LUSI LCLS Ultrafast Science Instruments

ENGINEERING SPECIFICATION DOCUMENT (ESD)	**Doc. No.** **SP-391-000-65 R0**	**LUSI SUB-SYSTEM** **CXI**

Engineering Specifications for the CXI 1 micron KB System

Prepared by:
Signature Date

Reviewed by:
Paul Montanez
CXI Lead Engineer
Signature Date

Reviewed by:
Sébastien Boutet
CXI Instrument Scientist
Signature Date

Approved:
Darren Marsh
Quality Assurance Manager
Signature Date

Approved:
Nadine Kurita
Chief Engineer
Signature Date

Approved:
Tom Fornek
LUSI Project Manager
Signature Date

Revision	Date	Description of Changes	Approved
R0	01AUG08	Initial release	

Table of Contents

1. Overview

The Coherent X-ray Imaging (CXI) instrument to be built at the Linac Coherent Light Source (LCLS) by the LCLS Ultrafast Science Instruments (LUSI) on the Stanford Linear Accelerator Center (SLAC) site requires a mirror system to produce a 1x1 micron^2 FWHM focal spot at the sample. The mirror system shall be made of 2 mirrors each with an elliptical figure and arranged in a Kirkpatrick-Baez (KB) configuration rotated by 45 degrees. The system is known as the CXI 1 Micron KB System or KB1.

The LCLS will produce a laser-like beam of X-rays in the 800 to 8300 eV range for the fundamental energy. Also, the 3rd harmonic will be present at up to 25 keV. The CXI instrument will use the hard X-ray branch which uses 2 offset mirrors that reflect energies between 2 keV and 25 keV.

The KB mirror combination shall reflect over 75% of the X-rays over the 2-18 keV range. This will be achieved by coating the mirrors with a bilayer of Rhodium (Rh) or Ruthenium (Ru) and Boron Carbide (B_4C) or Silicon Carbide (SiC).

These mirrors will be located in a Ultra-High Vacuum (UHV) environment (10^{-9} Torr). They require a very precise positioning system located inside a vacuum enclosure which will be mounted on a stable stand.

2. Scope

This document contains the specifications for the fabrication and delivery of a KB mirror system for the CXI instrument built by LUSI at LCLS. Multiple activities and components are required to build the complete mirror system. They are as followed.

Mirror Substrates (Described in Section 7)

Mirror Coating (Described in Section 8)

Mirror Metrology (Described in Section 9)

Mirror Mechanical Support System (Described in Section 10.1)

Mirror Bender System (Described in Section 10.2)

Vacuum Enclosure (Described in Section 10.3)

Support Stand (Described in Section 10.4)

3. Vendor options

Vendors are invited to provide quotations for completion of the work for a single part of the system or any of the combinations listed in this section and summarized in Table 1.

Option	**Mirror Substrate (Section 7)**	**Mirror Coating (Section 8)**	**Mirror Metrology (Section 9)**	**Mirror Mechanical Support (Section 10.1)**	**Mirror Bender System (Section 10.2)**	**Vacuum Enclosure (Section 10.3)**	**Support Stand (Section 10.4)**
3.1.1	✓						
3.2		✓					
3.3			✓				
3.4.1				✓			
3.5.1				✓		✓	
3.6.1				✓		✓	✓
3.7.1	✓			✓			
3.7.2	✓			✓	✓		
3.7.3	✓			✓	✓		
3.8.1	✓			✓		✓	
3.8.2	✓			✓	✓	✓	
3.8.3	✓			✓	✓	✓	
3.9.1	✓			✓		✓	✓
3.9.2	✓			✓	✓	✓	✓
3.9.3	✓			✓	✓	✓	✓
3.10.1	✓	✓					
3.10.2	✓	✓					
3.11.1	✓	✓		✓			
3.11.2	✓	✓		✓	✓		
3.11.3	✓	✓		✓	✓		
3.12.1	✓	✓		✓		✓	
3.12.2	✓	✓		✓	✓	✓	
3.12.3	✓	✓		✓	✓	✓	
3.13.1	✓	✓		✓		✓	✓
3.13.2	✓	✓		✓	✓	✓	✓
3.13.3	✓	✓		✓	✓	✓	✓

Table 1: List of options for potential vendors.

3.1. Mirror Substrates only

3.1.1. Pre-figured mirrors

The vendor shall provide mirrors with a machined permanent elliptical figure meeting all requirements of Section 7.

3.2. Mirror Coating only

The vendor shall provide the mirror coating meeting all the requirements described in Section 8 for 2 mirrors.

3.3. Mirror Metrology only

The vendor shall provide the metrology measurements on the mirrors meeting all the requirements described in Section 9.

3.4. Mechanical Support only

3.4.1. Pre-figured mirrors

The vendor shall provide the mirror mechanical support system meeting all the requirements for pre-figured mirrors as described in Section 10.1. This option is only available if the mirror substrate vendor provides pre-figured mirrors.

3.5. Mechanical Support and Vacuum Enclosure

3.5.1. Pre-figured mirrors

The vendor shall provide the mirror mechanical support system meeting all the requirements for pre-figured mirrors as described in Section 10.1, along with the vacuum enclosure described in Section 10.3. This option is only available if the mirror substrate vendor provides pre-figured mirrors.

3.6. Mechanical Support, Vacuum Enclosure and Stand

3.6.1. Pre-figured mirrors

The vendor shall provide the mirror mechanical support system meeting all the requirements for pre-figured mirrors as described in Section 10.1, along with the vacuum enclosure described in Section 10.3 and the support stand described in Section 10.4. This option is only available if the mirror substrate vendor provides pre-figured mirrors.

3.7. Mirror Substrates and Mechanical Support

3.7.1. Pre-figured mirrors

The vendor shall provide mirrors with a machined permanent elliptical figure meeting all requirements of Section 7. The vendor shall also provide the mirror mechanical support system meeting all the requirements for pre-figured mirrors as described in Section 10.1.

3.7.2. Flat mirrors with bender system

The vendor shall provide mirrors with a flat figure meeting all requirements of Section 7. The vendor shall also provide the mirror mechanical support system meeting all the requirements for flat bent mirrors as described in Section 10.1 and the mirror bending system described in Section 10.2.

3.7.3. Bimorph mirrors

The vendor shall provide bimorph mirrors with a flat figure meeting all requirements of Section 7. The vendor shall also provide the mirror mechanical support system meeting all the requirements for bimorph mirrors as described in Section 10.1 and the bimorph mirror bending system described in Section 10.2.

3.8. Mirror Substrates, Mechanical Support and Vacuum Enclosure

3.8.1. Pre-figured mirrors

The vendor shall provide mirrors with a machined permanent elliptical figure meeting all requirements of Section 7. The vendor shall also provide the mirror mechanical support system meeting all the requirements for pre-figured mirrors as described in Section 10.1 along with the vacuum enclosure described in Section 10.3.

3.8.2. Flat mirrors with bender system

The vendor shall provide mirrors with a flat figure meeting all requirements of Section 7. The vendor shall also provide the mirror mechanical support system meeting all the requirements for flat bent mirrors as described in Section 10.1 along with the mirror bending system described in Section 10.2 and the vacuum enclosure described in Section 10.3.

3.8.3. Bimorph mirrors

The vendor shall provide bimorph mirrors with a flat figure meeting all requirements of Section 7. The vendor shall also provide the mirror mechanical support system meeting all the requirements for bimorph mirrors as described in Section 10.1, along with the bimorph mirror bending system described in Section 10.2 and the vacuum enclosure described in Section 10.3.

3.9. Mirror Substrates, Mechanical Support, Vacuum Enclosure and Stand

3.9.1. Pre-figured mirrors

The vendor shall provide mirrors with a machined permanent elliptical figure meeting all requirements of Section 7. The vendor shall also provide the mirror mechanical support system meeting all the requirements for pre-figured mirrors as described in Section 10.1 along with the vacuum enclosure described in Section 10.3 and the support stand described in Section 10.4.

3.9.2. Flat mirrors with bender system

The vendor shall provide mirrors with a flat figure meeting all requirements of Section 7. The vendor shall also provide the mirror mechanical support system meeting all the requirements for flat bent mirrors as described in Section 10.1 along with the mirror bending system described in Section 10.2, the vacuum enclosure described in Section 10.3 and the support stand described in Section 10.4.

3.9.3. Bimorph mirrors

The vendor shall provide bimorph mirrors with a flat figure meeting all requirements of Section 7. The vendor shall also provide the mirror mechanical support system meeting all the requirements for bimorph mirrors as described in Section 10.1, along with the bimorph mirror bending system described in Section 10.2, the vacuum enclosure described in Section 10.3 and the support stand described in Section 10.4

3.10. Mirror Substrates and Coating

3.10.1. Pre-figured mirrors

The vendor shall provide mirrors with a machined permanent elliptical figure meeting all requirements of Section 7 and coated as described in Section 8.

3.10.2. Flat mirrors

The vendor shall provide mirrors with a flat figure meeting all requirements of Section 7 and coated as described in Section 8.

3.11. Mirror Substrates, Coating and Mechanical Support

3.11.1. Pre-figured mirrors

The vendor shall provide mirrors with a machined permanent elliptical figure meeting all requirements of Section 7 and coated as described in Section 8. The vendor shall also provide the mirror mechanical support system meeting all the requirements for pre-figured mirrors as described in Section 10.1.

3.11.2. Flat mirrors with bender system

The vendor shall provide mirrors with a flat figure meeting all requirements of Section 7 and coated as described in Section 8. The vendor shall also provide the mirror mechanical support system meeting all the requirements for flat bent mirrors as described in Section 10.1 and the mirror bending system described in Section 10.2.

3.11.3. Bimorph mirrors

The vendor shall provide bimorph mirrors with a flat figure meeting all requirements of Section 7 and coated as described in Section 8. The vendor shall also provide the mirror mechanical support system meeting all the requirements for bimorph mirrors as described in Section 10.1 and the bimorph mirror bending system described in Section 10.2.

3.12. Mirror Substrates, Coating, Mechanical Support and Vacuum Enclosure

3.12.1. Pre-figured mirrors

The vendor shall provide mirrors with a machined permanent elliptical figure meeting all requirements of Section 7 and coated as described in Section 8. The vendor shall also provide the mirror mechanical support system meeting all the requirements for pre-figured mirrors as described in Section 10.1 along with the vacuum enclosure described in Section 10.3.

3.12.2. Flat mirrors with bender system

The vendor shall provide mirrors with a flat figure meeting all requirements of Section 7 and coated as described in Section 8. The vendor shall also provide the mirror mechanical support system meeting all the requirements for flat bent mirrors as described in Section 10.1 along with the mirror bending system described in Section 10.2 and the vacuum enclosure described in Section 10.3.

3.12.3. Bimorph mirrors

The vendor shall provide bimorph mirrors with a flat figure meeting all requirements of Section 7 and coated as described in Section 8. The vendor shall also provide the mirror mechanical support system meeting all the requirements for bimorph mirrors as described in Section 10.1, along with the bimorph mirror bending system described in Section 10.2 and the vacuum enclosure described in Section 10.3.

3.13. Mirror Substrates, Coating, Mechanical Support, Vacuum Enclosure and Stand

3.13.1. Pre-figured mirrors

The vendor shall provide mirrors with a machined permanent elliptical figure meeting all requirements of Section 7 and coated as described in Section 8. The vendor shall also provide the mirror mechanical support system meeting all the requirements for pre-figured mirrors as described in Section 10.1 along with the vacuum enclosure described in Section 10.3 and the support stand described in Section 10.4.

3.13.2. Flat mirrors with bender system

The vendor shall provide mirrors with a flat figure meeting all requirements of Section 7 and coated as described in Section 8. The vendor shall also provide the mirror mechanical support system meeting all the requirements for flat bent mirrors as described in Section 10.1 along with the mirror bending system described in Section 10.2, the vacuum enclosure described in Section 10.3 and the support stand described in Section 10.4.

3.13.3. Bimorph mirrors

The vendor shall provide bimorph mirrors with a flat figure meeting all requirements of Section 7 and coated as described in Section 8. The vendor shall also provide the mirror mechanical support system meeting all the requirements for bimorph mirrors as described in Section 10.1, along with the bimorph mirror bending system described in Section 10.2, the vacuum enclosure described in Section 10.3 and the support stand described in Section 10.4

4. Applicable Documents, Specifications and Codes

4.1. Stanford Linear Accelerator Center (SLAC) Specifications

- SLAC document No. SP-391-000-25, "Physics Requirements for the CXI 1 micron KB System"
- SLAC drawing No. DS-311-000-36, "Design Standards Supplement"
- SLAC drawing No. SC-700-866-47, "Specification Kly & Vac Machining Fluids"

4.2. Other Specifications

- MIL-PRF-13830B: "Optical Components for Fire Control Instruments; General Specification Governing the Manufacture, Assembly, and Inspection of."

5. Definitions

Mirror substrate vendor

The entity entering a contract with SLAC to provide mirrors meeting all requirements listed in Section 7.

Mirror coating vendor

The entity entering a contract with SLAC to provide coating for mirrors meeting all requirements listed in Section 8.

Mirror metrology vendor

The entity entering a contract with SLAC to provide metrology measurements on mirrors as described in Section 9.

Mirror support vendor

The entity entering a contract with SLAC to provide a mirror mechanical support system meeting all requirements described in Section 10.1 and, if specified, Section 10.2.

Vacuum enclosure vendor

The entity entering a contract with SLAC to provide a vacuum enclosure meeting all requirements described in Section 10.3.

Stand vendor

The entity entering a contract with SLAC to provide a stand meeting all requirements described in Section 10.4.

6. General Requirements

6.1. Location

The vacuum enclosure of the KB mirror system will be located in experimental hutch 5 in the Far Experimental Hall, known as FEH Hutch 5.

The midpoint between the 2 mirrors along the x-ray beam shall be located 384 m downstream of the exit of the LCLS undulator, which produces the X-ray beam. This same midpoint shall be located 8 m upstream of the focal point. The spacing between the 2 mirrors shall be kept to a minimum to minimize the overall length of the system.

6.2. Environment

The temperature and relative humidity in the FEH Hutch 5 will be maintained at 72°F +/- 1°F (22.2°C +/-0.3°C), and 45% +/-10%, respectively.

6.3. Lifetime

The expected service life of the device is 10 years.

7. Optical Requirements, Mirror Requirements

7.1. Scope

This section describes the requirements for 2 mirrors to be delivered to SLAC. Two options are available to vendors:

Pre-figured mirrors

The mirror substrate vendor shall meet all requirements listed in this section.

Flat mirrors

The mirror substrate vendor shall meet all requirements listed in this section except for the elliptical figure requirement. The mirror substrate vendor shall produce mirrors that are flat within the figure errors listed instead of elliptical within the figure errors. The flat mirror option requires the substrate vendor to also provide the mechanical system described in Sections 10.1 and 10.2 in order to produce the elliptical figure described in this current section.

7.2. Mirror Definitions

A pictorial definition of relevant terminology is given in Figure 1. The dimensions of the clear aperture are listed in Table 2 and Table 3. The clear aperture represents the optical surface where the surface quality requirements must be met. The requirements to the surface listed in Table 2 and Table 3 do not apply outside the clear aperture.

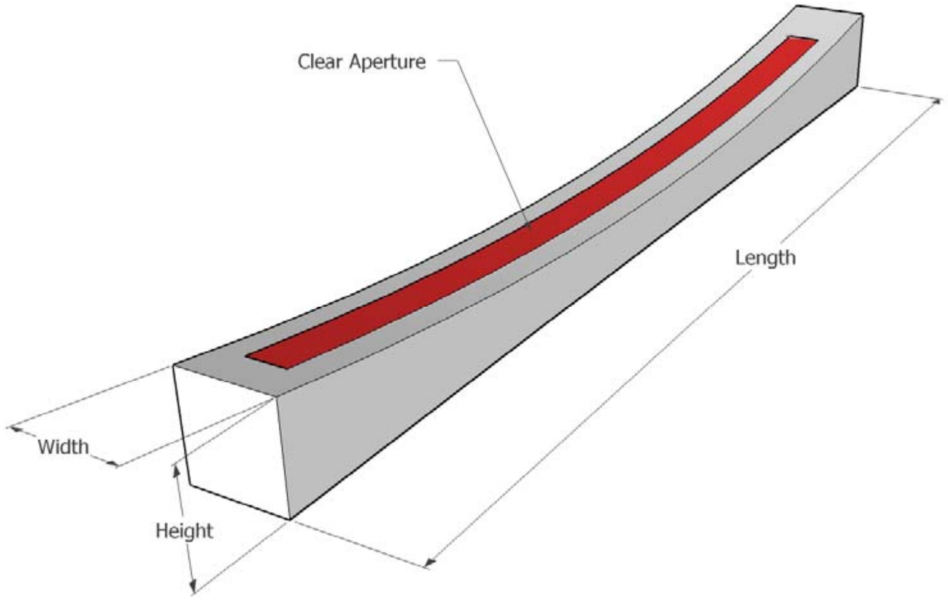

Figure 1: Pictorial definition of terminology

7.3. Performance Requirements

The mirrors will be used in a Kirkpatrick-Baez configuration rotated by 45 degrees (as shown in Figure 8) to produce a 1 micron FWHM focal spot. The mirrors will accept the full beam width (5 standard deviations or more) at all energies above 4 keV and will be > 86% reflective (each mirror for a total reflectivity > 75%) over the 2-12 keV range. The mirror parameters listed in Table 2 and Table 3 were chosen to meet these requirements.

7.4. Mirror Dimensions Requirements

The mirror substrate vendor shall produce mirrors with dimensions at least as large as the clear aperture defined in Table 2 and Table 3. The exact dimensions of the full mirror substrates, provided they are within the range listed in Table 2 and Table 3, are to be determined by the mirror substrate vendor. The mirror substrate vendor shall provide the exact dimensions of the mirror substrate to SLAC in response to the Request for Proposal from SLAC. These dimensions will be used as design parameters for the mechanical system of the mirrors (Section 10.1) and must be fixed from the beginning, with no possibility for change unless agreed upon by SLAC.

7.5. Optical Surface Requirements

7.5.1. Figure Requirements

The mirrors shall have an elliptical profile to provide longitudinal focusing. The elliptical profile shall be obtained by either machining, bending or with bimorph mirrors. The mirrors shall be flat in the sagittal direction. All roughness and slope errors are determined after subtraction of the best-fit elliptical reference surface from the clear aperture zone, in the case of pre-figured mirrors. Best-fit elliptical radii, tangential or sagittal, must meet the respective surface radii specifications outlined in Table 2 and Table 3.

In the case of flat mirrors that are to be bent by the system described in Section 10.2, all roughness and slope errors are determined after subtraction of the best-fit cylindrical reference surface from the clear aperture zone.

The figure error requirements are listed in Table 2 and Table 3.

Full-aperture, visible-light interferometry shall be used to determine the surface figure at the mirror substrate vendor's facility, after processing of the mirrors surface has been completed. Verification of the mirror figure will be performed by a third party after delivery of the mirrors as described in Section 9.

The mirrors will not be arranged in the standard KB configuration. They will be rotated by 45 degrees which will cause the overall deflection of the beam to be horizontal only (the +X direction). The distortion of the figure of the mirror due to gravity in this orientation shall be taken into account and the mirrors shall meet all the specifications of Table 2 and Table 3 when rotated to the 45 degree orientation. The first mirror shall deflect the beam 45 degrees down while the second mirror shall deflect the beam 45 degrees up, as shown on Figure 8.

It is the mirror substrate vendor's responsibility to demonstrate that the effects of interferometer measurement error and gravity distortion are either negligible or are removed from the data

	Parameter	Value	Units	Comment
1	Mirror Shape	Tangential ellipse		For pre-figured mirrors Or bent flat
2	Clear aperture length	350	mm	Length over which the coating will be applied and the surface specifications must be met
3	Clear aperture width	>5	mm	Width over which the coating will be applied and the surface specifications must be met
4	Mirror Length	390 ≥ length ≥ 360	mm	Extra length is to allow mounting during the coating process and mirror use
5	Mirror Width			No value is prescribed as long as it is larger than the clear aperture width
6	Mirror Thickness			No value is prescribed and it should be chosen to achieve the necessary figure
7	Substrate material	Si <100>		Single crystal

8	Surface Figure roughness	<0.75	nm rms	Over dimensions from 1mm to the clear aperture size
9	Mid-spatial roughness	<0.25	nm rms	Over the 10^{-3} to 0.5 µm^{-1} frequency range
10	High-spatial roughness	<0.25	nm rms	Over the 0.5 to 50 µm^{-1} frequency range
11	Tangential Slope error	<0.25	µrad rms	Over dimensions from 1mm to the clear aperture size
12	Sagittal Slope error	<1	µrad rms	Over dimensions from 1mm to the clear aperture width
13	Tangential Radius of curvature	4372-4662	m	Elliptical profile (see Figure 3 below). For pre-figure mirrors only
14	Sagittal radius of curvature	>4	km	
15	Maximum height of surface	3.43	µm	Surface profile is shown on Figure 2 below. For pre-figured mirrors only.
16	Focal length	8.2	m	
17	Maximum incidence angle	3.6	mrad	Angle of incidence at downstream end of the mirror
18	Average incidence angle	3.562	mrad	Angle of incidence at the mid-point of the mirror
19	Distance from source	406-439	m	Range for 2 keV to 8.3 keV photon beam
20	Vacuum pressure	$<10^{-9}$	Torr	
21	Temperature	22	^{o}C	

Table 2: Parameters for first mirror of KB1 system.

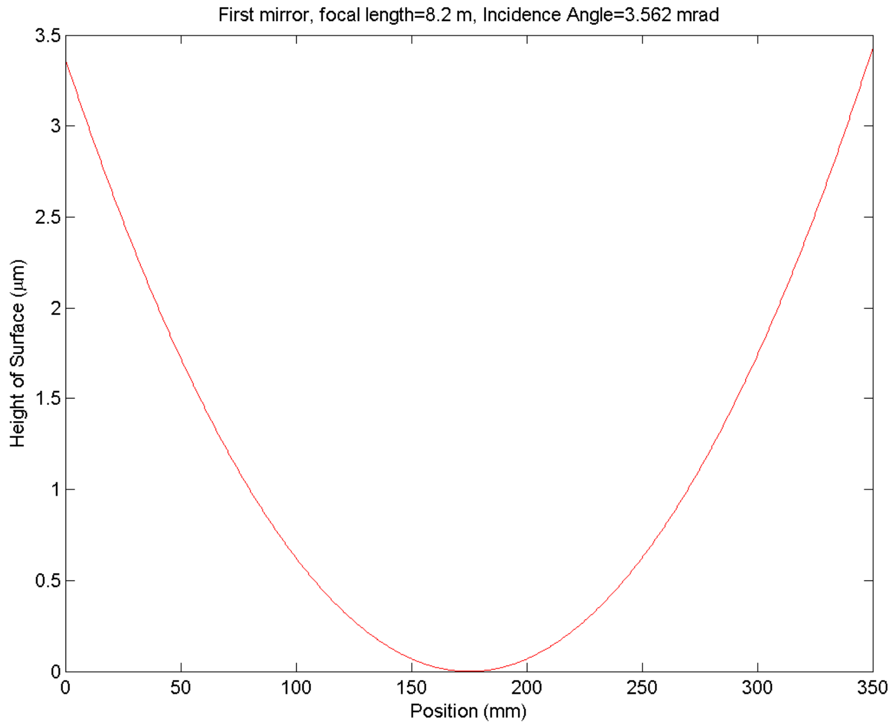

Figure 2: Surface profile of the first mirror.

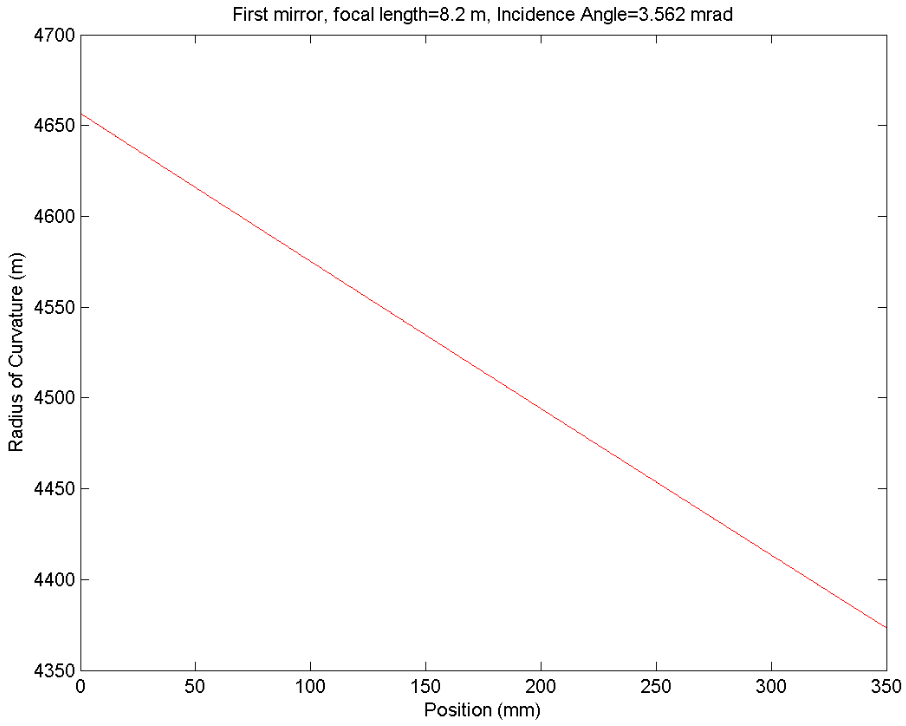

Figure 3: Radius of curvature of the first mirror surface as a function of position along the mirror.

	Parameter	Value	Units	Comment
1	Mirror Shape	Tangential ellipse		For pre-figured mirrors Or bent flat
2	Clear aperture length	350	mm	Length over which the coating will be applied and the surface specifications must be met
3	Clear aperture width	>5	mm	Width over which the coating will be applied and the surface specifications must be met
4	Mirror Length	390 ≥ length ≥ 360	mm	Extra length is to allow mounting during the coating process and mirror use
5	Mirror Width			No value is prescribed as long as it is larger than the clear aperture width
6	Mirror Thickness			No value is prescribed and it should be chosen to achieve the necessary figure
7	Substrate material	Si <100>		Single crystal
8	Surface Figure roughness	<0.75	nm rms	Over dimensions from 1mm to the clear aperture size
9	Mid-spatial roughness	<0.25	nm rms	Over the 10^{-3} to 0.5 µm^{-1} frequency range
10	High-spatial roughness	<0.25	nm rms	Over the 0.5 to 50 µm^{-1} frequency range
11	Tangential Slope error	<0.25	µrad rms	Over dimensions from 1mm to the clear aperture size
12	Sagittal Slope error	<1	µrad rms	Over dimensions from 1mm to the clear aperture width
13	Tangential Radius of curvature	4158-4448	m	Elliptical profile (see Figure 3 below). For pre-figure mirrors only
14	Sagittal radius of curvature	>4	km	
15	Maximum height of surface	3.60	µm	Surface profile is shown on Figure 2 below. For pre-figured mirrors only.
16	Focal length	7.8	m	
17	Maximum incidence angle	3.6	mrad	Angle of incidence at downstream end of the mirror
18	Average incidence angle	3.560	mrad	Angle of incidence at the mid-point of the mirror
19	Distance from source	406-439	m	Range for 2 keV to 8.3 keV photon beam
20	Vacuum pressure	$<10^{-9}$	Torr	
21	Temperature	22	°C	

Table 3: Parameters for second mirror of KB1 system.

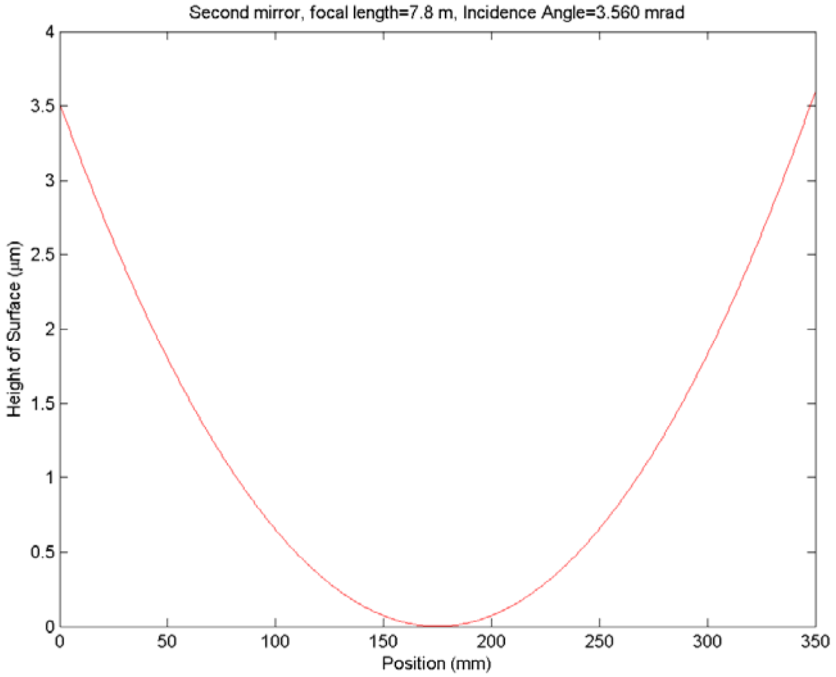

Figure 4: Surface profile of the second mirror.

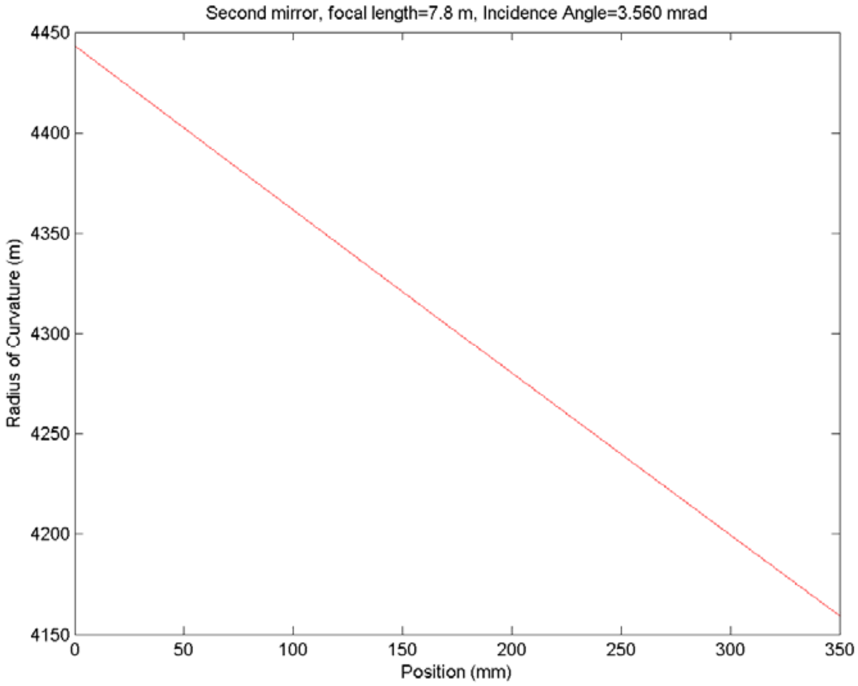

Figure 5: Radius of curvature of the second mirror surface as a function of position along the mirror.

7.5.2. Roughness Requirements

The roughness requirements are listed in Table 2 and Table 3.

Roughness shall be measured on each mirror after cleaning. A visible-light interferometer or profilometer shall be used for mid-spatial frequency measurements at the mirror substrate vendor’s facility. If available, an AFM instrument shall be used for high-spatial frequency measurements at the mirror substrate vendor’s facility. If an AFM instrument is unavailable, alternative arrangements must be made by the mirror substrate vendor.

Verification of the mid-spatial frequency roughness and the high-spatial frequency roughness will be performed by a third party with white-light optical profiling microscope and AFM capabilities as described in Section 9.

7.6. Design and Construction

7.6.1. Substrate Material

The mirror substrate material shall be single-crystal silicon, with a <100> direction oriented along the "Length" of the mirror. It shall additionally be free from defects such as dislocations, cracks, etc. Its resistivity shall be ≤ 10 Ω-cm.

7.6.2. Surface Finish

7.6.2.1. Optical Surface Area

The mirror optical surface shall be finished using a controlled grinding and polishing process to remove residual sub-surface damage and leave the optical surface in a stress-free condition.

The mirror optical surface shall have no striae under visible examination.

The mirror optical surface shall meet a scratch/dig requirement of 10/5 per MILPRF-13830B

7.6.2.2. Non-Optical Surface Areas

The mirror non-optical surface areas shall be finished using a controlled grinding process followed by wet-chemical etching to remove residual sub-surface damage and leave the non-optical surface areas in a stress-free condition. This process shall be staged such that all surfaces of the completed mirror, with the exception of the optical surface, shall be wet-chemical-etched surfaces.

7.6.3. Workmanship

Workmanship shall be consistent with the quality necessary for stable operation of sensitive optical devices under long-term exposure to an x-ray, ultrahigh vacuum (UHV) environment similar to that found in synchrotron radiation user facilities.

7.6.4. Handling and Cleaning

7.6.4.1. Handling

Full, UHV handling practice is required. Each mirror shall be handled in accordance with the Handling and Process Plan, as reviewed and approved by SLAC.

7.6.4.2. Cleaning

Each mirror shall be cleaned at the mirror substrate vendor's facility in a manner that is consistent with the figure, mid- and high-spatial frequency roughness requirements discussed in this section and that allows the mid- and high-spatial frequency roughness to be evaluated. Cleaning shall be performed at the mirror substrate vendor's facility in accordance with the methods outlined in the Handling and Process Plan provided by the mirror substrate vendor and approved by SLAC.

7.6.5. Packaging and Shipping

The mirror substrate vendor shall be responsible for design and fabrication of the mirror shipping container(s). Best protection against contamination and shock/vibration is essential. An all-metal, dust-free interior-most enclosure is desirable. A brief description of proposed packaging and shipping arrangements shall be included in the Handling and Process Plan.

7.6.6. Test Coupon Packaging and Shipping

The mirror substrate vendor shall be responsible for supplying test coupon shipping container(s). Best protection against contamination and shock/vibration is desirable. A dust-free interior, sealed enclosure is desirable. Coupons are to be restrained at the edges of the polished surface, to preserve the surface condition. A brief description of proposed packaging and shipping arrangements shall be included in the Handling and Process Plan.

7.6.7. Handling and Process Plan

All mirror processing shall take place in accordance with the methods described in the Handling and Process Plan supplied by the mirror substrate vendor. This document shall be provided in response to the Request for Proposal from SLAC, and must be reviewed and approved by SLAC. In that way, any materials compatibility issues for the completed mirrors can be identified and settled in advance. As noted in the sections above, the Handling and Process Plan shall include brief descriptions of the following:

(1) Fabrication process
(2) UHV handling procedures
(3) Mirror cleaning procedure
(4) Packaging and shipping arrangements

7.7. Quality Assurance Provisions

7.7.1. General

Prior to contract award, SLAC may perform a quality audit at the mirror substrate vendor's facility to ascertain the existing or planned quality program implementation and procedures as it pertains to this procurement. Existing manufacturing procedures to be used for this procurement shall be reviewed during this audit.

The mirror substrate vendor shall maintain documentation for all metrology and processes during fabrication and characterization of these mirrors.

7.7.1.1. Program Management

The mirror substrate vendor shall actively manage all matters relating to the performance of this contract to ensure that all specifications, schedule, and quality objectives are fully met. A single individual shall be named to serve as the Program Manager of this subcontract. The Program Manager shall act as the single point of contact with SLAC on all technical and programmatic matters.

The subcontract shall establish and apply a program control system to track progress regarding pre-established, measurable milestones. The subcontract shall identify corrective management actions in the event shortfalls are detected or anticipated. The mirror substrate vendor shall develop and provide a detailed project schedule to SLAC. The schedule shall be periodically updated and provided at least on a monthly basis to SLAC as part of progress reporting.

In the event SLAC determines that the program success is in jeopardy because of technical, schedule, or quality shortfalls, SLAC reserves the right to conduct special program reviews and audits, as necessary, at the mirror substrate vendor's facility.

7.7.1.2. Progress Reporting

SLAC and the mirror substrate vendor shall conduct, at a minimum, monthly status teleconferences. These teleconferences shall discuss general status of the program. Any item that has immediate effect on technical performance, schedule, or deliveries shall be brought to the immediate attention of SLAC.

7.7.1.3. Reviews

The vendor shall provide necessary support for an initial Technical Interface Meeting to discuss contract planning and to discuss any open contractual or technical action items.

7.7.1.4. Responsibility for Inspection and Tests

The responsibility for performing and documenting all specified tests and metrology shall rest with the mirror substrate vendor unless noted otherwise. The mirror substrate vendor shall submit an Inspection Test Procedure to SLAC for approval, as outlined in this document, describing each test or measurement to be implemented. SLAC reserves the right to perform in-process inspections at the mirror substrate vendor's facility. The mirror substrate vendor shall notify SLAC a minimum of 5 working days prior to the start of final inspection and testing. Drawings and equipment that may be required for adequate inspection and test shall be made available to SLAC. SLAC inspection shall in no way relieve the mirror substrate vendor of responsibility for ensuring the quality of the mirrors.

7.7.1.5. Inspection Test Procedure

The mirror substrate vendor shall prepare an Inspection Test Procedure in response to the Request for Proposal from SLAC. It must be reviewed and approved by SLAC, and shall include the following at a minimum:

(1) Acceptance verification matrix that list each requirement (including pass/fail criteria) and indicate by what methods and procedures the mirror substrate vendor shall verify the requirement.
(2) Sequence of measurements, both in-process and final
(3) Equipment to be used
(4) Accuracy of measurements
(5) Calibration techniques
(6) Proposed data sheets of results and data format for the Inspection Test Report

7.7.1.6. In-Process Inspection Points

Mirror substrate vendor in-process inspection points shall be specified as part of the Inspection Test Procedure (see Section 7.7.1.5). At a minimum, inspections shall be performed at the following points:

(1) After initial shaping of the non-optical surface areas
(2) Selected points during mirror surface polishing
(3) Final inspection after the mirror is finished

7.7.2. Quality Conformance Inspections

7.7.2.1. Visual Inspection

The completed mirrors shall be visually inspected for conformance to the requirements in Section 7.6, prior to performing the measurements described in Section 7.7.2.2. If visual inspections uncover defects, additional inspections and measurements, as needed, shall be performed to determine acceptability. Visual inspections shall use techniques that enhance the visibility of defects, and shall be described in the Inspection Test Procedure (Section 7.7.1.5). Illumination of the surface shall be 200 or more foot-candles (lumens per square foot). The mirror shall be viewed against a dark background and from a direction just off the line of specular reflection.

Mirror polish shall be evaluated by visual inspection. Areas with scratches, or pits in excess of the requirements of Section 7.5 are unacceptable.

Optical surface edges shall be visually inspected for digs and chips.

Overall appearance shall be free from all visible contamination and poor workmanship indications.

7.7.2.2. Characterization Metrology

Compliance with the Optical Surface Quality Requirements specified in Section 7.5 shall be demonstrated through measurements, and the resulting data provided in the Inspection Test Report. As also stated in Section 7.7.1.5, all measurement procedures must be proposed-to and approved-by SLAC prior to execution.

Measurements shall be made under the following environmental conditions:

Temperature: 20°C ± 2°C.

Humidity: 30% to 70% relative humidity (RH)

During all measurements, the article under test and the test equipment shall be in thermal equilibrium within the specified temperature range.

Mid- and high-spatial frequency roughness shall be measured at the locations specified in Figure 6. These measurements shall be made after cleaning of the mirrors, as also discussed in Sections 7.5.2.and 7.6.4.

Instrumentation used for the measurement of figure, mid- and high- spatial frequency roughness should be capable of accurately measuring the spatial frequency bandwidths specified in Sections 7.5.1.and 7.5.2., respectively. All equipment should be in current and traceable calibration.

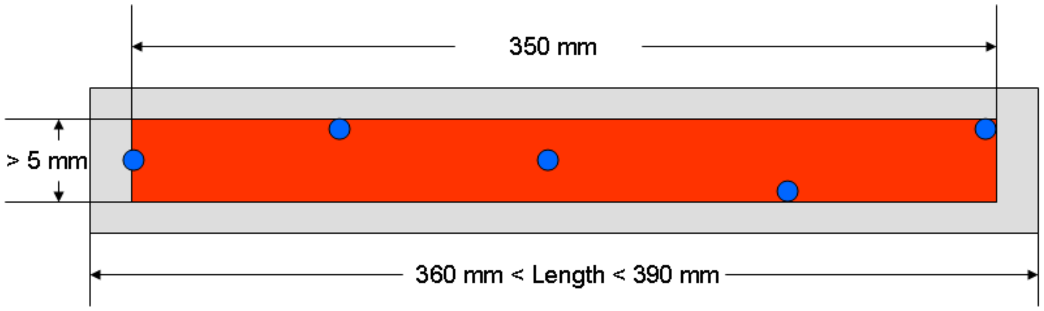

Figure 6: Location of roughness measurement sites, marked in blue. The clear aperture zone is marked in red.

7.7.3. Inspection Test Report

The mirror substrate vendor shall submit an Inspection Test Report of metrology results and associated raw data with each mirror at the time of delivery.

The Inspection Test Report shall include machine-readable raw data sets for all metrology performed. Data sets shall be in plain ASCII text, or another widely used format of mutual agreement. The mirror substrate vendor shall describe the file formats and supply necessary constants and parameters to permit independent data analysis of the raw data.

7.7.4. Test Coupons and Substrates

7.7.4.1. Test Coupons for Coating Qualification

The mirror substrate vendor shall provide three single-crystal silicon test polishing coupons, for qualification of the SLAC reflective coating deposition process described in Section 8. In order to make use of standard tooling, these test coupons should preferably be 2 inch diameter flat disks with a thickness of 3/8 inch. The exact shape and dimensions (including thickness) of the coupons are at the discretion of the mirror substrate vendor, but subject to negotiation and approval by SLAC. Each test coupon shall be polished/figured using the same processes to be applied on the full-size mirrors. The optical surface roughness in the mid-spatial and high-spatial ranges should meet the requirements in the Section 7.5.2. The specification for the surface figure is relaxed to only include a peak-valley surface height error of $\leq$ 158 nm (equivalent to $\lambda/4$ at 633 nm) over the central 80% of the coupon. These test coupons should be prepared and separately-delivered to SLAC as soon as feasible following the award of the contract, to expedite qualification of the reflective coating deposition process. Also note the packaging requirements outlined in Section 7.6.6.

7.7.4.2. Silicon Substrate for Handling and Mounting Procedures

The mirror substrate vendor shall provide one complete single-crystal silicon mirror substrate for verification of the SLAC mirror handling and mounting procedures, described in Section 10.1. This substrate should be prepared in the same manner as the primary mirror substrates. It should be cut to size, ground, prepared with the mounting holes and grooves, and wet-chemical etched with the other substrates. However, only relaxed specifications for figuring and polishing are required for the optical surface: A peak-valley surface height error of ≤ 158 nm (equivalent to $\lambda/4$ at 633 nm) is required over the clear aperture, after subtraction of best-fit cylinder reference surfaces (see Sections 7.5.1 and Figure 6) with a mid-spatial and high spatial roughness of ≤ 1.0 nm rms (see Section 7.5.2). This test substrate should be separately-delivered to SLAC as soon as feasible, to expedite finalization of the mirror handling and mounting procedures.

8. Coating Requirements

8.1. Coating Materials

Each mirror shall be coated with 2 reflective layers. The first layer to be deposited shall be a high atomic number material to be specified later by the SLAC group. The two likeliest candidate materials are Rhodium (Rh) and Ruthenium (Ru).

The second layer shall consist of a lower atomic number material also to be specified at a later date by the SLAC group. This material will likely be either Boron Carbide (B_4C) or Silicon Carbide (SiC). The materials are listed in Table 4.

8.2. Coating Figure

The coating process of the mirrors shall preserve the figure of the polished Silicon substrates as described in Section 7. Full-aperture, visible-light interferometry shall be used to determine the surface figure of each mirror at the coating vendor's facility, after deposition of each layer on the mirror surface has been completed. Verification of the mirror figure after coating will be performed by a third party after delivery of the coated mirrors as described in Section 9.

All roughness and slope errors shall be determined after subtraction of best-fit elliptical reference surface from the clear aperture zone. These best-fit elliptical radii, tangential or sagittal, for the mirror substrate will be provided to the coating vendor by the mirror substrate vendor as described in Section 7.

The figure roughness requirements listed in Table 4 shall not be exceeded after the coating is performed unless the mirror substrate that was delivered did not meet this specifications and a relaxed tolerance was agreed upon by the SLAC group.

Parameter	Value	Units	Comment

First coating layer material	Rh or Ru		
First coating layer thickness	40	nm	
Surface Figure roughness (1st layer)	<0.75	nm rms	Over dimensions from 1mm to the clear aperture size
Mid-spatial roughness (1st layer)	<0.25	nm rms	Over the 10^{-3} to 0.5 μm^{-1} frequency range
High-spatial roughness (1st layer)	<0.25	nm rms	Over the 0.5 to 50 μm^{-1} frequency range
Second coating layer material	B_4C or SiC		
Second coating layer thickness	30	nm	
Surface Figure roughness (2nd layer)	<0.75	nm rms	Over dimensions from 1mm to the clear aperture size
Mid-spatial roughness (2nd layer)	<0.25	nm rms	Over the 10^{-3} to 0.5 μm^{-1} frequency range
High-spatial roughness (2nd layer)	<0.25	nm rms	Over the 0.5 to 50 μm^{-1} frequency range

Table 4: Mirror coating requirements

8.3. Coating Roughness

Roughness shall be measured on each mirror after deposition of each coating layer. A visible-light interferometer or profilometer shall be used for mid-spatial frequency measurements at the coating vendor’s facility. If available, an AFM instrument shall be used for high-spatial frequency measurements at the coating vendor’s facility. If an AFM instrument is unavailable, alternative arrangements must be made by the coating vendor.

Verification of the mid-spatial frequency roughness and the high-spatial frequency roughness will be performed by a third party with white-light optical profiling microscope and AFM capabilities as described in Section 9 after the coating process has been completed.

8.4. Workmanship

Workmanship shall be consistent with the quality necessary for stable operation of sensitive optical devices under long-term exposure to an x-ray, ultrahigh vacuum (UHV) environment similar to that found in synchrotron radiation user facilities.

8.5. Handling and Cleaning

8.5.1. Handling

Full, UHV handling practice is required. Each mirror shall be handled in accordance with the Handling and Coating Process Plan described in Section 0, as reviewed and approved by SLAC.

8.5.2. Cleaning

Each mirror shall be cleaned at the vendor's facility in a manner that is consistent with the figure, mid- and high-spatial frequency roughness requirements discussed in this document, as well as the coating and that allows the mid- and high-spatial frequency roughness to be evaluated. Cleaning shall be performed at the vendor's facility in accordance with the methods outlined in the Handling and Coating Process Plan provided by the vendor and approved by SLAC, as described in Section 0.

8.6. Packaging and Shipping

The coating vendor shall utilize the same packaging and shipping procedure as the mirror substrate vendor as outlined in the Handling and Process Plan described in Section 7.6.7. The plan developed by the mirror substrate vendor will be communicated to the coating vendor by the SLAC group and the coating vendor is expected to follow this plan or submit its own plan to be approved by SLAC.

8.7. Test Coupon Packaging and Shipping

The coating vendor shall utilize the same packaging and shipping procedure for the test coupons as the mirror substrate vendor as outlined in the Handling and Process Plan described in Section 7.6.7. The plan developed by the mirror substrate vendor will be communicated to the coating vendor by the SLAC group and the coating vendor is expected to follow this plan or submit its own plan to be approved by SLAC.

8.8. Handling and Coating Process Plan

All mirror coating processes shall take place in accordance with the methods described in the vendor-supplied Handling and Coating Process Plan. SLAC will provide to the coating vendor the Handling and Process Plan supplied by the mirror substrate vendor (described in Section 7.6.7 and the coating vendor is expected to follow this plan or submit its own plan to be approved by SLAC. Also, an addendum to this plan shall be provided by the coating vendor to include a brief description of the mirror coating procedures. This addendum shall be provided in response to the Request for Proposal from SLAC, and must be reviewed and approved by SLAC. In that way, any materials compatibility issues for the completed mirrors can be identified and settled in advance.

8.9. Quality Assurance Provisions

8.9.1. General

Prior to contract award, SLAC may perform a quality audit at the coating vendor's facility to ascertain the existing or planned quality program implementation and procedures as it pertains to this procurement. Existing procedures to be used for this procurement shall be reviewed during this audit.

The coating vendor shall maintain documentation for all metrology and processes during coating and characterization of these mirrors.

8.9.1.1. Program Management

The coating vendor shall actively manage all matters relating to the performance of this contract to ensure that all performance, schedule, and quality objectives are fully met. A single individual shall be named to serve as the Program Manager of this subcontract. The Program Manager shall act as the single point of contact with SLAC on all technical and programmatic matters.

The subcontract shall establish and apply a program control system to track progress regarding pre-established, measurable milestones. The subcontract shall identify corrective management actions in the event shortfalls are detected or anticipated. The coating vendor shall develop and provide a detailed milestone schedule to SLAC.

In the event SLAC determines that the program success is in jeopardy because of technical, schedule, or quality shortfalls, SLAC reserves the right to conduct special program reviews and audits, as necessary, at the coating vendor's facility.

8.9.1.2. Progress Reporting

SLAC and the coating vendor shall conduct, at a minimum, twice monthly status teleconferences. These teleconferences shall discuss general status of the program. Any item that has immediate effect on technical performance, schedule, or deliveries shall be brought to the immediate attention of SLAC.

8.9.1.3. Reviews

The vendor shall provide necessary support for an initial Technical Interface Meeting to discuss contract planning and to discuss any open contractual or technical action items.

8.9.1.4. Responsibility for Inspection and Tests

The responsibility for performing and documenting all specified tests and metrology shall rest with the coating vendor unless noted otherwise. The coating vendor shall submit a Coating Inspection Test Procedure to SLAC for approval, as outlined in this document, describing each test or measurement to be implemented. SLAC reserves the right to perform in-process inspections at the coating vendor's facility. The coating vendor shall notify SLAC a minimum of 5 working days prior to the start of final inspection and testing.

Drawings and equipment that may be required for adequate inspection and test shall be made available to SLAC. SLAC inspection shall in no way relieve the coating vendor of responsibility for ensuring the quality of the mirrors.

8.9.1.5. Coating Inspection Test Procedure

The coating vendor shall prepare a Coating Inspection Test Procedure in response to the Request for Proposal from SLAC. It must be reviewed and approved by SLAC, and shall include the following at a minimum:

(1) Acceptance verification matrix that list each requirement (including pass/fail criteria) and indicate by what methods and procedures the mirror substrate vendor shall verify the requirement.
(2) Sequence of measurements, both in-process and final
(3) Equipment to be used
(4) Accuracy of measurements
(5) Calibration techniques
(6) Proposed data sheets of results and data format for the Coating Inspection Test Report

8.9.1.6. In-Process Inspection Points

Vendor in-process inspection points shall be specified as part of the Coating Inspection Test Procedure (see Section 8.9.1.5). At a minimum, inspections shall be performed at the following points:

(1) Upon receipt of the mirror substrate
(2) After deposition of the first layer
(3) Final inspection after the mirror coating is finished

8.9.2. Quality Conformance Inspections

8.9.2.1. Characterization Metrology

Compliance with the Optical Surface Quality Requirements specified in Sections 8.2 and 8.3 shall be demonstrated through measurements, and the resulting data provided in the Coating Inspection Test Report. As also stated in Section 8.9.1.5, all measurement procedures must be proposed-to and approved-by SLAC prior to execution.

Measurements shall be made under the following environmental conditions:

Temperature: 20°C ± 2°C.

Humidity: 30% to 70% relative humidity (RH)

During all measurements, the article under test and the test equipment shall be in thermal equilibrium within the specified temperature range.

Mid- and high-spatial frequency roughness shall be measured at the locations specified in Figure 6. These measurements shall be made after each layer has been deposited on the mirrors.

Instrumentation used for the measurement of figure, mid- and high- spatial frequency roughness should be capable of accurately measuring the spatial frequency bandwidths specified in Table 4. All equipment should be in current and traceable calibration.

8.9.3. Coating Inspection Test Report

The coating vendor shall submit a Coating Inspection Test Report of metrology results and associated raw data with each mirror at the time of delivery.

The Coating Inspection Test Report shall include machine-readable raw data sets for all metrology performed. Data sets shall be in plain ASCII text, or another widely used format of mutual agreement. The coating vendor shall describe the file formats and supply necessary constants and parameters to permit independent data analysis of the raw data.

8.10. Test Coupons

Test coupons will be provided by the substrate vendor as described in Section 7.7.4.1. These test coupons will be provided to the coating vendor for qualification of the coating process. The coating vendor shall use the test coupons to develop the coating procedure in the way that it sees fit.

9. Metrology Requirements

The surface properties of the mirrors shall be characterized at various stages of the fabrication process. This section outlines the specifications for metrology to be performed on the 2 mirrors described in Sections 7 and 8.

9.1. Frequency of Measurements

The metrology measurements described in Section 9 shall be performed after the delivery of the mirror substrates by the substrate vendor, described in Section 7, after the deposition of the first coating layer described in Section 8 and after the deposition of the second coating layer also described in Section 8.

9.2. Figure Measurements

Full-aperture, visible-light interferometry shall be used to determine the surface figure at the metrology vendor’s facility. All roughness and slope errors shall be determined after subtraction of best-fit elliptical reference surface from the clear aperture zone.

9.3. Roughness Measurements

A visible-light interferometer or white-light optical profiling microscope shall be used for mid-spatial frequency measurements at the metrology vendor's facility. An AFM instrument shall be used for high-spatial frequency measurements at the metrology vendor's facility. The spatial frequency ranges required for the measurements are described in Table 2, Table 3 and Table 4. The metrology vendor must be capable of performing measurements over all these spatial frequencies.

Mid- and high-spatial frequency roughness shall be measured at the locations specified in Figure 6.

9.4. Power Spectral Density

All the metrology results shall be combined into a Power Spectral Density (PSD) plot showing the surface height fluctuations over the entire spatial frequency range of the measurements. This shall be provided to SLAC in the Metrology Report.

9.5. Workmanship

Workmanship shall be consistent with the quality necessary for stable operation of sensitive optical devices under long-term exposure to an x-ray, ultrahigh vacuum (UHV) environment similar to that found in synchrotron radiation user facilities.

9.6. Handling

Full, UHV handling practice is required. Each mirror shall be handled in accordance with the Handling and Process Plan described in Section 7.6.7. This plan shall be supplied by SLAC to the metrology vendor and the metrology vendor is expected to follow this plan or submit its own plan to be approved by SLAC.

9.7. Packaging and Shipping

The metrology vendor shall utilize the same packaging and shipping procedure as the mirror substrate vendor as outlined in the Handling and Process Plan described in Section 7.6.7. The plan developed by the mirror substrate vendor will be communicated to the metrology vendor by the SLAC group and the metrology vendor is expected to follow this plan or submit its own plan to be approved by SLAC.

9.8. Handling and Metrology Process Plan

All mirror metrology processes shall take place in accordance with the methods described in the Handling and Metrology Process Plan supplied by the metrology vendor. SLAC will provide to the metrology vendor the Handling and Process Plan supplied by the mirror substrate vendor (described in Section 7.6.7) and the metrology vendor is expected to follow this plan or submit its own plan to be approved by SLAC. Also, an addendum to this plan shall be provided by the metrology vendor to include a brief description of the mirror metrology procedures. This addendum shall be provided in response to the Request for Proposal from SLAC, and must be reviewed and approved by SLAC. In that way, any materials compatibility issues or process issues can be identified and settled in advance.

9.9. Quality Assurance Provisions

9.9.1. General

Prior to contract award, SLAC may perform a quality audit at the metrology vendor's facility to ascertain the existing or planned quality program implementation and procedures as it pertains to this procurement. Existing procedures to be used for this procurement shall be reviewed during this audit.

The metrology vendor shall maintain documentation for all processes during coating and characterization of these mirrors.

9.9.1.1. Program Management

The metrology vendor shall actively manage all matters relating to the performance of this contract to ensure that all performance, schedule, and quality objectives are fully met. A single individual shall be named to serve as the Program Manager of this subcontract. The Program Manager shall act as the single point of contact with SLAC on all technical and programmatic matters.

The subcontract shall establish and apply a program control system to track progress regarding pre-established, measurable milestones. The subcontract shall identify corrective management actions in the event shortfalls are detected or anticipated. The metrology vendor shall develop and provide a detailed milestone schedule to SLAC.

In the event SLAC determines that the program success is in jeopardy because of technical, schedule, or quality shortfalls, SLAC reserves the right to conduct special program reviews and audits, as necessary, at the metrology vendor's facility.

9.9.1.2. Progress Reporting

SLAC and the metrology vendor shall conduct, at a minimum, twice monthly status teleconferences. These teleconferences shall discuss general status of the program. Any item that has immediate effect on technical performance, schedule, or deliveries shall be brought to the immediate attention of SLAC.

9.9.1.3. Reviews

The vendor shall provide necessary support for an initial Technical Interface Meeting to discuss contract planning and to discuss any open contractual or technical action items.

9.9.2. Metrology Procedure

The metrology vendor shall prepare a Metrology Procedure in response to the Request for Proposal from SLAC. It must be reviewed and approved by SLAC, and shall include the following at a minimum:

(1) Proposed tests and measurements to be performed and their method of accomplishment
(2) Sequence of measurements, both in-process and final
(3) Equipment to be used
(4) Accuracy of measurements
(5) Calibration techniques
(6) Proposed data sheets of results and data format for the Metrology Report

9.9.3. Characterization Metrology

The surface figure and roughness of the mirrors after fabrication of the substrate and after the coating process shall be characterized through measurements, and the resulting data provided in the Metrology Report. As also stated in Section 9.9.2, all measurement procedures must be proposed-to and approved-by SLAC prior to execution.

Measurements shall be made under the following environmental conditions:

Temperature: 20°C ± 2°C.

Humidity: 30% to 70% relative humidity (RH)

During all measurements, the article under test and the test equipment shall be in thermal equilibrium within the specified temperature range.

Mid- and high-spatial frequency roughness shall be measured at the locations specified in Figure 6.

Instrumentation used for the measurement of figure, mid- and high- spatial frequency roughness should be capable of accurately measuring the spatial frequency bandwidths specified in Table 2, Table 3 and Table 4. All equipment should be in current and traceable calibration.

9.9.4. Metrology Report

The metrology vendor shall submit a Metrology Report of metrology results and associated raw data with each mirror for each occurrence where metrology was required. A report shall be provided for the measurements of the bare substrate, the first coating layer and the second coating layer.

The Metrology Report shall include machine-readable raw data sets for all metrology performed. Data sets shall be in plain ASCII text, or another widely used format of mutual agreement. The metrology vendor shall describe the file formats and supply necessary constants and parameters to permit independent data analysis of the raw data.

10.Mechanical Requirements

10.1. Mirror Support System Requirements

10.1.1. Scope

The section describes the requirements and specifications of the mechanical system that will be used to support and position the KB mirrors. These mirrors and their coating are described in Sections 7 and 8. The mechanical system described in this section will be placed inside a vacuum enclosure (described in Section 10.2) and this enclosure will be supported by a stand (described in Section 10.4).

Each mirror will be between 350 and 390 mm long. The exact dimensions of the mirrors will be communicated to the mirror support vendor at the time of the Request for Proposals by SLAC.

A blank mirror made to the same specifications as the final mirrors except for a relaxed surface quality will be provided to the mirror support vendor for testing of their prototype(s) (if applicable) and final system.

10.1.2. Design and Analysis

The vendor shall provide analyses and design as required. The design items shall include, but not be limited to:

- Interface Definition
- Component Design
- Applicable Analysis
    - Stress and Thermal Analysis
    - Reliability analysis
- Stress and fracture mechanics analysis
- System Performance Analysis
- Risk and risk mitigation approach.
- Verification and Test Plans

10.1.3. Performance Requirements

The KB mirror system will be a very sensitive device which will require very precise manipulation and positioning. The mirror support system will require precise machining and precise motion in order to achieve the focusing and stability requirements. This section describes these requirements.

10.1.3.1. Precision motion

Three rotation axes and two translations shall be accurately controlled for each mirror. We define these 2 translations and 3 rotation angles for each of the two mirrors, shown on Figure 7.

x1: The direction perpendicular to the plane of reflection (sagittal direction).

y1: The direction normal to the reflecting surface.

Grazing angle (θ1): The angle between the LCLS beam and the surface of the upstream mirror. It can also be defined as the pitch angle of the upstream mirror.

In-plane rotation (ψ1): The angle between the LCLS beam and the long axis of the upstream mirror. It can also be defined as the yaw angle of the upstream mirror.

Perpendicularity (φ1): The angle between the two mirrors. It can also be defined as the roll angle of the upstream mirror.

The same angles and translations are defined for the downstream mirror (x2, y2, θ2, ψ2, φ2).

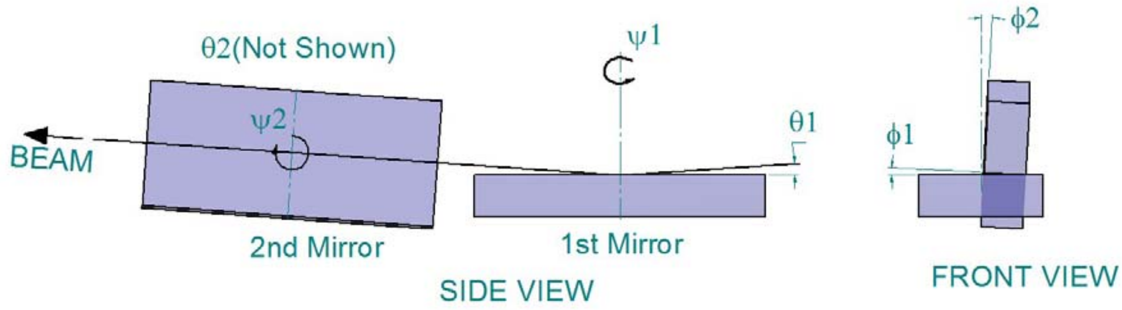

Figure 7: Rotation axes for each mirror. Note that the rotation axes are shown in the standard KB configuration but the mirrors are required to be arranged in the configuration shown on Figure 8. The mirror arrangement shown in this current figure was only chosen for clarity. The required arrangement is that of Figure 8.

The upstream mirror shall have the motorized motions listed in Table 5. The downstream mirror shall have the motorized motions listed in Table 6 . The resolution and repeatability are listed in Table 5 and Table 6. The stability requirement is over a period of a few (~10) minutes, while the number in parentheses is the longer term (1 day) stability requirement. All motions shall have encoders.

Motion	Nominal Position	Range	Resolution	Repeatability	Stability
x1	0	-10 mm < x < 2 mm	4 µm	4 µm	0.1 (1) µm
y1	0	-5 mm < y < 5 mm	4 µm	4 µm	0.1 (1) µm
Grazing angle (θ1)	5.0 mrad	3 mrad < θ < 6 mrad	0.5 µrad	0.5 µrad	0.01 (0.1) µrad
In-plane rotation (ψ1)	0	-10 mrad < ψ < 10 mrad	1 mrad	1 mrad	0.1 (0.1) mrad
Perpendicularity (φ1)	0	-10 mrad < φ < 10 mrad	5 µrad	5 µrad	0.1 (0.5) µrad

Table 5: Motion requirements for the upstream mirror. The stability number corresponds to short term (10 minutes) stability while the number in parentheses correspond to long term stability (over 1 day).

Motion	Nominal Position	Range	Resolution	Repeatability	Stability
x2	0	-10 mm < x < 2 mm	4 µm	4 µm	0.1 (1) µm
y2	0	-5 mm < y < 5 mm	4 µm	4 µm	0.1 (1) µm
Grazing angle (θ2)	5.0 mrad	3 mrad < θ < 6 mrad	0.5 µrad	0.5 µrad	0.01 (0.1) µrad
In-plane rotation (ψ2)	0	-10 mrad < ψ < 10 mrad	1 mrad	1 mrad	0.1 (0.1) mrad
Perpendicularity (φ2)	0	-10 mrad < φ < 10 mrad	5 µrad	5 µrad	0.1 (0.5) µrad

Table 6: Motion requirements for the downstream mirror. The stability number corresponds to short term (10 minutes) stability while the number in parentheses correspond to long term stability (over 1 day).

10.1.4. Positioning

The distance between the midpoints of the mirrors in the z direction shall be 400 mm and controlled to within 8 µm. This can be accomplished either via precise machining of the support system of with independent motorized z translation for each mirror. The decision is left to the mirror support vendor and the engineering solution shall be communicated to SLAC within the first 4 months of the award of the contract.

10.1.5. Dimensions

The dimensions of the system along all 3 axes shall be minimized to the extent possible since the mirror system will interface with other devices in close proximity. Keeping the device as small as possible at the downstream end of the second mirror is especially critical. The mirror support vendor shall propose a maximum size envelope for the system is response to the Request for Proposal from SLAC. The mirror support vendor shall produce a preliminary design within 4 months of the award of the contract. SLAC and the mirror support vendor shall at this point agree to a fixed size envelope that the mirror support vendor shall not exceed for the final system to be delivered.

10.1.6. Orientation

Following the normal convention where a counter-clockwise rotation is in the positive direction, the mirror support system shall hold the upstream mirror with reflecting surface at a roll angle at +135 degrees nominal. The roll angle of the downstream mirror shall be +45 degrees nominal. This is shown on Figure 8.

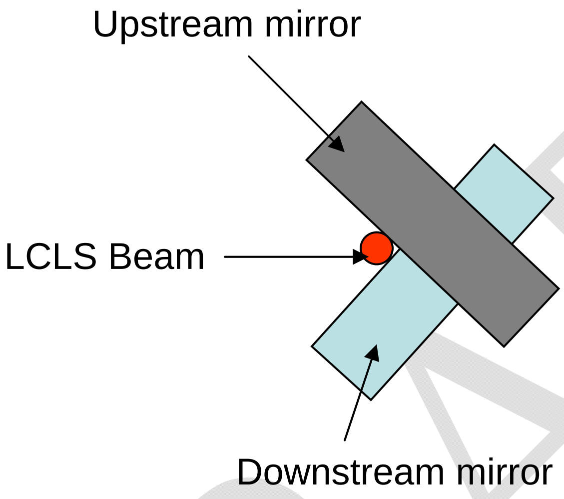

Figure 8: Orientation of the mirrors as seen from the upstream side of the mirrors.

10.1.7. Mirror Mounting

The mounting of the mirrors shall not distort the natural figure of the mirrors by more than the figure errors stated in Section 7.5 It is the responsibility of the mirror support vendor to calculate distortions to the mirror figure for their proposed design and the results of the calculations shall be communicated to SLAC. The vendor shall demonstrate that the design meets the figure distortion specifications either through calculations or measurements using a prototype of the system. The results shall be communicated to SLAC before the final manufacturing of the system begins.

The mirror mounting system shall not have any direct contact with the clear aperture area on optical surface of the mirrors.

The mounting system shall have a clear aperture at least as large as the mirror clear aperture described in Section 7 so that mounting system does not block the beam from impinging on the mirror surface.

10.1.8. Motion Limits

Limit switches shall be implemented to limit the motions of all translations and rotations as listed in Table 5 and Table 6. Hard stops shall also be implemented to limit the motions.

10.1.9. Cyclic Requirements

The linear and rotary motions are expected to be actuated over very short ranges(<1 mm), during the alignment procedure, on the order of 500 times each over a period of a few days.

Once the mirrors are aligned, the system is expected to not be actuated for a period of 2 months. Overall, every motion is expected to be actuated, in small steps, on the order of 3000 times per year for a period of 10 years. All actuators shall be capable meeting these cyclic expectations.

10.1.10. Mechanical Interfaces

The mirror support system will be mounted inside a vacuum enclosure, described in Section 10.3. It is the responsibility of the mirror support vendor to design a mounting structure to which the vacuum enclosure will interface. The details of how the vacuum enclosure will interface with the mirror support shall be the responsibility of the vacuum enclosure vendor as described in Section 10.3.

The mirror support system shall be assembled as a single unit and the mirror support vendor shall propose, design and build a mounting interface which should consist of a single mounting surface with a kinematic mount, or 2 mounting surfaces (1 for each mirror support), each with their kinematic mounts. The proposed mounting surface shall be approved by SLAC. It will be the responsibility of the vacuum enclosure vendor to design how the vacuum chamber interfaces with the mounting structure.

10.1.11. Vacuum

This device will be used in an Ultra-High Vacuum (UHV) of 10^{-9} Torr.

The average total pressure shall be 10^{-9} Torr or better. The mirror support system must not produce carbon-containing vacuum contaminants at partial pressures above 10^{-12} Torr after normal bake-out procedures in Ultra-High Vacuum, i.e. at total pressure less than 10^{-9} Torr.

All lubricants, cutting fluids, etc., used in manufacturing shall be "sulfur-free". SLAC document No. SC-700-866-47 is a compendium of SLAC approved lubricants. The use of sanding discs, abrasive paper or grinding wheels is typically prohibited. In special circumstances good vacuum practices should be followed when grinding and polishing is required. This process shall be reviewed and approved by the engineer for its vacuum compatibility.

All parts and subassemblies shall be cleaned for UHV. Once parts are cleaned for vacuum, they shall be handled only with clean latex or nitrile gloves in/on a clean room/surface. This includes all subassemblies. For storage or transportation, they shall be placed in clean sealed vacuum grade plastic bag that has been back-filled with nitrogen.

10.1.12. Materials

All materials used shall be compatible with a vacuum level of 10^{-9} Torr. The list of materials to be used shall be communicated by the mirror support vendor to SLAC in response to the Request for Proposal from SLAC. All ceramics must be vacuum fired to minimize water content. All fastening screws used in-vacuum must be silver plated and vented. Any proposed change or addition to the list of materials shall be approved by SLAC.

10.1.13. Thermal Issues

The thermal load on the mirrors will be less than 240 mW, which is the full power of the LCLS beam. Since each mirror is specified to reflect > 86% of the beam, the maximum absorbed heat load on each mirror is expected to be less than 34 mW. It is anticipated that no active cooling is required to be provided on the mirrors.

It is anticipated that the heat deposited on the mirrors can be removed via conduction through the support system with good thermal contacts that allow the heat to flow away from the mirrors. It is however the responsibility of the mirror support vendor to design and demonstrate a system which allows for the necessary heat removal.

The system designed shall be shown by the mirror support vendor either through measurements or calculations to meet the stability, positioning and repeatability requirements of Sections 10.1.3 and 10.1.3.1, as well as the figure requirements of Section 7.5 given this heat load. The measurements or calculations shall be communicated to SLAC for review and approval.

10.1.13.1. Radiation Damage Issues

The grazing angle of the mirrors and the chosen coating materials will protect the mirror surface from suffering damage due to the intense LCLS beam. However, the leading edge of mirrors as well as the mirror support system could get damaged if the beam impinges directly on them.

There shall be a block made of Boron Carbide (B_4C) placed upstream of each mirror to protect the leading edges. These blocks shall be 5 mm thick. The edge of the blocks shall be slightly offset from the edges of the mirrors so that the B_4C block is closer to the beam than the leading edge of the mirrors. The offset should always be positive (with the B_4C block closer to the X-ray beam) and controlled to a precision of 10 microns.

The mirror support system shall either be fully located below the optical surface of the mirrors so that the X-ray beam cannot hit it or exposed parts of the system shall be made of light materials that are resistant to damage from the beam. The mirror support vendor shall submit the design to SLAC prior to fabrication, along with the proposed materials, so that SLAC can determine the possible radiation damage issues that are present. Three weeks shall be required by SLAC to make this determination.

10.1.14. Alignment/Fiducialization

The fine alignment of the mirrors will be performed using the LCLS x-ray beam. Only rough alignment of the system is required. Fiducials on the support system along with their position relative to the mirrors shall be provided by the mirror support vendor. These fiducials will be used by SLAC to position the mirror support system inside the vacuum enclosure described in Section 10.3.

10.1.15. Stability

The stability requirements are listed in Table 5 and Table 6. The mirror positions and angles must be stable enough to keep the center of the focal spot stable to within 10% of its Full-Width Half-Maximum (FWHM) relative to the sample chamber which is located 8 meters away. The stability requirement not in parentheses is over a few (~10) minutes. The long term stability requirement is for the beam not to move by more than its FWHM over one day, relative to the CXI Sample Chamber, where the focal plane will be located. The environmental conditions listed in Section 6.2 will be the operating conditions under which these requirements must be met. The mirror support vendor shall assume that a stand meeting the stability requirements of Section 10.4 exists on which to mount the vacuum enclosure which contains the support system. The mirror support vendor shall demonstrate the stability of the system either through calculations or measurements using a prototype of the system. The results shall be communicated to SLAC before the final manufacturing of the system begins.

10.1.16. Kinematics/Supports

See Section 10.1.10.

10.1.17. Workmanship

Workmanship shall be consistent with the quality necessary for stable operation of sensitive optical devices under long-term exposure to an x-ray, ultrahigh vacuum (UHV) environment similar to that found in synchrotron radiation user facilities.

10.1.18. Handling and Cleaning

Full, UHV handling practice is required. Each component of the mirror support system shall be handled in accordance with the Mirror Support Handling and Process Plan described in Section 10.1.20. This plan shall be supplied by the mirror support vendor to and approved by SLAC.

10.1.19. Packaging and Shipping

The vendor shall be responsible for design and fabrication of the mirror support shipping container(s). Best protection against contamination and shock/vibration is essential. An all-metal, dust-free interior-most enclosure is desirable. The suggested method of accomplishing this requirement is to ship the mirror support system in a sealed state with dry nitrogen. A brief description of proposed packaging and shipping arrangements shall be included in the Mirror Support Handling and Process Plan. Design of the packaging container is subject to SLAC approval.

10.1.20. Mirror Support Handling and Process Plan

All mirror support fabrication shall take place in accordance with the methods described in the vendor-supplied Mirror Support Handling and Process Plan. This document shall be provided in response to the Request for Proposal from SLAC, and must be reviewed and approved by SLAC. In that way, any materials compatibility issues for the completed mirrors can be identified and settled in advance. As noted in the sections above, the Mirror Support Handling and Process Plan shall include brief descriptions of the following:

(1) Fabrication process
(2) List of materials
(2) UHV handling procedures
(3) Cleaning procedure
(4) Packaging and shipping arrangements

10.1.21. Electrical Requirements

The mirror support vendor shall terminate all in-vacuum electrical wires and cables with connectors that are compatible with 10^{-9} Torr vacuum. The mirror support vendor shall propose connectors to be approved by SLAC and the mirror support vendor shall communicate the complete list of connectors before the start of fabrication. It will be the responsibility of the vacuum enclosure vendor to use the proper vacuum feedthroughs to match the connector, as described in Section **Error! Reference source not found.**. All electrical components shall comply, to the fullest extent possible, with applicable codes, as evidenced by appropriate certification of these components (certified, listed, or labeled by a Nationally Recognized Testing Laboratory, NRTL)

10.1.22. Quality Assurance Provisions

10.1.22.1. General

Prior to contract award, SLAC may perform a quality audit at the vendor's facility to ascertain the existing or planned quality program implementation and procedures as it pertains to this procurement. Existing manufacturing procedures to be used for this

The mirror support vendor shall maintain documentation for all testing, calculations, prototyping and processes during design and fabrication of the mirror support system.

The vendor shall supply SLAC with evidence that the completed mirror chamber meets the vacuum compatibility requirements of Section 10.1.11. The nature of the test used to ensure compliance shall be a residual gas analysis at ultra-high vacuum pressures. SLAC must approve the details of the test method proposed by the vendor and will offer guidance as to how the test shall be conducted if so requested. Use of the services of an independent testing laboratory is subject to the approval of SLAC.

10.1.23. Quality Assurance Requirements

It is SLAC's intent to use the vendor's existing procedures, manufacturing processes and methods to the maximum extent possible to meet quality assurance requirements. Any discrepancies shall be resolved before contract award. Where appropriate, individual requirements of this section may be deleted or modified with SLAC's concurrence in order to most cost-effectively meet the overall quality, reliability, and risk mitigation objectives of the system provided.

The vendor's quality assurance program shall be consistent with ISO 9001. Before contract award, the vendor shall submit for review the Quality Assurance (QA) Plan and internal relevant manufacturing procedures that ensure that QA requirements contained herein are met. The Quality Assurance Plan or internal manufacturing procedures should minimally include the following:

(1) Introduction (title, scope, table of contents, and organization introduction).
(2) The Quality policy and objectives of the organization.
(3) Description of the organization, responsibilities, and authorities (with or without a flowchart).
(4) A description of the elements of the quality system.

10.1.23.1. Configuration Control

Procedures shall be implemented for configuration control of all hardware, analysis software, and engineering documentation, including design drawings, calculations, process, fabrication and inspection standards, and test procedures. The configuration control procedures shall ensure that all such documents and document changes are properly approved; that document revision levels applicable to the piece part or assembly, test, and handling are clearly specified in the assembly procedures and records; and that required changes to fabricated hardware are completely incorporated and properly documented.

For new component and subsystem designs, fabrication of the first production unit may be performed with changes documented by a properly documented and Configuration Management controlled document markup process, provided that:

- The initial fabrication drawings are approved in accordance with normal company procedures
- Changes are annotated in a single master drawing set, with each change approved by the appropriate personnel before incorporation
- All markup changes shall be formally incorporated with normal configuration control.

In the event a markup process is adopted, the responsibilities and procedures for implementation shall be as described in the vendor's Quality Assurance (QA) Plan. For the final production units a formal change process must be instituted consistent with the vendor’s Configuration Management Process and the document markup process shall not be performed.

10.1.23.2. Program Management

The vendor shall actively manage all matters relating to the performance of this contract to ensure that all specifications, schedule, and quality objectives are fully met. A single individual shall be named to serve as the Program Manager of this subcontract. The Program Manager shall act as the single point of contact with SLAC on all technical and programmatic matters.

The subcontract shall establish and apply a program control system to track progress vis-à-vis pre-established, measurable milestones. The subcontract shall identify corrective management actions in the event shortfalls are detected or anticipated. The vendor shall develop and provide a detailed project schedule to SLAC. The schedule shall be periodically updated and provided at least on a monthly basis to SLAC as part of progress reporting.

In the event SLAC determines that the program success is in jeopardy because of technical, schedule, or quality shortfalls, SLAC reserves the right to conduct special program reviews and audits, as necessary, at the vendor’s facility.

10.1.23.3. Progress Reporting

SLAC and the vendor shall conduct, as a minimum, monthly status teleconferences. These teleconferences shall discuss general status of the program.

(1) Technical progress and programmatic information such as design updates, procurement actions, drawing releases, manufacturing status, integration status, and test status.
(2) A program schedule shall be provided that shows completion status against all major milestones.
(3) Status items submitted to SLAC for information, review, and/or approval.
(4) Any item that has immediate effect on technical performance, schedule, or deliveries shall be brought to the immediate attention of the SLAC Subcontract representative.

10.1.23.4. Reviews

The vendor shall provide necessary support for the following reviews. The vendor shall provide review packages for the Conceptual Design Review (CDR), Preliminary Design Review (PDR) and Final Design Review (FDR) at least 5 days before each review.

10.1.23.4.1. Technical Interface Meeting

The vendor shall host a Technical interface meeting to discuss contract planning and to discuss any open contractual or technical action items. This meeting will be held no later than one month After Receipt of Order (ARO)

10.1.23.4.2. Design Reviews (CDR, PDR, FDR) and Manufacturing Readiness Review (MRR):

The vendor shall prepare for and conduct a CDR within 2 months of contract award, a PDR within 4 months of contract award (consistent with Sections 10.1.4 and 10.1.5) an FDR and an MRR where the status of the design is presented in detail, and the readiness of the vendor to proceed is determined.

10.1.23.4.3. Pre-Ship Review (PSR)

The vendor shall prepare for and conduct a Pre-Ship Review where the system status is presented in order to determine acceptability of hardware for delivery.

10.1.24. Manufacturing and Assembly

10.1.24.1. Manufacturing

The vendor shall supply a Fabrication, Assembly, and Inspection Flow Plan (with manufacturing process/procedures numbers) that shall include a prescriptive procedure that describes the method of fabrication, assembly, procedures, and inspection from piece parts to the completely assembled system. This shall be provided prior to the Manufacturing Readiness Review (MRR). Should the vendor intend to subcontract any portion of work, such intentions, possible subcontractors, and the scope of their involvement shall be included in the vendor's proposal.

The mirror support vendor shall deliver the system fully assembled if it is deemed safe to do so by the mirror support vendor. If the possibility of damage during shipping is deemed too great by the mirror support vendor, then shipping the system disassembled is acceptable. The mirror support vendor shall in either case provide all drawings (in PDF format), all models (2D or 3D in a format to be agreed upon with SLAC) and a detailed assembly procedure to SLAC upon delivery.

10.1.24.2. Verification and Test Plans

The vendor shall provide a qualification and acceptance verification matrix that shall list each requirement and indicate by what methods and procedures the vendor shall verify the requirement.

The vendor shall include pass/fail criteria for each item to be verified. Test plans shall be provided that clearly indicate the test environments, durations, procedures, and test configurations.

10.1.24.3. Inspection Requirements

Fabrication and inspection planning shall be prepared. Manufacturing planning with inspection points shall be available for SLAC review at the vendor's facility. The plan shall describe:

(1) The fabrication steps required
(2) In-process and end item inspection points
(3) References to applicable inspection criteria

For each inspection activity, the procedure and accept/reject criteria shall be documented.

10.1.24.4. Non-Conformance Control

The vendor shall have a closed-loop system for review, analysis, and disposition of failures and discrepancies. Nonconformance reports shall be made available for SLAC review and included as part of the final documentation package.

10.1.24.5. End Item Data Package

The End Item Data Package shall include at a minimum:

1. Part Name
2. Buyer's Part Number/Source Control Drawing Number and Revision
3. Procurement Specification Number and Revision
4. Purchase Order and Item Number
5. Seller Part Number

6. Seller Serial Number
7. Material and Parts Traceability / Certification Reports
8. Analysis reports
9. Relevant data from in-process testing to verify critical processes
10. Nonconformance Reports
11. As built record (drawings and CAD files). This record shall include serial numbers of detail parts and assemblies and justification of any changes in manufacturing process from qualification article baseline
12. Acceptance Test Data Sheets
13. Cleanliness Certification
14. Certificate of Compliance
15. Notes and Comments as required.

Vendor format for this data package is acceptable.

10.1.25. Installation

The mirror support vendor shall provide on-site assistance at SLAC as required for assembly of the system upon delivery and during the final installation of the mirror support system in the CXI instrument.

It will be the responsibility of the LUSI project to mount the mirrors in the support system and to install the support system inside the vacuum enclosure.

10.2. Mirror bending Requirements

The mirrors provided by the mirror substrate vendor may be flat mirrors that will be required to be bent to the elliptical profile described in Section 7. In the case flat bendable mirrors are chosen as the preferred solution, the mirror support vendor, responsible for Section 10.1, shall also in addition be responsible for the mirror bending requirements listed in this section.

10.2.1. Mirror Bending Mechanism

The bending mechanism shall be determined by the mirror support vendor such that the figure and compact size requirements can be met. Both mechanical and bimorph bending systems are acceptable. The mirror bending mechanism must be provided with encoders to provide a guide for the mirror figure.

10.2.2. Mirror Figure and Figure Accuracy

The bending mechanism shall be demonstrated by the vendor through a prototype to be able to meet the figure and figure error requirements listed in Section 7.

10.2.3. Mirror Bender Electrical Requirements

Same as Section 10.1.21.

10.3. Vacuum Enclosure Requirements

The mirrors fabricated by the mirror substrate vendor are described in Section 7. They will then be coated by the mirror coating vendor as described in Section 8. After characterization by the metrology vendor, described in Section 9, they will be mounted on the mirror support system described in Section 10.1 and 10.2 (10.2 is only applicable if the mirror figure is achieved through bending).

The fully assembled system will then be placed in the mirror vacuum enclosure designed and built by the vacuum enclosure vendor.

Note: If the same vendor is awarded the mirror support and vacuum enclosure contracts, then both systems (support and enclosure) may be designed as a single entity allowing motors external to the vacuum enclosure to control the positions and rotations of the mirrors described in Section 10.1. Vendors are encouraged to propose such an alternative in response to the Request for Proposal from SLAC.

10.3.1. Performance Requirements

The vacuum enclosure shall be compatible with 10^{-9} Torr or better vacuum pressure.

10.3.2. Dimensions

The exact dimensions of the mirror support system will be communicated to the vacuum enclosure vendor by SLAC prior to the award of the contract (or the dimensions will be determined by the vacuum enclosure vendor if it is also awarded the mirror support contract). The system will be at least 0.8 m long. The vacuum enclosure shall be as compact as possible given the mirror support system. Of special importance is keeping the vacuum enclosure as short as possible past the end of the second mirror on the downstream end of the mirror system due to interface requirements with other devices. The vacuum enclosure vendor shall provide SLAC with exact dimensions for the vacuum enclosure within 6 weeks of the reception of the mirror support dimensions from SLAC.

10.3.3. Kinematics/Supports

The vacuum enclosure shall have a kinematic mount to allow reproducible mounting to within 100 microns on the mirror support stand described in Section 10.4.

10.3.4. Mechanical Interfaces

The vacuum enclosure will be linked to its environment as follows:

Entrance port: A 6” non-rotatable flange upstream centered on a beam height of 1400mm

Exit port: A 6” rotatable flange downstream centered on a beam height of 1398.6 mm

The vacuum enclosure entrance and exit ports must accommodate the 180° included angle between the incident and reflected x-ray beam. The mirror’s reflecting surface should line up with the centers of the entrance and exit ports

The downstream and upstream flanges will be able to support a gate valve that will isolate the chamber from its external environment.

Both downstream and upstream components of the KB mirror vacuum enclosure will be linked to it by a welded bellows assembly.

10.3.5. Ports

The ports listed in Table 7 shall be provided on the vacuum enclosure. The exact location of the ports shall be approved by SLAC prior to the start of fabrication.

	Port type or use	Orientation	Location	Purpose
1	Viewport (4.5”)	Along ψ1 axis	Midpoint along z of mirror 1	Future addition of interferometer
2	Viewport (4.5”)	Along θ1 axis	Midpoint along z of mirror 1	Future addition of interferometer
3	Viewport (4.5”)	Along ψ2 axis	Midpoint along z of mirror 2	Future addition of interferometer
4	Viewport (4.5”)	Along θ2 axis	Midpoint along z of mirror 2	Future addition of interferometer
5	Vacuum gauge (2.75”)	Any	Anywhere	Measure the pressure
6	Vacuum gauge (2.75”)	Any	Anywhere	Measure the pressure
7	Rough pumping (2.75”)	Any	Anywhere	Pump down the enclosure from atmosphere
8	Ion Pump (6”)	Any	Bottom of enclosure	Create Ultra-high vacuum
9	Feedthrough (6”)	Any	Near the back side of mirror 1	Connect cables for motorized motions
10	Feedthrough (6”)	Any	Near the back side of mirror 2	Connect cables for motorized motions
11	Miscellaneous (6”)	Any	Anywhere	Future expansion
12	Miscellaneous (6”)	Any	Anywhere	Future expansion
13	Miscellaneous (2.75”)	Any	Anywhere	Future expansion
14	Miscellaneous (2.75”)	Any	Anywhere	Future expansion

Table 7: List of ports required on the vacuum enclosure of the KB mirror system.

10.3.6. Vacuum Requirements

This device will be used in an Ultra-High Vacuum (UHV) of 10^{-9} Torr.

The average total pressure shall be 10^{-9} Torr or better. The vacuum enclosure must not produce carbon-containing vacuum contaminants at partial pressures above 10^{-12} Torr after normal bake-out procedures in Ultra-High Vacuum, i.e. at total pressure less than 10^{-9} Torr.

All lubricants, cutting fluids, etc., used in manufacturing shall be "sulfur-free". SLAC document No. SC-700-866-47 is a compendium of SLAC approved lubricants. The use of sanding discs, abrasive paper or grinding wheels is typically prohibited. In special circumstances good vacuum practices should be followed when grinding and polishing is required. This process shall be reviewed and approved by the engineer for its vacuum compatibility.

All parts and subassemblies shall be cleaned for UHV. Once parts are cleaned for vacuum, they shall be handled only with clean latex or nitrile gloves in/on a clean room/surface. This includes all subassemblies. For storage or transportation, they shall be placed in clean sealed vacuum grade plastic bag that has been back-filled with nitrogen.

10.3.7. Seals

Only metal seals shall be used on the vacuum enclosure.

10.3.8. Materials

All parts and materials for the device shall be new and compatible with the performance requirements of this specification. Mil source certifications, including heat number, chemical analysis for all materials used in the manufacturing of the device shall be furnished. All ceramics must be vacuum fired to minimize water content. All fastening screws used in-vacuum must be silver plated and vented. Use of Teflon is specifically prohibited.

10.3.9. Mirror Support Mount

The mirror support system described in Section 10.1 shall be mounted inside the vacuum enclosure. The vacuum enclosure vendor shall design and fabricate a suitable mount to adapt to the mirror support system. The details of the mounting surface(s) of the mirror support system will be provided to the vacuum enclosure vendor by SLAC at the time of the award of the contract.

10.3.10. Thermal Issues

The vacuum enclosure will be located in the environment described in Section 6.2. The expected environmental thermal variations shall not cause fluctuations in the position and orientation of the mirror support system larger than the requirements listed in Table 5 and Table 6. The mirror support mounts described in Section 10.3.9 shall be stable to within these requirements, independent of the details of the mirror support system. The vacuum enclosure vendor shall demonstrate the stability of the mount using either calculations or a prototype and shall communicate the results to SLAC for approval to proceed to fabrication.

10.3.11. Alignment/Fiducialization

References outside the chamber, with known relationship to the mirror positions and angles, must be provided for the purpose of surveying the vacuum enclosure into position at the beamline. The preferred references are six holes of 0.25 (+0.0003 -0.000) inch diameter, four defining the horizontal plane and the two others visible from the top defining the path of the x-ray beam.

10.3.12. Stability

See Section 10.3.10.

10.3.13. Workmanship

Workmanship shall be consistent with the quality necessary for stable operation of sensitive optical devices under long-term exposure to an x-ray, ultrahigh vacuum (UHV) environment similar to that found in synchrotron radiation user facilities.

10.3.14. Handling and Cleaning

Full, UHV handling practice is required. Each component of the vacuum enclosure shall be handled in accordance with UHV practices.

10.3.15. Packaging and Shipping

The vacuum enclosure vendor shall be responsible for design and fabrication of the shipping container(s). Best protection against contamination is essential. An all-metal, dust-free interior-most enclosure is desirable. The suggested method of accomplishing this requirement is to ship the vacuum enclosure in a sealed state with dry nitrogen. Design of the packaging container is subject to SLAC approval.

10.3.16. Electrical Requirements

The vacuum enclosure vendor shall provide all the necessary vacuum ports and feedthroughs to connect all the wires and cables needed for the mirror support system. The list of in-vacuum connectors specified by the mirror support system vendor will be provided to the vacuum enclosure vendor before the start of the final design of the vacuum enclosure. All electrical components shall comply, to the fullest extent possible, with applicable codes, as evidenced by appropriate certification of these components (certified, listed, or labeled by a Nationally Recognized Testing Laboratory, NRTL)

10.3.17. Quality Assurance Provisions

The requirements described in Section 10.1.22 shall apply to the vacuum enclosure system.

10.3.18. Quality Assurance Requirements

The requirements described in Section 10.1.23 shall apply to the vacuum enclosure system.

10.3.19. Manufacturing and Assembly

The requirements described in Section 10.1.24 shall apply to the vacuum enclosure system.

10.3.20. Installation

It will be the responsibility of the LUSI project to mount the support system inside the vacuum enclosure and to install the vacuum enclosure on the support stand.

10.3.21. Maintenance and Accessibility

Maintenance to the in-vacuum components of the mirror system and the mirrors themselves is expected to occur infrequently (roughly once per year). Large maintenance and repair operations are expected to require the entire in-vacuum mirror system to be removed from the vacuum enclosure as a single unit. The design shall allow for the mirror system to be removed from the vacuum enclosure without the need to remove the vacuum enclosure from the beamline.

The design shall also allow for rapid access to the mirror system, through the removal of a single CF flange for minor maintenance not requiring the entire system to be removed from the vacuum enclosure. Access shall be provided to the front and back side of each mirror. Provision (e.g. lifting fixtures on the chamber lid) to open the chamber to provide complete access to the mirror, mounting, and associated mechanism for installation and maintenance shall be provided.

The accessibility of the area where the KB mirror system will be located is most typically highly accessible. Therefore the device design should be reasonably elegant, should minimize safety issues (no pinch points, trip hazards, loose cables/hoses, etc) and should have coatings/platings and finishes that reflect high design standards.

10.3.22. Documentation

The vacuum enclosure vendor shall provide all drawings (in PDF format), all models (2D or 3D in a format to be agreed upon with SLAC) and a detailed assembly procedure to SLAC upon delivery.

10.4. Stand Requirements

This section describes the requirements for the stand which supports the vacuum enclosure of the KB1 system.

10.4.1. Performance Requirements

The performance requirements of the stand are simply stability requirements. The stability requirements are listed in Table 5 and Table 6. The thermal stability and vibrational stability of the stand shall meet these requirements, independently of the stability characteristics of the mirror support system and the vacuum enclosure.

10.4.2. Mechanical Interfaces

The mechanical interface to the stand occurs only on the ground and at the vacuum enclosure for the KB mirror system. The design of the vacuum enclosure and its mounting system described in Section 10.3.3 will be provided to the stand vendor before proceeding with the final design of the stand. The stand vendor shall design and fabricate a stand which is compatible with the vacuum enclosure mounting structure.

10.4.3. Materials

Materials shall be chosen by the stand vendor for their thermal and stability properties so the stability requirements can be meet. No issues with vacuum compatibility exist.

The stand shall be painted with 2 coats of red paint that meets federal color standard FS11140. Alternative color shall be approved by SLAC.

10.4.4. Thermal Issues and Stability

The thermal stability of the stand shall be considered given the environment described in Section 6.2. The mirrors are required to be stable in position and angle with respect to the sample chamber. The thermal expansion of the vacuum enclosure stand and that of the sample chamber stand should be matched to minimize the effects of thermal fluctuations. SLAC shall provide the mirror stand vendor with the design information of the sample chamber stand prior to the final design of the vacuum enclosure.

10.4.5. Structural Issues

The load supported by the vacuum enclosure stand may be close to or over 400 pounds, which would require it to be certified by the SLAC earthquake safety committee. The vacuum enclosure stand vendor shall provide the final design to SLAC before start of fabrication and allow 6 weeks for SLAC to seek the necessary certification.

10.4.6. Motion

The mount of the vacuum enclosure shall allow for ±12.5 mm of coarse manual translation range (in 3 orthogonal directions) for initial positioning of the mirror system with a precision of 0.1 mm. The orientation adjustments are to be permitted via configuration of linear motions in a triangular kinematic mount with the base of the triangle perpendicular to the beam direction and its height along the beam direction.

10.4.7. Documentation

The stand vendor shall provide all drawings (in PDF format), all models (2D or 3D in a format to be agreed upon with SLAC) and a detailed assembly procedure to SLAC upon delivery.

10.4.8. Quality Assurance Provisions

The requirements described in Section 10.1.22 shall apply to the stand.

10.4.9. Quality Assurance Requirements

The requirements described in Section 10.1.23 shall apply to the stand.

10.4.10. Manufacturing and Assembly

The requirements described in Section 10.1.24 shall apply to the stand.

10.4.11. Installation

It will be the responsibility of the LUSI project to mount and align the vacuum enclosure on the support stand and to install the support stand in the CXI instrument.

11. Major Interfaces

11.1. Stand and Vacuum Enclosure

The interface between the support stand and the vacuum enclosure is described in Section 10.4.2 and shall be defined by the stand vendor.

11.2. Vacuum Enclosure and Mirror Support

The interface between the vacuum enclosure and the mirror support system is described in Section 10.3.4 and shall be defined by the vacuum enclosure vendor.

11.3. Mirror Support and Mirrors

The interface between the mirror support system and the mirrors shall be defined by the mirror support vendor. In the case of bent mirrors, it is required that the same vendor provides the mirror substrates and the mirror support and bending mechanism.

11.4. Differential Pumping

The base pressure of the CXI instrument will be 10^{-7} Torr. It will be the responsibility of the LUSI project to design appropriate differential pumping to maintain the 10^{-9} Torr pressure inside the vacuum enclosure of the KB1 system. The LUSI project shall provide the necessary interface information to the vacuum enclosure vendor to allow the integration of the differential pumping system.

11.5. Both LUSI KB systems must be identical

The LUSI project will be procuring a second KB system capable of producing a 100x100 nm focus, known as the CXI 0.1 Micron KB System. This system shall be identical in every aspect to the 1 micron KB system described in this document except for the curvature of the mirrors and the differential pumping. The vendors shall demonstrate, in whichever way possible, in response to the Request for Proposal by SLAC that the propose 1 micron KB system is also fully capable of producing a 100 nm beam when the mirrors are place 10 times closer to the focal plane and they have a roughly 10 times higher curvature. The Engineering Specifications Document for the CXI 0.1 Micron KB System (LUSI ESD # 391-000-64) will be provided to the possible vendors along with this current document.

12. Installation

The LUSI project is responsible for the installation of all components in the CXI instrument. The mirror substrate vendor and the mirror support system vendor shall provide on-site assistance during installation as required by the LUSI project.

13. Controls

The KB mirror system will be remotely operated and controlled for all motions. If the design allows it, it is preferable but not required that the actuators used are compatible with the Experimental Physics and Industrial Control System (EPICS) software tools and have existing EPICS drivers.

Developing the controls will be the responsibility of the LUSI project. The motors and stages used by the vendors shall first and foremost meet the positioning requirements. However, if multiple options exist, the LUSI project requests that the vendors select devices for which EPICS software already exists. The list of EPICS supported hardware is available here http://www.epics.org/.

All functions of the KB system shall be controlled remotely.

An interlock shall be provided by LUSI for the vacuum system. A vacuum gauge will control the vacuum level in the KB vacuum enclosure. An interlock will trigger the closing of the upstream and downstream gate valve in the case of an abnormal pressure rise.

Software limits shall be provided by LUSI to restrict the range of motion of the mirrors once they are aligned.

An interlock shall be provide by LUSI between the PPS photon stopper and the mirror positioning stages in order to make sure the X-ray beam is turned off during large motions of the system.

14.Environmental Safety and Health Requirements

14.1. Earthquake

The support stand will be approved by the SLAC Earthquake Safety Committee in the event the total weight of the KB system exceeds 400 pounds.

14.2. Radiation Physics

The KB system will be installed inside hutch 5 which is not accessible while the X-ray beam can enter the hutch. Therefore no radiation shielding for personnel protection is required.

14.3. Pressure Vessel/Vacuum Vessel

10CFR851. Use of burst disk, pressure relief valve. Engineering calcs with SF4.

15.Demonstration of Capabilities by Vendors

The vendors shall provide SLAC with a demonstration of their capabilites in response to the Request for Proposals from SLAC. The vendors can use similar past projects as an example of their capabilities.

SLAC reserves the right to reject proposals if the vendor has not satisfactorily demonstrated the necessary capabilities to meet the requirements described in this document.

16.Acronyms

AFM: Atomic Force Microscope

ARO: After Receipt of Order

CDR: Conceptual Design Review

CXI: Coherent X-ray Imaging

EPICS: Experimental Physics and Industrial Control System

FDR: Final Design Review

FEH: Far Experimental Hall

FEL: Free Electron Laser

FWHM: Full-Width Half-Maximum

KB: Kirkpatrick-Baez

LCLS: Linac Coherent Light Source

LUSI: LCLS Ultrafast Science Instruments

MRR: Manufacturing Readiness Review

NRTL: Nationally Recognized Testing Laboratory

PDR: Preliminary Design Review

PSR: Pre-Ship Review

QA: Quality Assurance

rms: Root Mean Square

SLAC: Stanford Linear Accelerator Center

UHV: Ultra-High Vacuum

17. Appendix A: Mirror Specification Summary