10 Years of Safe Operation at the Canadian Light Source – A Radiation Safety Perspective

G. Cubbon[1], A. Albert[1], P. Chowdhury[1], D. Street[1]

[1]*Canadian Light Source Inc., 44 Innovation Boulevard, Saskatoon, SK S7N 2V3, CANADA*

Abstract

The Canadian Light Source (CLS) project began in 1999, with installation and commissioning of the Linac, Booster Ring and Storage Ring completed in 2003. Installation and commissioning of seven Phase I beamlines in 2004 led to the first external Users being scheduled in 2005. CLS has completed 10 years of routine operation since our first external User. In 2014, the facility had 1835 User visits by 896 different Users, and employed 269 permanent and part time staff along with 85 contractors. The presentation will review the CLS radiation protection program over the 1st 10 years including radiation monitoring, shielding development and testing, interlock systems, and events related to radiation safety. A discussion of the direction of the radiation safety program in the future is also included.

1. Facility Description

The Canadian Light Source (CLS) is a 3rd generation synchrotron facility operating at 2.9 GeV. The facility and grounds covers 3.32 Hectares on the University of Saskatchewan Campus, located in Saskatoon Saskatchewan, Canada. Construction of the facility began in 1999 and incorporated an existing research linear accelerator (Saskatchewan Accelerator Laboratory – SAL).

CLS currently operates in decay mode only. The injection cycle begins with a 220 keV electron gun and a 300 MeV LINAC, which are located 2 stories underground. The 6 section LINAC normally operates at 200 – 250 MeV producing a 140 nS pulse. At the end of the LINAC the beam is compressed in an Energy Compression System. A 70 meter transfer line connects the LINAC to the Booster Ring located at ground level in the main experimental building.

The 20 dipole Booster Ring and two conventional radiofrequency (RF) cavities ramp the beam energy to 2.9 GeV before transferring the pulse to the Storage Ring where the electrons are stored. The injection cycle operates at 1Hz, and it takes less than 10 minutes to fill the Storage Ring to 250 mA. The injection cycle is repeated every 12 hours during normal operation.

The storage ring is comprised of 24 dipole magnets in a 12-fold periodic repeating array. Each section consist of a 5.2 meter straight section followed by 2 dipoles and other focusing and defocusing magnets. Beam power is replenished via a superconducting RF cavity. CLS currently has 14 operational beamlines, 2 diagnostic beamlines, and 7 beamlines in various stages of planning and commissioning.

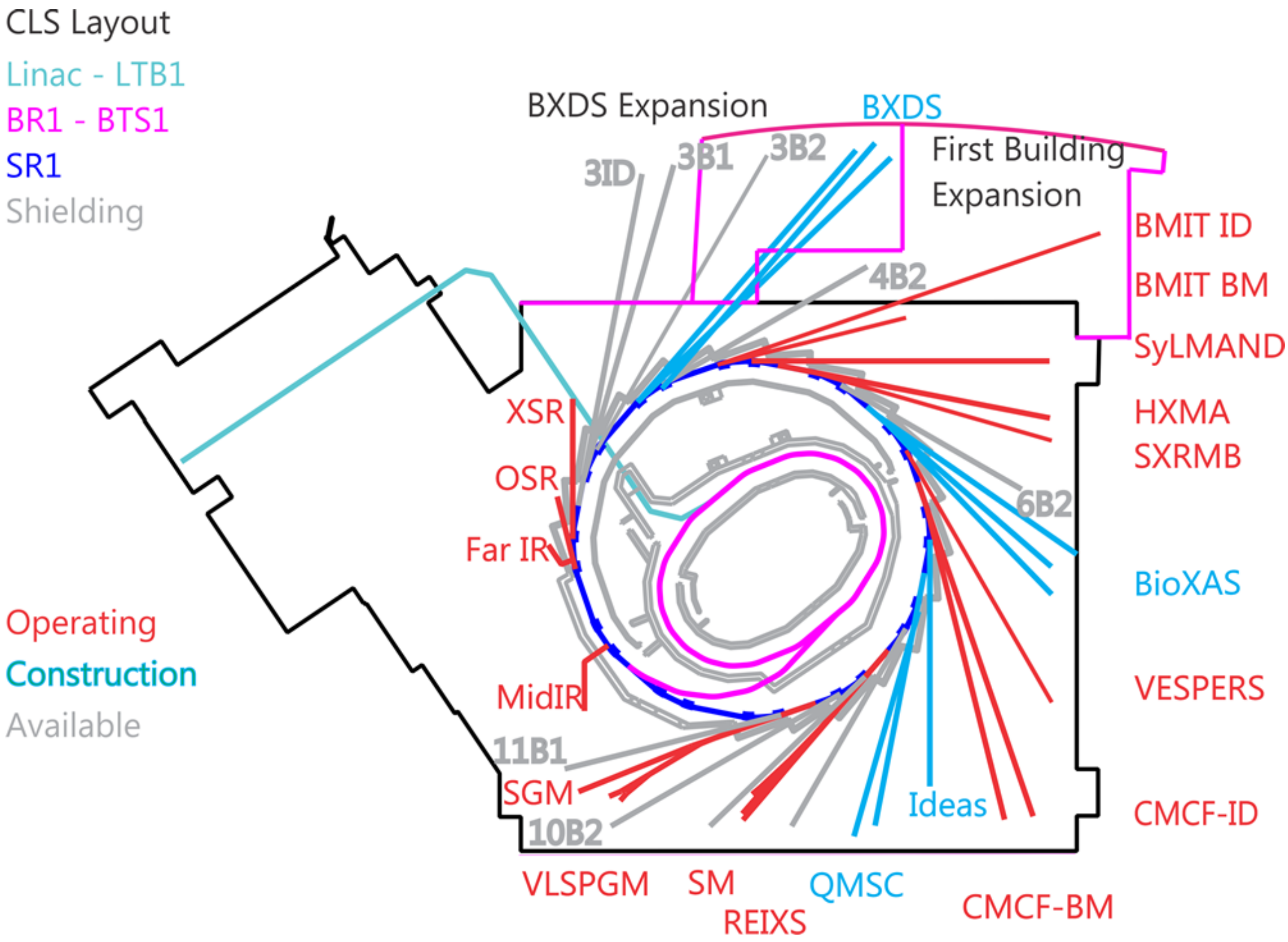

Fig.1 – CLS Facility Schematic Layout

2. Radiation Protection Program

2.1. Shielding Considerations

The Canadian Light Source is licenced as a Class IB facility by the Canadian Nuclear Safety Commission (CNSC). The CNSC creates regulations and provides regulatory oversight to a variety of nuclear facilities including power plants (Class IA). Other Class IB facilities include accelerators > 50 MeV, nuclear fuel fabrication, nuclear waste disposal, uranium mines, and facilities using or producing isotopes in amounts greater than 10^{15} Bq per year. Class II include accelerator facilities > 1 MeV but not a Class IB facility.

In addition to a Safety Report that describes the hazards and mitigation associated with operating a synchrotron facility, the regulatory oversight framework includes a collection of CLS documents that describe the programs necessary to fulfill compliance with 14 Safety Control Areas (SCA). These documents, along with several regulatory documents, are referenced in a Licence Conditions Handbook (LCH) document associated with the operating licence. The LCH also contains guidance on the verification criteria for each SCA and expectations of the regulator for the licencee.

Canadian Radiation Protection Regulations have adopted international standards including:

- 50 mSv per annum regulatory dose limit for a Nuclear Energy Worker
- 100 mSv per 5 year dosimetry period regulatory dose limit for a Nuclear Energy Worker
- 1 mSv per annum regulatory dose limit to a member of the public

The CLS facility design incorporated additional constraints including:

- Annual dose < 10 mSv above natural background for Nuclear Energy Workers;
- Annual dose < 50 μSv above natural background for members of the public outside the facility; and
- Total dose < 1.0 mSv to any person for any single beam-loss incident.

The bulk shielding design was based on not exceeding a maximum dose rate of 5 μSv/h at 30 cm from the accelerator, Booster Ring, and Storage Ring shielding walls when operating with 500 mA stored beam and an injection cycle of 15 minutes every 4 hours. Beamline optical enclosures were designed to maintain personal exposures below 2 μSv/h outside the enclosure walls. Initial accelerator shielding design was based on IAEA 188 (Swanson), H.G. Moe et al while computer based models STAC8 and TVDose were used for synchrotron enclosure shielding calculations [1,2,3,4].

Where required, local shielding was added to ensure radiation exposures would be kept ALARA. Radiation monitoring was completed during commissioning and at regular intervals since routine operation began to verify compliance is maintained. Routine inspection of shielding is completed prior to start-up of after an extended shut-down period.

2.2. Access Control and Interlock Systems

The Access Control and Interlock System (ACIS) is designed to ensure personnel are not present in hazardous areas during beam operation. The system design enforces an area search along a prescribed path before an area can be deemed secure. The system includes devices (horns and lights) to indicate an area is deemed secure, position sensors on entry points, and emergency shut-off buttons to ensure that the radiation source will be disabled should someone be missed during the search or gain access into a hazardous area.

The CLS ACIS uses redundant and independent radiation source shut-off systems to disable the electron gun and one or more of the LINAC – Booster Ring – Storage Ring RF systems depending on the breach condition. For beamline enclosures, the safety shutter protecting an enclosure is also closed. The ACIS employs separate and independent relay based logic and Programmable Logic Controller (PLC) based systems, or two PLC based systems. The systems are tested rigorously after installation and commissioning, and then annually to ensure safety is maintained. Work on the ACIS is strictly controlled, and any changes require a re-verification of the system involved. All staff and Users who are required to perform the lockup of an ACIS are trained by qualified staff.

2.3. Radiation Monitoring

All staff, users, and contractors working at the CLS are individually monitored for radiation exposures. Initially all monitoring was completed with Thermoluminescent dosimeters however in 2007 CLS switched to Landauer Luxel dosimeters due to the increased sensitivity. The dosimeters include an aluminum oxide crystal (Al_2O_3:C), sensitive to gamma and beta radiation from 5 keV to in excess of 40 MeV, and a CR-39 chip sensitive to thermal and fast neutrons. The dose sensitivity is 10 μSv and 200 μSv for gamma and neutron radiation respectively [5].

Initially all CLS staff were considered Nuclear Energy Workers. However in 2006 all administrative and most scientific staff were reclassified to non-NEW. All dosimeters are exchanged quarterly. Internal quarterly action levels, where an internal investigation of a reported radiation exposure is required, are 0.6 mSv and 0.2 mSv for NEW and non-NEW respectively. Electronic personal dosimeters are available for use with facility tours or for commissioning and other special requirements where real time personal exposure information is required.

As shown in figure 2, the annual collective dose to all staff, users, and contractors is very low. The maximum radiation dose to personnel (figure 3) did not exceed the 1 mSv annual public limit for any worker.

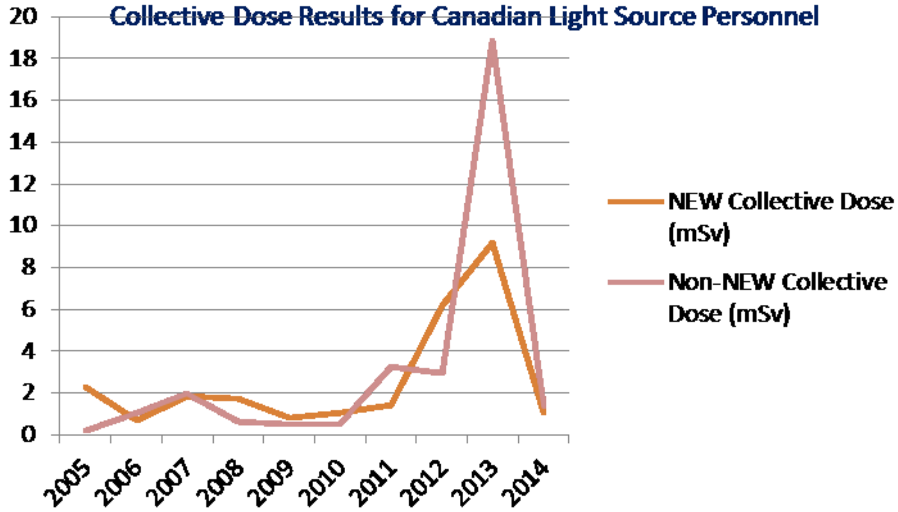

Fig.2 – Annual Collective Dose Results for CLS Personnel

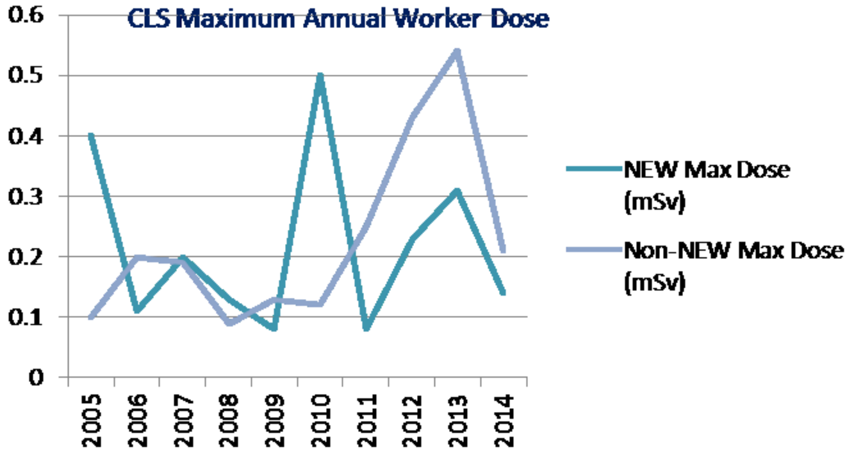

Fig.3 – Maximum Annual CLS Worker Radiation Dose

After the change to Luxel dosimeters in 2007, an upward trend in low radiation exposures as the number of personnel monitored at the facility increased was observed. This was eventually traced to the background radiation difference (~ 50%) between the old and new buildings that comprise the CLS facility. The SAL is built primarily from concrete while the new experimental hall is constructed mainly of steel. Historically an average background subtraction for control dosimeters deployed on dosimeter storage racks across the facility was used. Initially there were only 2 dosimeter storage racks. As the number of monitored personnel increased, the number of dosimeter storage racks in the new building was also increased, and therefore the average background dose reported was reduced. The lower reported average control dosimeter dose resulted in a measureable dose to dosimeters stored on the one rack located in the old building. This issue was resolved through administrative controls.

In 2013, elevated radiation exposure levels were reported on a large number of personal dosimeters. An investigation into the event showed the elevated exposure was due to in transit irradiation of the dosimetry shipment between the CLS and the dosimetry provider.

Overall, no CLS staff, user, or contractor dosimeter has ever recorded a neutron dose. Despite the issues with the control dosimeter subtraction, more than 95% of all assigned dosimeters are reported to have received less than the detection limit for each quarterly dosimetry period.

In addition to personal monitoring, CLS also uses Luxel dosimeters as part of a Passive Area Radiation Monitoring (PARM) program. The PARM dosimeters, either with or without the CR-39 neutron monitoring chip, are deployed strategically at over 500 locations within the facility. These dosimeters are used to monitor for trends and changes in machine operation, and help provide dose information for the development of shielding changes to help maintain personal exposures ALARA. PARM dosimeters are also exchanged quarterly.

An Active Area Radiation Monitoring System (AARMS) is deployed to track real-time radiation levels throughout the facility. Each AARMS station is comprised of a Canberra Area Display Monitor (ADM606), a Canberra Ion Probe (IP-100), a Canberra Neutron Probe (NP-100) with either a Helium or BF_3 based detector, and an alarm panel containing warning lights and a horn. The system dose information is displayed both locally and in the central control room. Each station is configured to alarm locally when a WARN dose rate of 50 µSv/h or a HIGH dose rate of 100 µSv/h is reached on one of the probes, and will also interlock the electron gun when a combined gamma and neutron cumulative hourly dose of 2.5 µSv is exceeded at stations on the experimental floor.

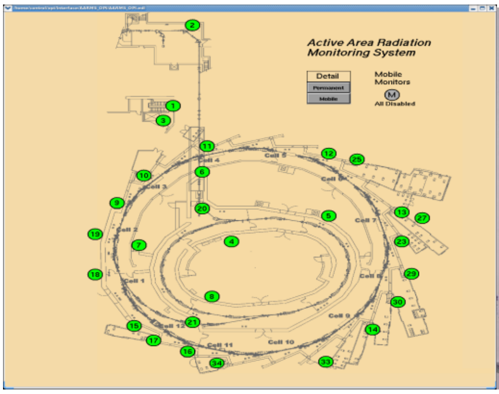

Fig.4a – CLS Facility AARMS Layout

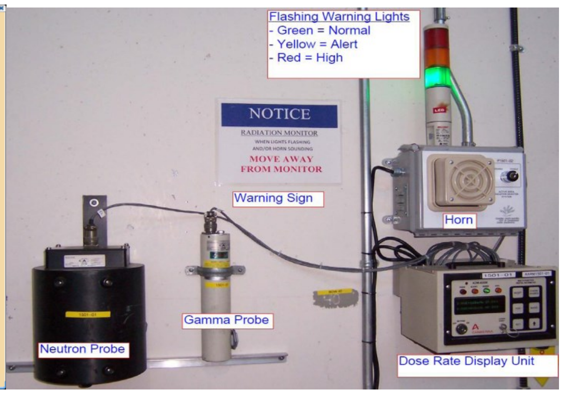

Fig.4b – CLS Facility AARMS Station

Routine prompt and residual radiation surveys are completed for stored beam, injected beam, and for residual radiation in accelerator areas after an operational period. A variety of hand-held survey monitors are available, including the Ludlum 2360 alpha/beta counter, Ludlum 9DP, Thermo FH40G-L10, and the Exploranium GR-135 Gamma Spec.

2.4. Radiological Events

In 2010 work on an upgrade to the LINAC to Booster Ring Transfer Line power supplies resulted in a reverse polarity to a dipole magnet. The issue resulted in mis-steering the beam at the Booster Ring injection point creating elevated radiation levels in a Radiological Controlled Area. The issue was discovered during start-up when repeated efforts to get the beam from the LINAC to the Booster Ring finally resulting a radiation alarm at an AARMS station. The maximum dose rate measured during the event was 82 µSv/h, however a controlled recreation of the event showed that had the steering attempts continued a dose rate in the mSv range could have been attained. No personal exposures were recorded as a result of the event. Local shielding was added in the affected area and work management procedures were strengthened as a result of the event.

In 2012 a CLS worker using a 3.43 MBq Fe-55 sealed source accidentally punctured the protective window. It was found that approximately 0.7 MBq of Fe-55 had escaped from the sealed source capsule as a result of the event. No dose was recorded to any worker. Improved handling procedures and a more robust window on a new Fe-55 sealed source occurred as a result of this event.

2.5. Medical Isotope Production Facility

The Canadian Light Source is also home to a 35 MeV Linear Accelerator designed to test the feasibility of the production Mo-99 from Mo-100 using accelerator based technologies. The new accelerator has been located in a refurbished area of the former Saskatchewan Accelerator Laboratory and has been commissioned to 10 kW. Production of Mo-99 began in 2015 with weekly shipments of approximately 20 – 50 GBq Mo-99 to the separation facility located off-site. Clinical trials are anticipated to start in the fall of 2015 and the planning for a large scale production facility off-site is underway.

3. Future Changes

3.1. Top-Up Operation

Preparation for Top-Up Operation at CLS began in 2012. However due to several factors the project has been delayed and is not currently a high priority project for the CLS. Work on completing the safety case for the Top-up is expected to resume in 2016, however technical difficulties may delay implementation of Top-up Operation.

3.2. Staff Dosimetry

With personal dosimetry results at the CLS historically being very low, a re-evaluation of the dosimetry requirements is planned for 2016 with the goal being a reduction in the number of personnel dosimeters.

Summary

The Canadian Light Source has operated for 10 years as a user based facility. The radiation protection program has developed and continues to adapt to the changing needs of the facility while maintaining a high standard of work practices and controls to keep radiation exposures to all staff, users, and contractors ALARA.

References

[1] Swanson, W. P. (1979). Radiological Safety Aspects of the operation of electron Linear Accelerators. Vienna: IAEA Technical Report Series No. 188.

[2] 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

[3] Y. Asano, 1998. Shielding Design Calculation of SPring-8 Beamline Using STAC8. J. Synchrotron Rad., 5, 1.

[4] Bassey, B. et al. "TVDose-An Analytical Code for Synchrotron Radiation Shielding Design" RADSYNCH15 Conference Proceedings

[5] Landauer Luxel+ Technical Specifications http://www.landauer.com.au/Content/Specsheets/LuxelSpecSheet.pdf