Unreviewed Safety Issue (USI) Evaluation Form

USI Evaluation No.: NSLS-II-EVAL-2017-002

Title of USI Evaluation and Sponsor or Condition Owner:

Installation and Operation of 27-ID (HEX) Beamline w/Superconducting Wiggler

Steven Moss, NSLS-II Authorization Basis Manager

I. Description of Proposed Activity or Discovered Condition

The HEX Beamline will fill a special niche not served by other NSLS-II beamlines in high energy (150 KeV+) X-ray. It supports the NSLS-II program to examine materials in-situ and in-operando with the high energy of the X-rays provided by HEX allowing the examination of large samples, such as working batteries, both through diffraction and imaging studies. The conceptual design for HEX was based on the highly productive NSLS Beamline X-17, and like X-17 will be based on a Super Conducting Wiggler (SCW) source producing a wide fan of high energy X-rays. The SCW used at NSLS-II will be of modern design, utilizing an integrated closed liquid Helium system rather than a separate cryogenic plant, and will be optimized for the characteristics of the NSLS-II Storage Ring. The baseline scope of the HEX project will consist of the central line branch line and include a Satellite End-station Building (SEB). This provides the requisite beamline length for performing phase contrast imaging and space required for performing experiments on large samples. Future expansion anticipates two additional branches being built off the main. The proposed port for the HEX Beamline is 27-ID and the proposed HEX-SEB is patterned after the one constructed for HXN, and will be attached to the side of the LOB 2 Building (742).

REFERENCES

1) *Unreviewed Safety Issue Determination Procedure*, PS-C-ESH-PRC-002, Ver. 4, June 27, 2014.

2) *Safety Assessment Document for the National Synchrotron Light Source II*, PS-C-ESH-RPT-001, Ver. 3, May 2015.

3) *Amendment No. 1 to NSLS-II SAD of May 2015;* dated December 21, 2015 [containing DOE Approval of USI Evaluation No. NSLS-II-EVAL-2015-004, Rev. 1: *Re-Statement of NSLS-II ASE Stored Beam Lower Energy Limit for Storage Ring,* dated December 1, 2015]

4) *Amendment No. 2 to NSLS-II SAD of May 2015;* dated June 3, 2016 [containing DOE Approval of USI Evaluation No. NSLS-II-EVAL-2016-005: *Authorized*

Alternative for Lowering the Minimum NSLS-II Booster Electron Injection Energy Limit, dated May 25, 2016]

5) *Amendment No. 3 to NSLS-II SAD of May 2015;* dated January 30, 2017 [containing DOE Approval of USI Evaluation No. NSLS-II-EVAL-2017-001: *PPS Functional Testing and Recertification / Revalidation Interval Change from Every Six Months to Twelve Months,* January 17, 2017]

6) *Accelerator Safety Envelope (ASE) NSLS-II,* PS-C-ESH-ROASE-001, Ver. 5, January 2017.

7) *RSI for the Superconducting Wiggler Source and Front End for the HEX Beamline,*[NSLSII-27ID-RSI-001, Ver. 1 dated September 2017].

8) USI Evaluation No. NSLS-II-EVAL-2015-003, Rev. 1: *Installation and Operation of ABBIX Beamlines,* February 2, 2016.

II. Does the proposed activity or discovered condition affect information presented in the Safety Assessment Document (SAD) (e.g., regarding equipment, administrative controls, or safety analyses)?

NO – Within the Safety Assessment Document for the National Synchrotron Light Source II [PS-C-ESH-RPT-001, Ver. 3 dated May 2015], the following sections were reviewed without impact:

Section 3.3 – Accelerator Systems, especially **Subsection 3.3.5 – Beamline Front Ends** and **Subsection 3.3.3.8 – Photon Sources** which includes **Table 3.9 – Basic Parameters of NSLS-II Radiation Sources for Storage Ring Operation at 3.0 GeV and 500 mA** where there are listed a variety of devices including not only In-Vacuum Undulators (IVU), Elliptically Polarizing Undulators (EPU), Damping Wigglers (DW), Bending Magnets (BM), Three-Pole Wigglers (3PW), but also Superconducting Wiggler (SCW). Their characteristics are provided as typical for the specific type of Photon Source they represent, but do NOT constitute an absolute limit for any of the characteristics provided.

Section 3.9 – Radiation Protection Systems, including all subsections.

Section 3.12 – Beamline Installation and Operations, including all subsections.

Section 4.15 – Ionizing Radiation Hazards during Routine Operations, including all subsections. It has been noted that while Section 3.3.3.8 and Table 3.9 do include reference to superconducting wiggler(s) being photon sources, no specific superconducting wiggler is included for typical guidance for shielding of First Optics

Enclosures in Section 4.15.5 (Table 4.16 Shielding Guidelines for NSLS-II First Optics Enclosures); nor in Section 4.15.6 – Shielding Guidelines for the Experimental Enclosures (Table 4.18 Shielding Guidelines for Experimental Enclosures. A representative sample SCW will be added to each of those Tables when detailed calculations are completed to provide guidance. (Copies of affected pages are attached and marked).

Section 5.2 – Bases for Credited Controls for Operations at the NSLS-II Facility, and all subsections.

It should be noted that within Section 3.3.5 – Beamline Front Ends, it states:

As with insertion devices, front-ends will be continually added as NSLS-II expands. For devices of similar design to those already installed as part of the NSLS-II project, the devices will be designed, reviewed and installed in accordance with NSLS-II standard operating procedures. For devices of differing design, a USI evaluation will be performed prior to their installation to ensure there are no new or significantly different hazards associated with that device.

As a Superconducting Wiggler source was already listed in Table 3.9 within the SAD, the use of one here does not represent a new or significantly different hazard. While the specific characteristics of the Superconducting Wiggler being used for the HEX Beamline (27-ID) may slightly differ from the characteristics of the one already included within Table 3.9, it lies well within limits given in the table based upon the values shown for the device in Reference 7- *RSI for the Superconducting Wiggler Source and Front End for the HEX Beamline,* [NSLSII-27ID-RSI-001, Ver. 1 dated September 2017]. Specifically within Table 3.9, Row labeled "horizontal Angular Power Density [kW/mrad] has values which range from 0.023 to 16. The values for SCW60 are given as 6.6 for 3.5T and 11 for 6T. The actual SCW to be used here has a peak field of 4.3 T which corresponds to somewhere between 7.88 and 8.10 kW/mrad. This is about midway within the already given range.

as long as the NSLS-II Shielding Policy is complied with and established applicable Credited Controls are maintained as operational, there will be no increase in any previously acceptable risk.

III. **Does the proposed activity or discovered condition affect any of the requirements of the Accelerator Safety Envelope (ASE)?**

NO – The proposed beamline will conform to the requirements specified within the DOE-approved NSLS II ASE [PS-C-ESH-ROASE-001], Ver. 5 dated January, 2017;

the following sections were reviewed for impact on requirements, without any impacts found:

Section 2.2 – Credited Controls for Radiation Hazard; Criteria 2.2.1, 2.2.2, 2.2.3, and 2.2.5

Section 3 – Credited Control Supports; Criteria 3.1, 3.2, 3.3, and 3.5.

Section 4 – Calibration, Testing, Maintenance and Inspection That Maintain Credited Controls; Criteria 4.3 and 4.4.

IV. USI Evaluation Criteria

1. Could the change or discovered condition significantly increase the probability of occurrence of an accident previously evaluated in the SAD?

   ☐Y or ☒N

   Justification: As the SAD already describes a beamline based on the use of a Superconducting Wiggler source (though with slightly different characteristics than the one to be used for HEX), said beamline, so long as it complies with NSLS-II Shielding Policy and maintains applicable Credited Controls as operational, could NOT significantly increase the probability of occurrence of an accident previously evaluated in the SAD.

   Installation and operation of 27-ID (HEX) Beamline utilizing a Superconducting Wiggler source does NOT significantly increase the probability of occurrence of an accident, previously evaluated in the SAD.

2. Could the change or discovered condition significantly increase the consequences of an accident previously evaluated in the SAD?

   ☐Y or ☒N

   Justification: As the SAD already describes a beamline based on the use of a Superconducting Wiggler source (though with slightly different characteristics than the one to be used for HEX), said beamline, so long as it complies with NSLS-II Shielding Policy and maintains established applicable Credited Controls as operational, could NOT significantly increase the consequences of an accident previously evaluated in the SAD. The only way to increase the consequence of any accident event previously evaluated within the SAD would be to make a major change to a key parameter of the event itself or to add additional concurrent events to an already analyzed event. That cannot happen here as long as the commitment to NSLS-II Shielding Policy and established applicable Credited Controls are maintained. The installation and operation of 27-ID (HEX) Beamline utilizing a Superconducting Wiggler source could NOT significantly increase the consequences of an accident, previously evaluated in the SAD.

3. Could the change or discovered condition significantly increase the probability of occurrence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD?

   ☐Y or ☒N

   Justification: As the SAD already describes a beamline based on the use of a Superconducting Wiggler source (though with slightly different characteristics than the one to be used for HEX), said beamline, so long as it complies with NSLS-II Shielding Policy and applicable Credited Controls designated within the ASE are maintained, could NOT significantly increase the probability of occurrence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD.

   Installation and operation of 27-ID (HEX) Beamline utilizing a Superconducting Wiggler source does NOT significantly increase the probability of occurrence of a malfunction of equipment important to safety (e.g., engineered credited controls), previously evaluated in the SAD.

4. Could the change or discovered condition significantly increase the consequences of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD?

   ☐Y or ☒N

   Justification: As the SAD already describes a beamline based on the use of a Superconducting Wiggler source (though with slightly different characteristics than the one to be used for HEX), said beamline, so long as it complies with NSLS-II Shielding Policy and established applicable Credited Controls as designated within the ASE are maintained, could NOT significantly increase the consequences of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD. The only way to increase the consequence of any malfunction of equipment important to safety event previously evaluated within the SAD would be to make a major change to a key parameter of the event itself or to add additional concurrent events to an already analyzed event. That cannot happen here as long as the commitment to NSLS-II Shielding Policy and established applicable Credited Controls are maintained. The installation and operation of 27-ID (HEX)

Beamline utilizing a Superconducting Wiggler source could NOT significantly increase the consequences of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD.

5. Could the change or discovered condition create the possibility of a different type of accident than any previously evaluated in the SAD that would have potentially significant safety consequences?

   ☐Y or ☒N

   Justification: The SAD already describes a beamline based on the use of a Superconducting Wiggler source (though with slightly different characteristics than the one to be used for HEX); said beamline, so long as it complies with NSLS-II Shielding Policy and established applicable Credited Controls are maintained, could NOT create the possibility of a different type of accident than any previously evaluated in the SAD that would have potentially significant safety consequences. The installation and operation of an alternate beamline with a Superconducting Wiggler creates no new or different type of accident than any previously evaluated in the SAD that would have potentially significant safety consequences.

6. Could the change increase the possibility of a different type of malfunction of equipment important to safety (e.g., engineered credited controls) than any previously evaluated in the SAD?

   ☐Y or ☒N

   Justification: Based upon the answers to Questions 3 and 4; the installation and operation of a new beamline utilizing a Superconducting Wiggler source could NOT increase the possibility of a different type of malfunction of equipment important to safety (e.g., engineered credited controls) than any previously evaluated in the SAD.

V. USI Determination

A USI is determined to exist if the answer to any of the 6 questions above (in Section V) is "Yes." If the answers to all 6 questions are "No," then no USI exists.*

Does the proposed activity (or discovered condition) constitute a USI?

☐ Yes – DOE approval required prior to implementing, or discovered condition remedied in accordance with the Section 6.4 of PS-C-ESH-PRC-002, *Unreviewed Safety Issue Determination Procedure.*

☒ No – Proposed activity may be implemented with appropriate internal review, or no further action is required to address the discovered condition's impact on accelerator safety (other actions may be required to meet other PSD or Laboratory requirements).

*According to the SBMS Subject Area, *Accelerator Safety; Section 8 – Unreviewed Safety Issue (USI) Process; Step 6:* **If the USI Process determination is that the discovery or planned change will impact credited controls**, existing MCIs, create new MCIs or cause an increase in the risk classification as per the SAD risk table, **it is a USI**.

Steven H Moss 10/03/17

Prepared by: (Qualified Evaluator) *Date*

Robert J Lee 10-4-17

Approved by: *Date*

The shutter thickness under consideration is calculated for a contact dose of <0.05 mrem/h at the downstream end of the shutter. To satisfy this specified dose criterion, a minimum tungsten thickness of at least 18 mm is necessary. Being the most conservative case, this shutter thickness has been selected as the standard design for other beamlines.

4.15.5 Shielding for the FOE

Shielding must be provided in the FOE that is adequate to reduce the scattered radiation from both the bremsstrahlung and synchrotron beam sources. Table 4.16 gives the combined results of the STAC8 and EGS4 calculations for the shielding guidelines of the FOE for the project NSLS–II Beamline sources. Shielding thickness for each panel has been calculated for bremsstrahlung and synchrotron radiation and the thickness for the dominant source has been given. Enclosure dimensions are nominally taken as 2 m wide, 3 m high, and 10 m long. The lateral panel is at a distance of 1 m and the roof is at distance of 1.5 m from the Beamline in these calculations. If the final design of the stations and sources are different than the initial design the shielding estimates will need to be re–evaluated. The shielding thickness for the downstream panels of the FOEs is dominated by forward–scattered bremsstrahlung. Therefore a thickness of 50 mm for the FOE downstream panels has been recommended for the ID Beamline and 30 mm for the BM and 3PW Beamlines. Additional collimators and local shielding may be required around the beam pipe and wall penetration, depending on the Beamline configuration.

TABLE 4.16

4.16 SHIELDING GUIDELINES FOR NSLS–II FIRST OPTICS ENCLOSURES

BEAMLINE SOURCE	LATERAL PANEL (Pb)	ROOF PANEL (Pb)	DOWNSTREAM PANEL (Pb)
DW90	18 mm	10 mm	50 mm
EPU45	18 mm	5 mm	50 mm
IVU20	18 mm	6 mm	50 mm
3PW/BM	5 mm	4 mm	30 mm
SCW	TBD	TBD	TBD

To Be Added When Calculated

4.15.6 Shielding Guidelines for the Experimental Enclosures

Shielding in the experimental enclosures will be determined by the intensity of the synchrotron beam and is calculated using the STAC8 computer program. It is assumed that bremsstrahlung has been completely stopped in the first optics enclosures. Therefore EGS4 simulations are not necessary to estimate the shielding thickness for the subsequent experimental enclosures. Five reflections (111, 333, 444, 555, and 777) with corresponding bandwidths have been considered for these calculations with the lowest energy as 22 KeV. Monochromatic beam bandwidths are determined by the optics used. There are analytical (dynamical diffraction theory) and simulation codes (e.g. XOP) that are used to calculate the appropriate bandwidth. Currently, almost all monochromatic beams have bandwidths < 1%. Furthermore, the majority of them have 0.01% bandwidths (Silicon 111). Therefore, for monochromatic beam line shielding design, the process is that the designer calculates the optics bandwidth using available tools. That information is then used as input for radiation shielding calculations using FLUKA or STAC8.
Table 4.17 gives the energies and bandwidths considered for these calculations. Enclosure dimensions are assumed to be 2 m wide x 3 m high. Side panels are at a distance of 1.0 m and the roof is 1.5 m away from the beam centerline.

TABLE 4.17

4.17 ENERGIES AND BANDWIDTHS USED FOR EXPERIMENTAL ENCLOSURE SHIELDING CALCULATIONS

MONOCHROMATIC BEAM ENERGIES CONSIDERED (KeV)	MONOCHROMATIC BANDWIDTHS CONSIDERED (keV)
22	2.2×10^{-3}
66	5.3×10^{-4}
88	5.3×10^{-4}
110	1.3×10^{-4}
154	4.0×10^{-5}

The results of these calculations for five NSLS–II sources are provided in Table 4.18. The calculated shielding thicknesses in Pb or Fe for the side panels, roof, and upstream/downstream panels have been given for the contact dose rate of <0.05 mrem/h.

TABLE 4.18

4.18 SHIELDING GUIDELINES FOR EXPERIMENTAL ENCLOSURES

BEAMLINE SOURCE	LATERAL PANELS TO SHIELD<0.05 mrem/h	ROOF TO SHIELD< 0.05 mrem/h	UPSTREAM & DOWNSTREAM PANELS TO SHIELD < 0.05 mrem/h
DW90	4 mm Pb	3 mm Pb	4 mm Pb
EPU45	6 mm Fe	3 mm Fe	6 mm Fe
IVU20	6 mm Fe	3 mm Fe	6 mm Fe
BM	2 mm Fe	2 mm Fe	2 mm Fe
3PW	3 mm Fe	2 mm Fe	3 mm Fe

Add Row for 'SCW' with values TBD by calculation and inserted when Available

In most cases, the pink beam experimental enclosures (assuming 30–50 keV mirror cut–off energy) need the same shielding thickness as the monochromatic enclosures because of the absence of higher energy harmonics in the pink beam.

4.15.7 Shielding Guidelines for the Experimental Beam Transports

The beam transport pipes between the FOE and the experimental enclosures may require shielding depending on the source and experimental–beam characteristics of the Beamline. In every case, careful ray tracing of the synchrotron radiation must be carried out to ensure that no part of the beam hits the transport pipe.

STAC8 calculations have been carried out using 10 m of air at one atmosphere as the potential scatter source inside the beam transports, simulating a vacuum loss accident. For transport shielding calculations, the same conservative beam harmonic energies and bandwidths have been used as in the experimental enclosure shielding calculations. As loss of vacuum is an accidental condition, the dose rate criteria adopted for these calculations were <5 mrem/h on contact of the transport pipe. Calculations have also been carried out for the presence of potential solid scatterers such as flags/screens, etc. inside the beam transports, as this may require additional local shielding. The dose rate criteria applied for this operating condition is <0.05 mrem/h on the surface of the transport pipe. Table 4.19 summarizes these results.

In most cases the pink beam transports (assuming 30–50 keV mirror energy cut–off) have the same shielding thickness as the monochromatic beam transports because of the absence of higher energy harmonics in the pink beam. Thermal load handling of the pink beam needs separate analysis. However, bremsstrahlung component is assumed to be completely absent in the experimental beam.

TABLE 4.19

4.19 SHIELDING GUIDELINES FOR THE EXPERIMENTAL BEAM TRANSPORTS

BEAMLINE SOURCE	SHIELDING REQUIRED FOR < 5 mrem/h DUE TO COMPLETE VACUUM LOSS IN THE BEAM TRANSPORT	SHIELDING REQUIRED LOCALLY ON BEAM TRANSPORT FOR < 0.05 mrem/h FOR A SOLID SCATTERER
DW90	3 mm Pb	7 mm Pb
EPU45	1.5 mm Pb	3.0 mm Pb
IVU20	1.5 mm Pb	3.0 mm Pb
BM	2 mm Fe	3.0 mm Pb
3PW	3.0 mm Fe	3.0 mm Pb
SCW	TBD	TBD

To Be Added When Calculated

4.15.8 Abnormal Operating Conditions, Including Maximum Credible Incident

The combination of concrete and supplemental shielding described above for normal operation is based on the beam losses defined in those sections. Higher beam losses are possible during operation of the accelerators because of mis–set operational parameters or equipment failure. Fault Studies were conducted during commissioning to empirically measure the consequences of mis–set parameters and verify the shield design. Results of the Linac Fault Studies are reported in Appendix 15. A summary of the results of the Fault Studies and a comparison to calculations are presented in this section.

Linac

The maximum energy of the Linac assuming all three klystrons are fully tuned and powered has been calculated to be 250 MeV. During normal operation, the Linac can deliver a maximum of ~22 nC per pulse–train at a maximum rate of 1 pulse train per second. Analysis of failure modes within the Linac gun has identified highly unusual, but possible, fault scenarios in which an electron pulse of 100 nC could be produced at a repetition rate of 1 Hz or 360 μC averaged over one hour (Appendices 16 and 17). The MCI analysis for Linac assumes an electron energy of 250 MeV and a current of 100 nC/s.

The consequences of beam losses during Linac operation and transport were examined using FLUKA for beam mis–steering by quadrupoles or dipoles (see Appendix 6a). The resulting ambient dose equivalent was calculated for potentially occupied areas in the Linac Klystron Gallery and Booster enclosure, and on the berm on the top and side of the Linac enclosure. The highest calculated dose rates in each of the three regions of interest were scaled to 100 nC/s and are shown in Column 2 of Table 4.20 below. The peak measured rates for the Linac Fault Study scaled to 100 nC/s are shown in the third column.

TABLE 4.20

4.20 COMPARISON OF LINAC PEAK CALCULATED DOSE RATES TO PEAK MEASURED VALUES DURING COMMISSIONING FAULT STUDIES

(All Values Scaled to 100 nC/s) (Dose rates are in mrem/h)

LOCATION	PEAK FLUKA ESTIMATE	PEAK MEASURED DOSE RATE
Klystron Gallery (through wall)	50	5
Klystron Gallery (through penetration)	300	67
Booster Enclosure	20	42
Berm top	<2	Background