Commissioning of CLS Phase II Beamlines

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CLS Facility on the UofS Campus

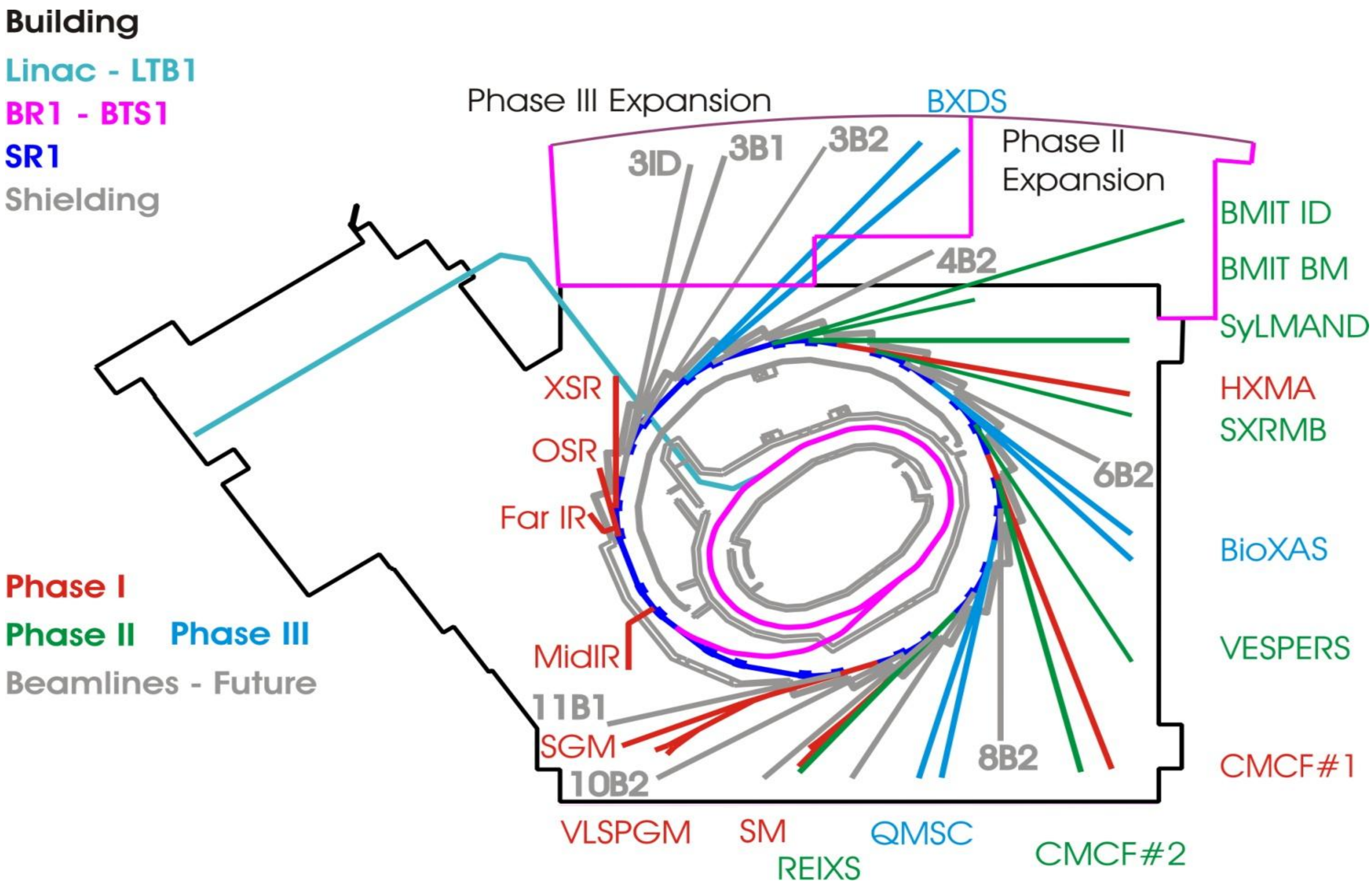
Outline

- Introduction
- CLS Beamlines
- Beamline Commissioning Plan
- Implementation of Commissioning Plan
  - BMIT Wiggler FE tests
  - Vespers POE
  - Sylmand POE
- Conclusions/Future Plans

CLS Facility

- Located on the University of Saskatchewan campus
- CLSI has the responsibility for operating the synchrotron facility in Canada and providing infrastructure support for the Canadian synchrotron research community as well as contributions to international synchrotron projects.
- It includes:
  - Linac - a 250 MeV electron accelerator, which was part of the former SAL,
  - Booster Ring - a 250 MeV to 2.9 GeV electron accelerator,
  - Storage Ring - a 2.9 GeV storage ring and the source of the SR,
  - Beamlines - for transport of SR to experimental target stations, where scientific experiments or processes requiring SR are carried out (infrared to hard X-rays, 0.01 eV – 100 keV)
- Facility Conventional Construction
  - began ~ June 1999 and completed ~ January 2001
  - Bulk shielding completed April 2001
  - Building expansion on the north-east to accommodate BMIT beamlines completed in December 2007
- Accelerator commissioning
  - began ~ June 2001 and completed ~ May 2004
- Routine Operation
  - began in August 2004 and includes 7 research beamlines and 2 diagnostic beamlines (Phase I)
  - Users other than CLSI staff were allowed to access synchrotron beamlines for research
- Top-up mode
  - Preliminary radiological studies completed in December 2005
- Phase I beamlines
  - The CLS Phase I project was finished in 2005 and included first set of 7 beamlines.
- Phase II Beamlines Projects
  - 7 additional Phase II beamlines are in the final stages of commissioning.
  - Expected to be available for general users by the end of 2009.
- Phase III Beamlines Projects
  - Three projects together comprise five new beamlines and are in planning/design/Early construction phase
  - Commissioning phase to start by 2012.
  - Building expansion required to house some of the Phase III beamlines

CLS Beamlines
Existing, Planned, and Future



Phase II Beamlines

- Phase II beamlines are in the final phase of commissioning and should be available for general user by end of 2009.
- Beamline front ends were installed by end of the second quarter of 2007
- Radiation shielding enclosures were installed by the end of the third quarter of 2007.
- Three of the beamlines (SXRMB, VESPERS, SyLMAND) began technical commissioning in 2007 and three more (CMCF2, REIXS, BMIT BM) began technical commissioning in 2008.
- The remaining beamline (BMIT ID) began technical commissioning of its insertion device beamline in January of 2009.
- Commissioning beamlines follows a well defined process in which the combination of verification and validation of the access control interlock system, configuration control and shielding adequacy tests is carried out.
- The implementation of this process for CLS Phase II beamlines is discussed with particular emphasis on the radiation and ozone measurements that were completed in 2007 and 2008.
- The BMIT beamlines are designed to allow research into x-ray imaging methods on living animals and humans. The technical commissioning process for these beamlines has its own challenges – some of which are discussed.

Beamlines Enclosures Shielding Design

- Generic shielding design has been adopted with a set of beam and target parameters for ID and BM beamlines.
- STAC8 code developed by Asano was used to calculate ambient dose equivalent due to SR outside shielding enclosures.
  - ID or BM source spectrum generated within Stac8 using CLS beamline parameters.
  - Cu and inclined Si were used as targets
- Analytic model based on Klein Nishina equations was used to estimate BMIT ID beamline shielding design due to SR source.
- EGS code was used by Asai to calculate absorbed doses due to GB outside the shielding enclosures
  - EGS simulations using photon spectrum up to 2.9 GeV
  - Photon spectrum based on gas target of ~ 8 m for ID and 12 cm for BM, 1 nTorr gas pressure, effective Z of 8.
  - Cu or Si targets used

Phase II Beamlines – Energy Range

Beamline	Port	Energy Range	Shielding Enclosures
Resonant Elastic and Inelastic X-ray Scattering (REIXS)	10ID-2	80 eV - 2,000 eV Ec = 4.15 keV	1 POE Shared with Existing Phase I Beamline (SM)
Soft X-ray Microcharacterization Beamline (SXRMB)	06B1-1	1,700 eV – 10,000 eV Ec = 7.572 keV	1 POE, 1 SOE
Synchrotron Laboratory for Micro and Nano Devices (SyLMAND)	03B2-1	1,000 eV – 15,000 eV Ec = 7.572 keV	1 POE
Very Sensitive Elemental and Structural Probe Employing Radiation from a Synchrotron (VESPERS)	07B2-1	6,000 eV – 30,000 eV Ec = 7.572 keV	1 POE, 1 SOE
Canadian Macromolecular Crystallography Facility (CMCF 2)	08B1-1	4,000 eV – 18,000 eV Ec = 7.572 keV	1 POE, 1 SOE
Biomedical Imaging and Therapy (BMIT-BM)	05B1-1	8,000 eV – 40,000 eV Ec = 7.572 keV	2 POE Shared with BMIT ID beamline
Biomedical Imaging and Therapy (BMIT-ID)	05ID-2	20,000 eV – 100,000 eV Ec = 22.4 keV	3 POE, 1 SOE

Shielding Thickness of Phase II beamline Enclosures

ENCLOSURE TYPE	Beamline #	LEAD THICKNESS REQUIREMENTS (mm)	LEAD THICKNESS REQUIREMENTS (mm)	LEAD THICKNESS REQUIREMENTS (mm)
		ROOF	SIDEWALL (FRONTWALL)[5]	BACKWALL
POE[1]	08B-1 07B-2 06B-1 05B1-1*! 05ID-2*! 03B-2	5 5 5 15 15 5	5 5 5 15(35 locally)[3,4] 15(35 locally)[3,4] 5	10(30 locally)[4] 10(30 locally)[4] 10(30 locally)[4] 50 50(130 locally)[3,4] 10(30 locally)[4]
POE[1]	05ID -2* 05B1-1*	15 15	15(35 locally)[3] 15(35 locally)[3]	50(130 locally)[3] 50
POE[1]	051D-2	15	15(30 locally)[3]	50 (130 locally)[3]
SOE[2]	08B-1 07B-2 06B-1 05ID-2	2.0 2.0 2.0 8.0	2.0 2.0 2.0 8.0	4.0 4.0 4.0 8(23 to 43 locally)[6]

B = Bending Magnet Beamline; ID = Insertion Device Beamline
* - Shared POE(s)
! – Total lead thicknesses on BMIT (first POE only) equivalent to that specified for an Insertion Device (ID) and a Bending Magnet (BM) beamline (Section 2.1.10.6)
Frontwall thickness dimension refers to Frontwall of SOE only.
Incremental local lead shielding for Backwall of SOE on beamline 05ID-2 (defined in Section 2.1.10.7 and Reference [6].

Bending Magnet GB Fan

BM Beamline	SR Wall Collimator D (mm)	SR Wall Collimator H (mm)	SR Wall Collimator V (mm)	Effective GB Fan H (mrad)	Effective GB Fan V (mrad)
Sylmand 05B2-1	8,650	114.5	40.0	10.94	3.33
Vespers 07B2-1	8,650	32.0	32.0	1.11	0.81
BMIT 05B1-1	7,080	105.0	40.0	13.56	4.16
SXRMB 06B1-1	7,080	52.0	40.0	4.45	3.48
CMCF2 08B1-1	7,080	52.0	40.0	2.61	2.17

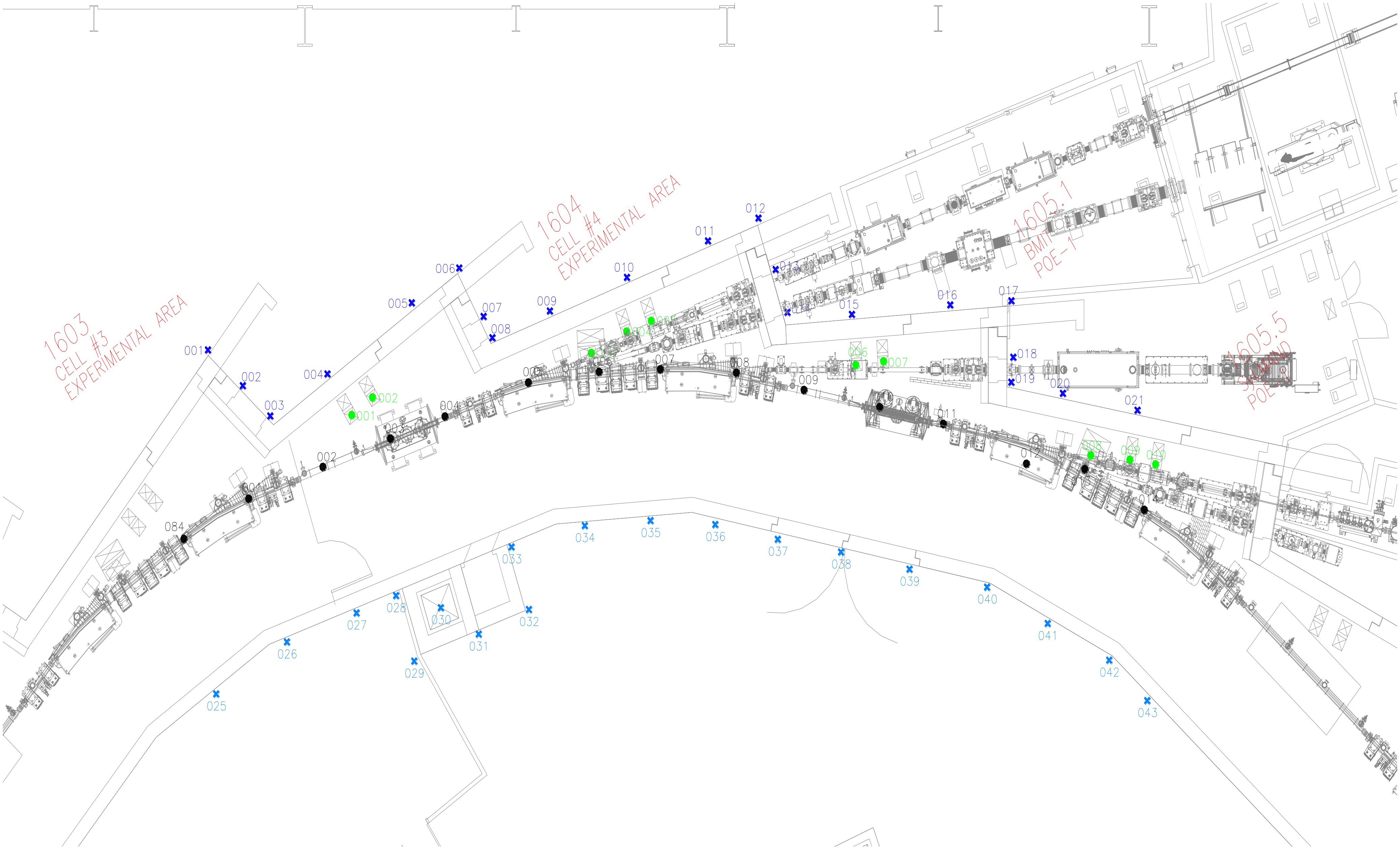
Beamlines Commissioning Plan

- Regulatory requirements:
  - Commissioning Plan is part of our operating license with the CNSC
  - Changes to plan requires approval from CNSC.
  - Results of safety tests such as verification and validation of ACIS and beamline enclosures shielding validation must be kept.
- The first step in beamline commissioning is to bring the radiation from the source (bending magnet or insertion device), through the front end, and into the POE, then SOE (or end station for soft xray beamlines)
- The CLS commissioning plan
  - describes the principal components of the generic CLS beamline from the radiation source (bend magnet or insertion device), through the frontend, and into one or more the primary optical enclosures (POE) and then into one or more secondary optical enclosures (for hard X-ray beamlines). For soft X-ray beamlines, this experimental target area will normally not be enclosed within an optical enclosure.
  - defines the actions required to commission the beamline components to meet specified requirements. Components which are commissioned include those which produce the synchrotron radiation and those which safely transport a controlled release of ionizing radiation from the storage ring tunnel into the beamline and through the beamline to the experimental area at the end of the beamline.

FE Commissioning

- **Step 1: Control and Monitoring of Frontend Components**
  - all required components are installed, aligned and controlled.
  - all operating parameters are properly measured for each component (for example, the "in" and "out" positions of the SSH are known).
  - the operating logic opens and closes the components in the correct sequence and in response to the correct inputs (for example, that the photon shutter that thermally protects the safety shutters is driven into position when the safety shutters are driven in).
- **STEP 2: SR Verification of Front End Components within Tunnel**
  - The main goal is to use SR to verify operational parameters of the front end components within tunnel.
  - Completion of this step will allow the solid lead/concrete plug in the transverse shielding wall to be replaced with an effective collimator that encases the photon beam transport pipe and extends the vacuum system through the transverse shielding wall.
  - The solid lead/concrete plug may be removed earlier provided that administrative controls prevent the opening of the safety and photon shutters until the appropriate measurements verify that it is safe to remove these administrative controls.
- **STEP 3: TERMINATION OF THE GAS BREMSSTRAHLUNG BEAM IN THE POE**
  - The goal of this step is to verify that gas bremsstrahlung will be successfully and safely contained within the pOE.

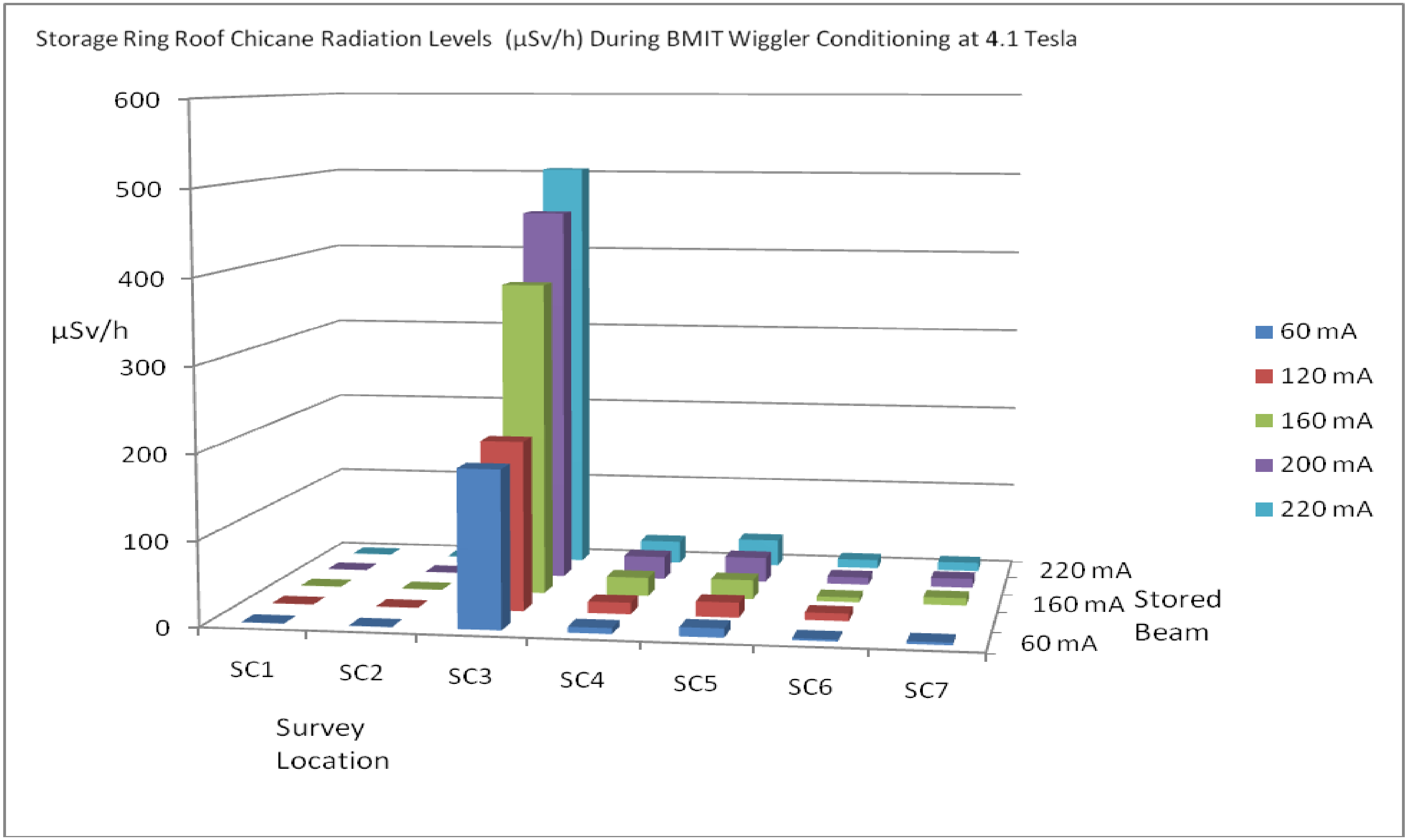
BMIT ID FE Radiation Tests



BMIT Wiggler Preliminary Tests (Nov 2007)

- With 16 mA of current stored in SR1 and the BMIT Wiggler at 4.0 Tesla
  - all points measured less than 200 nSv/hr from the floor to 2.0 meters above the floor on the SOW, SIW, and SRF (SRF1 – SRF 8) were less than 200 nSv/h.
  - The radiation levels on mechanical and electrical chicanes were all below 200 nSv/h except for a ventilation chicane (SC3) near BMIT Wiggler where levels reached 30 µSv/h.
- At 60 mA levels reached 110 µSv/h at SC3 Since the BMIT Wiggler power was the same as for the 16 mA test, the radiation measured at SCW scales linearly with the SR1 current.
- The radiation measured was due to scattered SR since the radiation disappears when the wiggler is off.

BMIT Wiggler Radiation Tests



Storage Ring Roof Chicane Radiation Levels During BMIT Wiggler Conditioning on February 19, 2008

BMIT ID FE Tests (Nov 2008)

- During a routine maintenance shutdown in October of 2008, the BMIT ID PFM was removed and evaluated.
- Discoloration of the copper mask had occurred indicating the synchrotron beam was hitting the PFM. Since the mask position could not be adjusted, the opening of the mask was increased in size to ensure that all synchrotron radiation from the SCW that passed through the storage ring absorber would also pass through the PFM.
- On November 4, 2008 a final test was completed on the BMIT FE ID line. Detailed radiation measurements were completed with 50 mA, and again with 240 mA stored beam, with a 4.3 T field on the SCW for both measurements
- All radiation measurements with 50 mA stored beam were less than 200 nSv/h at all locations.
- The results from the 240 mA stored beam, all results are less than 5 μSv/h. At SC3, 0.56 μSv/h was measured.

POE Commissioning

- Once the insertion device (if any) and the associated frontend has been commissioned, the full GB beam and the full power SR beam can be safely terminated by those components of the frontend inside the storage ring. The full GB beam can be safely terminated inside the POE.
- The next step is to verify the shielding of the POE against scattered radiation from the incident SR/GB beam. A cooled absorber in front of the GB stop terminates the SR beam during these measurements.

POE Shielding Commissioning

- Two methods are possible:
  - POE can be commissioned before any components not part of the frontend or not required for the commissioning process itself are installed in the enclosure. In this case, “worst case” scatterers are used for both GB and SR, and this allows the most flexible use of the enclosure. In particular, it allows certification of an enclosure without necessarily having detailed knowledge of each component that will use it.
  - In other cases, it may be convenient to install beamline components before the radiation shielding validation has been completed.
    - Actual scatterers would be used (the crystal in the monochromator or the actual x-ray optical element), and these elements will be moved over their entire intended range of motion during the radiation verification and validation.
    - The configuration control will ensure that these devices are not operated outside the tested range of motion. Each such item will be visibly identified and an allowable range of motion indicated on or near the item.
    - The main advantage of this method is that actual scatterers may be used, rather than the estimated “worst case” scatterers, making the radiation verification and validation less dependent on simulation.

POE Shielding Commissioning

- Store a low electron current in the storage ring. Open the safety shutters and the photon shutter and bring the SR beam into the POE.
- At this point, the following targets are used to scatter the SR and GB based on the calculations
  - Cooled SR target to intercept/scatter the SR beam
  - Thick GB target to scatter GB
  - GB stop thermally protected by a cooled SR absorbed and some of the components of the frontend
  - additional components of the photon beamline may be installed if their presence will not interfere with POE commissioning.
- Measure for leakage of scattered SR and GB and correct any problems in the POE shielding if feasible.
- Repeat this sequence for gradually increasing the stored electron current, iterating the measure/repair process until the POE shielding is verified for maximum stored electron current.
- When the POE is verified to safely contain scattered SR/GB for the full stored current, the vacuum envelope within the enclosure can be extended and optical devices can be allowed to intercept the photon beam.
- For hard X-ray beamlines, there may be more than one POE. Each POE in a beamline will be commissioned using the procedure outlined above.
  - If there is more than one pOE, the commissioning process may involve moving the bremsstrahlung stop out of the beamline so the SR and GB can pass together through a WBT and into the next pOE. There will always be a “last” POE in which a GB stop is permanently mounted in a geometry sufficient to terminate the entire electromagnetic shower.
- A final radiation survey will be required once all beamline components within the POE are installed and functioning properly.

SOE Shielding Commissioning

- Commissioning each SOE (after the first POE is commissioned) requires operation of the components within each previous enclosure, and measurements must be made to indicate that those components are in fact functioning.
- The beam pipe connecting POEs is designed to safely contain both the GB which may pass through the POE and the SR.
- Commissioning "white beam transport (WBT)" will verify that radiation levels outside this transport pipe are within acceptable levels.
  - A sufficiently massive "guillotine" will be used each time a beam pipe exits an optical enclosure.

Vespers Beamline

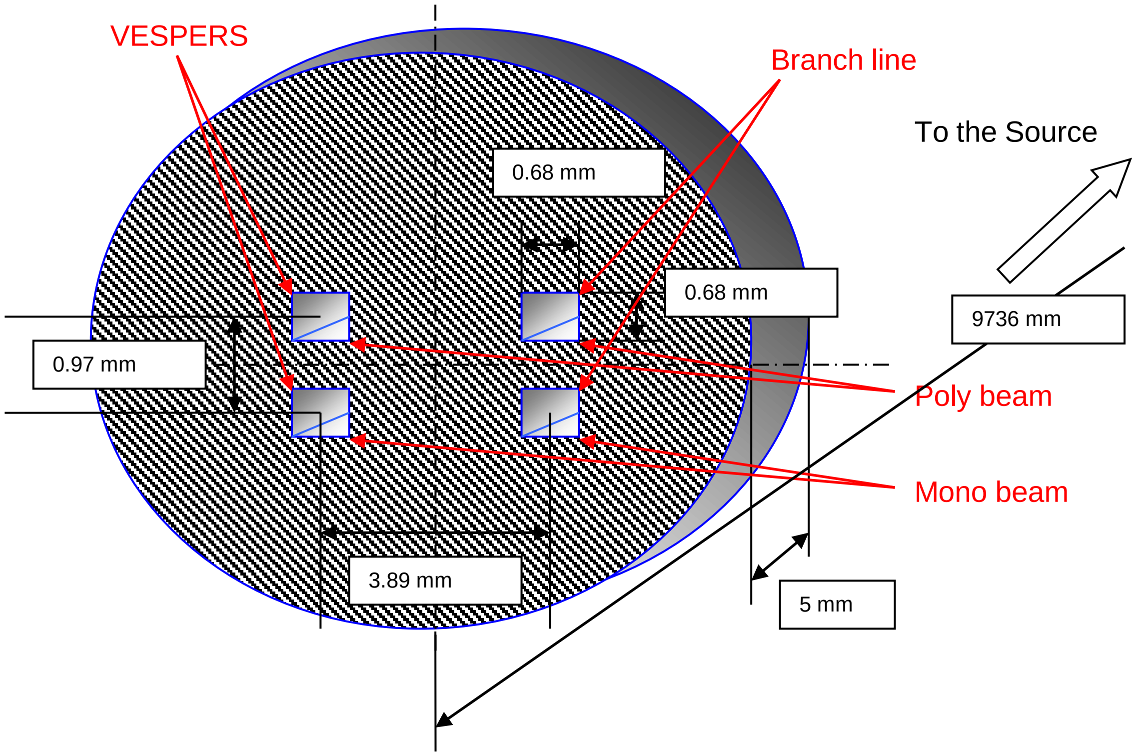
- The VESPERS beamline receives SR from the second bend magnet on cell 7 in the CLS storage ring (Port: 07B2-1).
- SR critical Energy: ~ 7 keV and SR Power: 75 W/mradH
- Intended to deliver a micro-focused hard X-ray beam to solid materials in such a manner that a microscopic volume can be analyzed by X-ray diffraction (XRD) and X-ray fluorescence (XRF) spectroscopy
- The optimum energy is ~ 15 keV, with a range of 5 – 30 keV photons being delivered for experiments.

VESPERS Front End Conditioning

- The VESPERS beamline FE was installed during the October 2006 shutdown.
- The FE safety shutters were locked in the closed position, and a beryllium window was installed on the end of the beam pipe to preserve vacuum.
- Radiation measurements of the storage ring shielding near the FE were completed during the start-up radiation measurements at the beginning of Run 29 (November/December 2006).
- All measurements indicated radiation levels were less than 200 nSv/h.

Vespers Fixed Mask

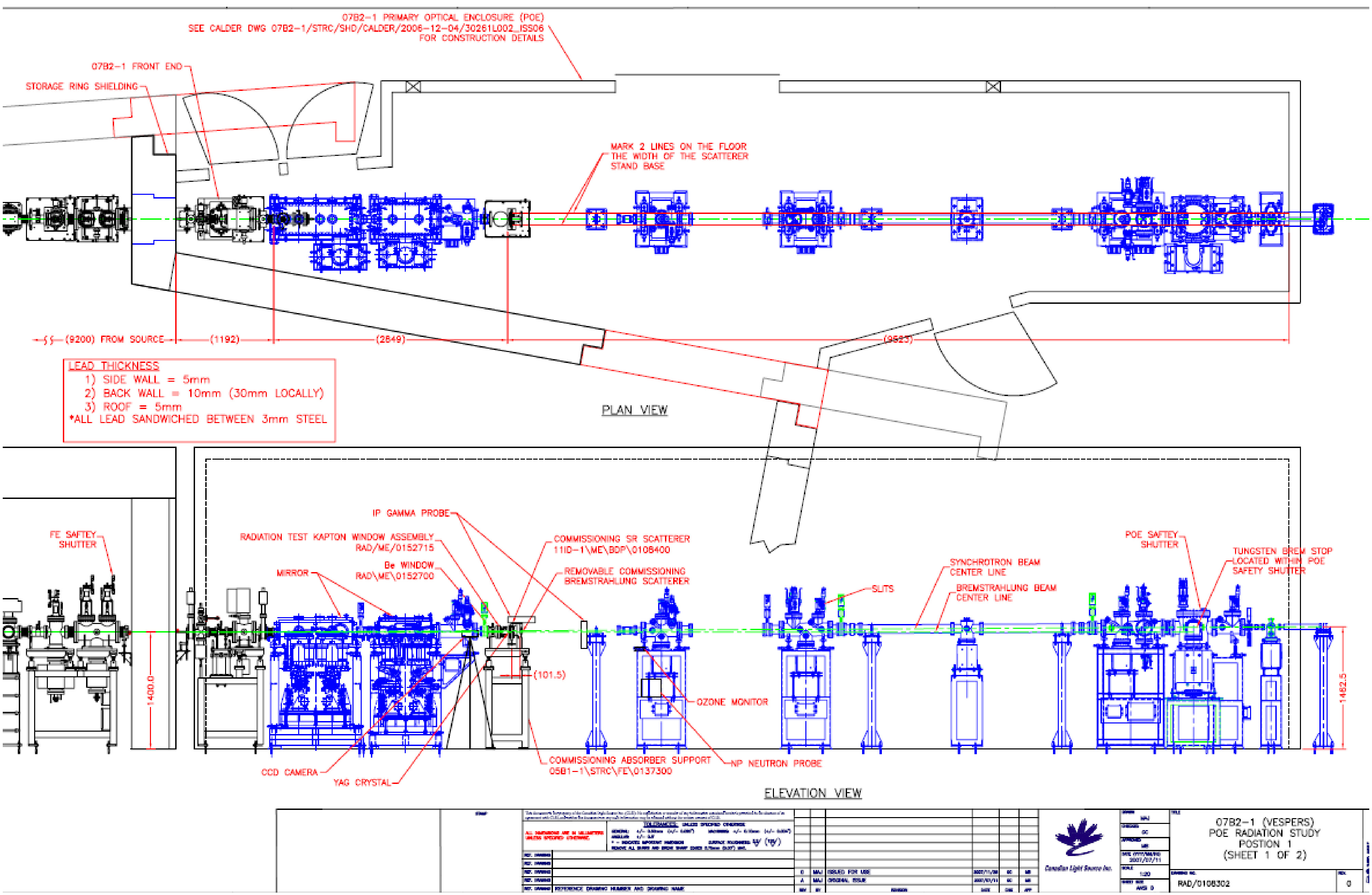
- A fixed mask made of 5 mm tungsten allows the SR through four 0.68mm X 0.68 mm openings. The fixed mask minimizes the synchrotron radiation from the BM significantly, and is located near the end of the FE just inside POE approximately 9.7 m from the bend magnet



VESPERS POE Radiation Measurements

- Detailed measurements were made on all the enclosure walls, the enclosure roof, and the enclosure chicanes with 50 mA and 250 mA stored beam in SR1 and the scatter target in the 1st position.
- Radiation levels measured were below 200 nSv/h at all locations.
- No counts above background radiation levels were found at any location.

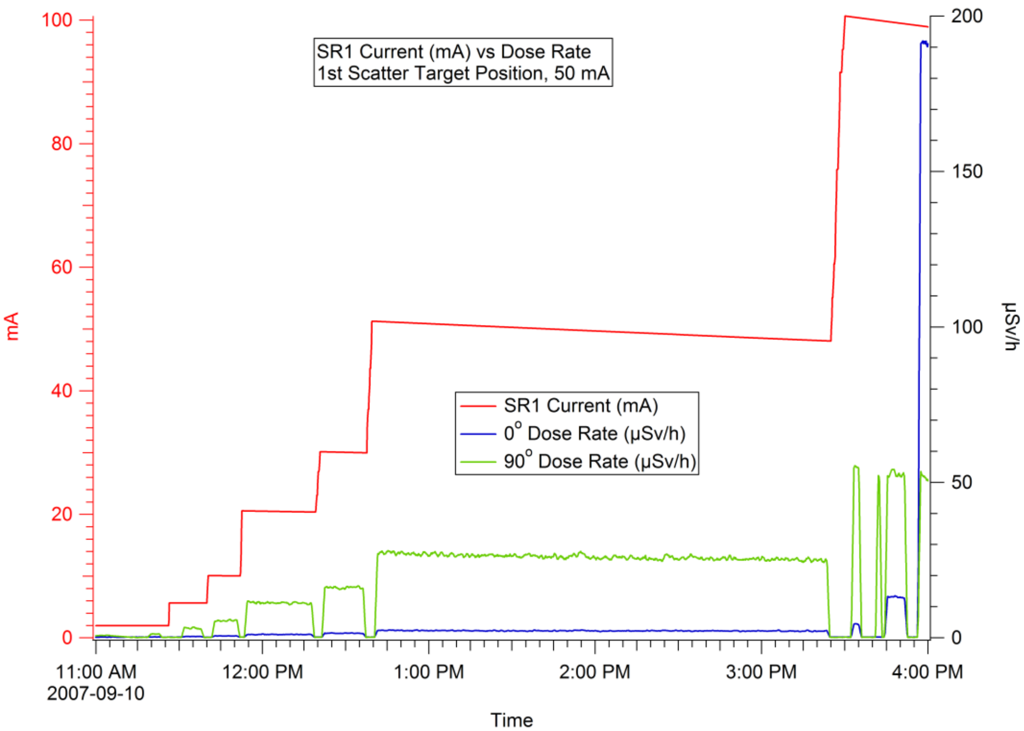
Target 1 Radiation Setup

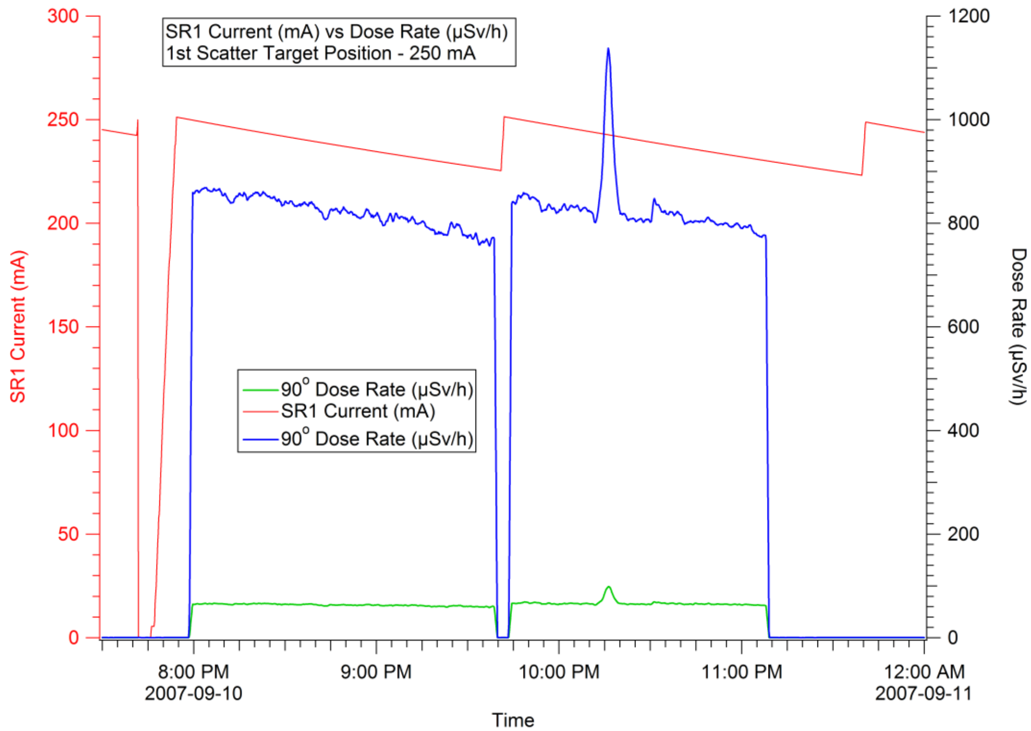


Radiation Inside the Vespers POE

- An IP100 was set up both directly above and directly behind the scatter target during the radiation testing.
- During the initial commissioning, beam was stored in SR1 at increasing levels until 50 mA was reached. At each current level, the FE SSH's were opened, and spot check radiation surveys were completed on the enclosure to check for major shielding issues.
- During the 50 mA test, radiation dose rates were approximately 1 µSv/h downstream of the scatter target and approximately 14 µSv/h above the scatter target.
- A small adjustment was made to the position of radiation probe at 0^{o} to the scatter target. The increase in electron beam current from 50 mA to 100 mA resulted in an increase in dose rate from 1 µSv/h to 190 µSv/h, or 2 orders of magnitude increase.
- The low dose rate coupled with the position sensitivity of the radiation probe show that the beam is well collimated prior to striking the scatter target.
- At 100 mA, the IP100 at 90^{o} measured 50 µSv/h, but with 250 mA only 30 µSv/h was recorded. The IP100 at 0^{o} recorded approximately 190 µSv/h but at 250 mA recorded approximately 800 µSv/h.

Radiation Levels Inside POE



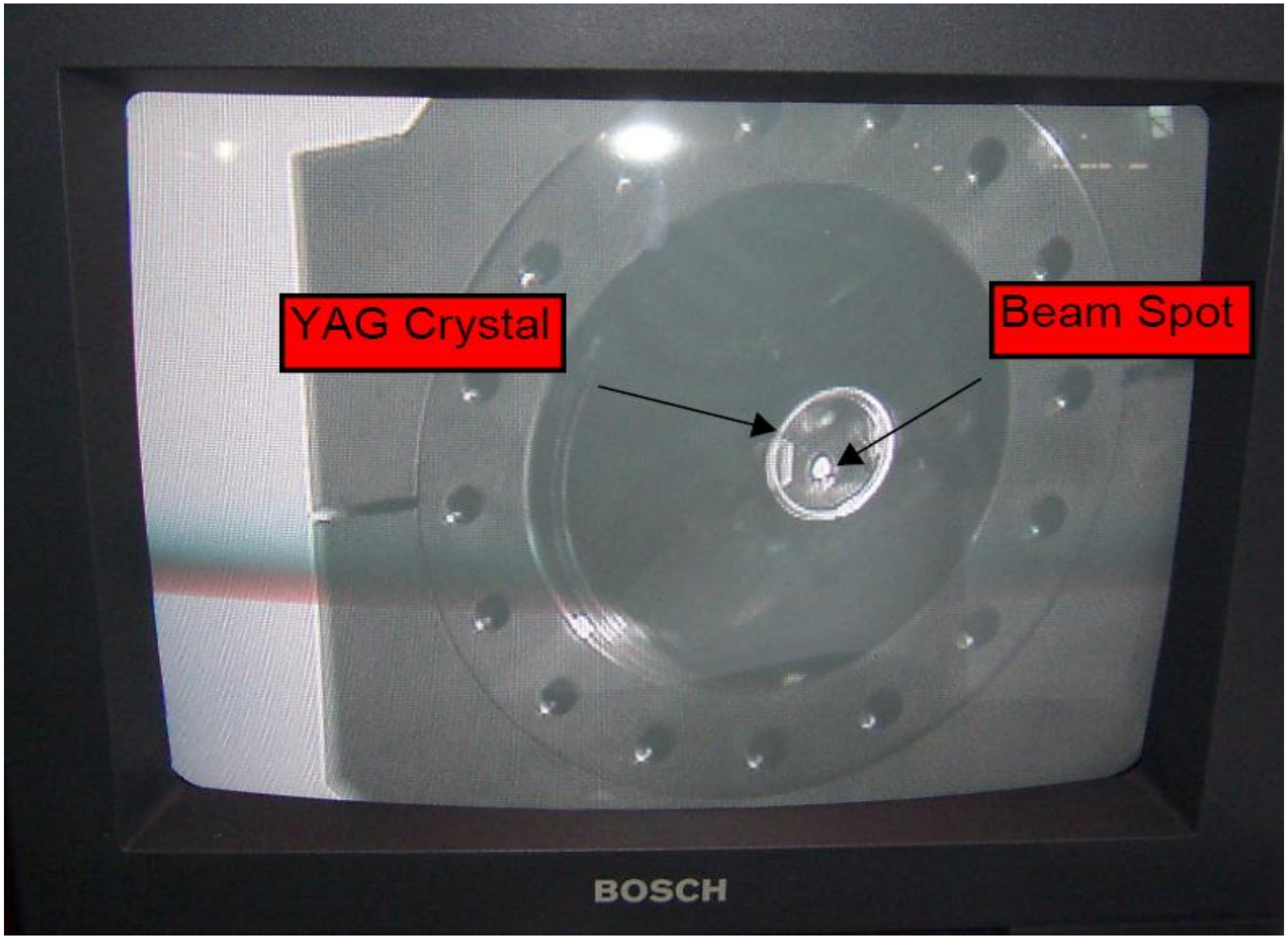


NOTE: The spike in the radiation levels seen on both radiation monitors was due to an adjustment that was made at another insertion device magnet. The adjustment caused a perturbation in the electron beam orbit, which resulted in the observed increase in the radiation levels measured near the scattering target.

When the beam orbit was returned to normal, the radiation measured returned to the previous levels.

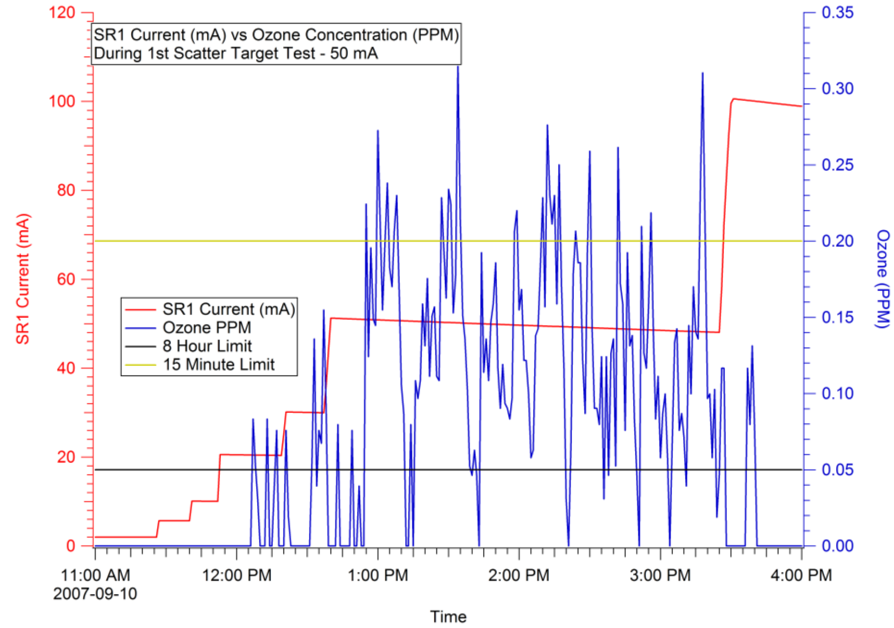
YAG Crystal Image

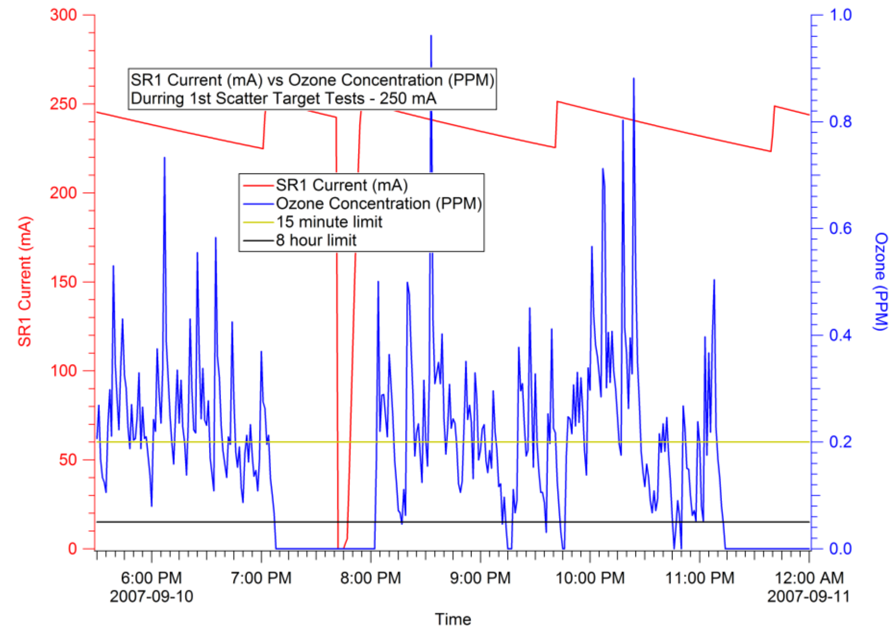
- A photograph of the YAG crystal image from a video camera taken while the 50 mA tests were being conducted



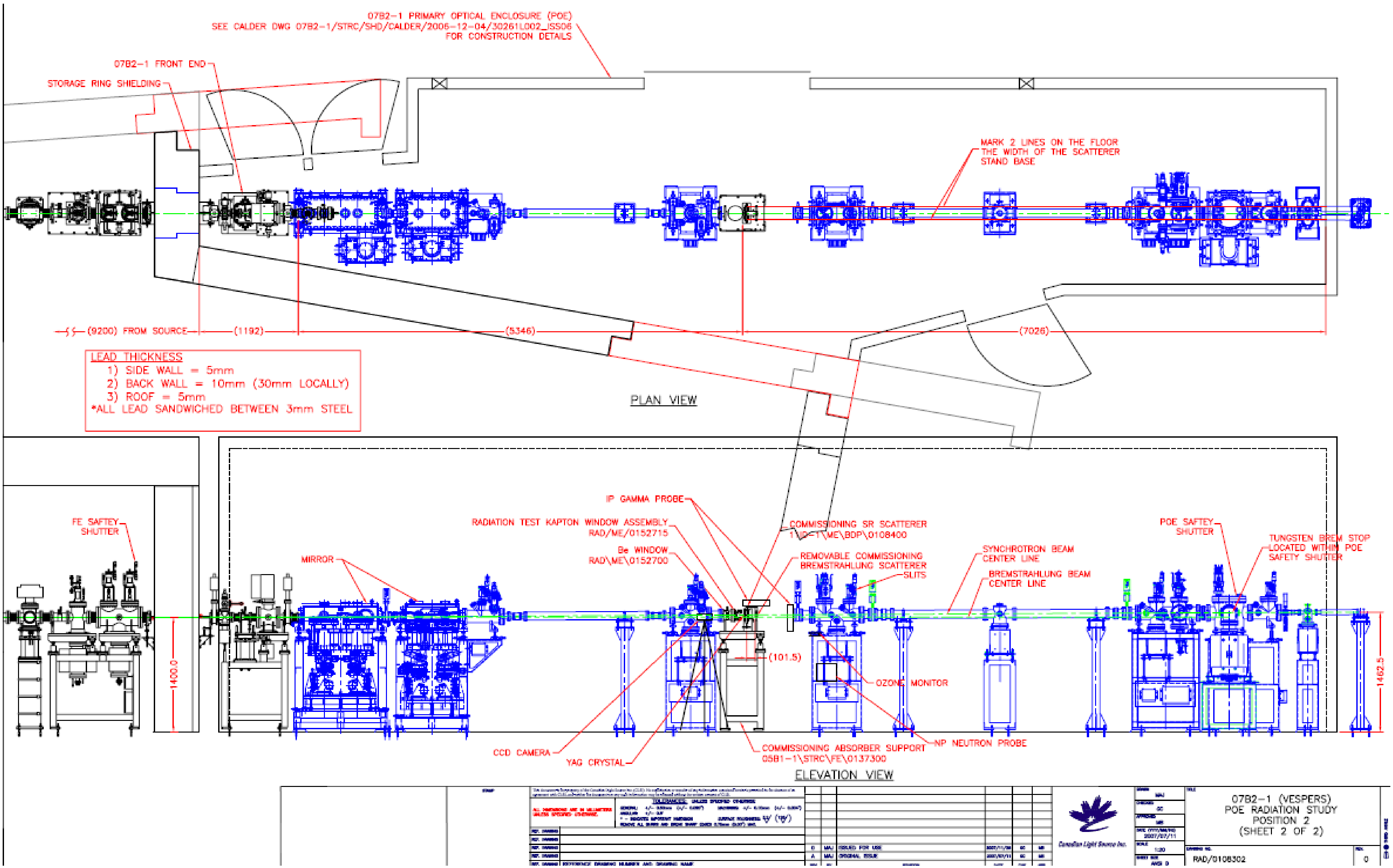
Ozone measurements inside Vespers POE

- Ozone measurements were completed at 50 mA and 250 mA stored current.
- The ozone monitor was placed slightly off beam axis behind the scattering targets.
- The regulatory limits for 15 minute and 8 hour ozone exposures are 0.2 and 0.05 ppm respectively.
- Maximum ozone concentrations measured inside the POE were:
  - 50 mA: 0.32 ppm
  - 250 mA: 0.95 ppm



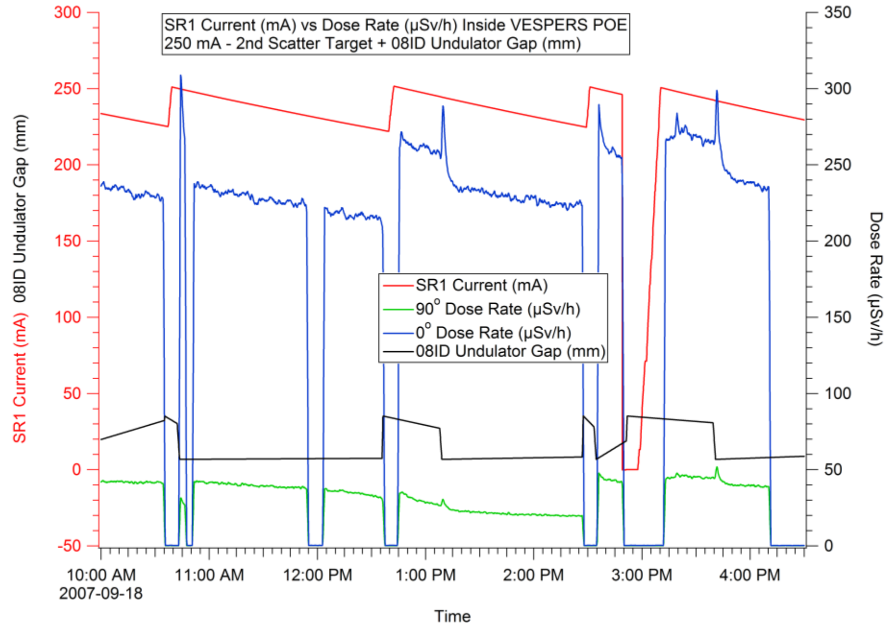


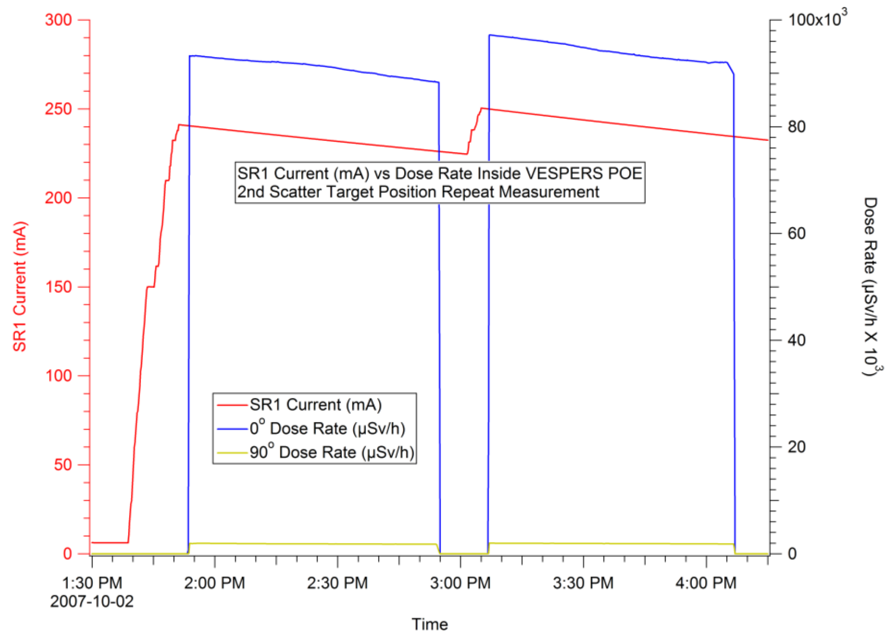
Vespers POE – 2nd Target Location



2nd Target Location Tests

- Radiation levels were significantly lower than the measurements taken at the 1st scatter target position with 250 mA. This was likely due to proper placing radiation monitors.
- The gap of the 08ID in-vacuum Undulator is shown along with the SR1 current and the dose rate. The undulator gap is measured in millimeters, and creates a 6 mm aperture inside the storage ring when fully closed. The gap is forced open automatically prior to beam injection.
  - The initial closure of the undulator creates a spike in radiation levels inside the POE.
  - that radiation levels idrop approximately 10 % when the undulator gap is changed from fully open to the minimum aperture.
- As beamline commissioning proceeded, it was discovered that the fixed mask was slightly misaligned.
- The tungsten fixed mask was adjusted by 1 mm.
- The expected 4 spots were more visible on the YAG crystal and the dose rate on the 0º probe reached approximately 100 mSv/h with 250 mA stored beam.
- No radiation above background levels was observed outside the VESPERS POE at any time during the commissioning.

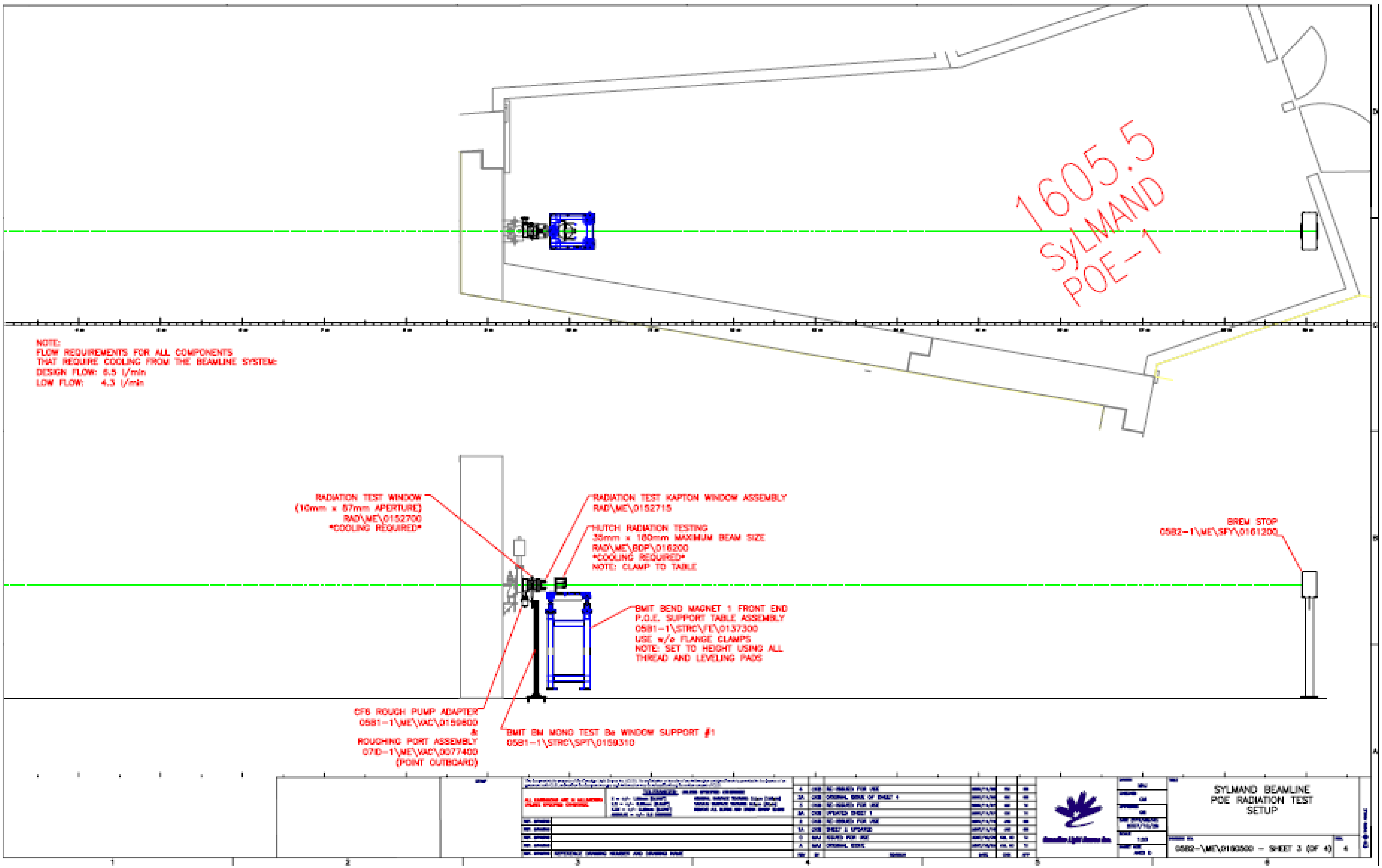




Vespers SOE Radiation Measurements

- SOE radiation measurements were completed at 3 stored currents.
- 5 mA:
  - No counts above background radiation levels were found with the LEX at any location outside SOE.
- 50 mA:
  - Using an Inovision 451P survey meter placed in the beam path inside the SOE and set to cumulative dose mode, a 5 minute data collection recorded 490 mR, or approximately 59 mSv/h dose rate from the 'pink beam' allowed into the SOE.
  - No counts above background radiation levels were found with the LEX at any location outside SOE.
- 250 mA:
  - No counts above background radiation levels were found with the LEX at any location outside SOE.

Sylmand POE Shielding Commissioning – Target setup

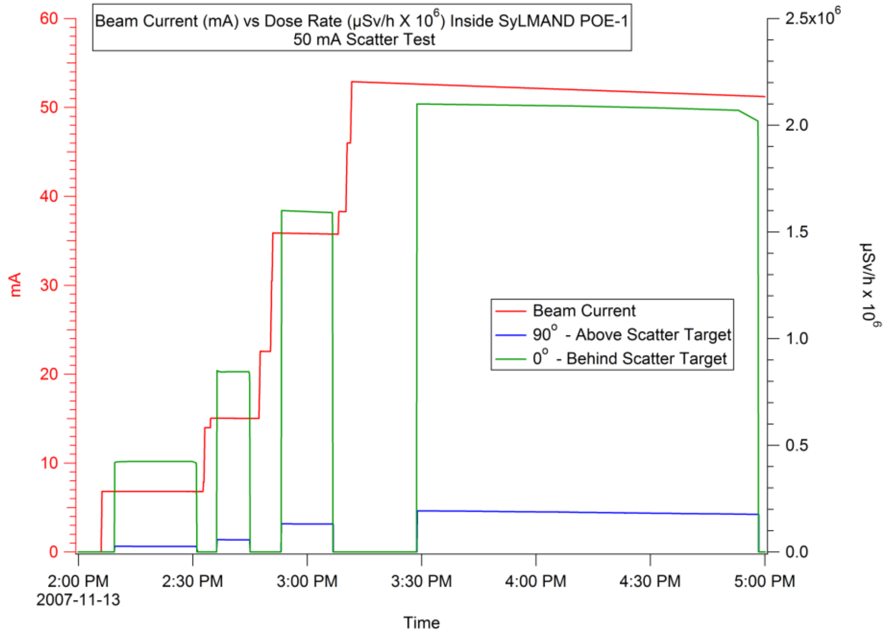


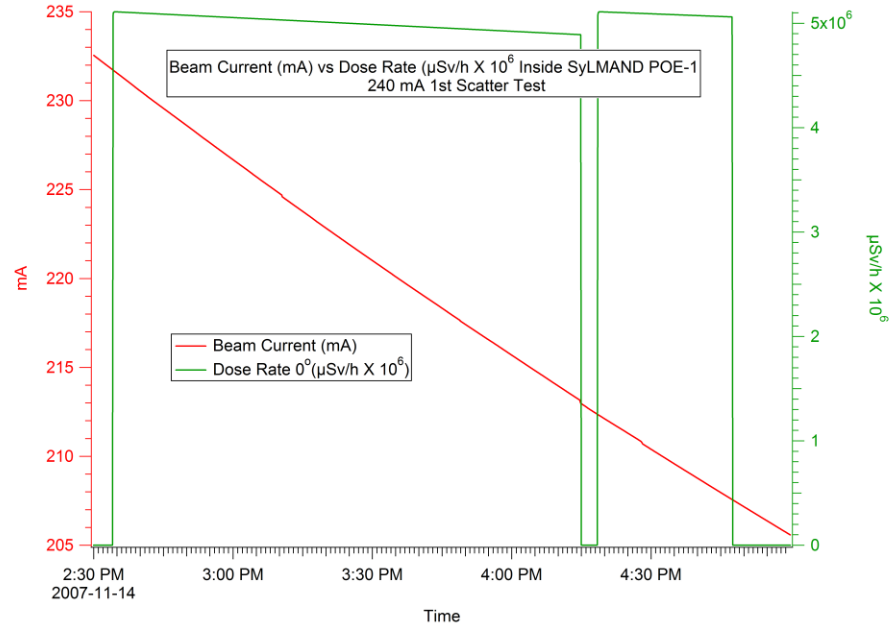
Radiation outside Sylmand POE

- Radiation levels measured outside Sylmand POE were below 200 nSv/h at all locations.
- Radiation was detected at one ventilation chicane that is designed to allow air movement into the SyLMAND enclosure.
  - The design has been implemented for Phase II beamline enclosures that require special ventilation chicane and is different than the conventional chicanes used for the beamline mechanical and electrical utility requirements.
  - The larger opening of the ventilation chicane appears to allow scattered photons to move further into the ventilation chicane than the conventional chicanes.
  - 1.2 μSv/h was measured at the exit point of chicane during the maximum stored beam. This is however below design criteria of 2.0 μSv/h
  - Connection of the ventilation duct work is expected to reduce or eliminate the radiation levels.

Radiation inside Sylmand POE

- Radiation levels exceeded 2 Sv/h downstream of the scatter target during the 50 mA test.
- whereas in the 240 mA test, the radiation levels reached 5 Sv/h near the 0º orientation.
- Despite the high level of radiation inside the enclosure, no radiation was detected outside the enclosure except at chicane C4 as noted above.





Summary

- No radiation leakage were observed on any of the Phase II bending magnet beamlines
  - Small radiation were measured through Sylmand ventilation chicane.
- Radiation levels inside the BM POE varied among the various BM beamlines and are quite sensitive to the exact location of the radiation detectors.
- Ozone above regulatory limits were measured inside the BM POE
- Elevated radiation levels were observed during BMIT ID FE tests.
- Radiation tests for BMIT ID POE are continuing, preliminary tests showed:
  - Localized radiation leakage observed outside POE1 during the BMIT ID commissioning – local shielding around beamline scatter components may be required.
  - Elevated ozone levels measured inside the BMIT ID POE while beam from ID is allowed inside the enclosure – ventilation fans were deployed and access restrictions implemented.
  - Adopted different commissioning plan for the BMIT ID beamline using actual beamline components such as slits as targets.
    - Reduced radiation leakage outside the POE1 enclosure
    - Drastic reduction in the ozone production inside the POE1.

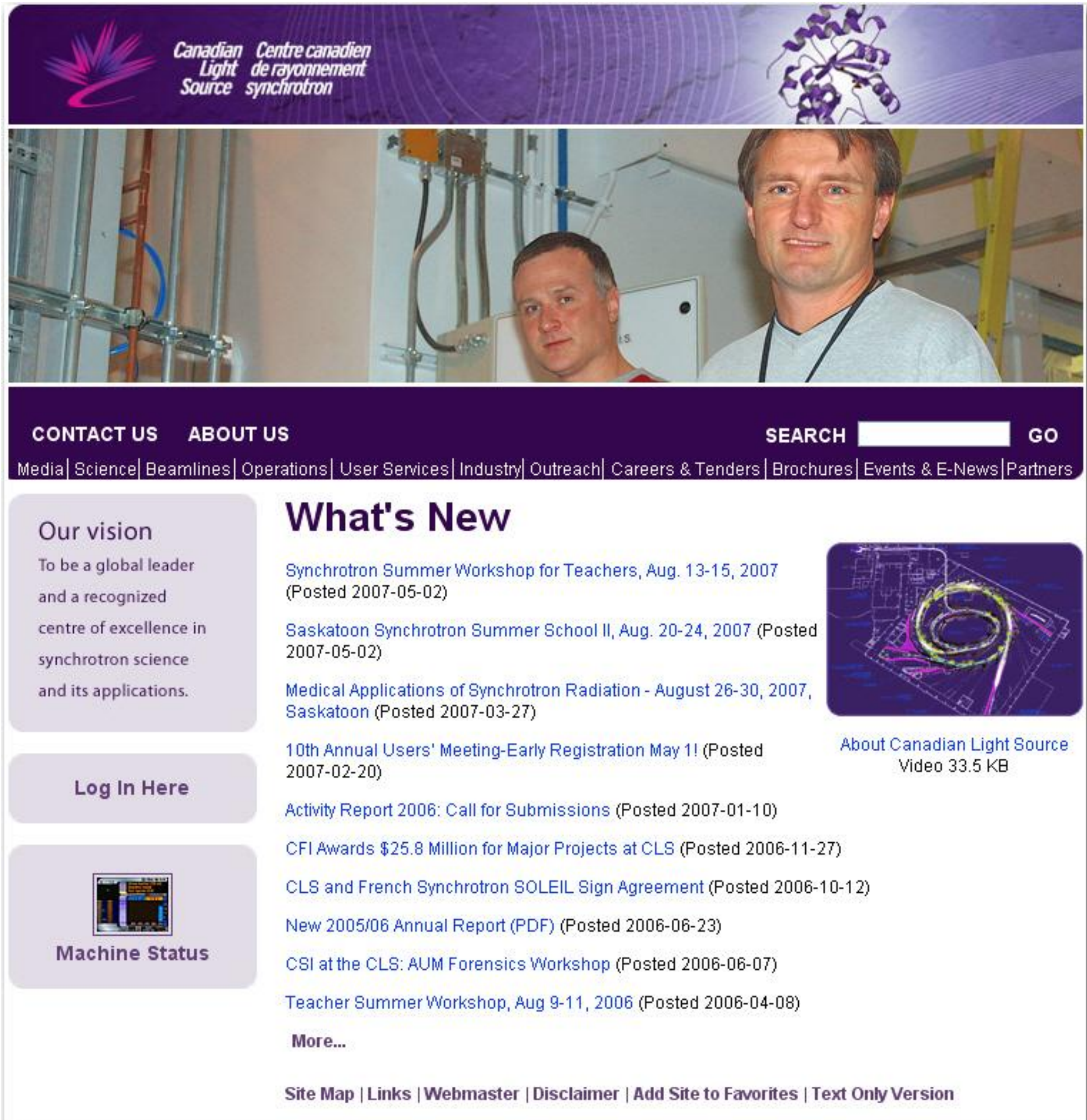
Future Plans

- Beamline Shielding design:
  - Treat SR and GB using the same code such as Fluka
  - Carry out beamline specific shielding calculations using actual beamline components and locations.
  - Revisit shielding design for BM beamline
  - Complete Phase III beamlines shielding design
- Beamline radiation enclosure commissioning
  - Complete shielding validation of BMIT ID beamline
  - Complete shielding validation of CMCF2 SOE
  - Review implementation of commissioning plan for phase III beamlines

Future Plans – Phase III Beamlines

- Under Phase III of beamlines of the CLS facility, three projects included a total of five new beamlines.
- The north west of the facility front wall will need to be expanded to accommodate Phase III beamlines
- these beamlines are expected to begin planning/design/ construction phase to start in 2009 and commissioning phase by 2012.

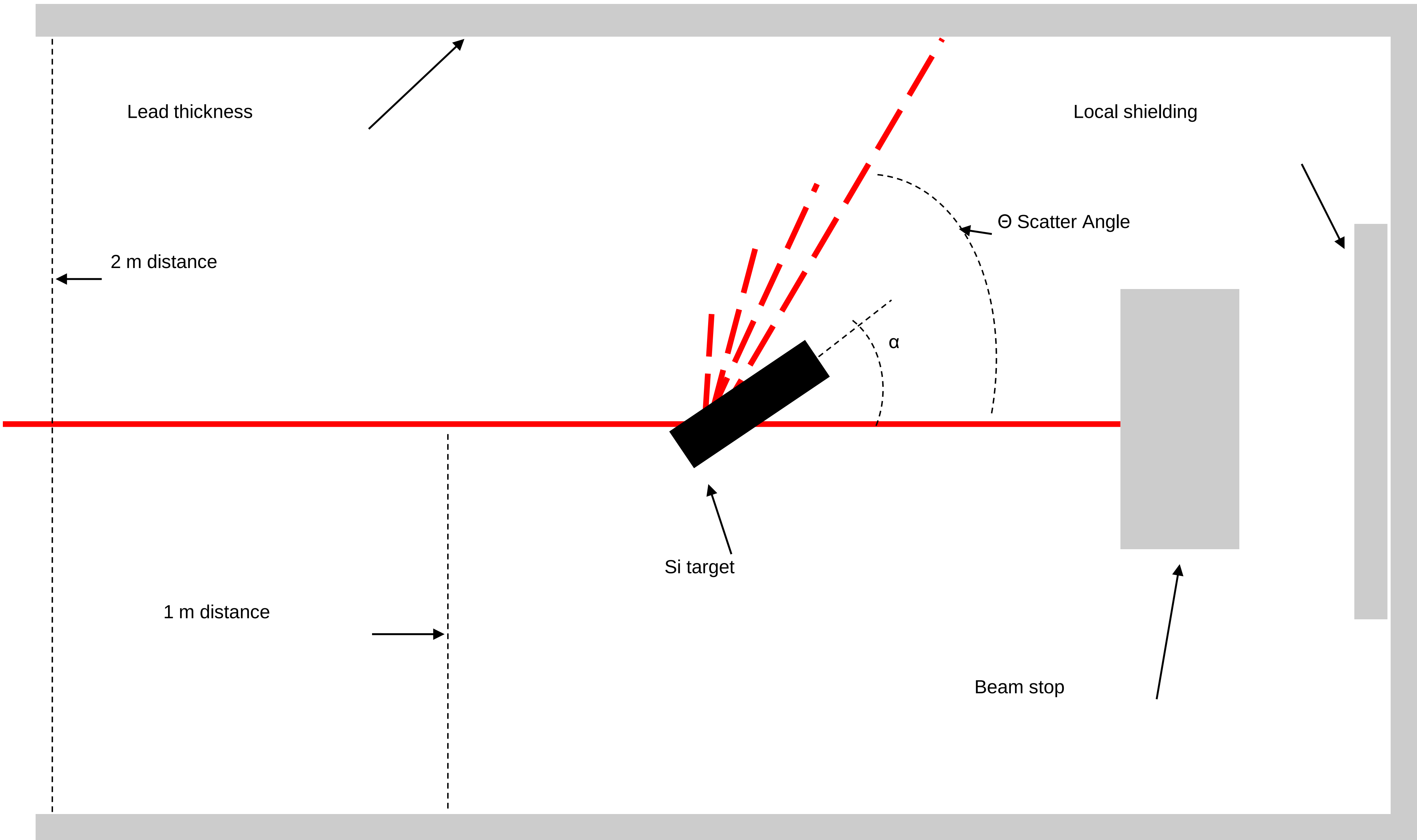
Thank you for your attention



Radiation Instrumentations

Manufacturer	Model Number	Function	Detector Type	Energy Response	Dose Rate Range	Comments
Canberra	ADM606M	Digital Display, local alarm	---------	---------	---------	Includes Digital display, local alarm, and can directly communicate with control room
	IP100	Gamma/x-ray, pulsed or static fields	Proportional Ionization Chamber	50 – 1.25 MeV	0.1 µSv/h – 1 Sv/h	
	NP100	Neutrons, pulsed or static	He or BF_3 Proportional counter with polyethylene moderator	0.025 eV - 15 MeV	0.1 µSv – 200 mSv/h	
	GP100	Gamma/x-ray static field	Geiger-Mueller Chamber	50 keV - > 3 MeV	0.10 µSv/h – 10 Sv/h	
ThermoEberline	FH40G-L10	Gamma/x-ray static fields	Proportional Counter	33 keV - > 4 MeV	0.5 µSv/h – 100 mSv/h	
ScionexHolland LEX	51BD51/2	Low	NaI(Tl)	Minimum Energy 7 keV	-----------	Thin Al Window over detector, LEX connected to EG&G Ortec Digibase
Aeroqual	Aeroqual 500	Ozone Detection	Gas sensitive semi-conductor	-------------		Concentration Range: 0.5 – 20 ppm
		Illuminate under exposure to ionizing radiation	YAG Crystal (Yttrium, Aluminum, Garnet)			Used as a confirmation of beam reaching scatter target
Inovision	451P	Gamma/x-ray, pulsed or static fields	Ionization Chamber	> 25 keV	0.1 µSv/h – 50 mSv/h	

Geometry for Beamline Enclosure Shielding Calculation



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- [2] CLSI, "05B2-1 (SyLMAND) Radiation Commissioning Report", CLSI Document No. 11.18.53.14.Rev.0 (2008).
- [3] CLSI, "07B2-1 (VESPERS) Radiation Commissioning Report", CLSI Document No. 11.18.53.15.Rev.0 (2008).
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