BNL-210962-2019-TECH

NSLSII-ESH-TN-092

Supplementary Shielding Specifications for the NSLS-II Booster Enclosure

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May 2012

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U.S. Department of Energy

USDOE Office of Science (SC), Basic Energy Sciences (BES) (SC-22)

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NSLS II TECHNICAL NOTE BROOKHAVEN NATIONAL LABORATORY	NUMBER **NSLSII-ESH-TN-092**
AUTHOR P. K. Job	DATE May 21, 2012
TITLE Supplementary Shielding Specifications for the NSLS-II Booster Enclosure –Rev3	

Bulk shielding at NSLS-II has been designed to reduce the ambient dose rates to < 5.0 μSv/h (0.5 mrem/h) at the exterior surface of the concrete shielding, during typical operation. This limits the maximum exposure to < 10 mSv/y (1,000 mrem/y) at the occupied areas, assuming 2,000 hours of occupancy per year.

The shielding strategy employed at NSLS-II for the accelerator enclosures is to use concrete bulk shielding to provide global shielding for probable distributed beam loss during normal operation. This shielding may need to be supplemented by additional local shielding, employing lead for bremsstrahlung and polyethylene for neutrons, to reduce radiation dose from the probable high beam loss to acceptable limits of < 5.0 μSv /h (< 0.5 mrem/h) at the occupied areas.

1. *Beam Loss Assumptions for Booster Shielding Computations*

Table 1 gives the beam loss assumptions used for the booster bulk shielding and supplementary shielding calculations. The bulk shielding computations are based on normal operational beam loss of a certain fraction of the beam power. To estimate the bulk shielding for the booster enclosure a point beam loss of 2% at the energy of 3000 MeV and 15 nC/m is assumed during top-off operation. The concrete bulk shielding requirements for the lateral walls and the roof of the booster tunnel have been calculated based on this beam loss scenario. For the supplementary shielding calculations of the linac to booster injection septum, a 50% loss of the injected beam at 15 nC/s of 200 MeV is assumed for 1 Hz injection. Similarly at the booster to storage ring extraction septum 20% injected beam loss of 3 nC/s at 3000 MeV is assumed for the supplementary shielding calculations.

Table 1: Beam Loss Assumptions for the Booster Shielding Calculations (for concrete bulk shielding and supplementary shielding).

	Beam loss (%)	Energy (MeV)	Power loss (W)	Charge loss (nC)
Booster Accelerator system	~ 2 %	3000	0.015	0.3 nC/min
Linac to Booster Injection Septum	~ 50 %	200	1.5	7.5 nC/s
Booster to Storage Ring Extraction Septum	~ 20 %	3000	9.0	3 nC/s
Booster Beam Stop	100%	3000	45.0	15 nC/s

The bulk shielding estimates in terms of concrete-equivalent thickness for the NSLS-II booster enclosure are given in Table 2. A 70-cm thick standard concrete with 2.35 g/cm^3 of density at the lateral walls and at the roof will limit the dose rate to < 0.5 mrem/h at the exterior of the bulk shielding on contact. When berm replaces concrete, thickness enhanced by a factor of 2 to 1 will provide the bulk shielding.

Table 2: Bulk Shielding Estimates of the Booster Enclosure Walls of NSLS-II.

	Lateral Wall Concrete Thickness (cm)	Roof Concrete Thickness (cm)
Booster synchrotron	70	70
Calculated Dose Rates (mrem/h)	0.32	0.32

The bulk shielding and the supplementary shielding of the booster to storage ring interface wall are based on an assumed beam loss of 20% of 15 nC/s at the booster to storage ring transfer line dipole. The calculations have been carried out with the forward-directed bremsstrahlung dose factors corresponding to 3.0 nC/s beam loss. The bulk shielding thickness of the booster to storage ring interface concrete wall is 100 cm of normal density concrete, enhanced by 35 cm of Pb supplementary shielding in the wall penetration.

2. *Booster Supplementary Shielding Specifications*

Preliminary supplemental shielding requirements have been analyzed in Appendix 1 (NSLS-II Technical Note 31, *Preliminary Material Requirement for the Supplementary Shielding at NSLS-II*, P.K. Job and W.R. Casey, July 2007). These calculations were later updated as more accurate accelerator parameters and beam loss estimates became available from accelerator simulations. The following materials and thicknesses have been established for supplementary shielding inside the booster enclosure. Table 3 summarizes the locations and specifications for these supplementary shielding.

2.1 *Booster to Storage Ring Wall Penetration:* Booster to storage ring wall penetration has been enhanced by lead. The thickness of lead has been determined by the beam loss assumptions at the booster to storage ring transfer line dipole. The forward component of bremsstrahlung for 3.0 nC/s beam loss at 3000 MeV has been considered. The shielding thickness has been calculated for a dose rate of ≤0.5 mrem/h at the exterior of the concrete bulk shielding inside the storage ring. This requires shielding of 35-cm thick lead with 100 cm x 100 cm transverse dimensions through the booster-to-storage ring interface wall penetration in addition to 65 cm of concrete bulk shielding.

2.2 *Linac to Booster Injection Septum:* An injection beam loss of 7.5 nC/s, at beam energy of 200 MeV, is assumed at the linac to booster injection septum. The bulk shielding of the booster enclosure at the injection septum location is concrete and berm. The supplementary shielding thickness in Pb has been calculated based on the total photon and neutron dose rates at the exterior of the berm. The required supplementary shielding for the injection septum is ≥ 10 cm-thick lead in the transverse directions (lateral and roof). The neutron shield (in polyethylene) is not necessary at the injection septum, because the probability for soil activation is negligible and the berm is not accessible during booster operation (ref NSLS-II Technical Note 88). It has been further decided by the SAOS task force that the inner wall supplementary shielding for the booster injection septum can be eliminated because the affected berm surface will be interlocked during operation. The dose rate at the berm surface adjacent to the septum without the supplementary shielding, during 1 Hz injection of 15 nC/s into the booster, is estimated to be ~25 mrem/h assuming a 50% injection loss.

2.3 Booster to Storage Ring Extraction Septum: A beam loss of 3 nC/s, at the beam energy of 3000 MeV, is assumed at the booster to storage ring extraction septum for the supplementary shielding calculations. The supplementary shielding thickness in Pb and polyethylene has been calculated based on total photon and neutron dose rates ≤0.5 mrem/h at the occupied regions. The required supplementary shielding for the extraction septum is 15 cm-thick lead in the forward direction; and 15 cm-thick lead and 20 cm polyethylene in the transverse direction at the storage ring side, and 10 Pb and 0 cm poly at the transverse berm side and 20 cm Pb and 25 cm poly at the top. The neutron shield (polyethylene) is not necessary at the berm side of the extraction septum, because the probability for soil activation is negligible and the berm is not accessible during booster operation (ref NSLS-II Technical Note 88). It has been further decided by the SAOS task force that the inner wall supplementary shielding for the booster extraction septum can be eliminated because the affected berm surface will be interlocked during operation. The dose rate at the berm surface adjacent to the septum without the supplementary shielding, during 1 Hz injection of 15 nC/s into the booster, is estimated to be ~22 mrem/h assuming a 20% injection loss.

2.4 Booster Beam Dump: A 100% of injected beam loss of 15 nC/s, at beam energy of 3000 MeV, is assumed at the booster beam dump. The supplementary shielding thickness has been calculated for total photon and neutron dose rates of ≤ 0.5 mrem/h at the exterior of the concrete bulk shielding inside the storage ring and the injector building. The core dump is ≥15 cm equivalent iron with transverse dimensions of ≥20 x 20 cm^2. The required shielding around the dump is; ≥ 35 cm thick Pb, and ≥ 35 cm-thick polyethylene in the forward direction; and ≥ 20 cm -thick lead and ≥ 25 -cm thick polyethylene in the transverse directions (lateral and top).

2.5 Booster to Storage Ring Transfer Line Dipole: The dipole in the booster to storage ring beam transfer line is shielded for likely mis-steering of the beam due to wrong settings of the magnetic field. Beam tracking simulations will be carried out to determine the maximum mis-steering angles as a function of magnetic field settings and the dose effects at the occupied regions. The required shielding will be calculated after the results of the tracking simulations are available.

2.6 *Booster Ramping Dipole Shadow Shields:* Booster ramping dipole shadow shields in lead, to shield the forward peaking bremsstrahlung component from beam loss at the ramping magnet vacuum chambers (the tangential component of bremsstrahlung radiation due to potential beam loss) from every two ramping dipole magnets is shielded by a single shadow shield protecting the occupied regions in the adjacent Storage Ring and the Injection Service Area. The forward bremsstrahlung component for a beam loss of 0.3 nC/s at 3000 MeV is assumed at the vacuum chambers for this shielding design. 20 cm thick lead blocks in the forward direction with appropriate transverse dimensions as specified in Table 3 is installed as the shadow shields.

2.7 Booster Extraction Kicker: A beam loss of 0.02 nC/s at 3000 MeV has been provided by the Accelerator Division for the calculation of the supplementary shielding at the booster extraction kicker in the booster to storage ring transfer line. The extraction kicker region is shielded by concrete and berm on the roof and one side. The supplementary shielding required for the storage ring side and the storage ring mezzanine has been calculated as 0.0 cm of Pb for this assumed beam loss.

2.8 Cable Tray and Wave Guide Penetrations: RF wave guide and cable tray penetrations are shielded for the same beam loss as the concrete bulk shielding. These penetrations are on the lateral walls at ~ 2.5 m above the floor. The required shielding for these penetrations is 10 cm of lead, preferably staggered wherever possible, and will be enhanced as determined by the radiation surveys during commissioning.

2.9 *Mekometer Ports for Survey and Alignment:* There are two Mekometer ports through the ceiling of the booster enclosure for the survey and alignment of the booster components. These are 30 cm-diameter circular openings through the booster enclosure ceiling that require the same shielding as the roof of the enclosure. Calculations have been carried out for the same loss of beam energy, as the concrete bulk shielding, 0.3 nC/s at 3000 MeV. The required shielding is calculated as 26.5 cm dia steel plates of thickness 25 cm, fitted into the circular Mekometer ports.

Table 3: Booster Supplementary Shielding Thickness Specifications.

Location	Beam Energy (MeV)	Beam Loss (nC/s)	Forward (cm)	Transverse SR side (cm)	Transverse Berm side (cm)	Top/Roof (cm)
Booster to SR Wall Penetration 100 cm x 100 cm transverse	3000	3.0	35 Pb, 65 Conc.	-	-	-
Booster Injection Septum[1]	200	7.5	15 Pb[2]	10 Pb[3] (berm)	0.0 Pb	10 Pb[3] (berm)
Booster Extraction Septum[1]	3000	3.0	15 Pb[2]	15 Pb 20 Poly (SR)	0.0 Pb	15 Pb 15 Poly
Booster Dump[1]	3000	15	15Fe,35Pb 35 poly	20 Pb 25 Poly	20 Pb 25 Poly	20 Pb 25 Poly
BtSR Transfer Line Dipole[4]	3000	15	TBD	20 Pb 25 Poly	-	TBD
Booster Extraction Kicker	3000	0.02	-	0.0	-	-
Booster Dipole Shadow Shields (extremal ray +3.6 cm transverse)[5]	3000	0.3	20 Pb	-	-	-
Cable tray/ wave guide penetrations	3000	0.3	-	10 Pb	10 Pb	-
Mekometer port shielding, 26.5 cm dia iron disks	3000	0.3	-	-	-	25 Fe

1. Length is determined by the component dimensions. (Nominal 15 cm overlap for splash back)
2. Dimensions determined by the forward ray tracing from the forward edge of the component
3. Poly shield is not necessary, analysis provided in Technical Note 88.
4. Waiting for mis-steered beam tracking analysis
5. Extremal ray from the upstream of the booster dipole magnets