Spectroscopy Soft and Tender Beamline Suite (SST)

IRR Functional Description

Contents

1 INTRODUCTION 3
Primary Research Capabilities 3
Beamline Staff 3

2 BEAMLINE DESIGN AND COMPONENTS 4
2.1 Beamline Performance Goals 4
2.2 Beamline Layout 4
The First Optical Enclosure: 6
The Soft Branch (SST-1): 6
The Tender Branch (SST-2): 6

3 BEAMLINE SAFETY 7
3.1 Radiation Shielding 7
3.2 Radiation Safety Components 7
3.2.1 Heat Load Management (white, pink, and monochromatic beams) 9
3.2.2 Primary Bremsstrahlung Radiation Management 10
3.2.3 Secondary (Scattered) Bremsstrahlung Radiation Management 10
3.2.4 Configuration control 10
3.3 Area Radiation Monitor (ARM) 10
3.4 Personnel Protection System (PPS) 10
3.5 Hazard Identification and Mitigation 10

4 INSTRUMENT READINESS 11
4.1 Survey and alignment 11
4.2 Utilities 11
4.3 Vacuum System and Pressure Safety 11
4.4 Controls 11
4.5 Equipment Protection System (EPS) 11

1 INTRODUCTION

Primary Research Capabilities

The National Institute of Standards and Technology (NIST) and the Department of Energy (DOE) have a 30 year ongoing partnership at the NSLS and NSLS-II developing advanced synchrotron measurement methods and delivering excellence in material science impacting important societal challenges in energy, health, environment, national security, and improving our quality of life. This partnership promotes innovation and enhances US industrial competiveness for inorganic and organic semiconductors, photovoltaics, self-assembled-monolayers, biological and environmental materials, batteries, catalysts, fuel cells, polymers, superconductors, ferroelectrics, and ferromagnets. Located at the NSLS, the NIST Synchrotron Methods Group of nine staff have operated a suite of three state-of-the-art spectroscopy beamlines (U7A, X24A, and X23A2) that span the entire absorption-edge energy range of the periodic table to establish structure function relationships in advanced materials. More than 200 industry and academic researchers each year have used the NIST Beamline Suite to accelerate the development of new materials into devices and systems with advanced functionality for a broad spectrum of industries. Building upon this success, NIST is currently in the process of establishing an NSLS-II spectroscopy suite of two state-of-the-art high throughput beamlines (with X-ray Diffraction capability) described in beamline development proposals; Soft and Tender X-ray Spectroscopy and Microscopy (100 eV to 7.5 keV canted sources) and Hard X-ray Absorption Spectroscopy and Diffraction (4.5 keV to 22 keV three-pole wiggler source). Taken together, the NIST NSLS-II Spectroscopy Beamline Suite will be capable of measuring the electronic, chemical, and structural properties of almost any material, often at the nanoscale. NIST is committed to fully funding the construction of its proposed Spectroscopy Beamline Suite and to continuous world leading improvements in synchrotron measurement science and technology. Furthermore, NIST will build upon its NSLS based Synchrotron Science Group to fully staff its stakeholder relationship in NSLS-II.

Spectroscopy Soft and Tender (SST) is part of this suite of state-of-the-art, high-throughput spectroscopy beamlines at the NSLS-II developed by NIST. It is located at port 7-ID and was constructed as a partnership between NIST and NSLS-II. SST consists of two beamlines, SST-1 and SST-2, based on two canted undulator sources. SST-1 provides soft x-rays (100 eV – 2200 eV), while SST-2 provides tender x-rays (1.0 keV – 7.5 keV). These beamlines will perform synchrotron-based x-ray photoelectron spectroscopy (XPS) and near edge x-ray absorption fine structure (NEXAFS) spectroscopy, which are complimentary experimental techniques to probe the occupied and unoccupied density of states. The ability to perform both measurements on the same sample achieves a complete, non-destructive, depth selective measurement of electronic structure, chemistry, and bond orientation.

For the initial commissioning and this readiness review, two high-throughput experimental stations – one on each branch – will be in place. The NEXAFS station on SST-1 and the HAXPES station on SST-2 will both be capable of NEXAFS and XPS measurements, at a beam spot size of 50 µm or better. The beamline is designed to contain a further five experimental stations; these remaining stations will be covered in subsequent safety reviews and are thus out of scope for this review. Several scientific examples can be found in the beamline development proposal.

Beamline Staff

NIST Project Leader	Daniel Fischer	
Lead Beamline Scientist, SST-1	Cherno Jaye	
Lead Beamline Scientist, SST-2	Conan Weiland	
Authorized Beamline Staff	Joseph Woicik	Beamline Scientist
	Johnny Kirkland	Controls Engineer

2 BEAMLINE DESIGN AND COMPONENTS

2.1 Beamline Performance Goals

Table 1 summarizes the design performance of the SST beamline suite. SST-1 is powered by an EPU-60 undulator and provides soft x-rays to a 35 µm spot. The mirrors can also be dithered to move the beam or provide a larger beam profile. SST-2 is powered by a U42 undulator and provides tender x-rays to a 50 µm spot.

Table 1: SST beamline performance goals

Parameter	Specification/Description	
	SST-1	**SST-2**
Insertion Device	EPU-60	U42
Operating Energy Range	100 eV to 2200 eV	1500 eV to 7500 eV
Monochromator	Plane grating monochromator	Double crystal monochromator
Beam size at sample (FWHM)	35 µm (NEXAFS)	50 µm (HAXPES)
Flux at sample at 500 mA storage ring current	10^{14} photons/s	10^{14} photons/s

2.2 Beamline Layout

The SST beamline layout is shown in **Figure 1**. The SST sources and front end were previously reviewed for readiness and commissioned and thus will not be described here.

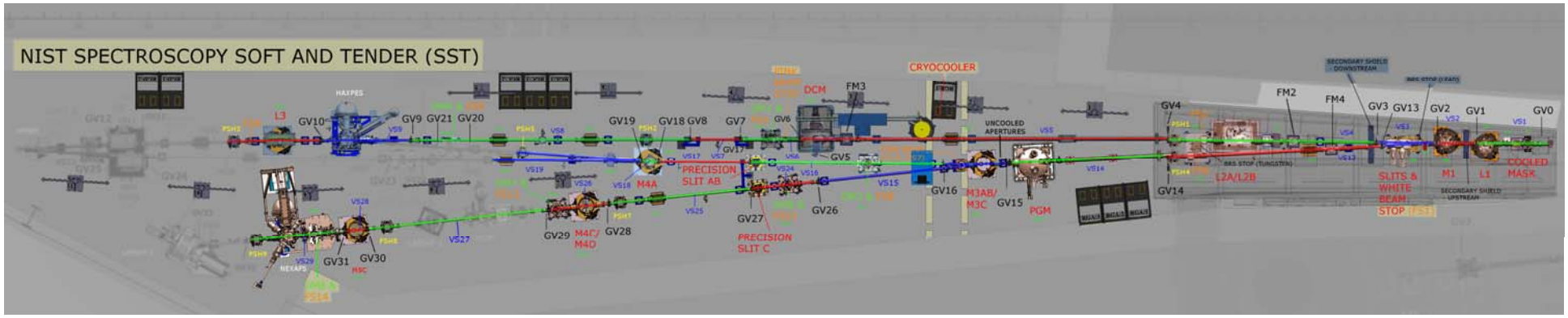

Figure 1: SST Beamline Layout

The First Optical Enclosure:

The layout of the first optical enclosure (FOE) is shown in **Figure 2**. The soft and tender beams exit the front end with a 2 mrad angle between the two beams; the soft beam is initially directed inboard, while tender is outboard. The tender beam is then deflected inboard by the planar L1 planar, while the soft beam is deflected outboard by the planar M1 mirror, leading to a beam crossover. The tender beam is then either focused using the toroidal L2A mirror, or deflected with the planar L2B mirror. The L2A and L2B mirrors are held within the same mirror chamber; switching between the two mirrors is accomplished using a vertical drive of the mirror chamber. All mirror chambers in the FOE are mounted on hexapods.

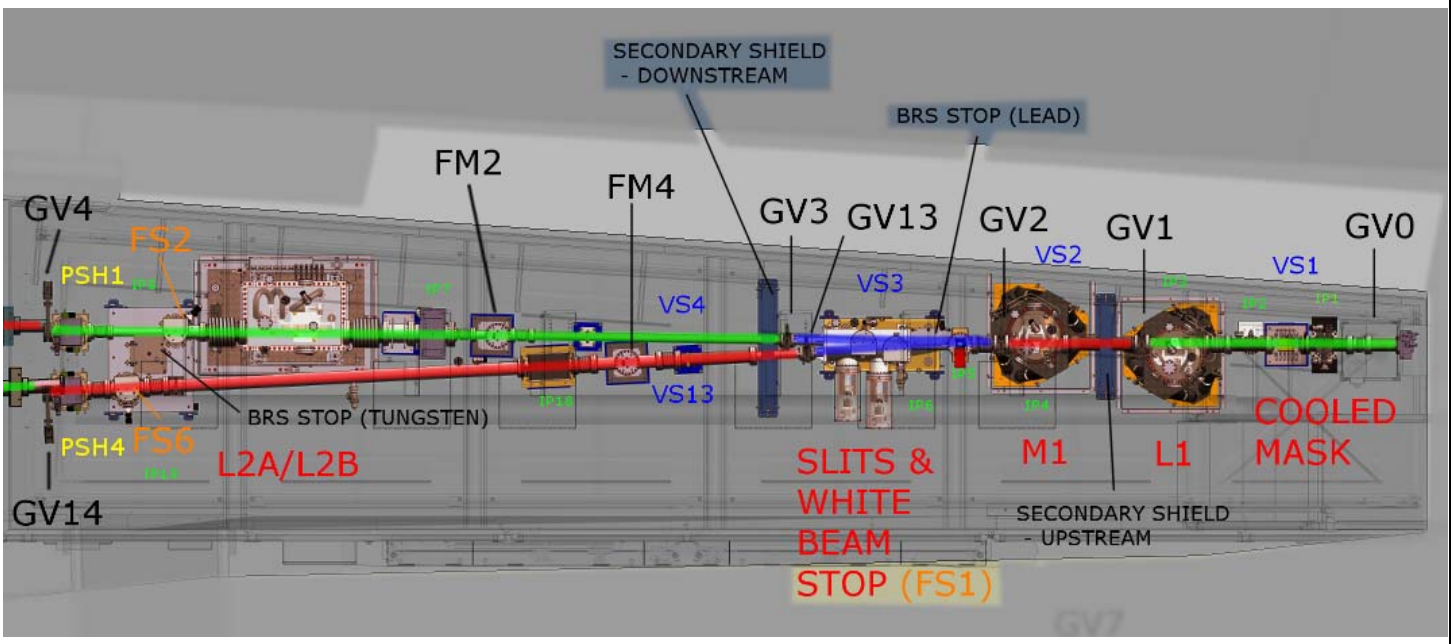

Figure 2: Zoomed in view of the SST FOE.

The Soft Branch (SST-1):

Soft beam exiting the FOE is impinged upon the plane grating monochromator (PGM) for energy selection. The PGM contains a planar mirror, M2, which directs the beam vertically onto the grating. This leads to a 15 mm vertical offset from the source. The PGM has three gratings (250 l/mm, 600 l/mm, and 1200 l/mm) for optimal photon flux and resolution in different energy ranges. After the PGM, the beam can either be directed outboard along the SST-1 branch using the M3C mirror, or inboard along the transfer branches to the SST-2 experimental stations by using the M3AB mirror. Both M3AB and M3C focus the beam at the exit slits located on either branch. For commissioning, only M3C will be used.

From the M3C mirror, the soft beam is then directed vertically and focused using the M4C mirror. Finally, the planar M5C directs the beam downward to the sample position in the NEXAFS experimental station. All mirrors downstream of the PGM are mounted on hexapods, and additionally have a piezo motor for fine control and dithering. The soft branch is terminated at photon shutter 9.

The Tender Branch (SST-2):

Tender beam exiting the FOE is impinged upon the double crystal monochromator (DCM) for energy selection. The DCM has two crystal pairs, Si (111) and Si (220). The beam exiting the DCM has a 15 mm vertical offset from the source height. The tender beam then traverses a long flight tube into the HAXPES experimental station.

A planar mirror, L3, located downstream of the HAXPES station deflects the tender beam towards a future endstation. The tender branch is then terminated at photon shutter 3.

3 BEAMLINE SAFETY

3.1 Radiation Shielding

The design of all radiation shielding (hutches and radiation safety components) has been analyzed to ensure that it follows guidelines to reduce radiation levels external to the beamline enclosures during normal operation to < 0.05 mrem/hr and as low as reasonably achievable. The shielding wall thicknesses follow released shielding guidelines.[1] The FOE has a lateral wall thickness 18 mm, a downstream wall thickness of 50 mm, and 10 mm of lead on the roof.

Photon shutters PSH4 and PSH1 are installed at the downstream end of the FOE on the soft and tender branches, respectively.

In the pink beam section between the FOE and the monochromators, the diameter of the pink beam transport pipe and a series of masks ensures that pink beam cannot impinge upon the transport tube. The transport tube exiting the FOE is additionally shielded with 8 mm of lead to provide additional collimation.

The thickness of stainless steel required to shield air scattered beam is shown in **Table 2**. Covers are installed over bellows and thin-walled sections of beam tube to ensure these requirements are met.

Table 2: Thickness of stainless steel required to shield air scatter.

Region	SST-1 (soft)	SST-2 (tender)
Upstream of PGM	4 mm	2 mm
PGM to PBS	2 mm	2 mm
PBS to Slits	1 mm	N/A

The PGM has a minimum chamber wall thickness of 6 mm, and the DCM 6.35 mm stainless steel and all mirror chambers have a minimum wall thickness of 4 mm, to provide shielding from scattered radiation from solid targets. All viewports in the pink beam section have leaded glass.

For the IRR, both soft and tender beams will terminate at locked photon shutter 3 on the tender branch, photon shutter 9 on the soft branch, photon shutter 5 on the transfer to HAXPES, and a stainless steel beam stop flange on the second transfer line.

3.2 Radiation Safety Components

In addition to the radiation shielding discussed above, there are a series of radiation safety components in place to contain the synchrotron radiation and gas Bremsstrahlung radiation. Diagrams of the radiation safety components are shown in Figure 3, **Figure 4**, and **Figure 5**. The location and dimensions of these components are determined based on the ray tracing and top off safety system analysis. These components are all documented in the ray tracing drawing. A full list of components are identified in the 7-ID radiation safety components checklist.

[1] W.-K Lee et.al., *Guidelines for the NSLS-II Beamline Shielding Design*, (LT-C-ESH-STD-001).

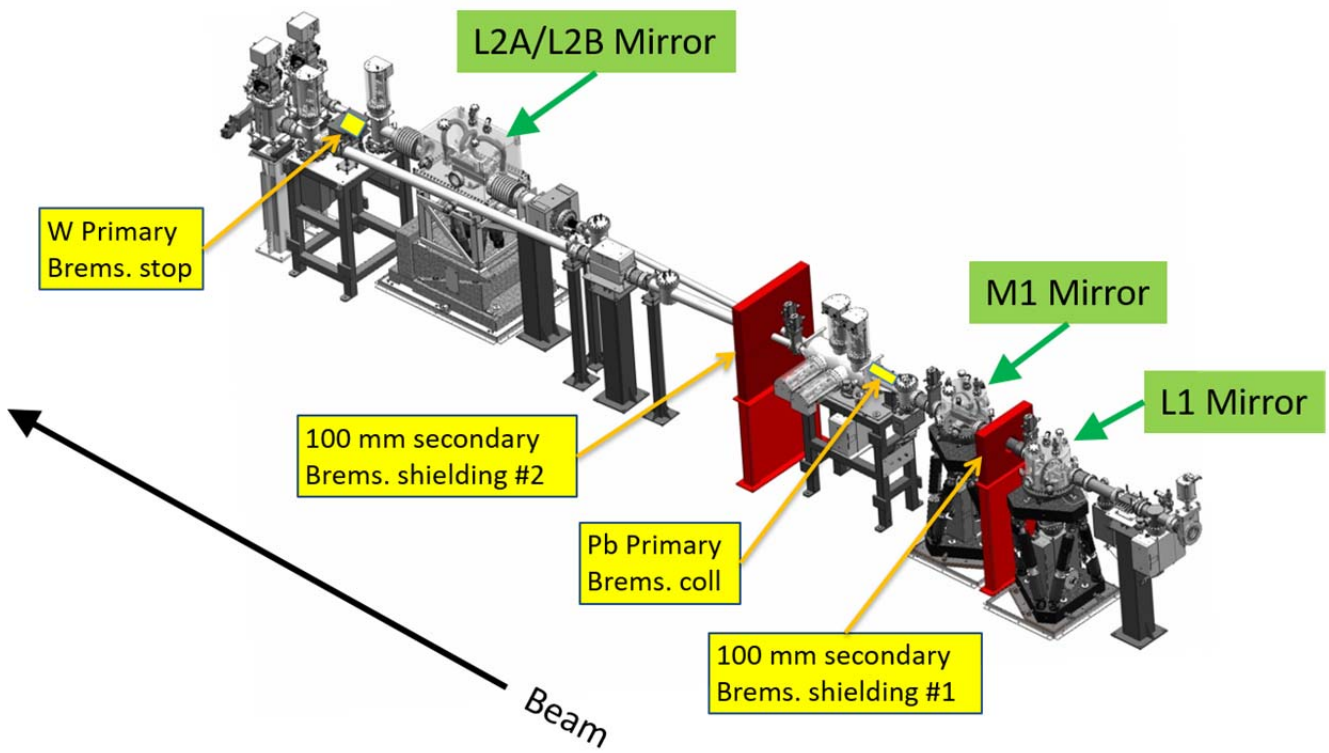

Figure 3: Primary (yellow) and secondary (red) Bremsstrahlung shielding within FOE.

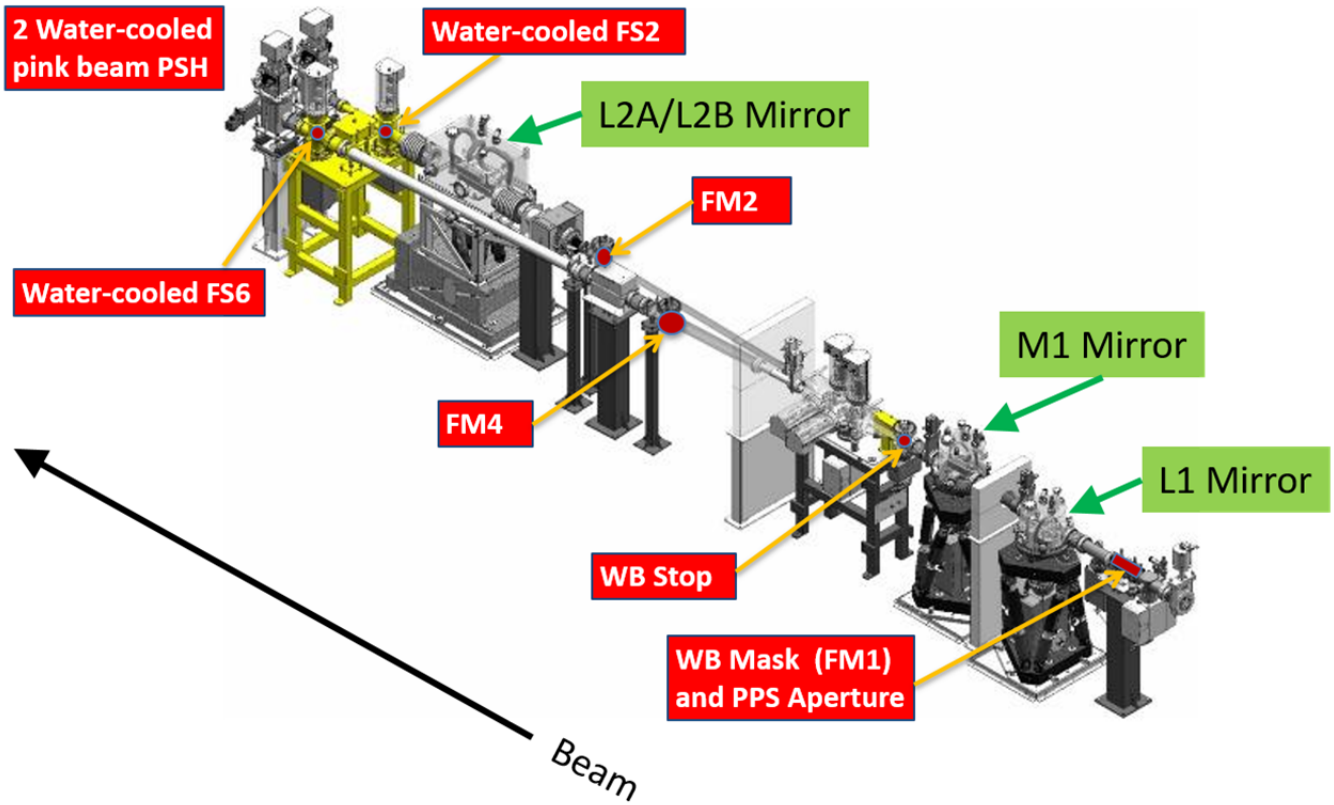

Figure 4: Radiation safety components inside the FOE (excluding Bremsstrahlung shielding).

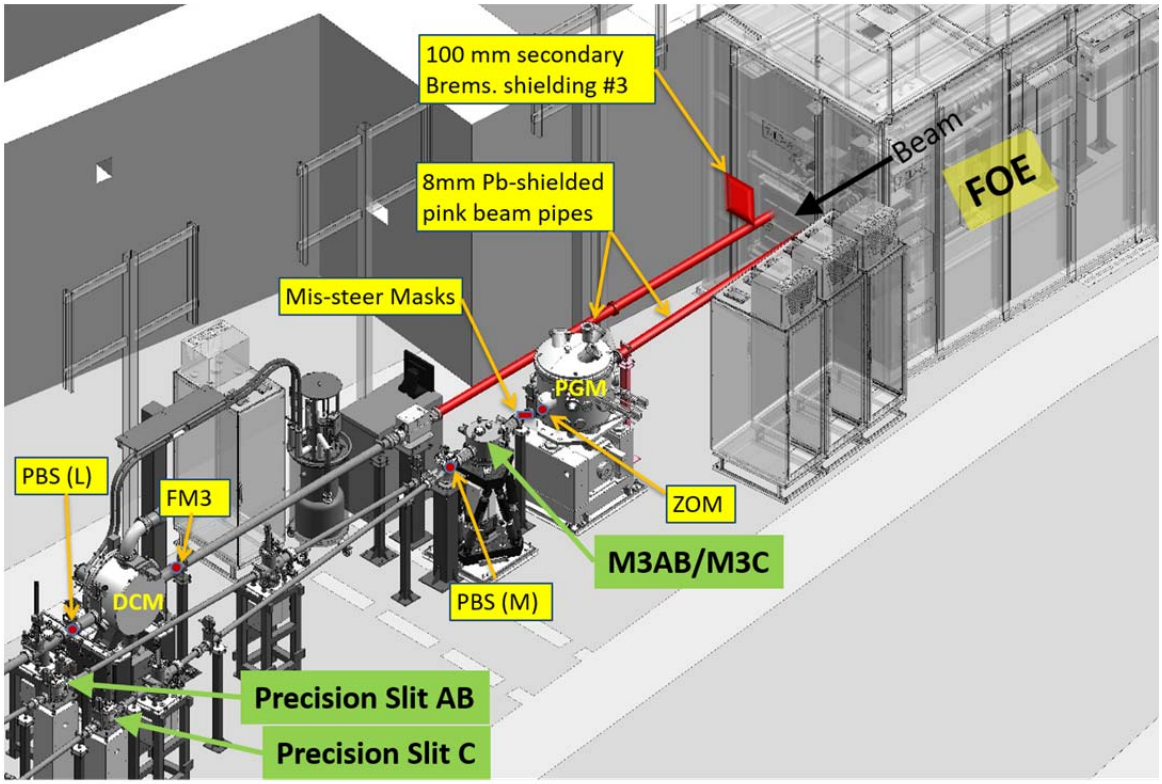

Figure 5: Radiation safety components located on the 7-ID beamline floor.

3.2.1 Heat Load Management (white, pink, and monochromatic beams)

The radiation safety components along the beam line (i.e. masks, white beam stop, etc.) are all water cooled using the PPS water circuits. For heat load management, all mirrors in the FOE and PGM are water cooled using the EPS water circuits and protected by a water-cooled disaster mask. The DCM crystals are cooled using a LN2 cryocooler.

If the L1 or M1 mirrors are removed, the white beam will be stopped by a water-cooled white beam stop. Transport tube is shielded from the pink beam by fixed masks (one on each branch), and by cooled frames (one on each branch). The pink beam photon shutters 1 and 4 are also water cooled. On the tender branch, if the PGM crystals are misplaced, the beam will hit a water-cooled pink beam stop. On the soft branch, if the M2 mirror and grating are not in place, the beam will be incident upon a water-cooled zero-order mask.

At 500 mA ring current, the total power exiting the 7-ID front end on the soft branch is 660 W. After passing through the white beam mask, the power is decreased to 350 W. The power reflected off of M1 at nominal angle (1.5° incidence) is then reduced to 30 W.

The power exiting the front end of the tender branch is 1200 W, which is reduced to 628 W by the front end mask. After reflection off of mirror L1 at nominal angle (0.6° incidence), the power is reduced to 270 W.

FEA analysis on downstream components was performed using the worst case scenario of 270 W, which represents the tender beam after a single bounce.

3.2.2 Primary Bremsstrahlung Radiation Management

There is one primary Bremsstrahlung shield and one primary Bremsstrahlung stop located in the FOE (Figure 3). The shield is a lead block located on the inboard side of the beam just downstream of the white beam stop. The stop is a tungsten block located between the soft and tender branches.

3.2.3 Secondary (Scattered) Bremsstrahlung Radiation Management

Based on NSLS-II guidelines, a series of secondary gas Bremsstrahlung shields have been installed. The first is located between the M1 and L1 mirrors inside the FOE (Figure 3). The second shield is located just downstream of the white beam slits also inside the FOE. The third Bremsstrahlung shield is installed outside of the downstream wall of the FOE (**Figure 5**).

3.2.4 Configuration control

All radiation safety components are under configuration control, in accordance with the NSLS-II Radiation Safety Component Configuration Management procedure (PS-C-ASD-PRC-055).

3.3 Area Radiation Monitor (ARM)

An area radiation monitor (ARM) is installed on the downstream wall of the 7-ID FOE as a part of the top-off safety analysis. The location is documented in the top-off safety analysis, NSLSII-TOS-RPT-016.

3.4 Personnel Protection System (PPS)

The PPS controls access to the hutch through an interlock system and search and secure procedure, to ensure personnel safety during normal operation of the beamline. The FOE hutch is equipped with a PPS-interlocked user labyrinth to facilitate temporary equipment access during user experiments.

The PPS also monitors critical DI water flow to safety critical components to ensure the safe operation of the beamline. In the event that water flow is lost, the PPS system closes the front end photon shutter to shut off the beam.

Ten vacuum switches are installed on mirror and experimental stations along the beamline as part of the PPS system. The vacuum switches will close the immediate upstream shutter in case of loss of vacuum in the vacuum section.

3.5 Hazard Identification and Mitigation

Overall, the SST beamline suite is similar to other beamlines that are already in operation at NSLS-II. A USI evaluation has been conducted and it was determined that the anticipated activities at the beamline do not violate the existing SAD and ASE. All relevant NSLS-II procedures and safety practices were followed during the design and construction of the beamline to mitigate the hazards identified in these document.

4 INSTRUMENT READINESS

4.1 Survey and alignment

The beamline components are installed according to the specifications and the respective final designs. Installations of the components are verified and documented by the NSLS-II Survey group, working closely with the beamline staff.

4.2 Utilities

The following services/capabilities are deployed at the beamline:

- Electrical power distribution: to all electrical power outlets, light fixtures, fans, etc. in the FOE and along the beamlines.
- Distribution of deionized water for high heat-load components.
- Distribution of process chilled water, water-cooled racks.
- Compressed air for pneumatic valves along the beamline.
- High pressure compressed air for pneumatic valves on the cryocooler.
- Dry nitrogen gas.
- Liquid nitrogen for the cryocooler.
- Ventilation in the FOE.
- Network connectivity.
- Cabling and piping support structures, for all utilities including EPS and PPS.

4.3 Vacuum System and Pressure Safety

The vacuum pressure for all beamline components in the pink beam section is expected to be in the 10^{-9}-10^{-8} Torr range or better. Along the beamline, the vacuum requirements are reduced to below 10^{-7} Torr. The vacuum system shares vacuum with the front end and ring, but is protected by a fast valve as well as the EPS system, which will close upstream and downstream gate valves when the pressure is out of specification for a given vacuum section.

Bleedup of vacuum chambers will be performed following the NSLS-II vacuum venting procedure.

4.4 Controls

All motorized components have been tested by the Controls Group and documented in the travelers. Controls System Studio (CSS) screens have been prepared to access the motors on the components. The individual motors are also accessible using standard EPICS Extensible Display Manager (EDM) screens and the XDAC system.

4.5 Equipment Protection System (EPS)

The EPS at the SST beamline performs the following functions:

1. Vacuum pressure monitoring and interlock for all the vacuum sections of the beamline.
2. Temperature monitoring and interlock for all non-safety related components, including components exposed to heat load in the white beam mirror system and monochromator.
3. Water flow monitoring and interlock for the cooling of mirrors

4. EPICS interface for components that require I/Os installed on the EPS PLC.