Top-up Operation Safety Features at the Canadian Light Source

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Canadian Light Source Centre canadien de rayonnement synchrotron
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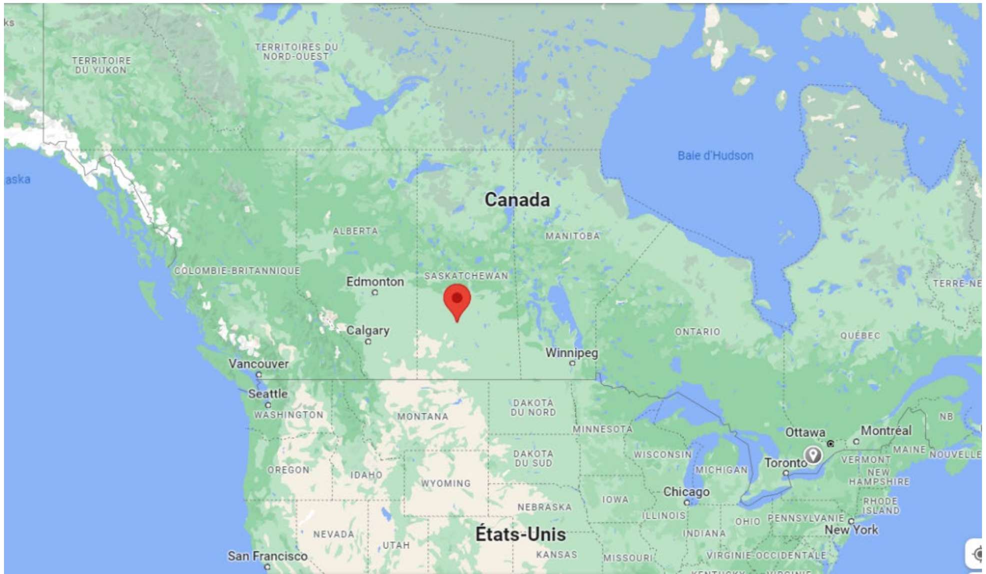
RADSYNCH2023 – ESRF, Grenoble France

OUTLINE

- Facility History
- Top-Up Hazard Assessment
- Top-Up Analysis and Testing
- Regulatory Approval



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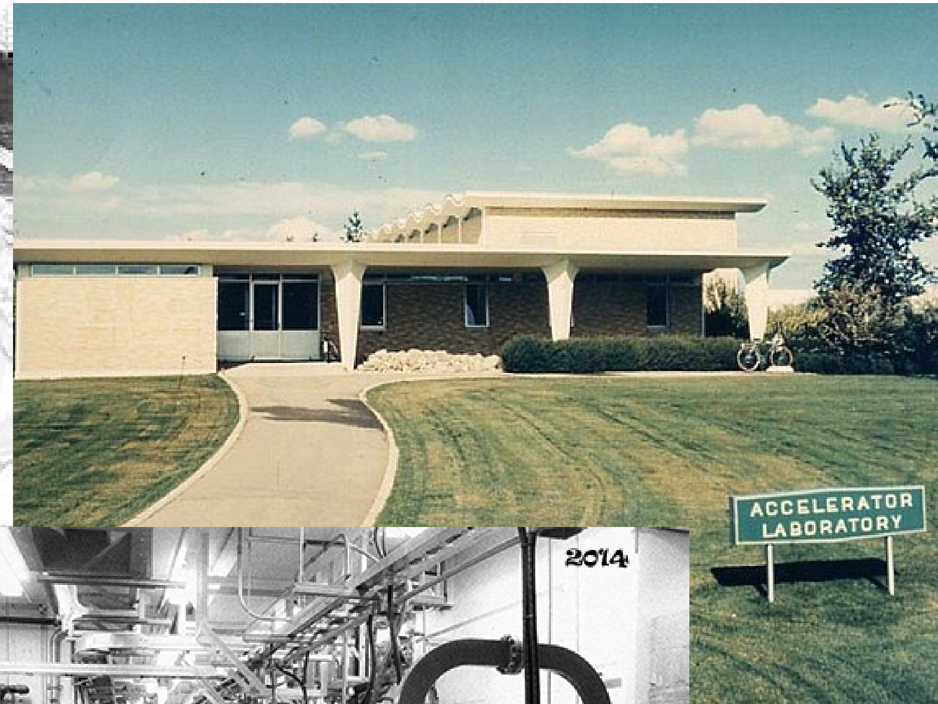
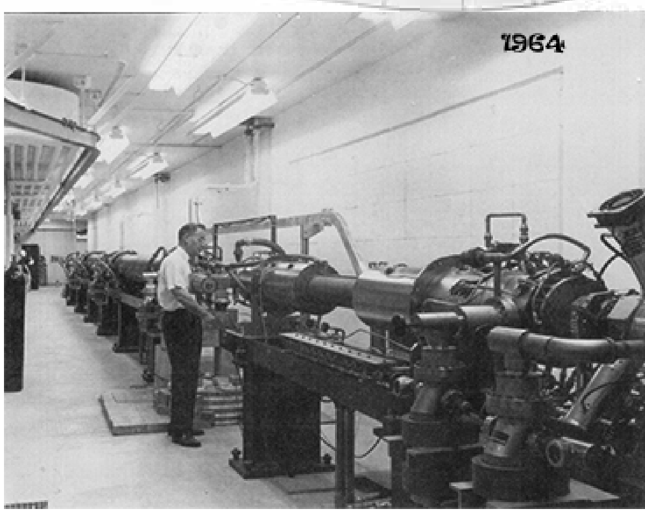
History

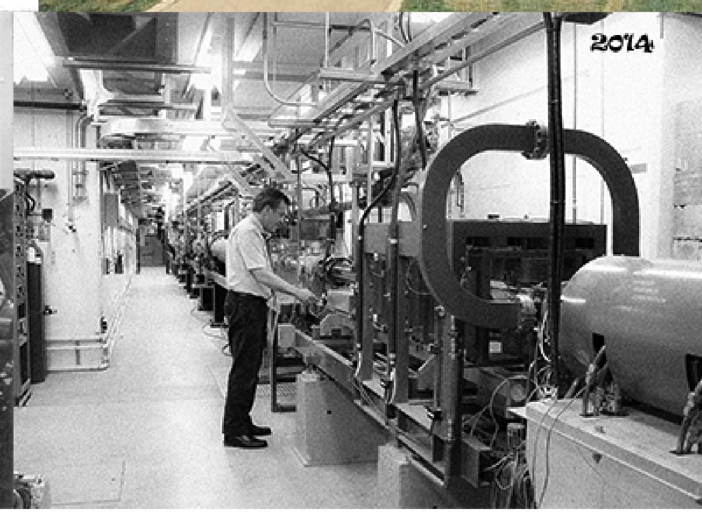
Saskatchewan Accelerator Laboratory

- 1964 -high energy physics research facility
- 300 MeV LINAC in ‘Old’ building
  - Owned by University of Saskatchewan (on Campus)
  - 360 Hz
    - Higher power operation than CLS 1 Hz
- 1,842 m^2 building
  - Brick and mortar

Saskatchewan Accelerator Lab (SAL)



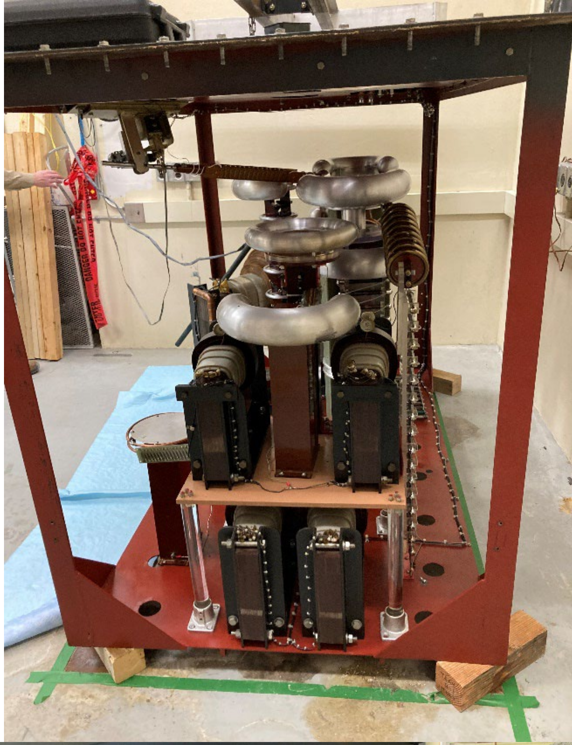




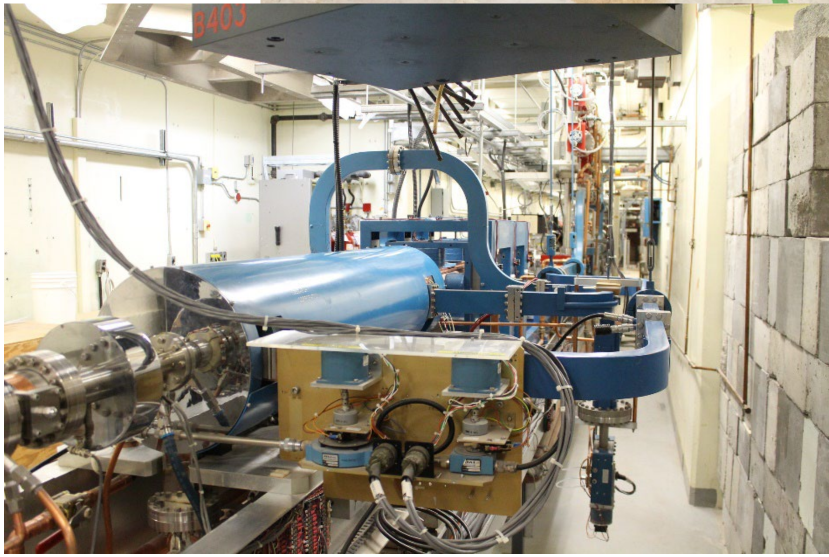
Overview of Synchrotron Facility

- Construction started 1999
  - 7.2 acre footprint
  - ~ 12,071 m^2 building
  - 5 levels
  - Transfer lines to bring beam up two floors to Booster Ring
  - Booster Ring ramps 250 MeV to 2.9 GeV
  - 2.9 GeV Synchrotron Storage Ring
  - Beamlines in 'new' section of building

Electron Gun



- 2 Stories undergound
  - Former SAL
- 220 KV
- 1Hz

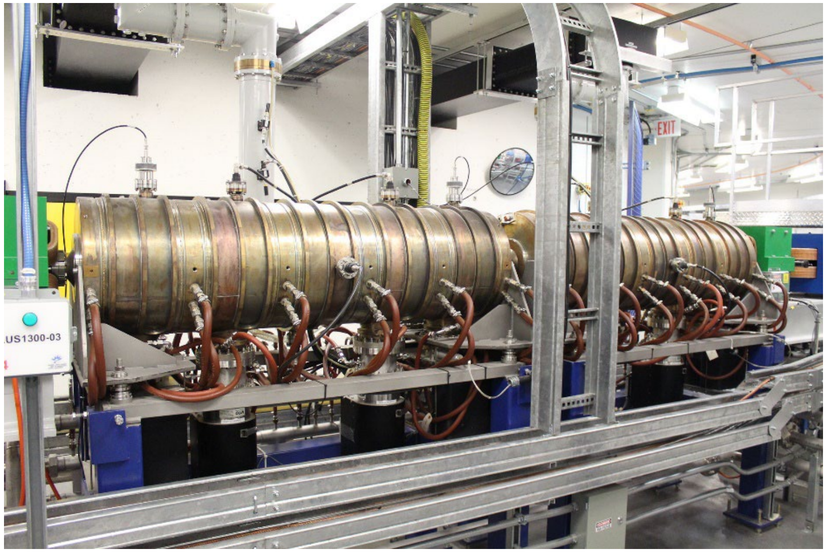


LINAC

- 6 Section
- 70 or 140 nS pulse
- 250 MeV
- 1 Hz
- Energy Compression
- Linac-to-Booster (LTB)
  - 70 meters long
  - Up two floors

Booster Ring

- 250 MeV to 2.9 GeV
- 10 mA design average operating current
  - 3 to 4 mA normal
- 20 dipoles
- 28 quadrupoles
- 2 RF cavities

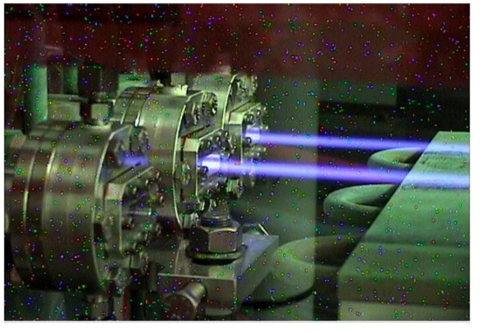


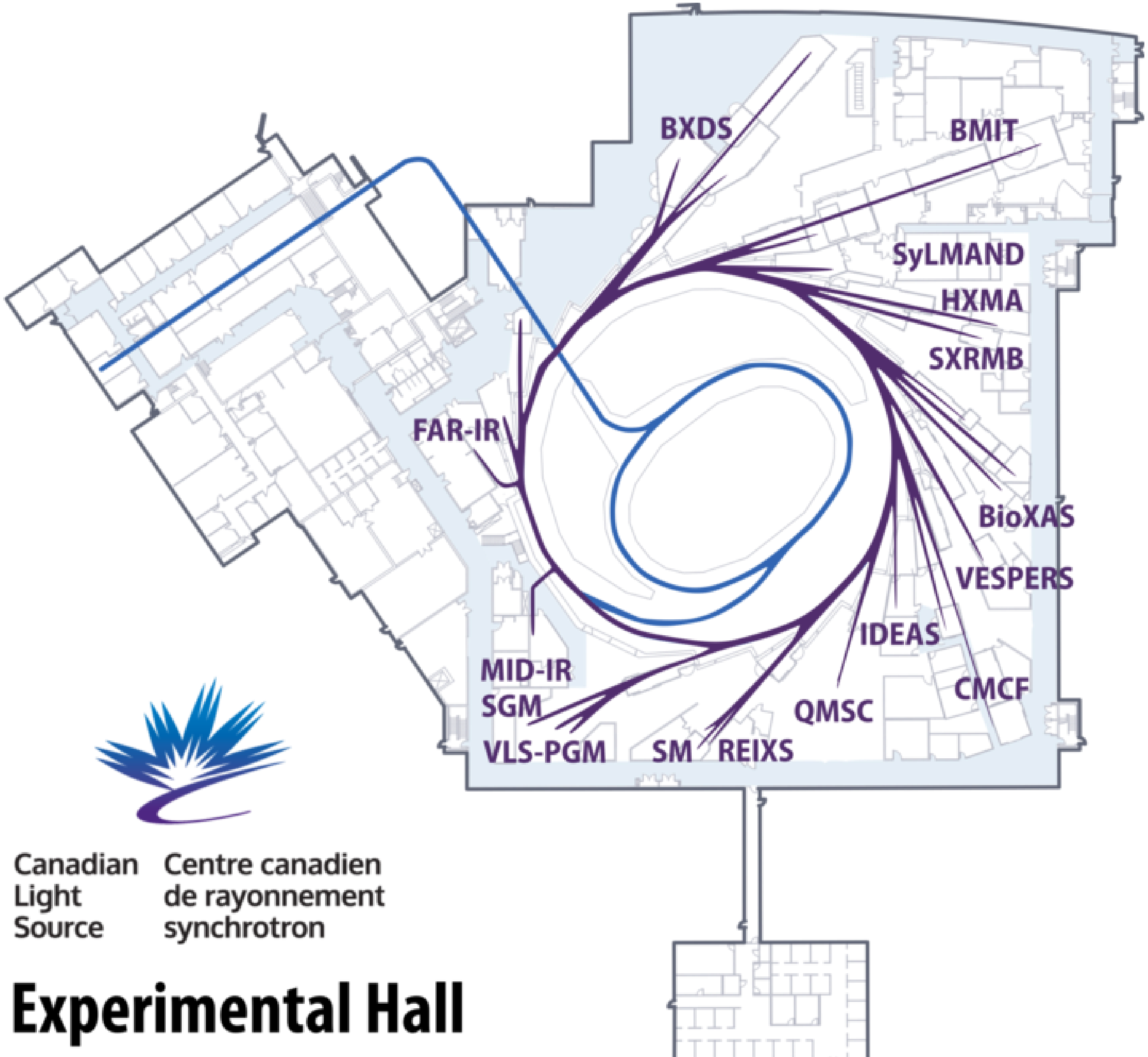
Storage Ring

- 24 Dipoles
- 12 straight sections
  - 9 available for insertion devices
- Superconducting RF cavity
- 2.9 GeV
- 170.88 m circumference

Beamlines

- 22 Operational Beamlines
- 2 diagnostic beamlines
- Infrared to Hard X-ray





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Experimental Hall

Regulatory

- **CNSC Dose Limits**
  - 20 mSv/Year (NEW)
  - 1 mSv/Year (non-NEW)
  - 50 µSv/Year (Outside Facility)
- **Facility Operations**
  - 10 mSv/Year (NEW)
  - 1 mSv/Year – accident scenario
  - <5 µSv/hour Experimental Hall

CNSC CCSN

Canadian Nuclear Safety Commission

Hazard Assessment

- Decay Mode vs Top-up
  – 2 operational modes of injection with safety shutters open considered

1. Refill of storage ring after 8 – 12 hours of operation
2. Frequent refill of storage ring

   (Top-up Mode)

Hazard Assessment

- Decay mode vs top-up
- Shutters open injection risk
- Internal Document "Top-Up Hazard and Risk Analysis"
  - Injected electrons travel down beamline
  - Beamline Shielding Inadequate
  - Storage Ring – Injector Energy Mismatch
  - Poor injection efficiency

Injected Electrons

– Internal ‘Failure Mode Analysis’ using DIMAD
  - Top-Up injection under normal conditions ‘safe’

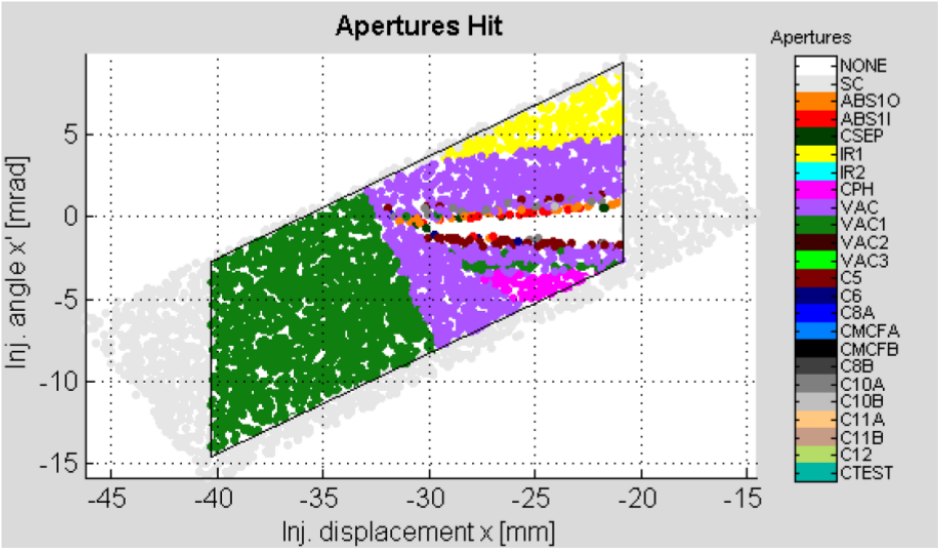


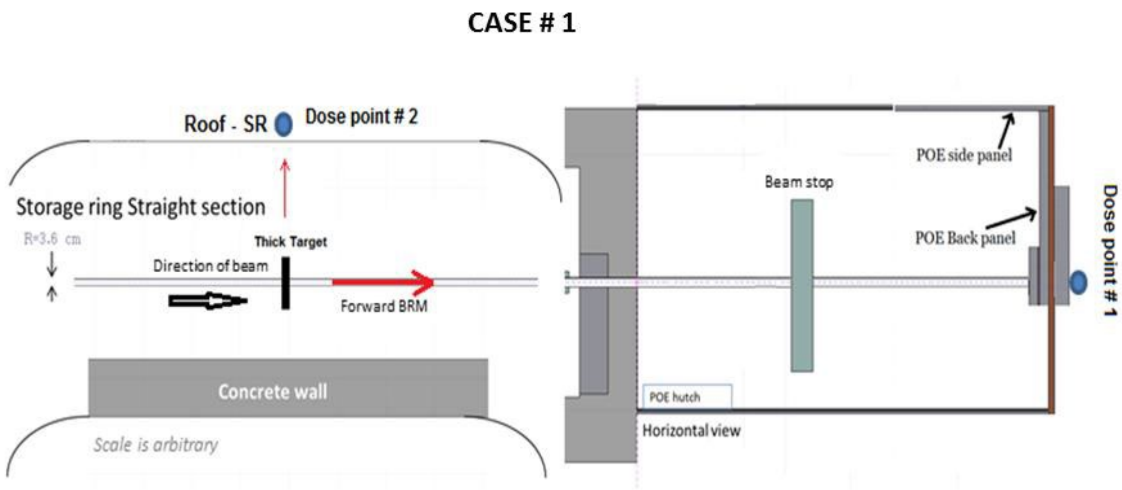
Figure 2. Example of plot showing at which aperture the injected beam is lost for particles launched by the shotgun injection. Plot is for no errors in the storage ring.

Injected Electrons

- Injection Failure Modes analyzed include:
  - Kicker Failure
  - Injection orbit misalignment
  - Off energy particles
  - Dipole short circuit

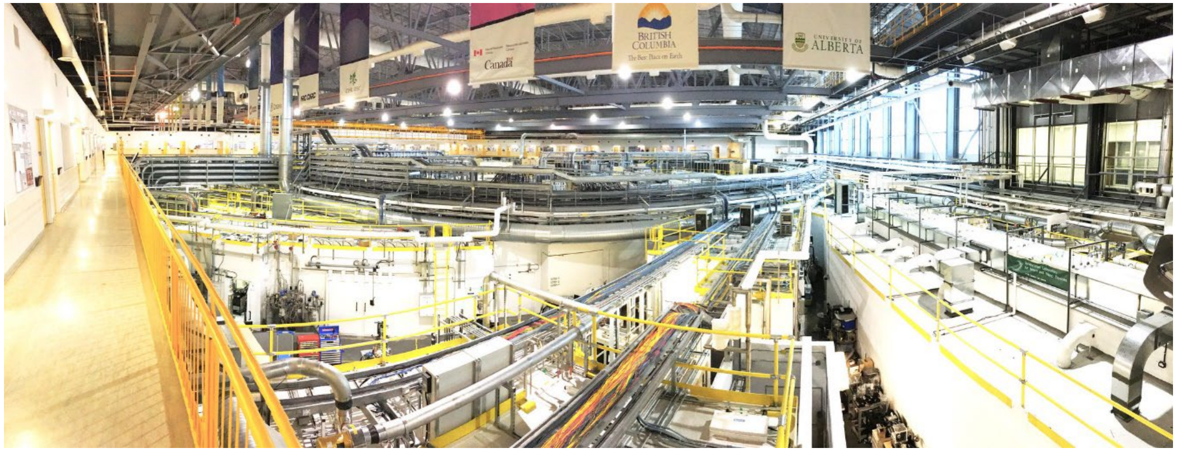
- Risk extremely low – further mitigated by design changes

Accident Scenario



Shielding

- Shutters Open Worst Case Beamloss Scenario
  - 1 nC pulse into POE
  - 402 μSv dose per pulse (1Hz) worst case.



Testing

- 3 Tests Completed
  - **Normal injection with shutters open**
    - Compare results of Area Radiation Monitors during injection with shutters closed
  - **Energy Mis-Match**
    - (1%, 2%, 4%)
  - **Close Vacuum valve at center of straight section**
    - Walls/Roof POE
    - Wall/Top of storage ring

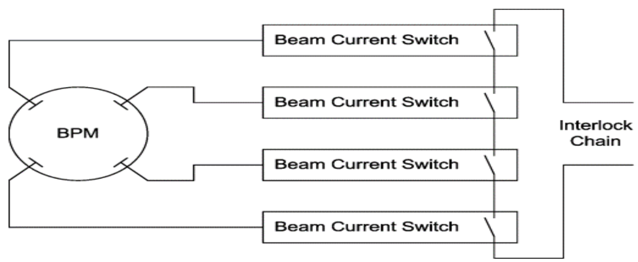
Test Results

- **Note:** Facility cleared except for commissioning personnel prior to all tests
- Normal injection:
  - All POEs << 2.5 µSv/h
- Accident Scenarios:
  - Energy Mismatch
    - Max dose rate measured < 100 µSv/h
  - Vacuum Valve Closed
    - All insertion beamlines tested
    - 1.4 mSv/h max

Top-Up Safety Features

Stored Beam Before Shutters Open Injection

- Forward-Reverse Power Switch



- Beam Current Switch

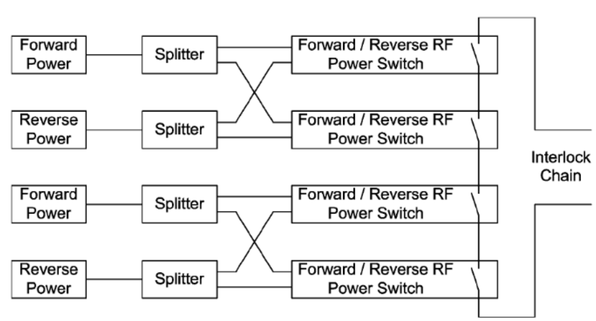
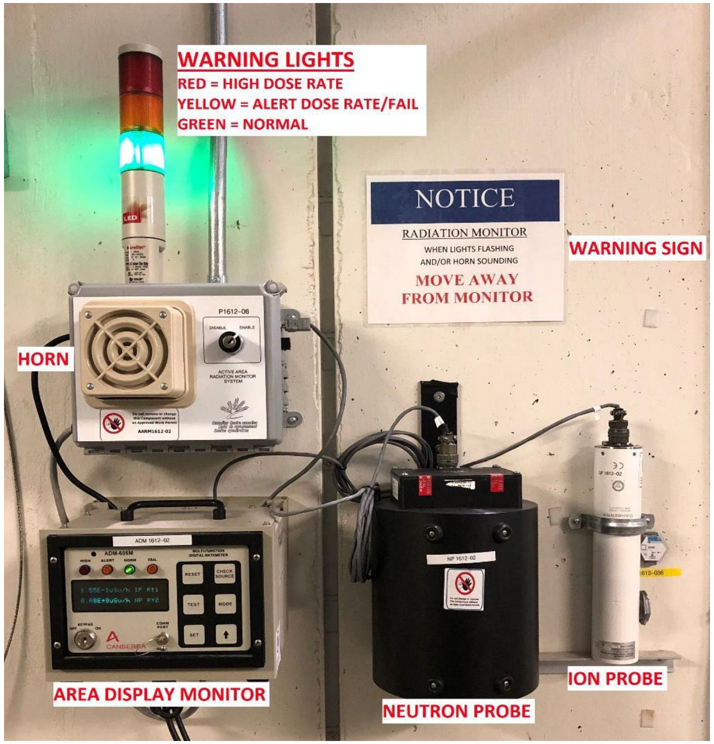


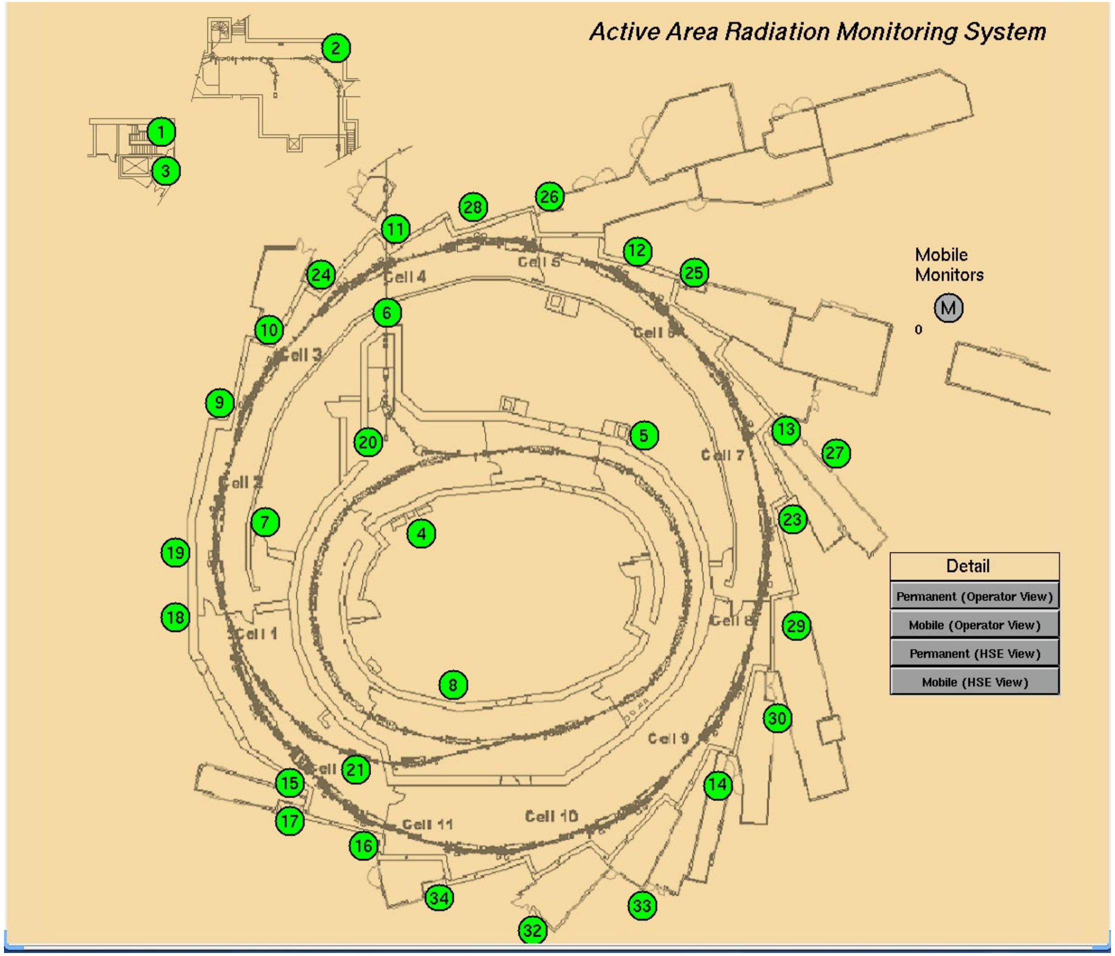
Fig. 1: Block diagram of the forward / reverse RF power switch system.

Top-Up Safety Features

- **Injection Interlock**
  - Active Area Radiation Monitoring System
  - 32 AARMS stations strategically located
  - 2.5 µSv cumulative hourly dose injection interlock



AARMS Locations



Defense in Depth

- Machine Protection
  - Dipole Energy Interlocks
    - Transfer line to SR1 dipole power supply (0.5%)
  - Bad orbit protection
    - Beam dumped when bad orbit detected
  - Injection Efficiency (> 90%)
    - Was 70% initially
  - Transfer Line Collimator
    - Shielding collimator in storage ring tunnel

Defense in Depth

- Radiation Protection Program
  - Shielding design
    - Accelerator and beamlines
  - Configuration Control
    - Bulk and local shielding
  - Accelerator and Beamline Lockup
  - Radiation Surveys - Commissioning and routine
  - Passive Area Monitoring
  - Active Area Monitoring
  - Controlled Work Process

Regulatory

- May 3, 2017: Documented safety case for Top-up forwarded to CNSC
  - Questions from CNSC staff resolved

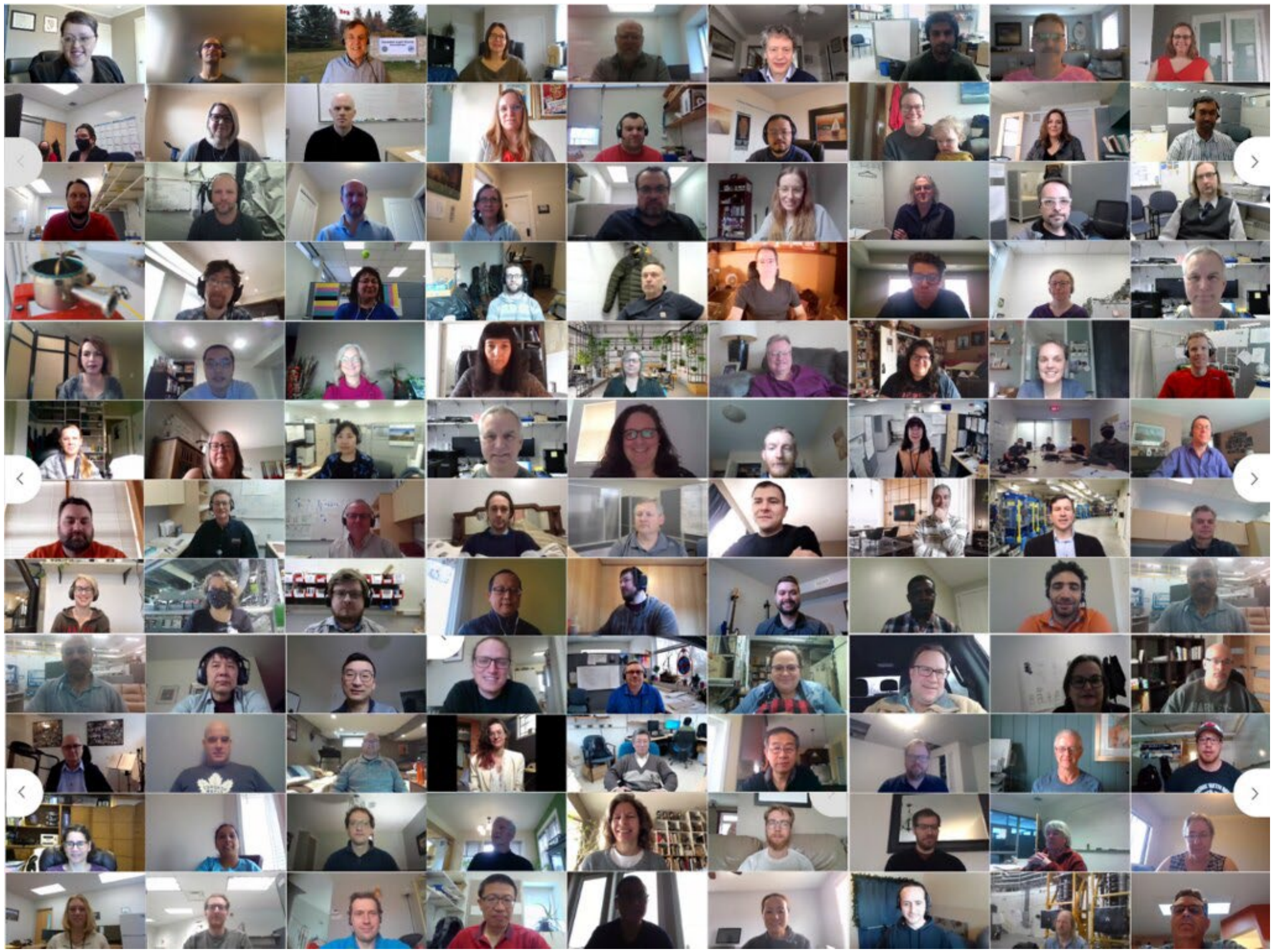
- October 17, 2017: CNSC staff forwarded request to Commission Panel for resolution

- February 20, 2018: Licence approval received

Top-Up Operation

- Move to Top-up Operation for User Beam complete
- No radiation dose to any workers > 1.0 mSv

Merci Beaucoup!



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Shielding Design

Shielding calculations for a given dose D derived by the equation:

$$D = P \times \sum_i \left(\frac{H_i}{r^2} \times e^{\left(-\rho d / \lambda_i \right)} \right)$$

References:

Moe, H. J. (1991). *Advanced Photon Source: Radiological Design Considerations.* Chicago, Illinois: APS Technical Note APS-LS-141 Revised.

Moe, H.J. (1997). *Radiological Considerations for the Ooperation of theAdvanced Photon Source Storage Ring – Revised.* Chicago, Illinois: APS Technical Note APS-LS-295 Revised.

IAEA Technical Report 188 (1979) - Radiological Safety Aspects of the Operation of Electron Linear Accelerators