Final Design Report
for the Final Phase
of the Nanoprobe Beamline
at the Advanced Photon Source

Part of the Center for Nanoscale Materials Project
at
Argonne National Laboratory
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1. Introduction

The Nanoprobe Beamline is being built as part of the Center for Nanoscale Materials (CNM) Project, which is DOE's Nanoscale Science Research Center at Argonne National Laboratory. The CNM will be a user facility for nanoscience research that provides facilities for the synthesis, processing, characterization, and modeling of a new generation of functional nanoscale materials. The Nanoprobe Beamline will provide capability for fluorescence, diffraction, and transmission imaging with hard x-rays at a spatial resolution of 30 nm or better.

The Nanoprobe Beamline will be the centerpiece of the x-ray characterization facilities at the CNM. The Hard X-ray Nanoprobe will advance the state of the art by providing the highest-spatial-resolution hard x-ray microscopy beamline in the world. A dedicated source, beamline, and optics have been designed to give optimum performance of the Nanoprobe. This unique instrument will not only be key to the specific research thrusts of the CNM, but will be of very general utility to the broader nanoscience community. It will offer diverse capabilities in studying nanomaterials and nanostructures, particularly for embedded structures. The scientific objectives, performance goals and preliminary design of the final configuration of the Nanoprobe Beamline are described in the Preliminary Design Report (PDR) dated Feb. 13, 2004.

This Final Design Report for the Final Phase of the Nanoprobe Beamline describes the final configuration of the beamline. All beamline components discussed in the preliminary design report will be installed for the Final Phase. The major optical components are the Mirror System, the Beam Defining Aperture, the Double Multilayer Monochromator, the Double Crystal Monochromator, the Polarizer, the Beam Chopper, and the Nanoprobe Instrument.

The final design will *differ* from the preliminary design in that a crystal monochromator with a vertical offset of 5.6 mm has been chosen, while the PDR had called for an offset of 20 mm. An offset of 5.6 mm was chosen to minimize motions of the 1st crystal with respect to the 2nd crystal, which would seriously compromise the spatial resolution of the nanoprobe. In order to allow operation with the reduced offset, the Nanoprobe Endstation, 26-ID-C, will be configured consistent with white beam operation. Bremsstrahlung and synchrotron radiation ray tracings have update to reflect this change.

2. Final Design – Final Phase

2.1 STORAGE RING PARAMETERS

The design is based on the standard storage ring parameters, with an emittance of ε = 3.0 nm-rad and a coupling of C = 2%. Other parameters used are (from "Nominal APS Storage Ring Parameters, July, 2004):

β_x [m]	14.4
β_y [m]	3.95
σ_x [μm]	242.0
σ_y [μm]	15.4
σ_x' [μrad]	14.4
σ_y' [μrad]	3.9

Typical synchrotron current during the Final Phase will be 100 mA. The maximum power output from two collinear insertion devices at 100 mA is 10.6 kW at a gap of 11 mm. The angular power density is 19.2 W/mrad^2. The performance of all beamline components installed during the testing phase has been evaluated these power conditions.

2.2 UNDULATORS

Two collinear insertion devices with a length of 2.4 m and a period of λ_u = 3.3 cm (APS undulator A) will be used as x-ray source. This will maximize the brilliance available for the range of photon energies of operation (3-30 keV) while keeping the power load at a level that can be handled by standard beamline components and the optical components chosen. In particular, this approach allows us to maximize the brilliance at high photon energies, where the coherent flux is small, while providing the option of opening one insertion device for operation at small photon energy if the large total power and power density negatively affect the performance of beamline optical components. The need for this will be evaluated in the Testing Phase.

Fixed phasing of undulators as well as active phasing using a phasing device in the storage ring has been considered [Dejus, 2004]. The optimum configuration in our case appears to be the use of fixed phasing, to maintain the full combined length of the insertion devices of 4.8 m. We have decided to phase the undulators for a fixed photon energy between 8 and 10 keV. Out-of-phase effects that could reduce the brilliance at other energies will be measured during the Testing Phase.

An insertion-device vacuum chamber with a standard size has been installed into the 26-ID front end. This chamber permits a minimum undulator gap of 10.5 mm. For the Final Phase, we request approval for a minimum gap of 10.5 mm.

2.3 FRONT END

In its final configuration, the Nanoprobe Beamline is designed to operate with two collinear undulators U33 at a gap as small as 10.5 mm for a synchrotron current of 180 mA. To meet the high total power and power density in the x-ray beam, a new front end has been designed and installed by the APS. For the Final Phase, we request that this front end will be operated at a minimum undulator gap of 10.5 mm, and at a maximum synchrotron current of 100 mA. This front end is the basis for beamline synchrotron and bremsstrahlung ray tracings provided with this report. The front end layout is shown in Fig. 1. The front end provides an exit synchrotron aperture of 2(H)×2(V) mm and an exit bremsstrahlung aperture of 10(H)×7(V) mm. The front end terminates with the beamline isolation valve (BIV), which is located at 26.43 m from the source. As in the Testing Phase, the Nanoprobe Beamline will be operated windowless in the Final Phase.

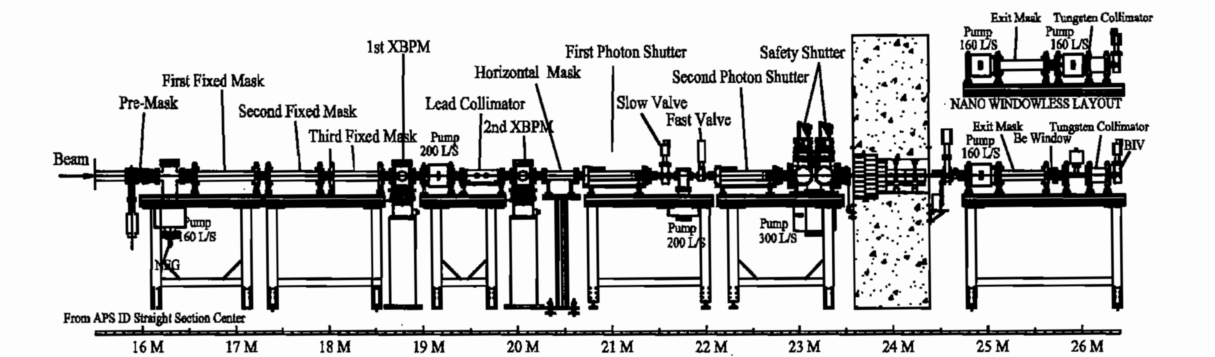

FIG. 1 Front end layout.

2.4 BEAMLINE OPTICS AND COMPONENTS

Overall Layout

The major components of the Nanoprobe Beamline are the Mirror System (MS) located at 30 m from the source, the Beam Defining Aperture (BDA) at 40 m from the source, the Double Multilayer Monochromator (DMM) located at 61.8 m from the source, the Double Crystal Monochromator (DCM) at 63 m from the source, the Polarizer (POL) located at 66 m from the source, the Beam Chopper (BC) located at 67 m from the source, and the Nanoprobe Instrument (NPI) located at 74 m from the source. MS and BDA are positioned in the First Optical Enclosure (FOE), 26-ID-A, DCM, DMM, POL and BC in the Second Optical Enclosure (SOE), 26-ID-B, and the NPI in the Nanoprobe Endstation (26-ID-C). In addition, a White Beam Slit will be positioned upstream of the Mirror System at 27 m, and a Pink Beam Slit upstream of the monochromators at 60.6 m.

Fig. 2 shows the layout of the beamline during the Final Phase. The beamline consists of the First Optical Enclosure 26-ID-A (FOE), the Second Optical Enclosure 26-ID-B (SOE), and the Nanoprobe Endstation 26-ID-C (NES). The FOE and the SOE are connected by the Shielded Transport Pipe (STP). FOE, SOE and NES have been designed as white-beam hutches. FOE, SOE and NES have been validated to allow white beam operation at a synchrotron current of 100 mA.

The FOE contains the front end exit mask with a differential pumping section, three masks (M26-A1, M26-A2, M26-A3), a White Beam Slits (WBS), the MS, the BDA, a diagnostic screen, and the 26-ID-A Photon Shutter and Safety Shutter Assembly. The front end exit mask is terminated by a differential pumping section inside the First Optical Enclosure (FOE), 26-ID-A, providing windowless operation. The WBS is positioned at 27 m. Mask M26-A1 will be positioned at 28.7 m to vertically limit missteered undulator beam to a position of 1.2 mm above the optical axis. The Nanoprobe Mirror System is positioned with the center of the first mirror at 30 m. The first mirror has a physical length of 464 mm, a cooled length of 380 mm, and will deflect the beam outboard. The second mirror has a physical length of 1000 mm, a cooled length of 900 mm, and will deflect the beam inboard and parallel to the undulators beam incident on the mirror system. The offset of the beam after the mirror system is 4.8 mm outboard. Mask M26-A2 is positioned at 32.5 m. It stops white undulators beam, and confines pink undulators beam to an aperture of 1.6 mm (H) x 6 mm (V). M26-A3 is located at 38.7 m. It stops pink beam missteered by the Nanoprobe Mirror System, and confines pink undulators beam to an aperture of 4 mm (H) x 6 mm. The Beam Defining Aperture is located at 40 m. It accepts focused pink beam from the mirror system and defines the lateral coherence length in the horizontal direction. The 26-ID-A Photon Shutter and Safety Shutter Assembly are located at 41 m. They stop undulator beam and bremsstrahlung to allow access to the SOE.

The SOE contains one mask (M26-B1), a pink beam stop (M26-B2), a Pink Beam Slit (PBS), DCM, DMM, POL, BC, and the 26-ID-B Photon Shutter and Safety Shutter Assembly. M26-B1 is positioned at 59.4 m. It confines missteered undulator beam to an exit aperture of 4 x 4 mm. The PBS is positioned at 60.6 m. It will be used to limit the size of the beam illuminating the monochromator. The DMM and the DCM are positioned at 61.5 m and 63.2 m, respectively. Both introduce a vertical offset of 5.6 mm into the beam centerline. The monochromatic beam after the DCM has a bandwidth of approx. $\Delta E/E = 10^{-4}$, and a total power of less than 1 W. The monochromatic beam after the DMM has a bandwidth of approx. $\Delta E/E = 10^{-2}$, and, has a power in the 1st diffraction order of less than 30 W. A polarizer is positioned at 65.8 m, a beam chopper at 66.5 m. Pink beam after the monochromators will be stopped by M26-B2, positioned at 64.5 m. The 26-ID-B Photon Shutter and Safety Shutter Assembly are located at 68.0 and 68.5 m. They stop monochromatic beam and bremsstrahlung from entering the NES.

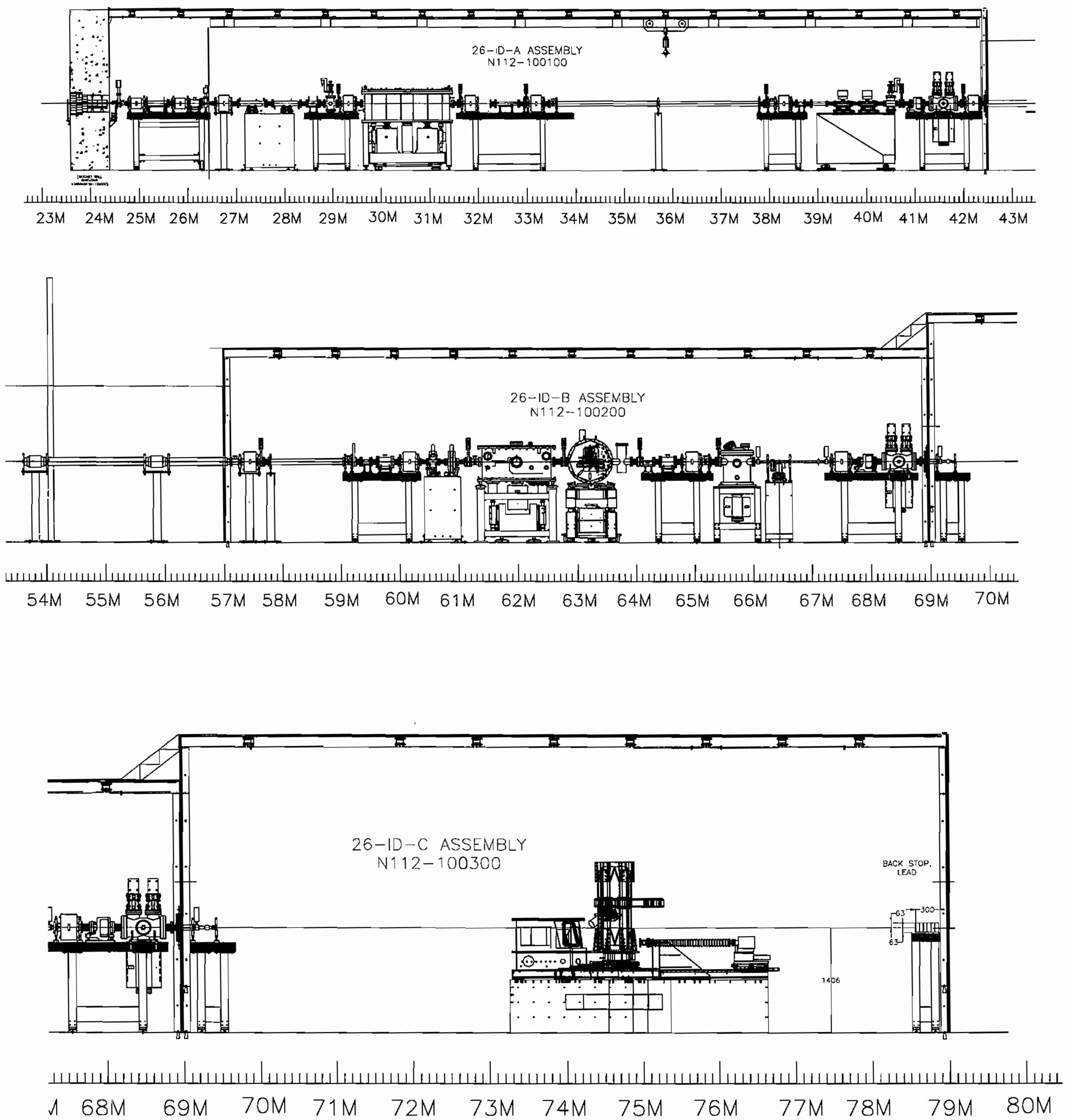

Fig. 2: Beamline Layout for the Final Phase

White beam slits, masks, photon shutters

White-Beam Slits, masks and photon shutters (L26-A, M26-A1, M26-A2, M26-A3, M26-B1, M26-B2, PS26-A, PS26-B) are modifications of existing standard designs. For both safety shutters, the front end design was used, with aperture sizes adjusted to satisfy radiation shielding requirements in the beamline. Using an existing design saved significant engineering time, and simplifies maintenance.

We have evaluated the thermal design of all FOE photon shutters and masks with regard to operation in the Final Phase. Reports on this evaluation are attached as Appendix V (aps_130965.pdf, aps_056679).

TABLE 1 Maximum total power and normal-incidence power density incident on various beamline components (at 100 mA ring current, gap of 11 mm (K=2.62), U3.3, 4.8m long). Power and Power density were calculated using the Program *XOP2.0* [Rio, Dejus, 2000]

Distance from source (m)	Component	Max. inc. total power (W)	Horizontal inc. beam size (mm)	Vertical inc. beam size (mm)	Peak. norm.-inc. power density (W/mm^2)
25.4	FE Exit Mask	7500	6.2	8.3	492
27.0	White Beam Slit	1610	2.1	2.1	432
28.7	Mask M26-A1	1610	2.3	2.3	385
30.0	Mirror System	1610	2.4	2.4	350
32.5	Mask M26-A2 (unfocused white beam)	1610	2.6	2.6	298
32.5	Mask M26-A2 (focused pink beam)	500 (at worst PD, θ = 1.5 mrad)	0.049	2.6	4000
38.6	Mask M26-A3 (focused pink beam)	660 (at θ = 1 mrad)	0.174	3.0	770
40.0	Beam Defining Aperture (focused pink beam)	460	0.212	3.1	630
41	Photon Shutter PS-26-A, Safety Shutter SS-26-A (focused pink beam)	460	0.234	3.2	560
59.4	Mask M26-B1	460	0.626	4.8	144
60.8	Pink Beam Slit	460	0.656	4.8	134
63.2	Monochromator	460	0.702	5.0	121
64.2	Pink Beam stop (M26-B2)	460	0.73	4.3	113
68	Photon Shutter PS-26-B, Safety Shutter SS-26-B	30	0.81	5.4	103

We provide the total power and power density incident on each component in Table 1. Table 1 shows the maximum normal-incidence peak power density and total power incident on various beamline components. The table assumes a synchrotron current of 100 mA for a smallest gap of 10.5 mm. For comparison, the thermal conditions encountered by the exit mask of the front end are included in the table. For components downstream of the mirror system, it was assumed that the mirror system is optimized to focus pink beam on the respective component. It was also assumed that the Pt stripe is used. A worst-case transmitted power of 460 W was used, corresponding to the total power transmitted through the mirror system for a grazing angle of 0.015 mrad. Higher numbers are shown for M26-A2 and M26-A3as these mask could be exposed to pink beam reflected by a single mirror only. The number of 500 W for M26-A2 is obtained for the condition of worst power density, corresponding to a grazing angle of 1.5 mrad. The number of 660 W for M26-A3 is obtained at 1 mrad, the larges angle under which singly reflected from M1a could pass M26-A2 and impinge on M26-A3. Note that these are "worst case" values, not typical operating values. The maximum power density for components in the FOE and SOE is determined by the maximum angular power density from the source (315 kW/mrad^2 for a two collinear undulator-A's at 11cm gap, and a ring current of 100 mA) divided by the square of the distance to the source. The total power depends on the size of the beam, which can be limited by the White Beam Slit, the grazing angle of the Mirror System and thereby its acceptance, and the bandpass of a component.

Nanoprobe Mirror System

The Nanoprobe Mirror System is designed to act as first, high-heatload optical component of the Nanoprobe beamline. It consists of consists of two horizontally deflecting mirrors, M1a and M1b, and several masks. M1a provides focusing of the incident beam on the Beam Defining Aperture at 40 m. M1b redirects the beam reflected off M1a to be parallel to the incident beam, and to improve harmonics rejection. The mirror system provides a offset of the pink beam with regard to the white beam of 4.8 mm in the outboard direction. The mirror system is designed to rotate M1a and M1b together to grazing angles between 2.4 mrad and 6 mrad, thus optimizing order rejection for photon energies between 3 keV and 30 keV. The 2nd mirror provides an additional degree of angular adjustment to provide fine pitch correction.

We wish to note two properties of the mirror system that bear on the design of the beamline.

1) A range of bending radii between 2.5 km and 6.25 km is required to allow focusing of the undulator beam on the Beam Defining aperture for grazing angles between $\theta = 2$ mrad and $\theta = 6$ mrad. This range of bending radii allows in principle focusing of pink beam on any beamline component positioned downstream of the mirror system. All masks, shutters and slits in the FOE downstream of the mirror system have therefore been designed to handle the power density of focused pink beam for a synchrotron current up to 180 mA.
2) The mirror system allows for a pathological configuration where, for a grazing angle of approximately 1 mrad, a pink beam reflected only off M1a can propagate through M26-A2 down the beamline (see APS_1191164). M26-A3 has been designed to stop all singly reflected pink beams.

TABLE 2: Mirror System parameters.

Overall Parameters

Position in beamline from center of straight section [m]	30
Range of grazing angles [mrad]	2.4 – 6.0

Beam offset [mm]	4.8 [outboard]
Coatings	Si, Cr, Pt
Integrated masks	Upstream of M1a; upstream of M1b
Maximum operating power* [W]	732
Maximum operating in-plane power density* [W/mm^2]	3.9
Maximum incident power** [W]	1105
Maximum in-plane power density** [W/mm^2]	5.53
Maximum vertical acceptance [mm]	1.0
Maximum horizontal acceptance [mm]	2.3
Grazing angle for optimized thermal performance [mrad]	2.4
Parameters, M1a	
Substrate material	Si
Substrate length [mm]	464
Substrate width [mm]	60
Substrate thickness [mm]	50
Cooled length [mm]	380
Useful surface length [mm^2]	300 x 40
Notch	Y
Surface figure	Flat, mechanically bent
Bending radii [km]	2.5 - ∞
Bender	U-bender, one actuator, encoded
Deflection	Horizontal, outboard
Parameters, M1b	
Substrate material	Si
Substrate length [mm]	1000
Substrate width [mm]	70
Substrate thickness [mm]	70
Cooled length [mm]	900
Useful surface length [mm^2]	900 x 40
Notch	N
Surface figure	Flat
Deflection	Horizontal, inboard
Bender	N
Vacuum specification	$< 5 \cdot 10^{-10}$ torr
Other	
* vertical beamsize: 0.5 mm, θ = 6 mrad	
** vertical beamsize: 0.5 mm, θ = 8.5 mrad	

To prevent damage, the white beam slit must be used to limit the size of the incident beam to less than 2.3 mm (H) x 1 mm (V)

Relevant Documentation: APS_1191165, APS_1191166

Crystal Monochromator (DCM)

For the Final Phase, we are using cryogenically cooled double crystal monochromator form Oxford/Danfysik. A primary issue for the resolution of the nanoprobe in scanning probe mode is the potential for degradation of the coherence length and flux due to distortions of the monochromator crystals. Slope errors of 0.2 μrad over the footprint of the coherent beam lead to wave front distortions that reduce the spatial resolution achievable in the nanoprobe instrument. Relative motions of the 1st crystal with regard to the second crystal leads to virtual source motions. Vibrations excited by the flow of coolant could lead to a reduction of the resolution. To minimize effects of relative motion of 1st and second crystal, we have decided to minimize the vertical offset of the monochromator. A vertical offset of 5.6 mm has been chosen. The motion of the 2nd crystal is flexure-based. The vertical offset is smaller than the 20 mm planned for in the PDR. The reduced vertical offset does not allow to protect the 26-ID-C hutch from bremsstrahung. The hutch will therefore be operated as white beam hutch.

TABLE 3 Crystal monochromator parameters.

Tuning range	-1° – 60°
Bragg angle resolution	2.5 urad
Crystal orientation	Si <111>
Energy range	3 – 30 keV
Offset	5.6 mm
Vacuum specification	10^{-7} – 10^{-8} Torr

Relevant documentation: DCM_RevA_14jul06.doc

Multilayer Monochromator (DMM)

A multilayer monochromator (DMM) from Oxford-Danfysik will be used for higher intensity, lower resolution imaging experiments, primarily in full-field transmission mode. The LBM will have an identical offset (5.6 mm minimum) as the DCM, and both will be designed to be translated out of the beam when the other is in use. It will have an energy range of 3 to 10 keV, and a bandwidth of 1%. Two water-cooled WSi_2/Si multilayers will be used as the optics.

Relevant documentation: E1623 Double Multilayer Monochromator Design Concept.doc

Polarizer

A crystal polarizer will be available in the beamline to convert linearly polarized x-rays into circularly polarized x-rays for magnetic studies. Crystal polarizers perform at high efficiency at energies above 10 keV; thin crystals (e.g. 160 μm thick) will be required to minimize absorption losses at low energy. The polarizer will introduce no offset into the beam, and be capable of polarization switching in the kHz frequency range.

Chopper

A mechanical beam chopper will select individual ~100 ps pulses from the storage ring fill pattern (under special asymmetric fill modes) for time-resolved studies. It will have a maximum opening size of 0.5 mm, and an opening frequency in the kHz range. The existing beam chopper design of APS/XOR will meet our requirements (opening frequency 2.6 kHz). It will be mounted downstream of the monochromators inside a vacuum housing in a manner that allows translation into or out of the beam.

Summary of component design types

Table 4 summarizes the design type of each beamline component as a standard component with existing design, a modified standard component, or a new design.

TABLE 4 Summary of component design types

S = APS Standard Component
M = Modified APS Standard Component
C = Commercial Component
N = New Design

WBS	Name	Design type	Design basis
1.1.2.3.1	White Beam Slits L26-A	M	L5-94
1.1.2.3.3	Mask M26-A1	M	4102040104-100000
1.1.2.3.3	Mask M26-A2	M	4102040104-100000
1.1.2.3.3	Mask M26-A3	M	4102040104-100000
1.1.2.10.1	Mask M26-B1	M	4102040104-100000
1.1.2.10.1	Mask M26-B2	M	4102040103-100000
1.1.2.3.4	Photon Shutter PS26-A	M	4102030105-100000
1.1.2.10.3	Photon Shutter PS26-B	M	4102030105-100000
1.1.2.3.4	Safety Shutter SS26-A	M	4102040109-100000
1.1.2.10.3	Safety Shutter SS26-B	M	4102040109-100000
1.1.2.3.5	Supports	M	4102040114-100000
1.1.2.10.4	Supports	M	4102040114-100000
1.1.2.4	Mirror System	C	Accel, A1579
1.1.2.5	Beam Defining Aperture	M	L5-80, L5-800000-02
1.1.2.10.2	Pink Beam Slits	M	L2-90
1.1.2.12	Multilayer Monochromator	C	Oxford S1623
1.1.2.11	Crystal Monochromator	C	Oxford S1614
1.1.2.14	Polarizer System	M	V3-320000-00-01
1.1.2.13	Chopper System	C	
1.1.2.15.6	Be Windows	S	W2-20
1.1.3.3	Nanoprobe Instrument	C	XRADIA X-ray Optics, Positioning Modules,

			Transmission Detector and Software for the Hard X-ray Nanoprobe Instrument

2.5 VACUUM, SURVEY AND ALIGNMENT

The beamline is ion-pumped to UHV all the way to the final window in the endstation separating the beamline from the nanoprobe instrument. The beamline and all components will comply with APS vacuum policy.

The front end is terminated by a differential pumping section. Two Be windows with a thickness of 0.25-mm will be mounted at the end of the beamline, on the upstream side of the 26-ID-C hutch.

Survey and alignment procedures will conform to standard APS practices and use APS personnel. External fiducial reference markers will be provided on all optical components, which will be surveyed with respect to internal optics during final assembly. These will be surveyed and aligned with respect to the beamline reference upon installation.

3. Schedule and WBS

3.1 SCHEDULE AND SCHEDULE COORDINATION

Coordination of APS support for installation, survey and alignment tasks has been scheduled for December 2006 – March, 2007. Component installation will be carried out by the CNM X-ray Imaging Group, as well as by the AES-MIS, AES-SI, AES-MED, AES-MOM groups. The detailed schedule for these tasks is being arranged by Jörg Maser and Robert Winarksi.

3.2 SCHEDULE AND WBS

Appendix VI contains the full WBS for the Nanoprobe Beamline to achieve its Final Phase configuration. Here, we explain, at the 4th level of the WBS, which components are to be installed and their schedule status. WBS items referred to as "Integration" are engineering tasks related to overall design of a beamline section, are listed in parenthesis, and not explained individually.

WBS 1.1.1: Undulators and Front End

<u>WBS 1.1.1.1: Undulators and Gap Controls</u>

Both undulators have been installed and commissioned.

<u>(WBS 1.1.1.2: Front End Integration)</u>

<u>WBS 1.1.1.3: Front End</u>

The Nanoprobe Beamline front end has been completely installed and commissioned.

WBS 1.1.2: Beamline Optical Systems

<u>WBS 1.1.2.1 (First Optical Enclosure Integration)</u>

<u>WBS 1.1.2.2: 26-ID-A, First Optical Enclosure (FOE)</u>

The FOE hutch is complete and surveyed.

<u>WBS 1.1.2.3 FOE Standard Components</u>

White Beam Slits: The FOE White Beam Slits has been installed in the SOE, It will be moved into the FOE. Installation is planned for December, 2006.

Masks: M26-A3 must be positioned in its position for the Testing Phase. Installation of M26-A1 and M26-A2 is planned for December, 2006.

FOE shutter: Both the FOE Photon Shutter (PS-26-A) and the FOE Safety Shutter (SS-26-A) have been installed at their final position.

FOE supports: Supports required for the Testing Phase have been installed in the FOE hutch. Additional supports required for the Final Phase will be installed in December, 2006.

WBS 1.1.2.4: Nanoprobe Mirror System

The Nanoprobe Mirror System will be delivered in March, 2007. Installation by the CNM-XIG members and Accel is planned for February and March, 2007.

WBS 1.1.2.5: Beam Defining Aperture

The Beam Defining Aperture is under fabrication, and will be delivered and assembled in December, 2006. Installation is planned for January, 2007.

WBS 1.1.2.6: FOE Vacuum Components

Transport pipes and bellows have to be partly removed from the FOE to allow installation of the White Beam Slit, the Nanoprobe Mirror System, M26-A1, and M26-A2. Vacuum Pumps, vacuum gauges and gate valves have been installed.

WBS 1.1.2.7: FOE Survey and Alignment

Survey and Alignment of FOE components is planned for March/April, 2006.

(WBS 1.1.2.8 Second Optical Enclosure Integration)

WBS 1.1.2.9: 26-ID-B, Second Optical Enclosure (SOE)

The SOE hutch is complete and surveyed.

WBS 1.1.2.10: SOE Standard Components

The SOE Masks M26-B1 and M26-B2 will be installed at their final positions, at 59.6 m and 64.5 m.

The Pink Beam Slit has been fabricated and assembled. Installation is planned for December, 2006.

SOE shutter: Both the SOE Photon Shutter (PS-26-B) and the FOE Safety Shutter (SS-26-B) have been installed at their final position.

SOE supports: Supports required for the Testing Phase have been installed in the SOE hutch. Additional supports required for the Final Phase will be installed in December, 2006.

FOE/SOE Diagnostic screens and beam position monitors. They will be installed in January, 2007.

WBS 1.1.2.11: Crystal Monochromator

The Crystal Monochromator is being fabricated by Oxford. Delivery is expected for March, 2007. Installation is planned for late March – early April, 2007. The monochromator will use LN2-cooled Si<111> crystals as optical elements.

WBS 1.1.2.12: Multilayer Monochromator System

The Multilayer Monochromator is being fabricated by Oxford. Delivery is expected for March, 2007. Installation is planned for April, 2007. Installation may be postponed til May, 2007.

WBS 1.1.2.13: Chopper System

Delivery of the Chopper System is planned for January, 2007. Installation is planned for May, 2007

WBS 1.1.2.14: Polarizer System

The Polarizer System is being assembled. Installation is planned for January/February, 2006.

WBS 1.1.2.15: SOE Vacuum components

Transport pipes and bellows have been installed in the SOE. Some have to be removed to allow installation of DMM, Polarizer and Chopper. Vacuum Pumps, vacuum gauges and gate valves have been installed.

WBS 1.1.2.16: SOE Survey and Alignment

Survey and Alignment of FOE components is planned for March/April, 2006.

WBS 1.1.3: End Station

(WBS 1.1.3.1: NES Integration)

WBS 1.1.3.2: 26-ID-C, Nanoprobe Endstation (NES)

A lead back stop and an additional 1 m x 1 m x 2" lead plate has to be installed on the downstream side of the NES hutch. Installation is planned for January, 2007.

WBS 1.1.3.3 Nanoprobe Systems

The Nanoprobe Instrument is being fabricated by XRADIA. Delivery is planned for late February, 2007. Installation is planned for March, 2007.

WBS 1.1.3.4: Zone Plate Optics

Phase I, Phase II have been delivered. Phase III zone plates will be delivered in April, 2007.

WBS 1.1.3.5 Nanoprobe Detectors.

Nanoprobe detectors are under procurement, and will be delivered in March, 2007.

WBS 1.1.3.6 NES Survey and Alignment

No NES Survey and Alignment will be required to complete the Final Phase configuration.

WBS 1.1.3.7 Beamline Data Acquisition and Controls

The Final Beamline Control Electronics components will be installed and tested during installation of the respective beamline components. A detailed schedule has been developed with Pete Jemian.

1.1.3.8: Beamline PPS/EPS

The Beamline PSS system hardware has been installed. The PSS logic needs to be modified to reflect the Final Phase configuration. Modification will be implemented in January, 2007.

The Beamline EPS has been installed. The EPS needs to be modified to accommodate the additional beamline components. The Final Phase will incorporate vacuum monitoring (ion pump current and ion gauge readings), valve control, and water flow monitoring. Installation will be coordinated with the Electrical Systems group, AES (Jon Hawkins). Installation and testing will be performed in March, 2006.

WBS 1.1.3.9: 26-ID-A, B, C Utilities

Beamline Power has been installed.

The Beamline Plumbing main lines and fittings needed for the Final Phase have been installed. The AES Mechanical Engineering (Water) group will be outfitting the 26-ID-A and 26-ID-B hutches with DI water and air lines for attachment to the beamline components as they are installed. A LN2 filling system for the Crystal Monochromator and related plumbing is being installed.

The heat exchanger and HVAC system will be installed for the Final Phase.

4. Safety Analysis

Sector Layout and Emergency Egress

The hutch layout is shown on the overall beamline layout drawing in Appendix I. It is determined by the required positions of the mirror, beam-defining aperture (BDA), and other optical components.

All hutch roofs have railings and ladderway access so that the space can be used for appropriate support equipment (e.g. ion pump power supplies, motor control electronics, etc.) with straightforward access. Utilities have been run at above-the-hutch-roof height along the railings on the outboard side of the hutches, with support poles to bridge the region between the FOE and SOE. A ceiling-mounted hoist was installed in the FOE to facilitate equipment movement in the restricted space. No permanent crane has been planned for the SOE. A crane has been added into the NES to allow lifting of nanoprobe instrument components.

The layout includes secondary egress routes complying with the requirements set forth in *Service-Corridor, Exit Aisles and Duck-Unders on the APS Experiment Floor* (*APS Beamline Design and Construction Requirements*). The primary and secondary egress routes are depicted on the attached layout drawing. There is one "duck-under" between the FOE and SOE to ensure a maximum length of 50 feet for the dead-end aisle between Sector 26 and 27. Although the design of 26-BM has not been developed, we plan that it will include a similar duck-under to ensure a maximum length of 50 feet for the dead-end aisle between 26-BM and 26-ID. Until 26-BM is developed, an egress aisle will be marked on the 26-BM floor area to ensure an appropriate path remains unblocked.

Shielding Design

The shielding complies with APS requirements set forth in ANL/APS TB-44.

All Optical Enclosures have been shielded for white beam. This includes lead covers on the windows of 26-ID-C. The lead covers are under configuration control. The FOE, SOE and NES have been validated for white-beam operation at a gap of 11 mm, and for a synchrotron current of 100 mA.

The First Optical Enclosure is longer than a standard FOE to enclose the BDA at 40 m from the source. Since the FOE extends across to the 27-BM ring shielding door, a large door in the FOE and a keep-clear area along the beamline have been provided to allow access. Similar FOE designs have been implemented previously at APS (e.g. in XOR). The photon shutter PS26-A at the end of the FOE has been designed to withstand the heat load in the Final Phase configuration (two undulator A's at a synchrotron current of 180 mA, focused by the Nanoprobe Mirror System on the shutter). The safety shutter SS26-A at the end of the FOE is designed as a bremsstrahlung stop.

The Second Optical Enclosure (SOE) as well as the shielded transport between the FOE and SOE have been shielded for white beam. The photon shutter PS26-B is identical in design to

PS26-A. The safety shutter at SS26-B at the end of the SOE is designed as a bremsstrahlung stop.

The Nanoprobe End Station (NES) hutch has been shielded for white beam, which allows operation of the beamline with a small offset of the monochromatic beam from the beam axis of 5.6 mm. It has validated for use with white beam. An anteroom outside the hutch door is planned as a clean-room air lock and, if needed, a gowning area. A control room outside the anteroom will further buffer the NES hutch from the APS Hall environment.

Vertical and horizontal bremsstrahlung and synchrotron radiation ray diagrams are provided in Appendix II. The shielding arrangement was developed in consultation with APS staff (P. K. Job and Kevin Randall). Since only a small (horizontal) beam displacement takes place in the FOE, primary bremsstrahlung can propagate into the SOE. Since only a small (vertical) beam displacement takes place in the SOE, a bremstrahlung stop in the SOE would not satisfy APS shielding policy. Therefore, no bremsstrahlung stop has been placed, and the NES will be operated as white beam hutch.

Personnel Safety System

The Nanoprobe beamline will operate in a similar manner to the majority of beamlines at the APS, with no special requirements for the implementation of the personnel safety system (PSS) for this beamline. APS standard PSS designs will be used including hutch access, critical component monitoring, and radiation safety.

The hutch PSS system will be standard for a beamline with three tandem hutches, and there are no unusual problems or concerns. There will be only one operating mode for the beamline. Each hutch has standard search and interlock controls, and there will be a one-to-one correspondence between hutches and safety shutters, as shown in Table 3. The searched-and-secure status of each of the three hutches will be interlocked to its corresponding safety shutter immediately upstream. Entry permit to each hutch will require that its shutter be closed; shutter open permit will require that its hutch be searched and secure. Locations for all standard PSS controls are indicated on the PSS drawing in Appendix I. These are located so that no user equipment will block access or view of hutch areas during search.

TABLE 3. One-to-one correspondence between safety shutters and hutches.

Hutch	Location of Corresponding Shutter
First Optical Encl. (26-ID-A)	End of Front End
Second Optical Encl. (26-ID-B)	End of First Optical Encl.
Nanoprobe Endstation (26-ID-C)	End of Second Optical Encl.

TABLE 4. Hutch entry and shutter permit logic.

To permit:	Requires:
Hutch entry	Corresponding shutter is closed
Shutter opening	Corresponding hutch is searched and secure

The Gen3-PSS Controls System has been installed. It will be upgraded to account for the small overlap (2.14 mm) of the pink beam stop M26-B2 beyond the extremal SR ray. This change will be integrated into the PSS system in January, 2006.

Equipment Protection System

A BL-EPS that allows vacuum monitoring of ion pump supplies and ion gauges has been installed. Beamline valves have been incorporated into the EPS system to allow automatic isolation of a beamline section. Water flow is monitored for some beamline components, including the white beam slits. Specifications for water flow rates are summarized in aps_131556.pdf. The BL-EPS needs to be updated to allow integration of new beamline components. APS will be providing the design, hardware, and installation of the EPS system for the Nanoprobe Beamline

Program-Specific Hazards

The operations that will be carried out on the nanoprobe beamline are expected to involve small articles that pose little to no risk to personnel or the environment. Although some may involve toxic substances, anticipated operations will not cause the release of such substances so they can cause ill effects.

With the possible exception of the occasional use of sealed check sources, there are no plans to handle radioactive materials.

There are no specific plans to handle biohazards and the design of the beamline incorporates no controls appropriate for biohazards. (All beamline operations will be analyzed prior to being conducted. Any proposed activity involving a biohazard will authorized only if the beamline has or can be provided with controls consistent with those required by ANL policy and recommended in *Biosafety in Microbiological and Biomedical Laboratories*).

Liquid nitrogen will be used both in cooling of the crystal monochromator. A LEGe detector will be cooled by LN2 from a 7L LN2 dewar in the NES.

Three standard bottles of inert compressed gases (He, N_2, and Ar) will be positioned outside of Station 26-ID-C. Each will be piped into the station. Under reasonably foreseeable circumstances, these gases pose no unacceptable risk and require no controls. The hazard associated with each is the ability to contribute to an oxygen deficient atmosphere; however, even if all three bottles simultaneously emptied into the station, they should not displace enough oxygen to create an unacceptable situation.[1]

There are no plans to propagate white beam through air in any experiment station, nor are there other plans that would lead production of hygienically significant ozone.

[1] This conclusion reflects, in part, the tendency of He to move to the highest part of the enclosure and then quickly find ways through openings near the top of the enclosure. The other two gases have molecular densities close enough to that to air to be expected to mix well with the atmosphere in the station.

References

[Dejus, 2004] A Comprehensive Computer Simulations Study of Phasing of Undulators (Rev. 0, Nov. 2004)
[Rio, Dejus, 2000] XOP2.0 –XOP: A Graphical User Interface for Spectral Calculations and X-ray Optics Utilities.

Appendix I

Beamline Layout Drawings

cnm-master-2006Nov13-LT.dwg
26ID-Hutches-A PSS and Doors 2005Sep23
26ID-Hutches-B PSS and Doors 2005Sep23
26ID-Hutches-C PSS and Doors 2005Sep23
26ID-Hutches-D PSS and Doors 2005Sep23
26ID-Hutches-E PSS and Doors 2005Sep23
26ID-Hutches-F PSS and Doors 2005Sep23

Appendix II

Ray Drawings

cnm-master-2006Nov13-LT.dwg

Appendix III

Standard Component Drawings

PS26-A1, PS26-A2	N1120304-100000
SS26-A1, SS26-A2	N120304-200000
M26-A1	N1120303-100000
M26-A2	N1120303-200000
M26-A3	N1120303-300000
M26-B1	N1121001-100000.
M26-B2	N1121001-200000.
White Beam Slit	N11203-100200
Pink Beam Slit	N11210-100300
Background Reduction Aperture K26-B1, K26-B2	N1120302-100000, N1120302-200000

Appendix IV

Beamline Optics - Drawings

Nanoprobe Mirror System:	Design drawings available upon request Final drawings available after February, 2007 Contact: Jörg Maser
Double Crystal Monochromator:	Design drawings available upon request Final drawings available after March, 2007 Contact: Martin Holt
Double Multilayer Monochromator:	Design drawings available upon request Final drawings available after March, 2007 Contact: Martin Holt
Polarizer:	Design drawings and final drawings available upon request Final drawings available after March, 2007 Contact: Robert Winarski
Beam chopper	Design drawings drawings available upon request Final drawings available after March, 2007 Contact: Brian Stephenson

Appendix V

Evaluation of the Thermal Design of the Nanoprobe Beamline Critical Components

Documents:

aps_056258.pdf
(FOE) Thermal Analysis Presentation to Mechanical Engineering Committee for the XFD Review of the Photon Shutters and Masks for the Nanoprobe Beamline, ICMS link:

aps_130965.pdf:	M26-A1, M26-A2, M26-A3, PS26-A
aps_131330.pdf	White Beam slits

Appendix VI

WBS Nanoprobe Beamline

P3_oct06.pdf

Appendix VII

Personnel Safety System

Relevant Documents:
26ID Personnel Safety System (PSS) Validation Procedure ESD-B (APS_081313)
26ID Personnel Safety System (PSS) Users Requirements Specification (APS_081312)
26ID PSS Software Source Code ESD-B (APS_128215)

Appendix VIII

Equipment Protection System

Relevant Documents:
26-ID Beamline Equipment Protection System (BLEPS) System Requirements Specification (APS_1028418)
26-ID Beamline Equipment Protection System (BLEPS) Verification Procedure (APS_1028417)
26-ID Beamline Equipment Protection System (BLEPS) PLC Code (APS_1028422)
26-ID Beamline Equipment Protection System (BLEPS) Local Rack Cable Listing (APS_1028420)
26-ID Beamline Equipment Protection System (BLEPS) Remote Rack Cable Listing (APS_1028421)

Appendix IX

Nanoprobe Beamline ES&H

Nanoprobe-ESH-rev1.pdf