

# Biomedical Imaging and Therapy Facility (BMIT) at the Canadian Light Source

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## BMIT – The Mission

The suite of BMIT beamlines provides a world class facility with unique synchrotron specific imaging and therapy capabilities. They will be used to study diverse problems in both human and veterinary medicine, agriculture and other biomedical areas.

## The Facility

The facility is comprised of 05ID-2 and 05B1-1 Beamlines and supporting laboratories. The bend magnet (BM) beamline, 05B1-1, will test and validate new ideas in imaging and therapy for eventual translation to BMIT's insertion device (ID) beamlines 05ID-2. Most of the 05ID-2 beamline is housed in a ~1100m<sup>2</sup> addition to the northeast corner of the CLS facility. The facility is arranged so that animal preparation and hutch entry is from inboard side of the beamline while the human research access is from the outboard side. Currently in the construction phase, with estimated completion dates of December 2007 (BM) and April 2008 (ID), these two beamlines will provide users with a capacity of research unique only to the BMIT labs.

## Synchrotron Beamlines for Biomedical Research

The beamline complex is made up of four hutches. The bend magnet beamline and the insertion device beamline share the first two hutches (POE-1 & POE-2). The BM beamline will be mainly used when the ID beamline is in "imaging mode" when the beam is transported to the downstream two hutches (POE-3 & SOE-1). Both POE-2 and SOE-1 are large experimental hutches with POE-2 being white beam capable (both for ID beam and BM beam). POE-2 has a 2.6 m deep pit to accommodate a human capable positioning system which can be located in either the ID or BM locations or in SOE-1. SOE-1 is a monochromatic beam hutch primarily for imaging applications, it will have provisions for a large animal positioning system – a 5 m diameter hole at the imaging location with a 4 m deep basement.

## Capabilities

The insertion device for the beamline is a 4.0+ T multi-pole superconducting wiggler (4.8cm period, 25 full field poles, 2 half field poles) which supplies useful x-radiation from ~20keV to over 100keV for imaging and therapy applications. The useful beam width is 4 milliradians which translates in to a ~12 cm wide beam in POE-2 and over 20 cm in SOE-1. Bent Laue double crystal monochromators in the ID beamline will provide medium bandwidth ( $\Delta E/E \sim 10^{-2}$ ) beams into the experimental hutches (POE-1 & SOE-1). A dual energy monochromator will provide x-ray energies above and below the K-edges of useful contrast elements (i.e. iodine, xenon, gadolinium) for a variety of imaging programs in SOE-1. A dedicated diffraction enhanced imaging or analyzer based imaging system will be available for the SOE-1 experimental program as well.

## Layout of the BMIT Facility

### Experimental Hutches: POE2 & SOE1

POE-2 and SOE-1 are the experimental enclosures that will host a number of imaging capabilities, including K-edge subtraction (KES), analyzer based imaging (ABI), diffraction enhanced imaging (DEI), multiple image radiography (MIR), phase contrast imaging (PCI), and normal absorption imaging in both projection and CT modes of operation. In addition, the ID beamline will have a filtered white beam capability for microbeam radiation therapy (MRT), monochromatic beam therapy methods and synchrotron stereotactic radiation therapy (SSRT).

### Optics Hutches: POE1 & POE3

POE-1 will house beamline optics for 05B1-1 and the first half of 05ID-2. Optical equipment will be comprised of fixed and variable apertures, filters, CT and DEI monochromators, and shutters. POE-3 contains the optical equipment for the second half of 05ID-2. Included in the optical hutch are fixed and variable apertures, filters, CT, KES, and DEI monochromators, and various imaging shutters.

### Human Examination Area ROOM 1123, 1124 & 1125

Developed in connection with the Saskatoon Cancer Centre and the Royal University Hospital the examination area will be a standard patient examination room for use by medical personnel to prepare people during experimental procedures.

### Electronic Equipment ROOM 1118 & 1126

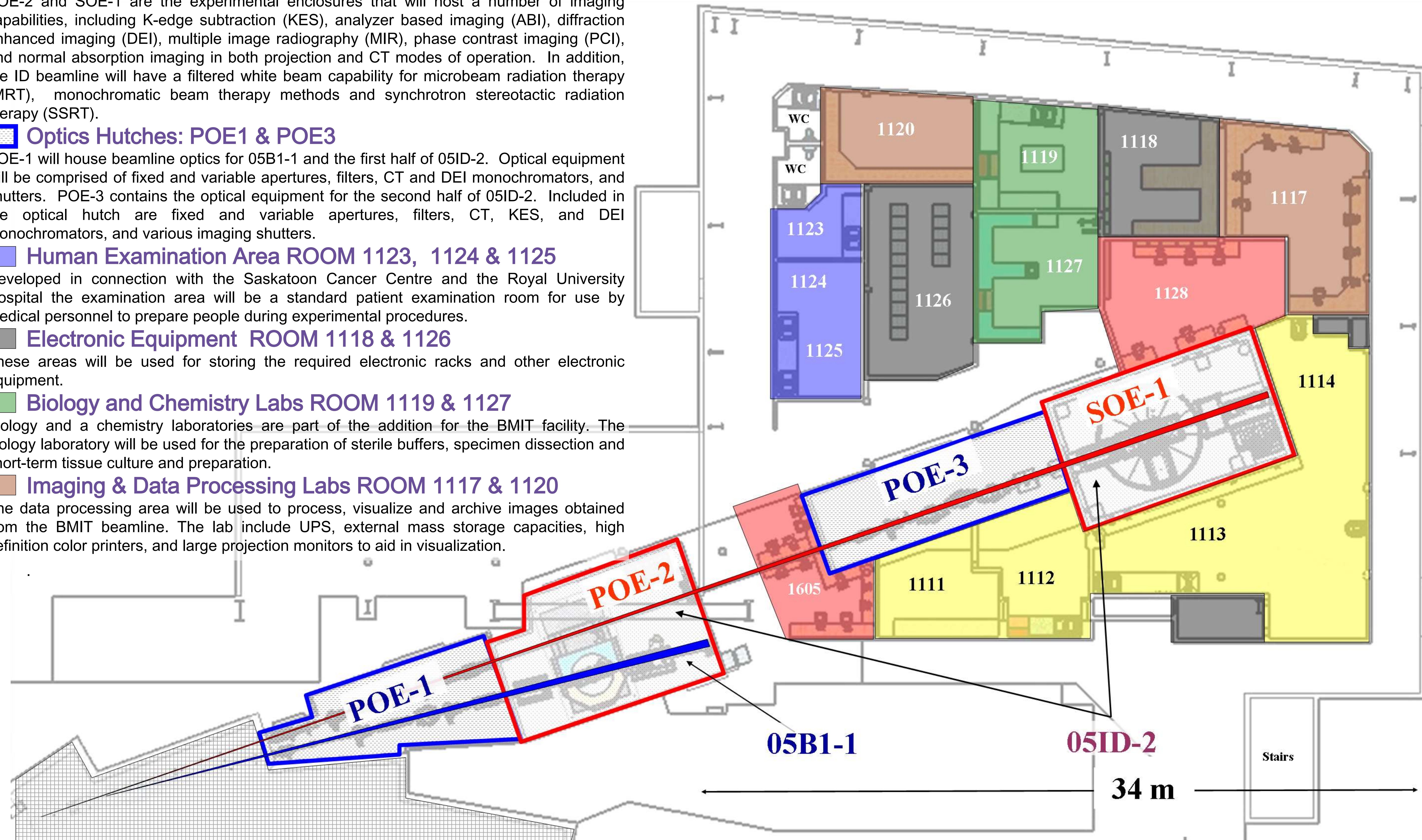
These areas will be used for storing the required electronic racks and other electronic equipment.

### Biology and Chemistry Labs ROOM 1119 & 1127

Biology and a chemistry laboratories are part of the addition for the BMIT facility. The biology laboratory will be used for the preparation of sterile buffers, specimen dissection and short-term tissue culture and preparation.

### Imaging & Data Processing Labs ROOM 1117 & 1120

The data processing area will be used to process, visualize and archive images obtained from the BMIT beamline. The lab include UPS, external mass storage capacities, high definition color printers, and large projection monitors to aid in visualization.



### Control Room Equipment ROOM 1128 & 1605

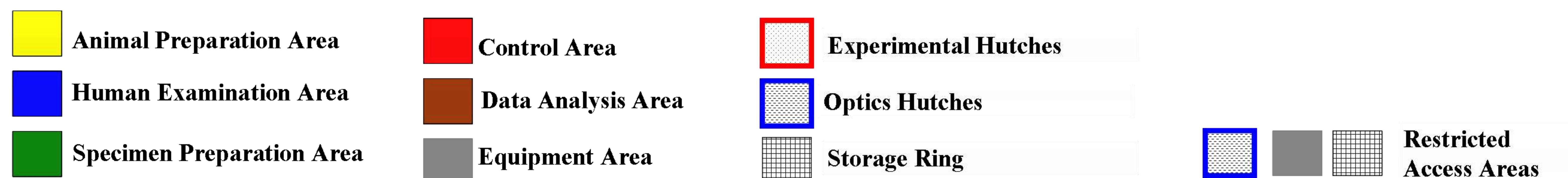
The control room is the command center for controlling either BM or ID beamlines

### Large Animal Preparation Area ROOM 1113 & 1114

Under the guidance of the Western College of Veterinary Medicine the large animal area will be a temporary housing area for a period of a few hours for all animals larger than dogs (i.e., pigs, small and large ruminants, horses). Longer term housing will be arranged with the Western College of Veterinary Medicine.

### Small Animal Preparation Area ROOM 1111 & 1112

Developed with the guidance of the Western College of Veterinary Medicine the housing for small animals (laboratory rodents to dogs and cats) will only be temporary; i.e., from hours to 1 day. All other housing will be arranged through other facilities on the University campus, such as the Western College of Veterinary Medicine and the Animal Care Resources Center.



# The Insertion Device Beamline:

## Station 05ID-2-POE-2

### Beamline 05ID-2-POE-2

#### Introduction

The BMIT labs will provide a world class facility with unique synchrotron specific imaging and therapy capabilities. It will be used to attack unsolved problems in both human and veterinary medicine, agriculture and other biomedical areas.

The BMIT POE-2 facility will provide both monochromatic beam ( $\Delta E/E \sim 10^{-2}$  for CT and projection imaging) as well as filtered white beam for programs such as Microbeam Radiation Therapy (MRT). The filtered white beam for MRT will deliver up to 3000 Gy/s. The energy range will be from ~20keV to over 100keV with beam width up to 12 cm. The monochromatic beam can also be used for a monochromatic beam therapy method such as synchrotron stereotactic radiation therapy (SSRT).

#### Science

The insertion device beamline (POE-2 & SOE-1) is designed for imaging and therapy research primarily in biomedical systems from mice to humans to horses, as well as tissue specimens including plants. Core research programs include human and animal reproduction, cancer imaging and therapy, spinal cord injury and repair, cardiovascular imaging and disease, bone growth and development, mammography, developmental biology, gene expression research, development of new imaging methods as well as extending present imaging capabilities.

At present, the focus of the research team is on developing strong experimental programs at other synchrotron facilities which will subsequently be transferred to the BMIT facility.

#### The Source

The source for the ID beamline is a multi-pole superconducting wiggler with the following parameters:

Max. On-Axis Field:	4.3 T	Period Length:	4.8 cm
Deflection Parameter, K:	18.4 maximum	Critical Energy:	24 keV maximum
Spectral Range:	20 – 100+ keV		
Photon Brightness:	3 x 10 <sup>15</sup> ph/s*mA*mr <sup>2</sup> *0.1%BW @ 20 keV		
Total Radiated Power:	30.1 kW (500 mA, 2.9 GeV); ~13.3 kW accepted into beamline		
e- Source Size:	441 $\mu$ m ( $\sigma_x$ ) x 30.86 $\mu$ m ( $\sigma_y$ )		

#### POE 1 & POE 2

The first primary optical enclosure (POE 1) accepts beam from both 05B1-1 and the insertion device. The ID beam is filtered, sized by slits, optionally monochromatized with a double crystal bent Laue device (CT monochromator), and shuttered in POE 1. A movable bremsstrahlung stop allows either the filtered white beam or monochromatic beam (20 – 100 keV) to enter the secondary optical enclosure (POE 2).

POE 2 is a white beam hutch which also accepts the bend magnet and ID beam. The ID beam will optionally terminate in POE 2 or can be safely transported to the downstream POE 3 / SOE by a shielded pipe. When the ID beam is terminated in POE 2, the filtered white beam or monochromatic beam can be used for imaging or therapy research using a large positioning system sited in a 2.6 m deep pit. The positioning system will be capable of a 0.7 m vertical excursion range with subjects as large as humans.

The properties of the CT monochromator are:

Double crystal bent Laue monochromator

Si (1,1,1) Resolution :  $\Delta E/E = 10^{-2}$

Allows white beam thru mode; 1st crystal can be translated out of direct beam

#### Experimental Methods

The experimental methods available in POE-2 on the ID beam are:

- Microbeam Radiation Therapy
- Synchrotron Stereotactic Radiation Therapy
- Absorption Imaging – projection and computed tomography

# The Insertion Device Beamline:

## Station 05ID-2-SOE-1

### Beamline 05ID-2-SOE-1

#### Introduction

The BMIT SOE-1 facility will provide monochromatic beam ( $\Delta E/E \sim 10^{-5}$  for DEI and  $\sim 10^{-3}$  for K-edge Subtraction and CT) with a wide tunable energy range from approximately 20keV to over 100keV. The energy range and beam width up to 22 cm will allow imaging and treatment of a wide variety of subject sizes (from mice to horses!) with spatial resolution as small as  $\sim 10 \mu$ m. The ID beamline will host a number of imaging capabilities, including KES, DEI or analyzer based imaging (ABI), multiple image radiography (MIR), phase contrast imaging (PCI) as well as normal absorption imaging in both projection and CT modes of operation. Additionally, the beamline will have a filtered white beam therapy capability for microbeam radiation therapy (MRT), monochromatic beam therapy methods and synchrotron stereotactic radiation therapy (SSRT).

Monochromatic X-ray flux of up to 10<sup>13</sup> ph/s/cm<sup>2</sup> will be available and filtered white beam for MRT will deliver up to 3000 Gy/s.

#### POE 3 & SOE 1

When the shielded pipe is installed in POE 2, the ID beam is transported to POE 3 which contains elements to filter, aperture and monochromatize the beam for the experimental program in the first secondary optical enclosure (SOE 1). POE 3 has three monochromators for normal absorption imaging, ABI/DEI/MIR, and KES. Additionally, an analyzer system is sited in SOE 1 to complete the ABI/DEI/MIR system. An optics table in POE 3 allows a flexible system of beam monitoring, characterization and filtration to be implemented for the wide variety of imaging and therapy programs that will be carried out in SOE 1.

SOE 1 has a basement structure 4 m below the experimental floor level to accommodate a positioning system capable of positioning and manipulating a horse. Additionally, this system will have a mode in which the positioning system from POE 2 can be rigidly mounted within it. SOE 1 (excluding the basement) is 6 m wide, 5 m tall and 10 m long with a removable back wall to accommodate the large positioning system. Several different cameras will be available with resolution ranging from 20 – 150  $\mu$ m.

#### Monochromator Parameters

##### CT Monochromator # 2 (47 m)

Double crystal bent Laue monochromator

Si (1,1,1) Resolution:  $\Delta E/E = 10^{-2}$

Allows white beam onto KES monochromator

##### Diffraction Enhanced Imaging (Analyzer Based Imaging) Mono (48 m)

Double crystal Bragg monochromator

Si (3,3,3) Resolution:  $\Delta E/E = 8 \times 10^{-6}$

Si (4,4,0) Resolution:  $\Delta E/E = 9 \times 10^{-6}$

##### K-edge Subtraction Mono (49 m)

Single crystal bent Laue monochromator with beam splitter

Si (1,1,1) Resolution:  $\Delta E/E = 10^{-3}$  each beam

Energy Gap: ~150-200eV about edge energy

#### Experimental Methods

The experimental methods available in SOE-1 are:

- Synchrotron Stereotactic Radiation Therapy
- Imaging – projection and computed tomography
- absorption imaging
- analyzer based imaging / diffraction enhanced imaging / multiple image radiography
- phase contrast imaging
- absorption edge imaging – K-edge Subtraction

# The Bend Magnet Beamline:

## Station 05B1-1-POE-2

### Beamline 05B1-1-POE-2

#### Introduction

The bending magnet beamline will mirror some of the ID. Additionally, 05B1-1 will host new imaging methods, such as imaging based on structural aspects of tissues by diffraction, absorption spectroscopy imaging, and fluorescence imaging, among others.

#### Science

The bending magnet beamline is intended to be the location for Diffraction Enhanced Imaging (DEI) and Phase Contrast experiments as well as where new ideas in imaging and therapy are tested and validated for eventual translation to BMIT's insertion device beamline 05ID-2. It will also accommodate some of the imaging research from the ID beamline.

#### Experimental Hutch

The experimental hutch has a very flexible system which allows imaging (CT and planar imaging) as well as irradiation application with both filtered white and monochromatic X-ray beams. The monochromatic spectral range will span 8–40 keV. In 2010 the upgraded stand for DEI experiment will be installed and the improved detector stage will be developed and commissioned which will complete this beamline.

#### Bend Magnet Parameters

Bend Magnet: 7.143 m radius, 1.354 T, 15 degree angle

Critical Energy: 7.57 keV

Photon Range: 0.3 – 1.6 Ångström

Spectral Range: 8 – 40 keV

Photon Brightness: 1.5 x 10<sup>13</sup> ph/s\*mA\*mr<sup>2</sup>\*0.1%BW @ 10 keV

Radiated Power: 70.5W/mr-horizontal (500 mA, 2.9 GeV)

e- Source Size: 173  $\mu$ m ( $\sigma_x$ ) x 30.8  $\mu$ m ( $\sigma_y$ )

#### Light Source & Beam (0 m)

Hor. Divergence: 10 mrad (0.57 degrees)

Vert. Divergence: 0.2 mrad (41.2 arc seconds)

Beam Length: 28.5 meters

Radiative Power: 697.2 W (500 mA, 2.9 GeV @ 10 horizontal milliradians)

Max. Power Dens.: 4.54 W/mm<sup>2</sup> (500 mA, 2.9 GeV)

#### Monochromator (13.2 m)

Bragg double crystal monochromator

Si (2,2,0) Resolution:  $\Delta E/E = 5 \times 10^{-5}$

Allows white beam thru mode.