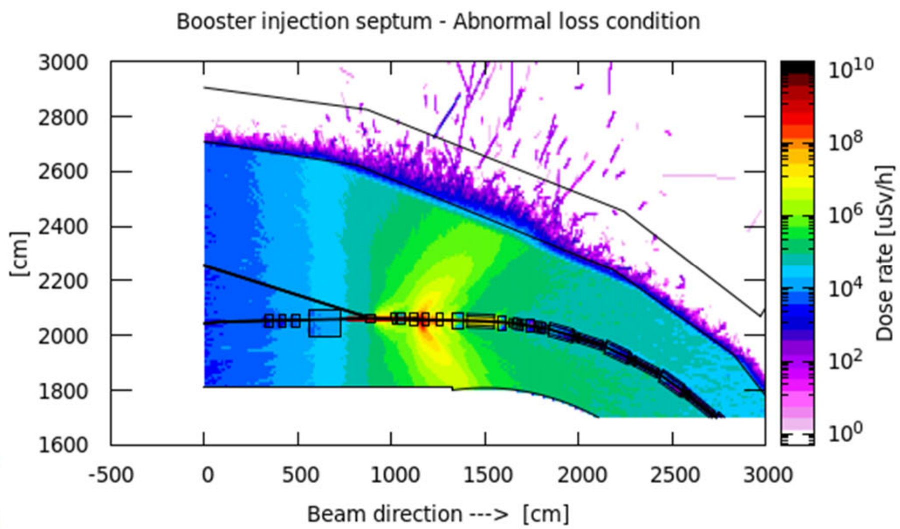
Fig 4: The Booster shield wall (upper) and roof (lower) due to 7.3E+07 electron loss/s at the extraction septum magnet.

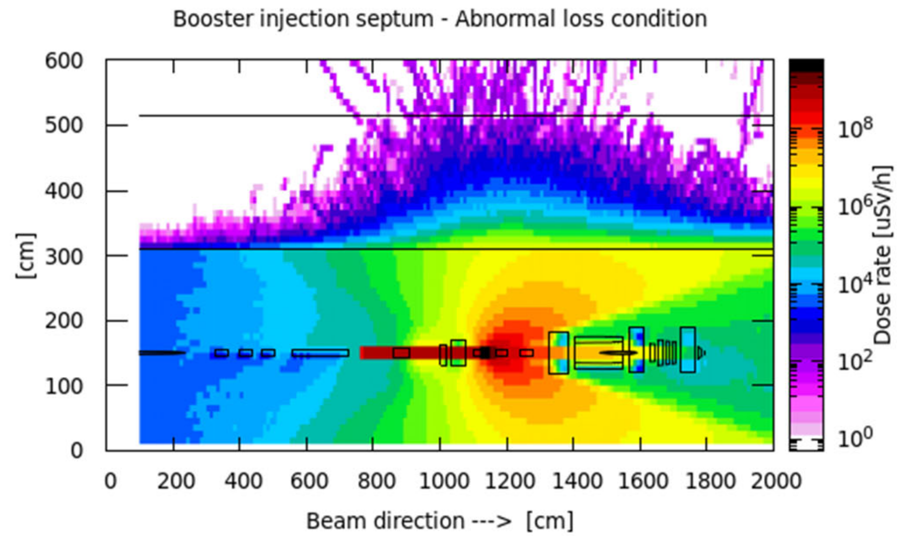
Booster Injection– abnormal loss

Loss Location	Losses e⁻/s	Dose rate outside shielding µSv/h	Comments
Injection Septum	2.3 10^{11}	<300 SW & R	34mm of Pb shall be installed parallel to the septum magnet.

SW = Side wall; R = Roof

Access to the roof will be restricted in the above conditions and only possible under a Permit to Work (PTW) procedure that ensures the Booster is off.



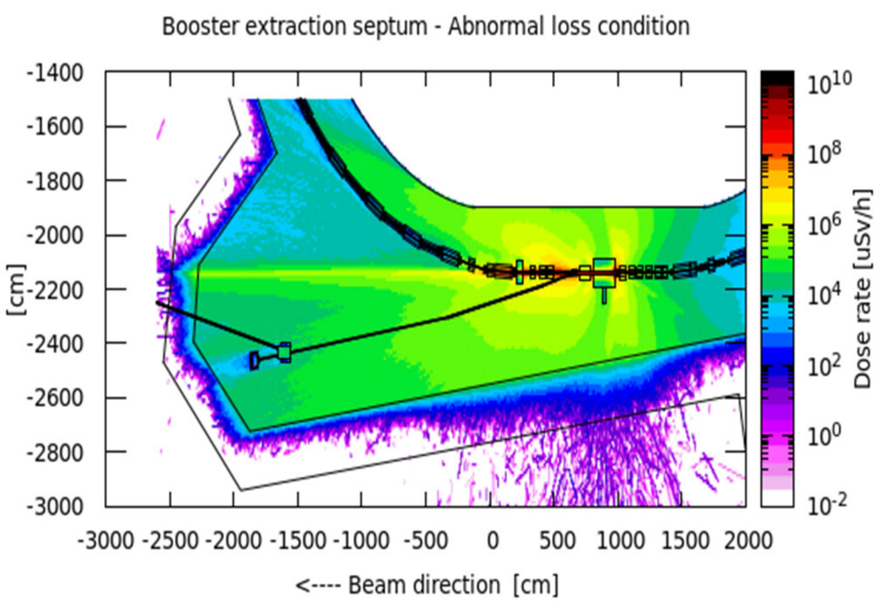


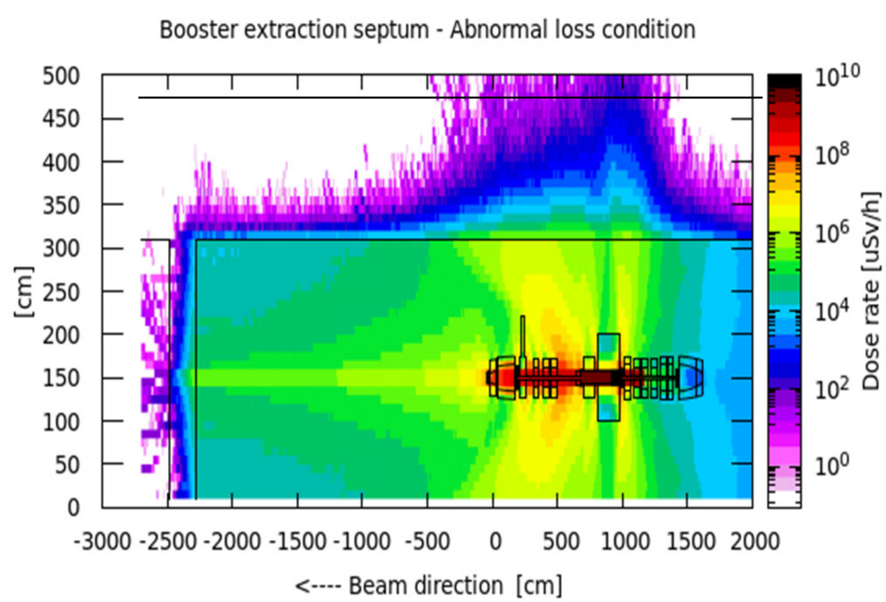
Booster Extraction– abnormal loss

Loss Location	Losses e⁻/s	Dose rate outside shielding µSv/h	Comments
Extraction Septum	2.3 10^{11}	<50 SW, <150 R	Local lead shielding (~17 mm) shall be placed around the septum.

SW = Side wall; R = Roof

Access to the roof will be restricted in the above conditions and only possible under a Permit to Work (PTW) procedure that ensures the Booster is off.



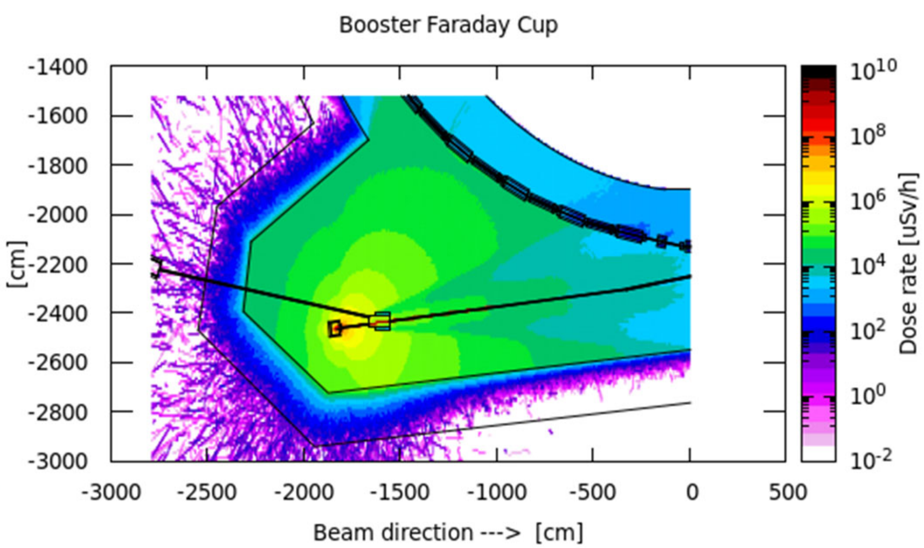


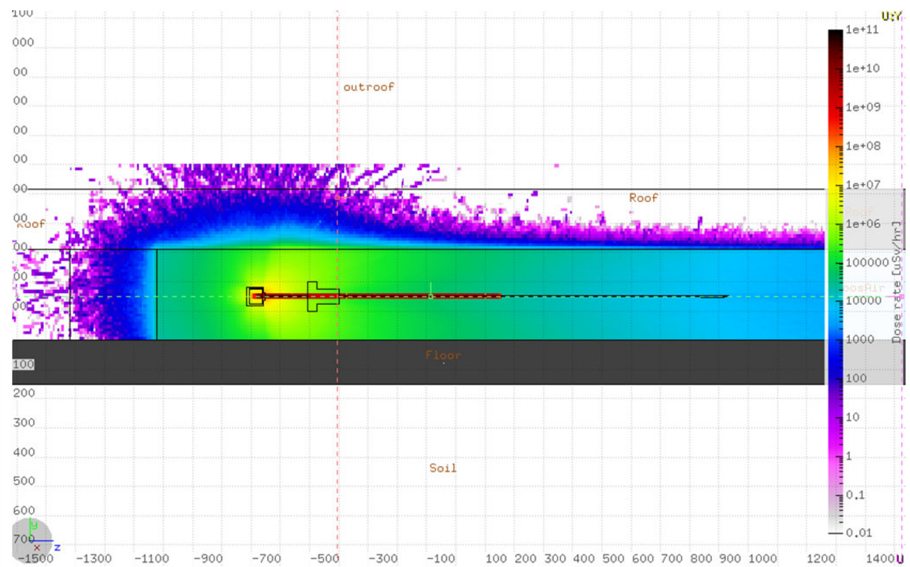
BTS Faraday cup – abnormal loss

Loss Location	Losses e⁻/s	Dose rate outside shielding µSv/h	Comments
BTS Faraday cup	$2.0\ 10^{11}$	<100 SW & R	local lead shielding (~24 mm) shall be placed around the Faraday cup.

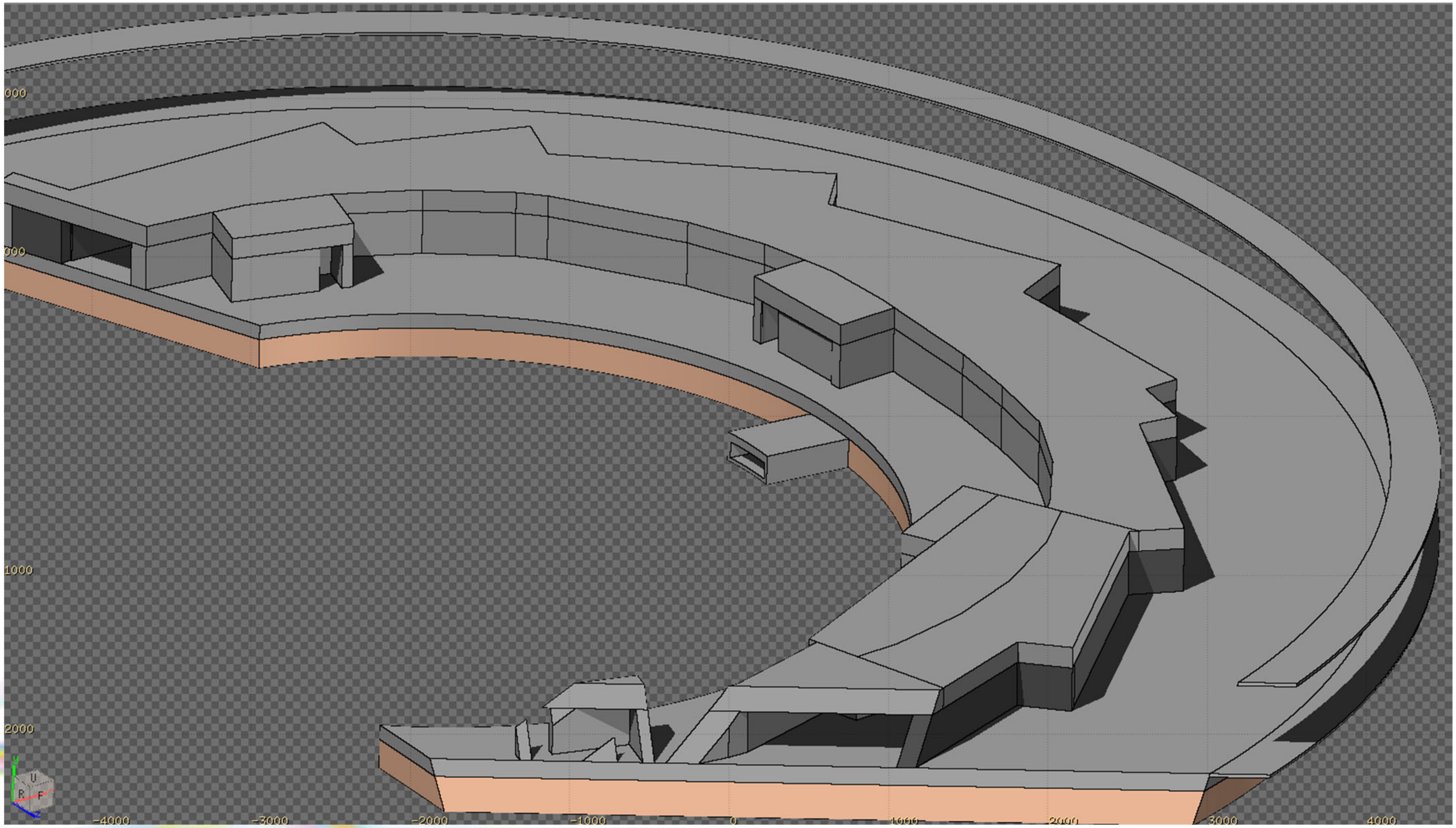
SW = Side wall; R = Roof

Access to the roof will be restricted in the above conditions and only possible under a Permit to Work (PTW) procedure that ensures the Booster is off.





Storage ring

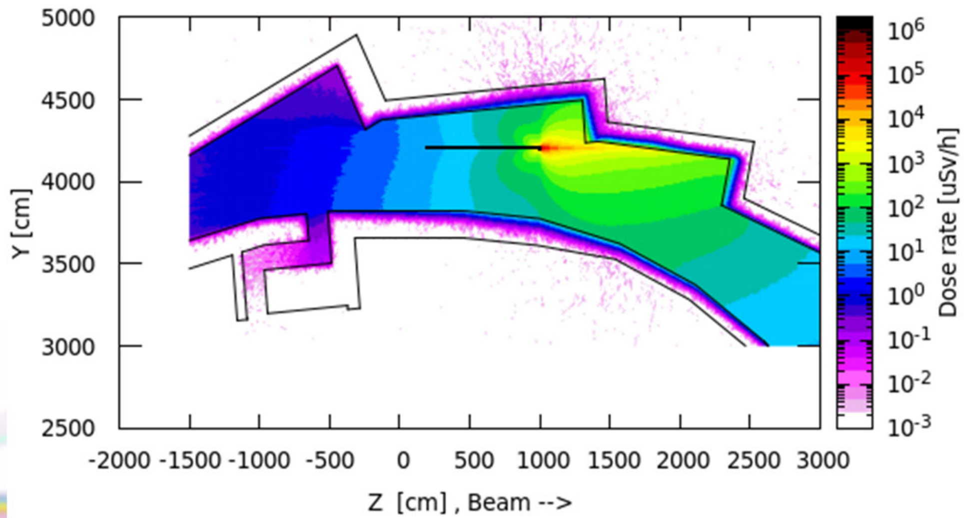


Storage Ring – normal loss

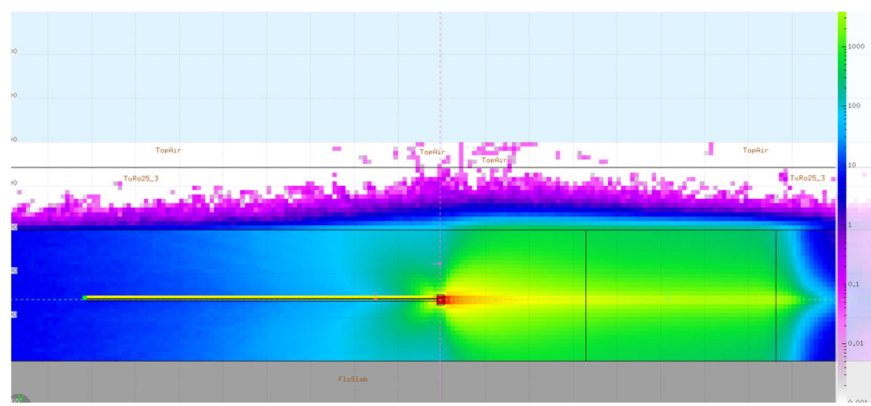
Loss Location	Losses e⁻/s	Dose rate outside shielding μSv/h	Comments
Cell12 Collimator	$4.2\ 10^8$	<0.02 [SW & R]	No additional controls are necessary for the hall area.

SW = Side wall; R = Roof

DLS2: Cell12 at collimator location for normal loss



DLS 2: Cell12 Roof dose distribution



Z [cm], Beam →

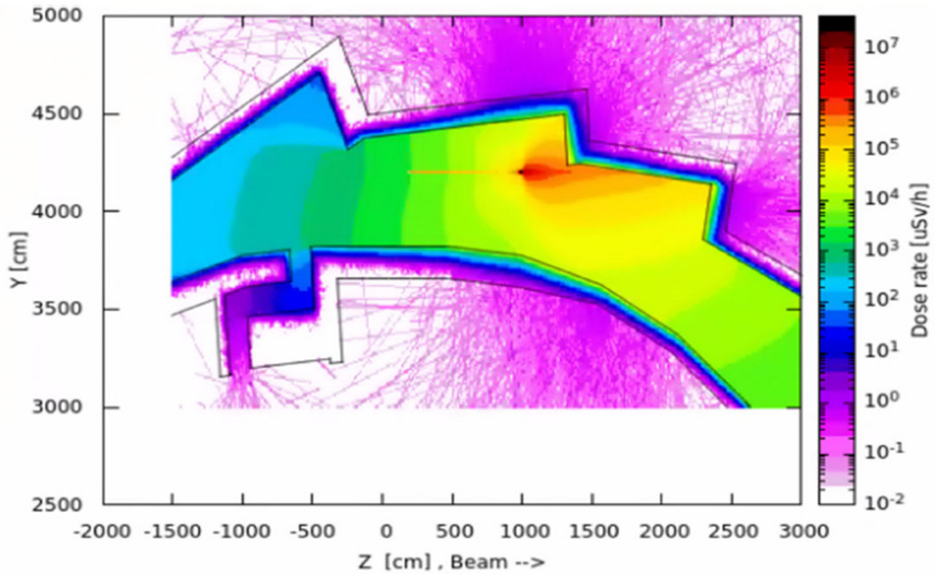
diamond

Storage Ring – abnormal loss

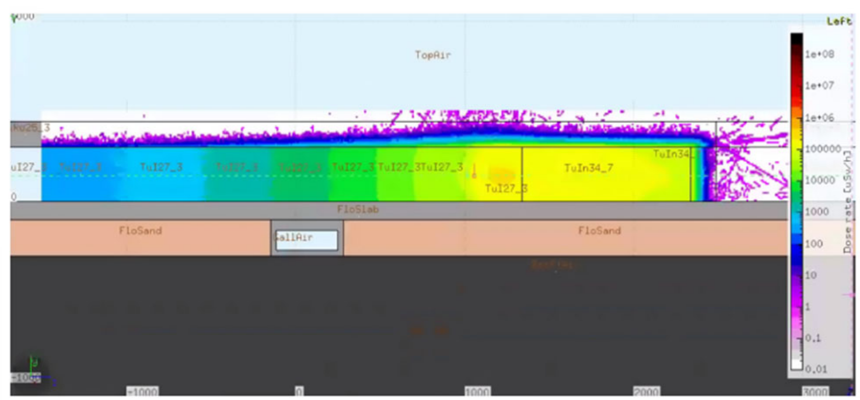
Loss Location	Losses e⁻/s	Dose rate outside shielding µSv/h	Comments
Cell12 Collimator	2.0 10^{11}	<0.5 [SW] <2.5 [R]	This would not require additional controls for the hall area. No additional roof controls are needed as the dose rate is below 7.5 µSv/h, and such conditions will not persist for a very long period.

SW = Side wall; R = Roof

DLS 2: Cell12 side wall dose distribution in an abnormal loss



DLS 2: Cell12 Roof dose distribution



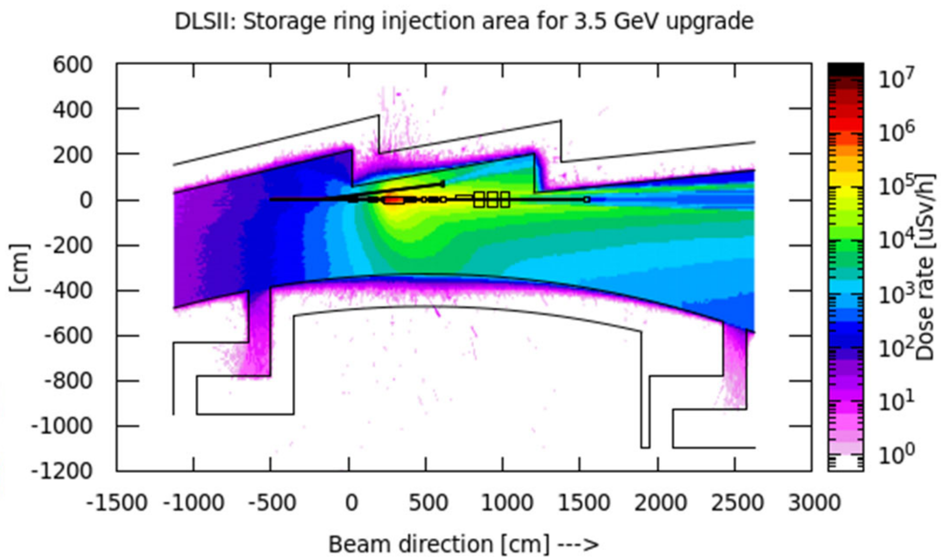
Z [cm], Beam →

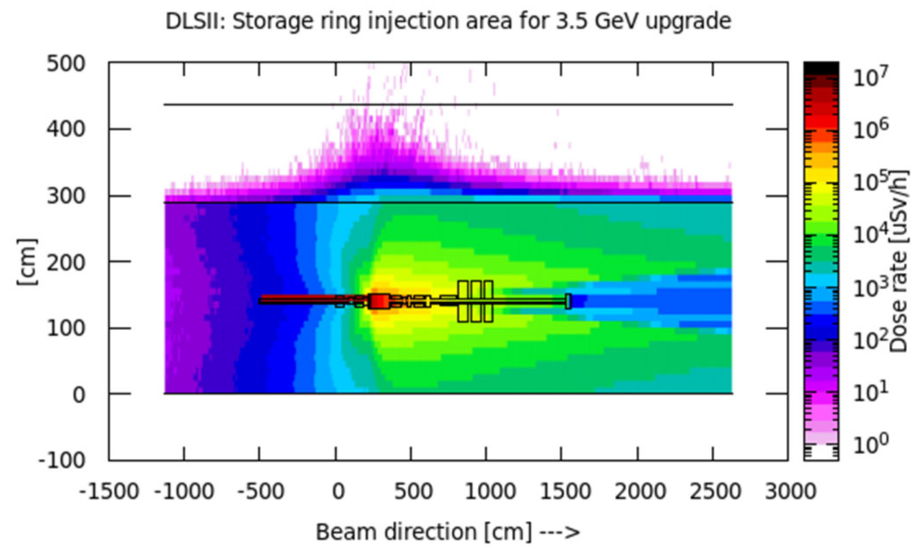
Storage ring: Injection area

The shielding is thicker in the injection area compared to other areas.

Loss Location	Losses e⁻/s	Dose rate outside shielding μSv/h	Comments
Injection Area	4.2 10^{8}	<0.02 [SW & R]	No additional controls are necessary for the hall area.
Injection Area	2.0 10^{11}	<0.5 [SW] <2.5 [R]	No additional roof controls are needed as the dose rate is below 7.5 μSv/h, and such conditions will not persist for a very long period.

SW = Side wall; R = Roof



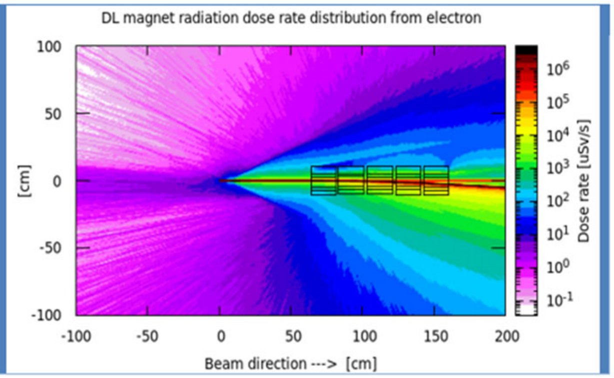


Ring component exposure dose /damage

Permanent magnet dose

Table 1 DL magnet Dose distribution from electron with collimator open.

Module	Face	Back
	(µSv/s)	
First	1400	200
Second	260	120
Third	230	140
Forth	280	190
Fifth	260	155



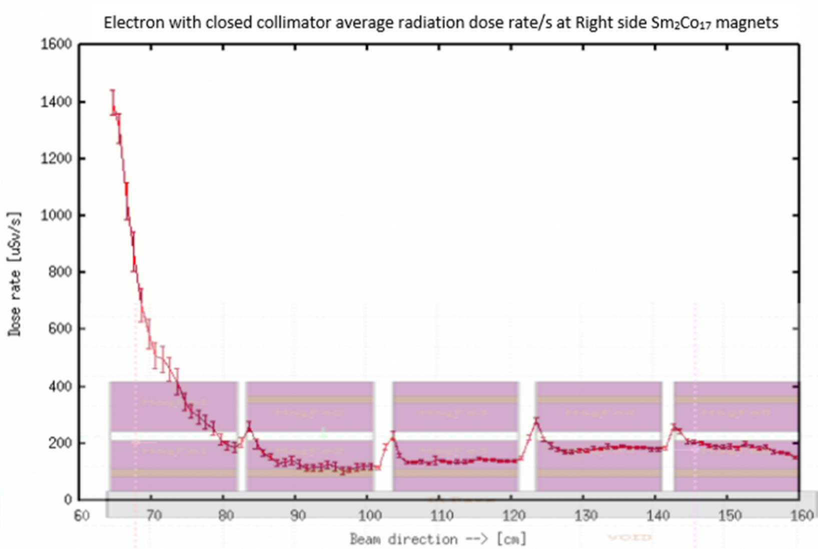


Figure 4 Electron dose rate with open collimator.

Collimator damage

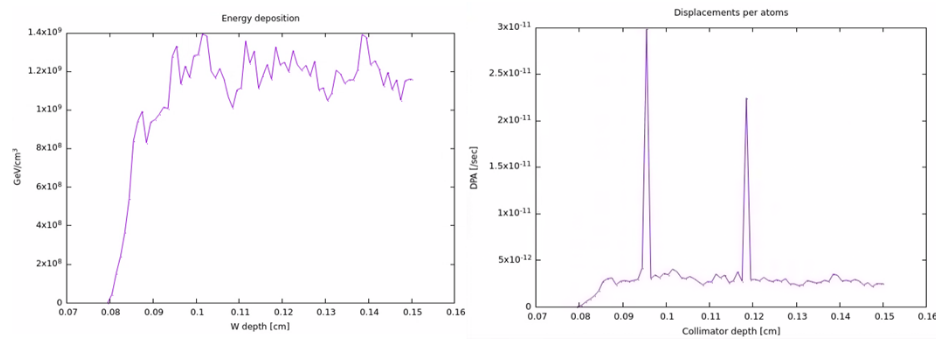


Figure - Total energy deposition by electrons over the target depth (left) and FLUKA DPA for e-loss condition – electron atomic displacements as a function of the target depth (right) at collimator open position.

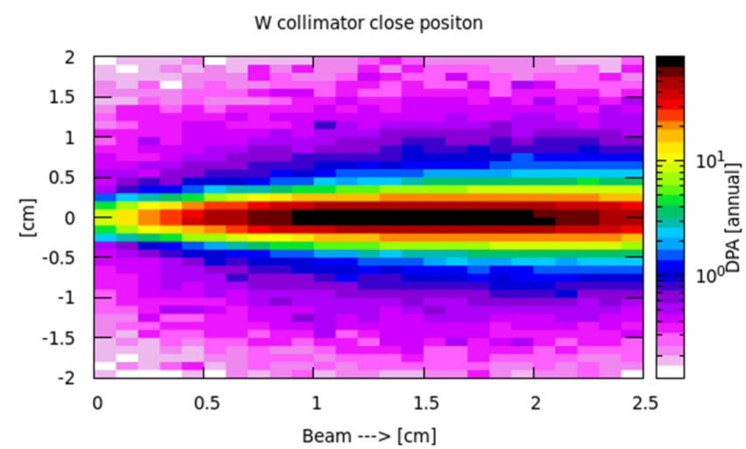


Figure 5 DPA from a year of exposure

Future work

Monte Carlo Models

- FLUKA MC activation calculations for Diamond-I decommissioning.
- Radiation dose assessment for the ring components for Diamond-II.

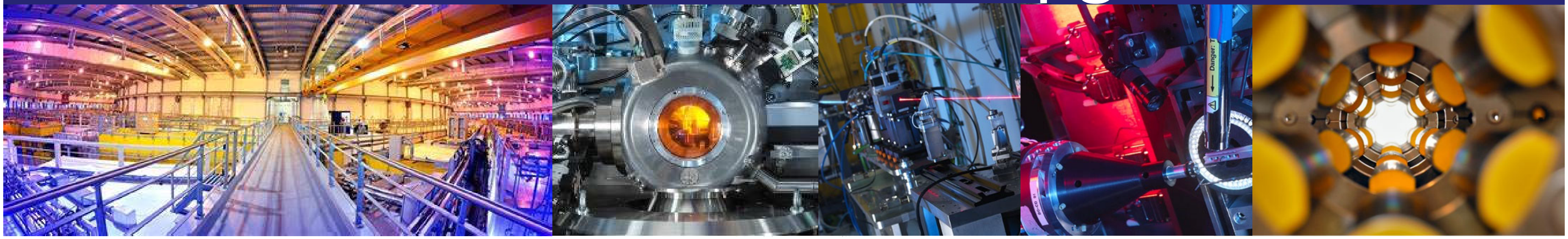
Finalise Beamline Shielding Calculations

FLUKA calculation for beamline optics hutch shielding.

Environmental impact assessment

Required by regulators for new facilities. This will assess the activation of ground water, cooling water and air etc.

Diamond II machine upgrade



Questions

Email: sanjeev.faruk@diamond.ac.uk
DLS website: https://www.diamond.ac.uk

Acknowledgement:

- FLUKA team & forum
- DLS Accelerator & Design Engineering team

References:

- "The FLUKA code: Description and benchmarking" G. Battistoni, S. Muraro, P.R. Sala, F. Cerutti, A. Ferrari, S. Roesler, A. Fasso`, J. Ranft, Proceedings of the Hadronic Shower Simulation Workshop 2006, Fermilab 6--8 September 2006, M. Albrow, R. Raja eds., AIP Conference Proceeding 896, 31-49, (2007)
- "FLUKA: a multi-particle transport code" A. Ferrari, P.R. Sala, A. Fasso`, and J. Ranft, CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773
- Gas Bremsstrahlung Considerations in the Shielding Design of the Advanced Photon Source Synchrotron Radiation Beam Lines, Nisy E. Ipe, Alberto Fasso , SLAC–PUB–6452.
- Impact of gas bremsstrahlung on synchrotron radiation beamline shielding at the advanced photon source, Nisy E. Ipe, Alberto Fasso SLAC–PUB–6410,