# In-Situ and Resonant X-ray Studies (ISR) Beamline

# IRR Functional Description

# Contents


1 INTRODUCTION ..... 3
1.1 Primary Research Capabilities ..... 3
1.2 Beamline Staff ..... 4

2 BEAMLINE DESIGN AND COMPONENTS ..... 4
2.1 Beamline Performance Goals ..... 4
2.2 Beamline Layout ..... 4
2.2.1 Source ..... 5
2.2.2 Optics and Diagnostics ..... 5

3 BEAMLINE SAFETY ..... 7
3.1 Radiation Shielding ..... 7
3.2 Radiation Safety Components ..... 8
3.2.1 Heat Load Management ..... 8
3.2.2 Primary Bremsstrahlung Management ..... 8
3.2.3 Secondary Bremsstrahlung Management ..... 9
3.2.4 Configuration Control ..... 9
3.3 Area Radiation Monitors ..... 9
3.4 Oxygen Sensors ..... 9
3.5 Personnel Protection system (PPS) ..... 10

4 INSTRUMENT READINESS ..... 10
4.1 Survey and alignment ..... 10
4.2 Utilities ..... 10
4.3 Vacuum System and Pressure Safety ..... 10
4.4 Controls ..... 11
4.5 Equipment Protection System (EPS) ..... 11

# 1 INTRODUCTION

## 1.1 Primary Research Capabilities

The beamline for In-Situ and Resonant X-ray Studies (ISR) will utilize the NSLS-II source's high undulator brightness coupled with versatile control of the beam size, energy, and polarization to create a world-leading, next-generation tender/hard x-ray diffraction facility that addresses key DOE Grand Challenges:[1]

- How do we characterize and control matter away – especially very far away – from equilibrium?
- How do remarkable properties of matter emerge from complex correlations of the atomic or electronic constituents and how can we control these properties?
- How do we design and perfect atom- and energy-efficient synthesis of revolutionary new forms of matter with tailored properties?

As illustrated schematically in Figure 1 below, addressing these Grand Challenges and making a societal impact requires advances in novel materials using sophisticated investigations with not just a single approach, but rather with a flexible and broad range of capabilities that can be utilized synergistically. To meet this challenge, the ISR beamline will enable the in-situ study of materials in a variety of environment chambers over a 2.4-23 keV energy range covering the absorption edges of many elements, and providing polarization control and microfocusing with ~1 m working distance from the focusing optic. In addition to facilitating studies of inhomogeneous materials, this will allow the entire beam intensity (~$10^{13}$ photons/s at 10 keV with Si(111) resolution) to be placed at grazing incidence on millimeter-size horizontal samples.

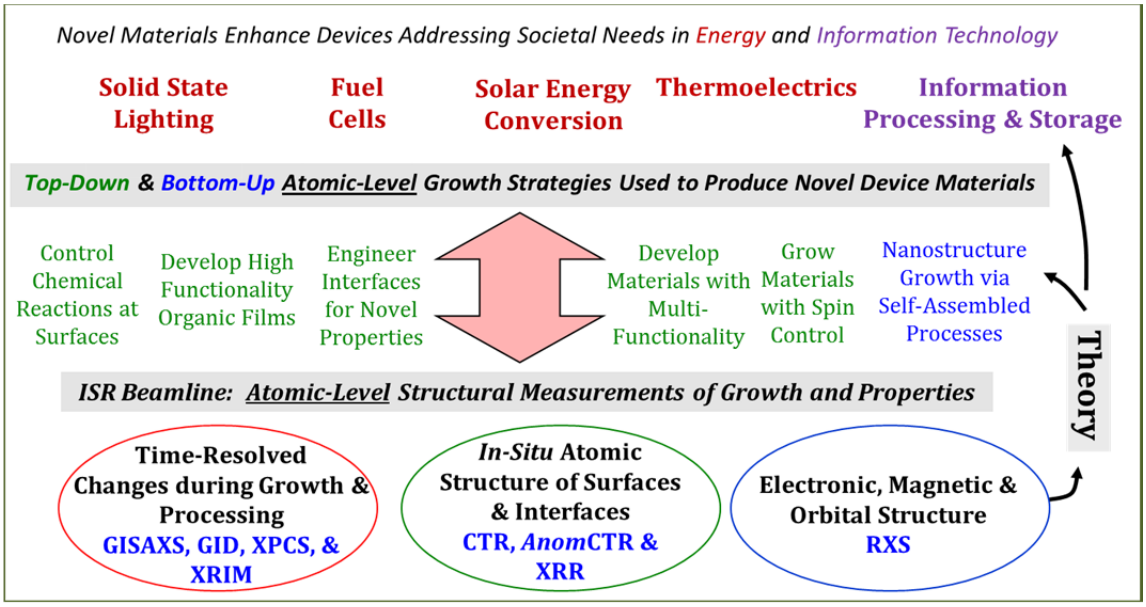


**Figure 1: The DOE Grand Challenges and ISR**

[1] J. Hemminger, Chair, DOE Basic Energy Sciences Advisory Committee, Graham Fleming and Mark Ratner, Co-Chairs, BESAC Subcommittee on Grand Challenges for Basic Energy Sciences, Directing Matter and Energy: Five Challenges for Science and the Imagination, Dec. 20, 2007.

## 1.2 Beamline Staff

| | | |
|---|---|---|
| Lead Beamline Scientist | Christie Nelson | |
| Authorized Beamline Staff | Kenneth Evans-Lutterodt | Beamline Scientist |
| | John Trunk | Mechanical Technician |
| | Zhijian Yin | Controls Engineer |
| Beamline Support Staff | Michael Lucas | Mechanical Engineer |

# 2 BEAMLINE DESIGN AND COMPONENTS

## 2.1 Beamline Performance Goals

Table 1 summarizes the designed performance of the ISR beamline. The beam size is selected based on the needs of the supported experiment, and the flux, harmonic suppression, and polarization control performance are estimated using calculations and/or simulations that include source and optical components' specifications.

**Table 1: Designed Performance of the ISR Beamline**

| Parameter | Specification/Description |
|---|---|
| Insertion device: | IVU23, 2.8-m long, in a high-β straight section |
| Operating energy range: | 2.4 – 23 keV |
| Monochromator: | Fixed-exit Si(111) |
| Beam size at sample (FWHM): | Tunable down to 20 (H) x 2 (V) $\mu m^2$ |
| Flux at sample at 500 mA storage ring current: | $\sim 10^{13}$ photons/s at 10 keV |
| Harmonic suppression: | $\sim 10^{-5}$ for third harmonic with fundamental at 3 keV |
| Polarization control: | $P_{L,C} \geq 0.9$ for 2.4 keV $\leq E \leq$ 13 keV |

## 2.2 Beamline Layout

The estimated performance, above, is based on the conceptual layout of the ISR beamline, shown in Figure 2. The source for the ISR beamline is an in-vacuum undulator (IVU), and the white beam optic is a horizontal focusing mirror (HFM) that deflects the beam inboard. A double crystal monochromator (DCM) selects the photon energy, and polarization control is provided by two Bragg transmission phase plates – made of single-crystal silicon or diamond – mounted in series in the dual phase plate assembly (DPP). The vertical focusing mirror (VFM) provides primary vertical focusing, and the double, harmonic rejection mirror (DHRM) is used for harmonic suppression. A secondary source aperture (SSA) can be used with secondary focusing optics, such as the KB mirrors, and there are three endstations: a base diffractometer for magnets, a 6-circle diffractometer, and a base diffractometer for UHV growth and processing chambers.

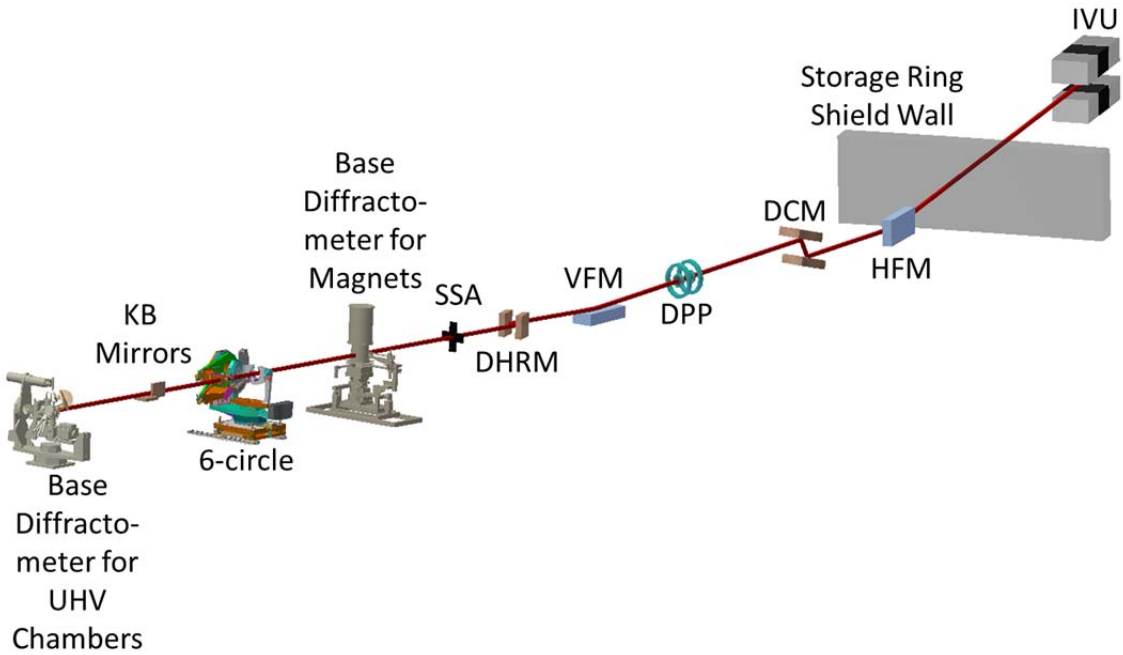


**Figure 2: Conceptual Layout of the ISR Beamline**

### 2.2.1 Source

The ISR IVU is a 2.8-m long device with a magnet period of 23 mm. The device is installed in the upstream part of 4-ID, which is a high-β, long straight section, leaving space for the future installation of a second insertion device in a planned canted build-out. The two devices are canted asymmetrically, as shown in Figure 3, with a 2 mrad canting angle between them.

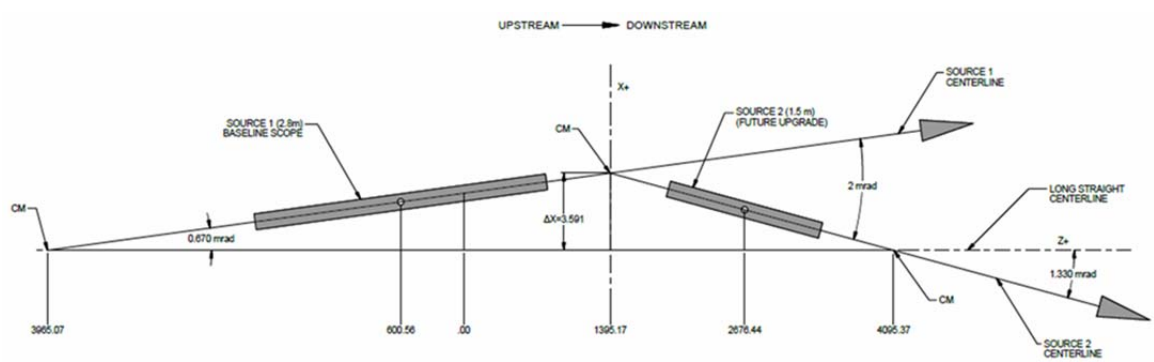


**Figure 3: Schematic of 4-ID straight section indicating locations of the baseline scope device and a 1.5-m long device for the future canted branch**

### 2.2.2 Optics and Diagnostics

The overall layout of the ISR beamline is shown below in Figure 4. The first optical enclosure (FOE) houses the HFM, DCM, DPP, and VFM; the second optical enclosure (SOE) houses the DHRM and SSA; Hutch C houses the magnet and 6-circle diffractometers; and Hutch D houses the KB mirrors and base diffractometer for in-situ growth and processing studies.

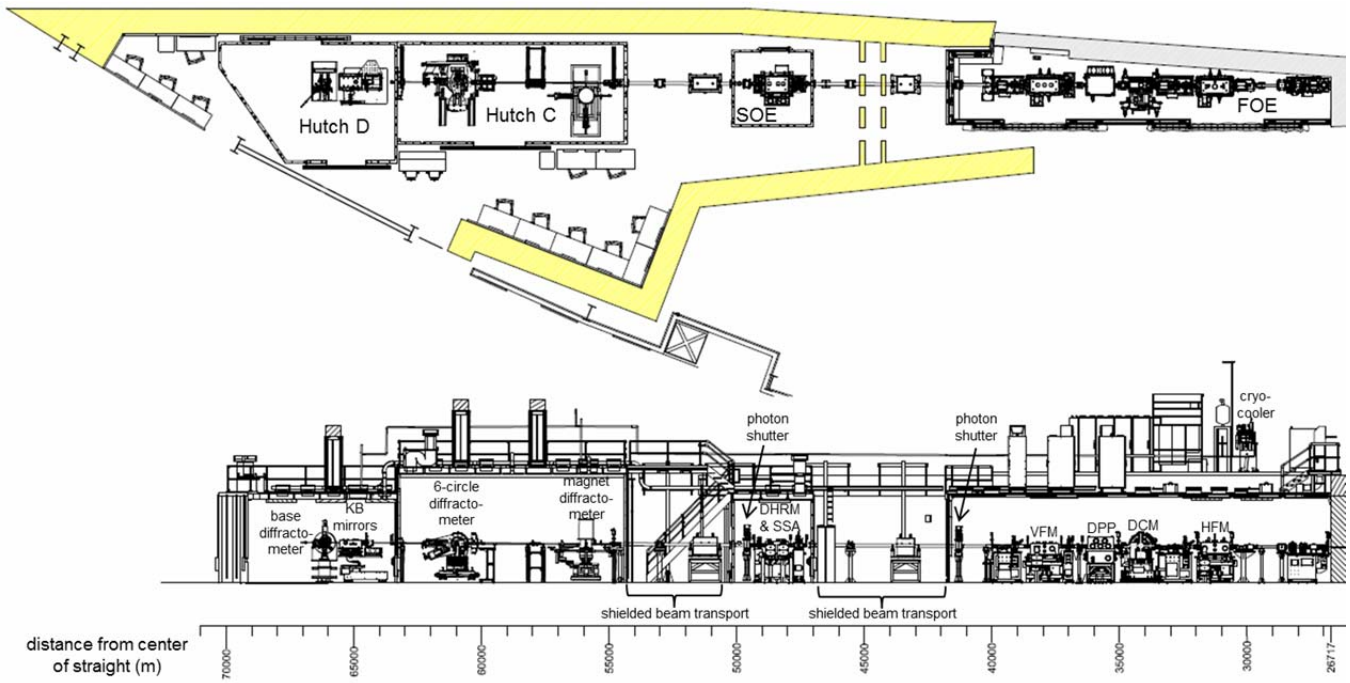


**Figure 4: ISR beamline Layout**

The ISR beamline has a flexible focusing scheme. Primary focusing optics, the HFM and VFM, can be used to focus to any of the three endstations, or can be used to focus the beam to the SSA. In the latter case, the beam will then be re-focused onto the sample using the KB mirrors.

As a function of energy, there are three optical configurations for ISR, as summarized in Table 2. Note that the optical path is identical for all configurations, except for a 4 mm outboard translation of the beam when the DHRM is inserted. The contamination windows, which are made of diamond and Be, mounted in gate valves, and are located between the DPP and the VFM, protect the surface of the VFM from outgassing by components within the DPP vacuum chamber.

**Table 2: Optical Configurations for the ISR beamline**

| Energy Range | HFM/VFM Stripe | DHRM Position | Contamination Window |
|---|---|---|---|
| 2.4 – 6 keV | uncoated Si | in | Be |
| 6 – 10 keV | uncoated Si | out | diamond |
| 10 – 23 keV | Pd | out | diamond |

The ISR beamline has three beam position monitors (BPMs) and two visual beam diagnostics (VBDs). The BPMs provide quantitative information about the beam intensity and position, and are located downstream of the dual fixed aperture mask (FAM), downstream of the DPP, and in the SOE upstream of the DHRM. The last of these three BPMs will provide feedback on the pitch and roll of the second monochromator crystal. The two VBDs are located downstream of each primary focusing mirror, and both direct and reflected beam can be viewed.

# 3 BEAMLINE SAFETY

## 3.1 Radiation Shielding

The design of all radiation shielding (hutches and radiation safety components) for the ISR beamline follows strict guidelines to reduce radiation levels external to the beamline enclosures during normal operation to as low as reasonably achievable. For the area downstream of the downstream wall of the FOE, the maximum dose is < 0.5 mrem/hr, while all other areas are shielded to < 0.05 mrem/hr. The shielding wall thicknesses follow released shielding guidelines:[2]

Hutch A (FOE, white beam hutch):

- Lateral wall: 18 mm lead
- Downstream wall: 50 mm lead
- Roof: 10 mm lead

Hutch B/C/D (monochromatic beam hutch):

- Lateral wall: 6 mm steel
- Downstream wall: 6 mm steel
- Roof: 3 mm steel

Shielded beam transport system:

- Pipes, pump enclosures, flange covers: 5 mm lead
- Hutch interfaces: 10 mm

Monochromatic beam shutters of the standard NSLS-II design are installed at the downstream ends of the FOE and SOE. A movable, monochromatic beam stop is installed in the wall between Hutches C and D (see Figure 5), and a second, fixed beam stop is installed at the end of Hutch D. During experiments in Hutch C, the movable beam stop is inserted and personnel access to Hutch D is allowed during operations. During experiments in Hutch D, the movable beam stop is removed, and no personnel access to Hutch C is allowed during operations.

**Figure 5: Movable beam stop in the wall between Hutches C and D, shown (left) in place for operations in Hutch C and (right) removed for operations in Hutch D**

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

## 3.2 Radiation Safety Components

Radiation safety components help contain the synchrotron radiation from the IVU and the gas bremsstrahlung radiation from the storage ring. The major components are shown in Figure 6 and are described in detail below. The locations and dimensions of these components are determined based on the ray tracing analysis and are documented in the ray tracing drawing (PD-ISR-RAYT-0001). Radiation safety components also include devices such as labyrinths and guillotines. The 4-ID radiation safety components checklist (PS-R-XFD-CHK-010) is the complete list of all components.

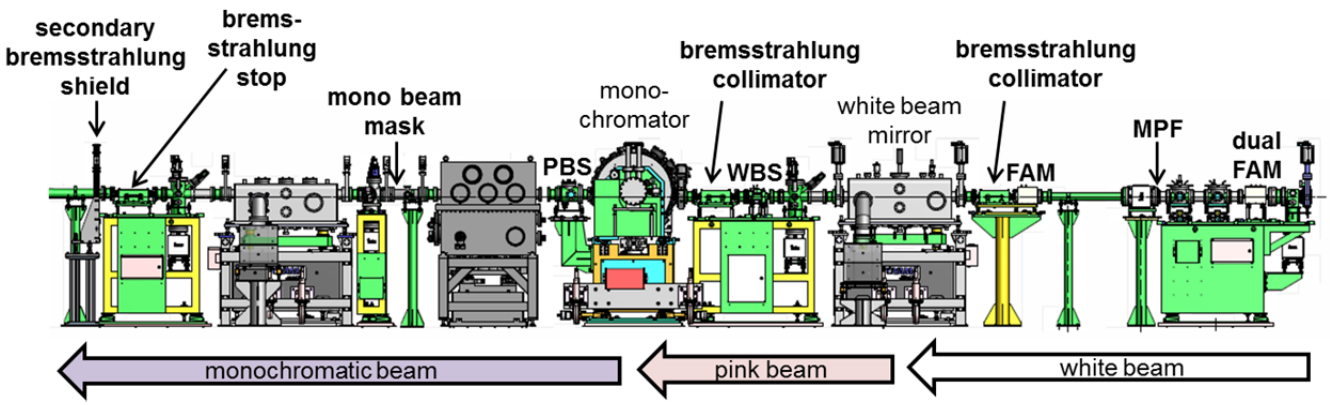


**Figure 6: Radiation safety components located in the FOE**

### 3.2.1 Heat Load Management

The maximum power from the IVU is 4.6 kW. A dual FAM with a downstream aperture of 5 mm x 5 mm reduces this power to 1.3 kW. Note that the dual FAM has two apertures – the inboard one is for the beam from the canted build-out source – and has been designed to withstand 4.6 kW from each source. At the present time (i.e., prior to the canted build-out), a mis-steer protection flange (MPF) will protect the lead in the first bremsstrahlung collimator from exposure to the synchrotron beam in the event of the beam going through the inboard aperture of the dual FAM. The second FAM, with a downstream aperture of 3 mm x 3 mm, further reduces the maximum power to 460 W. The HFM operates at a fixed incidence angle of 0.15˚, and the maximum power in the reflected pink beam is 340 W. The white beam stop (WBS) is designed to absorb the white beam in the event that the HFM is removed from the incident beam. In normal operations, the pink beam is reflected through a 3.15 mm (H) x 4 mm (V) aperture in the WBS, and is then incident on the DCM, which has a 25 mm vertical offset. A pink beam stop (PBS) is designed to absorb the pink beam, but should not see any beam during normal operations. Monochromatic beam masks between the DPP and VFM and upstream of the photon shutter in the SOE trim the synchrotron fan so that beam does not hit any bellows, transport pipes, or lead shielding.

The two FAMs and two beam stops are made of Glidcop and are cooled by deionized water. Two water circuits are used, each with two components connected in series: the two FAMs for one circuit, and the WBS and PBS for the other circuit.

### 3.2.2 Primary Bremsstrahlung Management

There are three components for primary bremsstrahlung shielding. The two bremsstrahlung collimators are located immediately downstream of the second FAM and the WBS, and the bremsstrahlung stop is located downstream of all FOE optics, ~1.5 m upstream of the photon shutter. An aperture in the bremsstrahlung stop, which is sufficiently distant from the extremal rays of the primary bremsstrahlung, permits the monochromatic beam to pass through.

### 3.2.3 Secondary Bremsstrahlung Management

Secondary bremsstrahlung radiation arises from scattering of primary bremsstrahlung radiation off the dual FAM, MPF, second FAM, HFM, and WBS. Based on NSLS-II guidelines, a secondary bremsstrahlung shield is installed downstream of the bremsstrahlung stop. FLUKA simulations were carried out to verify the shielding satisfies the requirements described in Section 3.1 at a ring current of 500 mA.

### 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 Monitors

Radiation levels in the area are actively monitored through an area radiation monitor (ARM) installed on the downstream wall of the FOE (Figure 7). The monitor has been certified in accordance with the procedure PS-C-ASD-PRC-008, *NSLS-II Area Radiation Monitor PPS Test.*

**Figure 7: Area Radiation Monitor Installed on the Beamline**

## 3.4 Oxygen Sensors

The double crystal monochromator uses liquid nitrogen (LN2) for cooling the two crystals, and LN2 is distributed to Hutches C and D for use with experimental equipment. The use of LN2 creates a potential oxygen deficiency hazard (ODH), which is mitigated by the installation of oxygen sensors inside the FOE (Figure 8), Hutch C, and Hutch D. The systems have been certified in accordance with procedure PS-C-XFD-PRC-005, Beamline Enclosures ODH Monitoring and Alarm System Certifcation and Inspection.

**Figure 8: Oxygen sensor installed in the FOE to monitor potential oxygen deficiency hazard associated with the use of LN2 for cooling the DCM**

### 3.5 Personnel Protection system (PPS)

The PPS controls access to the hutches through the interlock system and the search and secure procedure, to ensure personnel safety during normal operation of the beamline. Hutches B, C, and D are equipped with one or more PPS-interlocked user labyrinths to facilitate temporary equipment access during user experiments. A movable beam stop in the wall between Hutches C and D is also PPS-interlocked, as described in Section 3.1.

PPS also monitors the gas pressure in the PPS aperture, which is located upstream of the first FAM, and the critical deionized water flow to the two FAMs, the white beam stop, and the pink beam stop, in order to ensure the safe operation of these radiation shielding components. In the event that gas pressure decreases or water flow is lost, the PPS system will close the photon shutter to shut off the synchrotron beam.

# 4 INSTRUMENT READINESS

### 4.1 Survey and alignment

The beamline components are installed according to the specifications and the respective final designs. Installation of the components is 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 hutches and along the beamline
- Distribution of deionized water to the FOE only, for high-heat-load components
- Distribution of process chilled water to the roof of the FOE for the HFM heat exchanger, Hutches C and D, and all water-cooled racks
- LN2 distribution to Hutches C and D and a LN2 cryocooler on the mezzanine
- Compressed air
- Dry nitrogen gas
- Network connectivity
- Cabling and piping support for all utilities, including EPS and PPS

### 4.3 Vacuum System and Pressure Safety

The vacuum pressure for FOE components is expected to be $10^{-8}$ mbar or better. There is no physical barrier between the beamline vacuum and front end vacuum. However, ion pumps installed upstream and downstream of the FAM provide differential pumping, and the effectiveness of this scheme has been confirmed using calculations that show a two order of magnitude vacuum impedance. A fast gate valve sensor is installed upstream of the DCM, and the fast gate valve in the front end will close to protect the storage ring in the event of a vacuum failure. The diamond contamination window, which has been pressure-tested to 1.5 atm, is a vacuum barrier, although the Be contamination window is not. A vacuum failure in the DPP or the second BPM will result in the gate valve with the Be contamination window opening and the gate valve with the diamond window closing.

Downstream of the FOE, a commercial differential pump is installed in the section of the shielded beam transport system between the SOE and Hutch C. Endstations in Hutches C and D are separated from beamline vacuum by Be terminating windows.

Vacuum vessels with water or LN2 coolant – e.g., the HFM and DCM – are equipped with burst disks.

## 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.

## 4.5 Equipment Protection System (EPS)

The EPS at the ISR beamline performs the following functions:

- Vacuum pressure monitoring and interlock for all vacuum sections
- Temperature monitoring and interlock for all non-safety-related components, including those exposed to heat load in the monochromator and white beam mirror system, and in-vacuum motors
- Water flow monitoring and interlock for cooling of the white beam mirror and the white and pink beam diagnostics