FXI and ISR Mirror Bender Upgrade Package
Statement of Work and Technical Specifications

March 26, 2026

1. BACKGROUND:

NSLS-II is a synchrotron light source that has a highly optimized 3 GeV electron storage ring, full-energy injector, experimental beamlines and optics, and appropriate support equipment. The FXI and ISR mirror bender upgrades described in this document (referred to as "The Equipment") comprise of new Collimating Mirror (CM) and Toroidal Mirror (TM) benders for the FXI beamline, and new Horizontal Focusing Mirror (HFM) and Vertical Focusing Mirror (VFM) benders for the ISR beamline.

2. STATEMENT OF WORK:

This Statement of Work (SOW) is the basis for the procurement of the upgrading of the mirror benders for the FXI and ISR Beamlines at the National Synchrotron Light Source II (NSLS-II) at Brookhaven National Laboratory (BNL). This SOW outlines the Contractor's responsibilities and obligations necessary for completing the requirements as set forth herein.

2.1 In accordance with the Specification document and all referenced documents, the Contractor shall design, engineer, manufacture, and assemble the Equipment. The Contractor shall test the Equipment at the Contractor's facility, then deliver, install, and test the Equipment at BNL. It is the Contractor's responsibility to ensure that the Equipment complies with all specification requirements.

2.2 The Contractor shall be responsible for providing a final design review (FDR) report that reflects the state of the developed design of the Equipment in accordance with the specifications identified herein. A final design review meeting shall be held via video conference to review the FDR report between BSA and the Contractor. The Contractor shall be responsible for maintaining and submitting minutes of the FDR and shall also incorporate any agreed-to changes into the final FDR Report

2.3 Controls interface requirements are documented in BSA document NSLSII-CRL-RSI-001, *Experimental Facilities Requirements, Specifications and Interfaces for the Controls and Data Acquisition System*. Motor interfacing standards are found in BSA document NSLSII-CRL-STD-001, *Beamline Systems Instrumentation Interfacing Standard*. The vacuum criteria are described in BSA document LT-ENG-RSI-SR-VA-002, *Requirements for Design and Fabrication of Components for NSLS-II UHV Systems*.

2.4 All electrical equipment must be in accordance with U.S. standards, must comply with NFPA70, and shall be certified, listed or labeled by a Nationally Recognized Testing Laboratory (NRTL) or the BSA Authority Having Jurisdiction as specified in BNL-QA-101 document, clause 3.10. Note that the CE Mark is not a recognized NRTL Certification Mark.

2.5 For process piping requirements, the contractor shall use ASME B31.3 or equivalent approved by BSA in writing. The cooling water lines shall be designed to ASME B31.3 requirements. In all cases, 100% proof testing shall be completed on each component to 150% of the maximum

working pressure for hydrostatic tests, or 110% of the maximum working pressure for pneumatic tests.

2.6 The Contractor shall install the equipment at BNL.

2.7 The Contractor shall provide a Job Hazard Analysis (JHA), identifying hazards and required controls associated with performing the upgrade, to BSA for acceptance prior to the start of work.

2.8 The Contractor shall be responsible for providing PPE based off their equipment, repair, and supplier's operator's manual and the JHA.

2.9 No after hours or weekend work shall be performed unless approved by BSA Work Control Coordinator, 1 day prior to work.

2.10 The Contractor shall provide their own tools, equipment, and any necessary supplies to complete the job.

2.11 The Contractor shall follow the Quality Assurance requirements as set forth in BSA Form BNL-QA-101, "Brookhaven National Laboratory Supplier Quality Assurance Requirements," specifically sections: 3.2-3.22, 4.4, 4.6, 4.7, 4.7.1, 4.7.2, 4.7.3, 4.10, 4.10.1, 4.10.2, 4.10.3, 4.10.4, 4.14, 4.15, 4.16, 4.19, 4.21, 4.30, 4.31, 4.34, and 4.39.

2.12 The Contractor shall provide one (1) spare motor and one (1) spare encoder and readout of each type used on the Equipment.

2.13 The Contractor shall provide a warranty for the Equipment, against failure and defects for a period of two (2) years from final acceptance at BNL.

3. TECHNICAL SPECIFICATIONS:

3.1 Scope of Supply:

This section describes the requirements for the mirror benders upgrade.

The scope of supply **includes**:

- One (1) FXI Collimating Mirror (CM) Bender System
- One (1) FXI Toroidal Mirror Bender (TM) System
- One (1) ISR Horizontal Focusing Mirror (HFM) Bender and in-vacuum, double piping, metal cooling lines for existing mirror substrate
- One (1) ISR Vertical Focusing Mirror (VFM) Bender
- Cables in ultra-high-vacuum and high X-ray radiation environment from component to feedthroughs

The scope of supply **excludes**:

- Mirror substrates
- Mirror tanks
- Standard NSLS-II motion controller for stepper motors

The mirror benders shall be designed to fit into existing mirror systems already installed at BNL. The overall mirror dimensions are provided in the specific bender specifications. Interfacing details to the mirror systems will be provided by BNL to the Contractor one (1) week after the contract is awarded.

The Contractor shall design, manufacture, install, and test stepper-motors to control the tangential bending of the CM/TM mirror units at the FXI Beamline and HFM/VFM mirror units at ISR Beamline, replacing the currently used piezo-based bender systems. The new configuration shall not alter any motion performance in terms of travel range, resolution, accuracy, and repeatability; also, it shall provide a locking position functionality when the motor is de-energized, setting it at the last/closest full step position. The mirror bender design shall include provisions for ensuring the mirror is not damaged during bending actuation.

The motors shall be shielded from radiation with a 2 mm stainless steel plate . Cables from the motors and feedthroughs shall be provided for the in-vacuum section, as well as the feedthroughs themselves. Cables shall be radiation resistant or shielded from radiation. An additional double TC Type K feedthrough shall be provided (for the motors' temperature) and the connection in UHV shall be prepared. All in-UHV assemblies shall be UHV-conditioned (UHV cleaned and baked) before delivery.

In-air cables for motors, encoders, and limit switches shall be prepared for wiring up to the pre-existing breakout box.

One or two additional interface boxes, replacing the pre-existing one(s), shall be prepared for accepting inputs from the respective motor and limit switches, and for outputs from the BNL standard connectors (see NSLSII-CRL-RSI-001).

During the motor installation process at NSLS-II, functional testing of the bender stages shall be performed to ensure the proper functioning of both mechanisms and compliance with specifications.

3.2 Vacuum Requirements:

All components of the mirror benders shall be capable of operating in UHV conditions and shall comply with the criteria described in BSA document LT-ENG-RSI-SR-VA-002, "*Requirements for Design and Fabrication of Components for NSLS-II UHV Systems*". The benders shall not contaminate the UHV condition in the mirror vessels and shall be designed to avoid carbon contamination. All in-UHV assemblies shall be UHV-conditioned (UHV cleaned and baked) before delivery. The new components shall be resistant to high X-ray radiation environment in mirror vessels.

Specific UHV requirements are shown in Table 1.

Table 1: UHV System Requirements

Item	Requirement
Baking Temperature without encoders	150°C
Baking Temperature with encoders	120°C
Base Pressure	< 10^{-8}mbar

The flanges with feedthroughs shall comply with the specifications described in BSA document LT-ENG-RSI-SR-VA-002.

3.3 FXI Collimating Mirror Bender

Table 2: FXI Collimating Mirror Bender

Parameter/Description	Specification
Mirror temperature (no beam)	20-35°C
Vibrational stability of reflected beam	< 1.0 µrad in the 4-100 Hz range
Nominal tangential radius	13.4 km ± 2%
Bend radius range	Infinity (flat) to 5 km (collimating)
Bender actuator resolution [2]	0.2% of desired bend radius
Bender actuator repeatability [2]	0.5% of desired bend radius
Bender actuator encoder	Yes
Bender actuator encoder resolution	0.2% change in bend radius.

3.4 FXI Toroidal Mirror Bender

Table 3: FXI Toroidal Mirror Bender

Mirror Bender	Specification
Mirror temperature	20-25°C
Vibrational stability of reflected beam	< 1 µrad in the 4-100 Hz range
Mirror nominal tangential radius	10.8 km ± 2%
Bend radius range	Infinity (flat) to 5 km (collimating)
Bender actuator resolution [1]	0.2% of desired bend radius
Bender actuator repeatability [1]	0.5% of desired bend radius
Bender encoder	Yes
Bender actuator encoder resolution	0.2% change in bend radius.

3.5 ISR Horizontal Focusing Mirror Bender

The ISR HFM parameters and dimensions are provided in Table 4 for reference:

Table 4: ISR HFM Parameters and Dimensions

Parameter	Specification/Description
Substrate Material	Monolithic Block, Optical Grade Silicon Single-Crystal
Active Area	800 mm long x 20 mm wide
Orientation	Horizontally-deflecting, inboard
Shape	Cylindrical about Y-axis
Bender	Yes
Radius Range of Bender	7 km to ∞
Bender Resolution	2.5% of the radius, for radius of 7.5–14 km

3.6 ISR Vertical Focusing Mirror Bender

The ISR VFM specifications are provided in Table 5:

Table 5: ISR VFM Specifications

Parameter	Specification/Description
Substrate Material	Monolithic Block of Optical Grade Single-Crystal Silicon
Active Area	600 mm long x 20 mm wide
Orientation	Vertically-deflecting, upward
Shape	Cylindrical about X-axis
Bender	Yes
Radius Range of Bender	5 km to ∞
Bender Resolution	2% of the radius, for radius of 5.5–12 km

3.7 Testing

3.7.1 Factory Acceptance Testing

3.7.1.1 Dimensions: Verify that all components are fabricated to the specified dimensions and fit together correctly.

3.7.1.2 Vacuum readiness: Verify that all vacuum components are baked as specified and that the vacuum criteria are met, as described in BSA document LT-ENG-RSI-SR-VA-002, "*Requirements for Design and Fabrication of Components for NSLS-II UHV Systems.*"

3.7.1.3 Wiring and connections: Verify that all wiring and connections are made according to specifications.

3.7.1.4 Sensors: Verify that sensors are connected properly and show proper readings.

3.7.1.5 HFM cooling lines: Perform leak tests and over-pressure tests.

3.7.1.6 Motion system: Verify that all motions are implemented with the specified motion direction, range, resolution, repeatability, and stability.

3.7.1.7 Verify that the limits and encoders are implemented as specified.

3.7.1.8 Verify that all motors are running smoothly and are properly tuned.

3.7.1.9 The precision of these tests is limited to the capability of the Contractor's measurement instruments and the ambient environments.

3.7.2 Site Acceptance Testing

Repeat the above tests and perform the following tests:

3.7.2.1 Verification of installation: verify that all components are installed to their nominal locations, in respective mirror tanks, following the surveying procedures, and that all components are installed as specified.

3.7.2.2 Motion and calibration: test the motion direction, resolution, repeatability, and stability of motorized motions using BSA equipment. Check calibration of all motions.

3.7.2.3 Equipment protection: verify EPS functional performance, including the limit switches.

3.7.2.4 Vacuum: verify that the vacuum meets the vacuum specifications.

3.7.2.5 Cooling: verify that HFM cooling lines are connected to the utilities as specified. Verify that water is flowing at its nominal flow rate or pressure range. Verify that vacuum levels are meeting specifications with cooling.

3.7.2.6 Angular stability of HFM: measure the angular stability of the mirror, both with and without the closed-loop cooling system turned on.

3.7.2.7 Performance: Carry out performance tests on all beamline components to verify that the measured performance meets the specifications described.

4. MILESTONES AND DELIVERABLES:

Table 6: Milestones and Deliverables

Item	Deliverable	Due Date (weeks after contract award)
1	Final design review report	8 weeks
2	Equipment delivery	32 weeks
3	Installation and testing	38 weeks
4	Receipt of end item documentation package	With equipment delivery

5. ACRONYMS

ASME	American Society of Mechanical Engineers
BNL	Brookhaven National Laboratory
BSA	Brookhaven Science Associates
CM	Collimating Mirror
DSSI	Data Science & System Integration (group)
ESH	Environment, Safety & Health
FDR	Final Design Review
FXI	Full X-ray Imaging
HFM	Horizontal Focusing Mirror
ISR	Integrated In situ and Resonant
JHA	Job Hazard Analysis
NRTL	Nationally Recognized Testing Laboratory
PPE	Personal Protection Equipment
SOW	Statement of Work
SPC	Technical Specification
TC	Thermocouple
TM	Toroidal Mirror
VFM	Vertical Focusing Mirror