NSLS-II BDN BEAMLINE 4-BM (XFM) COMMISSIONING PLAN

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NSLSII-4BM-PLN-002
REV. 1
Acronyms

3PW  Three-pole Wiggler  KB  Kirkpatrick-Baez
BDN  Beamlines Developed by NSLS-II  mA  milli-Ampere
Be  Beryllium  MBV  Multi-beam Viewer
BM  Bending Magnet  MSK  Mask
BNL  Brookhaven National Laboratory  NSLS-II  National Synchrotron Light Source II
CSS  Control System Studio  PASS  Proposal, Allocation, Safety and Scheduling
DCM  Double Crystal Monochromator  PPS  Personnel Protection System
EPS  Equipment Protection System  PSD  Photon Science Division
ESH  Environment, Safety and Health  PUG  Partner User Group
ESR  Experiment Safety Review  SAF  Safety Approval Form
FE  Front End  SOE  Second Optical Enclosure
FOE  First Optical Enclosure  SR  Synchrotron Radiation
FLUKA  Fluktuierende Kaskade (Monte Carlo simulation software)  SSA  Secondary Source Aperture
GB  Gas Bremsstrahlung  TCP  Technical Commissioning Plan
GRW  Graphite Differential Pumping Window  TPW  Three-Pole Wiggler
ID  Insertion Device  XAFS  X-ray Absorption Fine Structure
IRR  Instrument Readiness Review  XFM  X-ray Fluorescence Microprobe
XRF  X-Ray Fluorescence
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1. **INTRODUCTION**

This plan outlines the actions needed to commission the NSLS-II BDN 4-BM (XFM [X-ray Fluorescence Microprobe]) Beamline from the accelerator enclosure ratchet wall to the endstation. Once the readiness process is complete and authorization to begin commissioning the beamline is received, the technical commissioning will proceed, initially hand in hand with a radiation safety commissioning, until the beamline is deemed to be radiation safe in standard X-ray operations. In the latter stages of technical commissioning, the main optical elements of the beamline are optimized for routine operations, and finally the end-stations are commissioned. There are several processes established to manage the risks associated with this task, which are outlined below.

The scope of this plan includes managing specific commissioning activities for the beamline, reviewing requirements for equipment not needed for commissioning, but planned for operations, and the basis for transitioning to operations. Technical commissioning of the FEs and IDs is managed separately from the beamline.

2. **SHIELDING**

Ray tracing and computer simulation (FLUKA) indicate that 4-BM is shielded for the maximum planned stored electron beam current of 500 mA. The primary Gas Bremsstrahlung ray traces have been completed in accordance with *Synchrotron and Bremsstrahlung Ray Trace Procedure* (PS-C-XFD-PRC-008) and *Insertion Device Front End Ray Tracing Procedure* (PS-C-ASD-PRC-147) and top-off safety analyzed, resulting in one primary Bremsstrahlung collimator and a primary Bremsstrahlung stop within the 4-BM-A hutch. Secondary Gas Bremsstrahlung collimators and shields were designed following NSLS-II guidelines. The scattering of Bremsstrahlung has been simulated using FLUKA, which showed that the secondary collimators and shields are adequate at 500 mA beam current. The summary of these simulations including the simulation of synchrotron beam containment in beam transport and endstation enclosures are provided in *4-BM XFM Beamline Radiation Shielding Analysis* (Tech Note #259).

3. **BEAMLINE COMMISSIONING**

The commissioning of the XFM beamline and its transition to operations begins with the IRR. This will be followed by the first two phases of the Technical Commissioning Plan (TCP), in which the electron beam current is gradually increased while monitoring equipment safety. The TCP is conducted in parallel with Radiation Survey Commissioning, which monitors radiation safety as the ring current is increased. When the beamline equipment has been demonstrated to be capable of safe operation during standard X-ray operations, there is a final comprehensive radiation survey. The TCP then moves on to a new phase, in which all the key optical components, such as the mirrors and monochromator, are commissioned in detail in order to determine optimal operating parameters. In a
final phase of the TCP, the endstations are commissioned. Scientific commissioning will then follow, with the participation of the Partner User Group (PUG), to verify that the beamline meets the design performance goals and to build up endstation and beamline parameters and configurations that optimize beamline performance for routine User Operations. Technical and Scientific Commissioning will follow a phased approach, wherein initial capabilities are commissioned for User Operations while later capabilities are still in the Technical or Scientific Commissioning stage, provided this is done in a safe manner.

3.1 Radiation Survey Commissioning

A comprehensive XFM Beamline (4-BM) Radiation Survey Procedure (NSLSII-4BM-PRC-001) was developed in accordance with NSLS-II Beamlines Radiation Safety Commissioning Plan (PS-C-XFD-PRC-004), which guides the steps needed to control radiological hazards. It includes specific hold points to manage identified radiation risks and maintain commissioning within an approved envelope. The Radiation Survey Procedure requires participation and coordination between Beamline, Operations, Radiological Control, and ESH Staff. It identifies specific radiation scatter points along the beamline and provides instruction for mechanical manipulation of the optics to allow for a comprehensive radiological survey along the beamline. Execution of the Radiation Survey Procedure, along with the evaluation of the data collected, will be used as a basis by the PSD Director and ESH Manager to approve commissioning activities at an electron beam current of up to 3 times the electron beam current measured during the survey. Approval of commissioning of the beamline at a higher electron beam current requires re-execution of the Radiation Survey Procedure. The maximum current allowed during commissioning is indicated on the Caution Tag that is applied by Operations Staff to the beamline enable key. Enabling the beamline at a higher current requires re-execution of the full Radiation Survey Procedure and re-approval by the PSD Director and ESH Manager.

3.2 Technical Commissioning

The TCP, described in Section 7 below, documents in some detail the sequence of activities planned to safely commission the beamline. The TCP starts with lowest ring current, and gradually increases ring current until it is at the value for standard operations. At the completion of the TCP, all major beamline components will be ready to use, and parameters that optimize their performance will be documented.

3.3 Scientific Commissioning

The XFM beamline is designed for microbeam X-ray Fluorescence (XRF) imaging and high-quality X-ray Absorption Fine Structure (XAFS) Spectroscopy. A scientific commissioning plan will be developed while the technical commissioning takes place. The goal of the scientific commissioning will be to define the beamline parameters and configurations needed for the anticipated scientific program, and the process to bring the complete beamline into routine operations for users.
4. **COMMISSIONING ACTIVITY APPROVAL**

Work planning needed for safe and efficient commissioning, requires a commissioning SAF, and is performed in accordance with *Experiment Safety Review* (PS-C-ESH-PRC-039). This process drives definition of scope, identification of hazards and controls, and review and approval of requirements for all commissioning activities. A commissioning SAF describing the commissioning tasks to be undertaken by the commissioning team will be submitted. This form will include the equipment and materials that will be used, the personnel authorized to participate in the commissioning and any controls that will be placed on the beamline (such as a current limit). This form will be submitted to the ESH Manager and PSD Director for approval. This commissioning activity approval process authorizes the commissioning team for a specific task or tasks (such as performing a radiation survey) thereby enforcing a step-by-step and HOLD point approach to commissioning. Most commissioning tasks are expected to take approximately one week to complete, though some may be longer. All commissioning activities will be reviewed on a weekly basis to determine if a new commissioning SAF is needed. This allows for flexibility in the commissioning process, but at the same time ensures that during commissioning the work is periodically reviewed and that the necessary controls are placed on the commissioning activities.

An approved commissioning SAF is required for the beamline to be enabled. Beamline enable is managed in accordance with *Enabling Beamlines for Operations* (PS-C-XFD-PRC-003). This procedure defines the process for enabling the beamline safety shutter and for giving control of that shutter to the Beamline Staff. The process requires participation and coordination between Beamline, Operations, and ESH Staff. A checklist is employed to assure systems are ready (PPS and safety system configuration control) and that staff is prepared to begin.

5. **END STATION EQUIPMENT ADDITIONS**

Experimental modules will be added to the end station as commissioning moves from technical to scientific, and the focus is shifted to optimizing the photon beam and preparing end station instrumentation for the expected scientific program. All equipment will be added in accordance with the *NSLS-II Process Description: Review Process for Facility Additions and Modifications* (PS-C-CMD-PLN-001), which provides a process for determining the type and extent of reviews warranted.

The end station equipment additions for the beamline have been evaluated and it has been determined that the addition of this equipment will not constitute a sufficient modification of the beamline instrument, and therefore will not require an IRR. These additions will be reviewed through the BNL ESR process, in accordance with *Experiment Safety Review* (PS-C-ESH-PRC-039). This system allows for the treatment of the end stations as experiment areas and provides an electronic mechanism to gather the information needed to define and review equipment and materials in that area. The BNL ESR system contains fields for entry of the equipment and materials to be used, task analyses, control requirement definition, and for ESH review and approval. This approach will be documented in a
Tailored Review Plan in accordance with the *NSLS-II Process Description: Review Process for Facility Additions and Modifications* (PS-C-CMD-PLN-001).

The ESRs will be posted at the end station so that they are readily available and provide an ESH envelope of the allowed equipment and activities in the area. This system is used in experiment spaces throughout BNL. Annual review and approval is required, but any change also triggers a system update with an approval requirement. This system will assure careful management of equipment additions and will be correlated with the ESR process planned for the management of User activities.

6. **End of Commissioning; Transition to Operations**

Commissioning ends when the beamline has shown, through the execution of procedures and surveys, that it meets the NSLS-II Shielding Policy, that radiation leakage or scatter is controlled to as low as reasonably achievable, that the photon beam is prepared for User Operations, that the beamline control system is ready for data collection, and that the necessary authorizations for beginning operations have been obtained. Prior to the beamlines commencing User Operations, the process outlined in *Beamline User Readiness* (PS-C-XFD-PRC-030) will be completed.

The safety of ongoing beamline operations will be managed with the *Experiment Safety Review* (PS-C-ESH-PRC-039) process, which will control materials, equipment, and tasks at the end station areas through the use of the BNL electronic ESR system. A Cognizant Space Manager is assigned to the area and has responsibility to assure that the system is current and accurate. This system provides a valuable envelope for the resources and allows operations at each location.

Individual experiments will be managed with the electronic SAF section of PASS; a system for Proposal, Allocation, Safety, and Scheduling for User science. The SAF will allow collection of information specific to each experiment and will be reviewed by NSLS-II Staff to determine what hazards are outside the safety envelope established. The SAF will provide the mechanism for definition of scope, analysis of hazards, establishment of controls, and collection of feedback for each experiment. Users must identify the materials and equipment they wish to bring along with a task analysis describing how those items will be used. An iterative review between the User, Beamline, and ESH Staff results in a final approval with definition of requirements.

The SAF process combined with the BNL ESR safety envelope provides the basis needed to assure ongoing control of beamline operation and changes. No additional readiness reviews are expected for the 4-BM beamline at this time.
7. XFM BEAMLINE TECHNICAL COMMISSIONING PLAN

7.1 XFM Beamline Subsystem Definition

a. Beamline vacuum system. This subsystem includes the following components:
   - Graphite differential-pumping window (GRW)
   - FOE Slits with ion pump
   - Mirror 1 with ion pump and NEG
   - Fixed Masks 1 & 2 (instrumented as beam viewer), and lead collimators 1 & 2
   - Shielded beam transport between FOE and SOE includes Fixed Mask 3 and lead collimator 3 (secondary Bremsstrahlung), ion pumps (IP5 – 8), pneumatic-driven diagnostic screen, and secondary source aperture (SSA)
   - Fixed Mask 4 and lead collimator 4 (secondary Bremsstrahlung)
   - Mirror 2 with ion pump
   - Double-crystal monochromator (DCM) with ion pump
   - Multi-beam viewer (MBV) diagnostic unit
   - Fixed Mask 5 and tungsten secondary Bremsstrahlung shield
   - Photon Shutter with ion pump
   - Beam tube and Be window at entrance to Endstation (4-BM-C)

b. Toroidal Mirror System (Mirror 1) for primary focusing

c. Diagnostic at mid-point of toroidal mirror focal length

d. Secondary Source Aperture (SSA)

e. Vertically Collimating Mirror System (Mirror 2)

f. Fixed-exit Double-Crystal Monochromator (DCM)

g. Multi-Beam Viewer (MBV)

h. Photon Shutter

i. Microscope Endstation, including slits, detectors, KB mirrors, and sample stage with optical camera

7.2 XFM Beamline Commissioning Without Beam

a. Beamline Vacuum System
   - Verify that all ion pumps and gauges are functional.
   - Pump down each vacuum section; vacuum leak check and remedy if necessary.
- Verify water flow in cooling system for mirrors, diagnostics and monochromator using flow switches integrated into the EPS system.
- Verify the functionality of the EPS system in response to vacuum failures, by simulating trip signals from the vacuum gauge controller.
- Verify the functionality of the EPS system in response to insufficient water flow on water-cooled components.
- Verify the functionality of the EPS system in response to temperature faults on water-cooled components.
- Test photon shutter and verify that the PPS system is functional.
- Verify the functionality of the CSS vacuum screen.

b. Toroidal Mirror System (Mirror 1) for Primary Focusing
   - Verify all motor motion, including the mirror support stages and the mirror bender
   - Verify the functionality of the CSS screen.
   - Place mirror in its nominal out-of-beam position based on the survey results obtained during installation, in preparation for alignment with beam.

c. Beam Visualization Diagnostics
   - Verify motion and move diagnostics into nominal position.
   - Verify diagnostic cameras are aligned and in focus based on visible references.

d. Secondary Source Aperture (SSA)
   - Verify all motor motion.
   - Verify the functionality of the CSS screen.

e. Vertically Collimating Mirror System (Mirror 2)
   - Verify all motor motion, including the mirror support stages and the mirror bender.
   - Verify the functionality of the CSS screen.
   - Place mirror in its nominal position out of beam based on the survey results obtained during installation, in preparation for alignment with beam.

f. Double-Crystal Monochromator (DCM)
   - Verify all motor motion: Bragg, second-crystal offset, second-crystal pitch, and second-crystal roll.
   - Place all motors in default position (out of beam) based on survey results obtained during installation.
g. Microscope Endstation Systems:
   o Slits:
     - Verify all motor motion.
     - Verify the functionality of the CSS screen.
   o Detectors:
     - Verify all connections.
     - Verify signal chain functions properly for commissioning activities.
   o KB mirrors for compound focusing:
     - Verify all motor motion.
     - Verify the functionality of the CSS screen.
     - Position mirrors in nominal position.
     - Note KB mirrors shall be moved out of the beam path for primary focus beam mode.
   o Sample stage with optical camera:
     - Verify all motor motion.
     - Set EPICS soft limits, as necessary.
     - Verify camera function.

h. Data Acquisition System
   o Test video from cameras that view various beam visualization screens.
   o Test data collection and handling as required for commissioning.
7.3 XFM Beamline Commissioning With Beam

Figure 1: Schematic illustration of XFM beamline optical scheme. For more details, see Appendix A: XFM Beamline Component Layout.

7.3.1 Pre-beam Commissioning Activities

The three-pole wiggler (3PW) source has been installed at 4-BM and will be commissioned by the Accelerator Division in September 2017.

Prior to the beamline commissioning activities, the following prerequisites shall be satisfied:

- IRR completed and pre-start findings closed
- PPS and EPS functional
- Accelerator operating at current determined by the accelerator division
- 3PW source and front end commissioned
- FE slits controllable by beamline control system, slit-current reading functional
- Cameras connected and working to align beam with respect to visualization screens
- Beamline control environment with basic capabilities (e.g., motor control) and basic graphics and user interface available
- For a given commissioning-with-beam activity, relevant commissioning-without-beam activities are completed

7.3.2 First-beam Extraction and Radiation Surveys

Accelerator studies time is required to conduct Gas Bremsstrahlung (GB) and Synchrotron white and pink beam radiation (SR) surveys as described in the Radiation Survey Procedure (NSLSII-4BM-PRC-
These radiation surveys are initially carried out at low electron beam currents; a succession of successful radiation surveys will allow increasing the electron current stepwise, with the goal to obtain authorization to operate the beamline during regular accelerator operations, for the purpose of beamline optics commissioning, beam characterization and endstation commissioning.

It should be noted that there is no optical component in the FE. Thus, upon the opening of the FE photon and safety shutters, white beam enters the FOE, where it can be shaped by the FOE slits before striking the toroidal focusing mirror (M1) as the first optical component. During the GB/SR radiation survey, the M1 mirror is positioned based on the survey results obtained during installation; FE and FOE slits shall be fully open; and diagnostic screens and cameras shall be used to visualize and verify the presence of beam.

### 7.3.3 Transition to Operation Condition & Beamline Optics Commissioning

#### 7.3.3.1 Prerequisites for Beamline Technical Commissioning

Preliminary commissioning phase of the 3PW and FE performed by the Accelerator Division:

- 3PW insertion
- Primary FE slits positioning and alignment, with electrometer current signals
- Vacuum conditioning

#### 7.3.3.2 Goals of Beamline Optics Commissioning

The goal is to achieve complete control and understanding of beamline optics operation, energy selection, beamline alignment procedure, and beamline optimization for different experimental configurations.

#### 7.3.3.3 Commissioning Sequence

**Basic Commissioning of the Photon Delivery System:**

- Initial alignment of FE slits:
  - Use the drain current measurements from the slit blades to obtain the beam center position for each of the 4 slit blade axes. Compare to surveyed mechanical center position.
  - Adjust the slit openings to set the nominal beam acceptance to 0.12 mrad H x 0.25 mrad V.
  - Monitor vacuum until the maximum beam current is reached.
- Initial alignment of FOE slits:
  - Using Fixed Mask 1 (instrumented for beam visualization), obtain the beam center position for each of the 4 slit blade axes.
- Adjust the slit openings to set the nominal beam acceptance to 0.12 mrad H x 0.25 mrad V.
- Monitor vacuum until the maximum beam current is reached.

  o Initial alignment of the horizontal-deflecting toroidal mirror (M1):
    - Begin with the mirror retracted from beam. Insert M1 upstream end to eclipse half of the beam to obtain a reference position. Retract upstream end and set pitch to nominal 3.0 mrad, observing reflected beam on MSK1 diagnostic screen.
    - Monitor vacuum and EPS status until the maximum beam current is reached.
    - Adjust yaw to center M1 vertically (recall M1 is horizontal-deflecting mirror).
    - Adjust pitch and X translation to direct reflected beam through MSK 1 diagnostic screen.
    - Observe reflected beam at MSK 2 diagnostic screen. Small adjustments to pitch and X translation may be required to direct beam through MSK 2.
    - Observe beam at mid-point diagnostic screen (mid-point of toroid focal length). Adjust M1 yaw to maintain symmetric reflection. Further adjust M1 pitch and X translation to direct beam through MSK 3.
    - With Secondary Source Aperture (SSA) fully open, observe focus on diagnostic screen downstream of SSA. Adjust pitch of M1 for vertical focus and bend for horizontal focus.
    - With M2 and DCM fully retracted, observe pink beam on diagnostic screen (MBV). Obtain reference position.

  o Initial alignment of the vertically collimating mirror (M2):
    - Begin with M2 (and DCM) retracted from beam. Configure lateral motion of M2 to select the bare Si stripe.
    - Observe pink beam on diagnostic screen (MBV). Insert M2 upstream end to eclipse half of the pink beam. Sweep pitch with downstream end (+/-), find and set zero pitch.
    - Set pitch to nominal 3.0 mrad, observing collimated pink beam (“purple” beam) on MBV.
    - Adjust M2 bend for crude collimation (fine collimation will require Hartmann tests); collimated beam height observed at MBV should be ~1 mm.
    - Retract MBV diagnostic.
- Adjust M2 pitch as needed to guide the reflected “purple” beam through the aperture in pink beam stop.
- Using camera and fluorescence screen on optical table for beam visualization, verify the presence of “purple” beam in the Endstation.
- Complete comprehensive radiation survey.
- Conduct initial flux and characterization measurements of “purple” beam in the Endstation. Configure lateral motion of M2 to select the Rh stripe and repeat flux and characterization measurements. Return to bare Si stripe.

  o Initial alignment of the monochromator (DCM):
    - Configure lateral motion of DCM cage for Si (111) crystals. Move Bragg angle so that the X-ray energy is near 10 keV.
    - Observe monochromatic beam on the MBV.
    - Adjust second crystal tilt to optimize intensity and profile of monochromatic beam.
    - Adjust second crystal roll to minimize horizontal beam motion when the Bragg angle is varied.
    - Monitor the effect of vibration on beam stability. Identify correlations to vibration sources.
    - Configure the Bragg motion of the monochromator, and the parallel and perpendicular motions of the second crystal, over the full energy range of the beamline in order to fully define an energy axis for the monochromator operating with a fixed exit height.
    - Retract MBV diagnostic. Observe monochromatic beam using ion chambers and/or fluorescent screen, with the camera on optical table in the Endstation.
    - Perform rocking curve measurements of the second crystal at several monochromator angles.
    - Perform energy calibration using foils and a variety of standard XAFS measurements using the monochromatic beam.

At this stage, a number of beam position, flux and characterization measurements will be conducted in the Endstation to establish optimal alignment of M2 and the DCM. For example, Hartmann tests will be used to fine-tune M2 collimation for optimal energy resolution. In practice, the beamline will be functional as a transmission XAFS beamline using the primary focus provided by the M1 mirror. Following these beam position, flux and characterization measurements of monochromatic beam (including XAFS spectroscopy measurements across the full energy range of the instrument), the beamline will commission compound focusing using the combination of M1 and KB mirrors.
- Initial alignment of the KB mirrors:
  - Perform slit scans to locate monochromatic beam. Match entrance slits aperture to KB mirror acceptance (~0.7 x 0.7 mm).
  - Align KB enclosure to monochromatic beam, such that beam passes mirror benders and exits the enclosure; X-ray sensitive “burn” paper could be helpful for the initial alignment.
  - Visualize beams (unfocused, H-line focus, V-line focus, and 2D focus) on fluorescence screen at sample position; depending on pitch and height of mirrors, not all may be visible at once. Find unfocused beam, then set KB mirror height to eclipse half of the beam and sweep pitch (+/-), find and set zero pitch, set pitch to nominal angle (3.5 mrad).
  - Observe beam on a YAG screen at the sample position and optimize focus (at small SSA aperture) using bend adjustments of both KB mirrors. Confirm optimization of focus over a range of SSA settings, while monitoring flux in the downstream ion chamber.
  - Using appropriate test patterns and knife edges, beam intensity monitors etc., characterize and tabulate spot size and flux at various SSA settings.
  - Perform a variety of standard transmission-mode micro-XAFS spectroscopy measurements with standard reference materials (e.g., foils).
  - Perform transmission-mode micro-XAFS spectroscopy measurements on particles of similar size to microfocused beam.
  - Identify and resolve any beam motion during energy scanning.
  - Monitor the effect of vibration on beam stability. Identify correlations to vibration sources.

7.3.3.4 Experimental Station and Data Acquisition Commissioning

Having completed the activities described above, the beamline will meet the baseline for a functioning micro-XAFS spectroscopy endstation. It will be capable of step-scanning, transmission mode micro-XAFS spectroscopy throughout the entire energy range of the beamline using primary or compound focused beam. The full scientific scope of the beamline requires additional capabilities and integration of other detector systems. These developments will extend over many months following completion of the basic technical commissioning activities.
8 REFERENCES

1. NSLSII-4BM-PRC-001, *XFM Beamline (4-BM) Radiation Survey Procedure*
2. PS-C-ASD-PRC-147, *Insertion Device Front End Ray Tracing Procedure*
3. PS-C-CMD-PLN-001, *NSLS-II Process Description: Review Process for Facility Additions and Modifications*
4. PS-C-ESH-PRC-039, *Experiment Safety Review*
5. PS-C-XFD-PRC-003, *Enabling Beamlines for Operations*
6. PS-C-XFD-PRC-004, *NSLS-II Beamlines Radiation Safety Commissioning Plan*
7. PS-C-XFD-PRC-008, *Synchrotron and Bremsstrahlung Ray Trace Procedure*
8. PS-C-XFD-PRC-030, *Beamline User Readiness*
9. Tech Note #259, *4-BM XFM Beamline Radiation Shielding Analysis*
APPENDIX A: XFM BEAMLINE COMPONENT LAYOUT (beam direction right to left):
XFM FOE (4-BM-A) Components:

XFM SOE (4-BM-B) Components: