Phase I Beam Commissioning Report Radiological Characterization

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1.0 OVERVIEW

The Canadian Light Source (CLS) facility is a national science research laboratory for the production of high-brightness synchrotron radiation (SR) from the infrared, visible and ultraviolet to x-ray region of the electromagnetic spectrum. The CLS facility is a major expansion of the existing Saskatchewan Accelerator Laboratory (SAL) located on a 3.3-hectare (8.2 acres) parcel of land on the University of Saskatchewan (U of S) Campus. CLS Inc. (CLSI), a non-profit corporation wholly owned by the U of S, operates the CLS facility. CLSI holds the Canadian Nuclear Safety Commission (CNSC) license to construct (Licence No. PA1CL-825.00/2004) and operate the CLS facility (Licence No. PAIOL-0200/06).

The current schedule for phased commissioning of major synchrotron components is as follows:

• Phase I	Linac ready for commissioning	2001 June
• Phase II	Booster ready for commissioning	2002 June
• Phase III	Storage Ring and initial beamlines ready for commissioning	2003 March
• Phase IV	Normal operation	2004 January and beyond

A complete description of the CLS facility can be found in the facility Safety Report [1].

The sequencing of commissioning activities involved:

1. Pre-commissioning actions,
2. Radiological surveying,
3. Verifying model predictions,
4. Ensuring radiation levels in occupied areas are within design levels,
5. Collecting and analyzing data,
6. Preliminary commissioning report issued on October 9, 2001, and
7. The final report.

The principal hazards encountered during commissioning included physical hazards and potential exposure to high radiation levels.

2.0 PURPOSE

Beam commissioning takes place after construction and installation of the beam components. It is a process involving the technical operations of the accelerating system. The purpose is to configure the electron beam and the accelerator components so as to operate under the design specifications of the facility.

The other aspect of beam commissioning is the validation of the radiological design aspect of the facility. It is a process that involves the radiological surveys preformed both during accelerator operation and after shutdown. All these activities take into account the health and safety requirements for operating personnel and the general public, and any implications for the environment. The purpose of this report is to describe the analysis of the radiation data that was collected by the CLSI Department of Health Safety and Environment. The radiation measurements were carried out in two parts, one of which included measurements below the nominal operating energy of 250 MeV.

3.0 SCOPE

This report provides the information attained in the commissioning of Phase I of the CLS accelerator system. The objective was to conduct radiological surveys during operation and after shutdown to allow unrestricted operation of the Linear Accelerator (Linac) and Linac-To-Booster (LTB) transfer line up to the beam stop BST0004-01. The term “unrestricted operation” means that there will be no future restrictions on the operation of this sector of electron accelerator system other than following the normal lockup procedures.

Phase I was conducted in two parts. Part 1 dealt with measurements taken at energy of 180 MeV, which ran from August 28, 2001 until September 23, 2001. Part 2 dealt with a higher energy of 250 MeV, and ran from January 17, 2002 until March 3, 2002. To remain in compliance with the operating license, the bending magnet B0004-01 was not connected to its power supply and therefore could not be energized. During part 1 of the beam commissioning, B0004-01 was not installed. This phase of commissioning was concerned with radiation levels in the new part of the CLS facility. The old building was part of the SAL. The SAL operated at a much higher power than the CLS intends to. Therefore the radiation levels were acceptable in the old part of the building, because the occupied areas in the old building are shielded adequately. Areas of radiological concern were focused on the new building, especially in the occupied areas above Room 0004. Therefore, most measurements were taken around Room 0004 in the new building.

4.0 PRECAUTIONS DURING COMMISSIONING

The following precautions were implemented during this phase of commissioning.

- The principle of ALARA (As Low As Reasonably Achievable) was practiced at all times.
- A card access system was installed and personnel were issued Access Cards.
- A Closed Circuit Camera System (CCTV) was installed and was monitored during commissioning.
- Signs were posted at the building entrances to warn anyone entering the building that commissioning was in progress and that they must report to the control room.
- All personnel not part of the beam commissioning team were requested to leave the new building and the new building was inspected to ensure that everyone had left.
- Commissioning team members were issued electronic personnel dosimeters (EPDs) and they were worn while they were in the new building.
- Area radiation monitors were positioned in areas of concern and monitored from the Control Room.
- Barricades were erected to indicate areas of concern.
- The lock-up area remained locked until the next day and residual radiological surveys were conducted around the accelerator components being commissioned.
- The Residual Radiological Survey results were posted at accelerator entrances on a weekly basis. Radiological Caution Signs were updated on a daily basis.
- The Lock-up procedure ensures that all personnel have evacuated the radiological controlled areas prior to starting the beam.

5.0 DESCRIPTION

This section describes the various areas, components and structures that were included in the scope of the Phase I commissioning.

The accelerator system that is included in this Phase I commissioning incorporates:

- Linac, which comprises of an electron gun, prebuncher cavity, buncher accelerating cavity (section 0), three quadrupole magnets and six accelerating sections.
- Part of the LTB transfer line, which includes the Energy Compression System (ECS), an accelerating section (Section 7)
- The Energy Spectrometer System (ESS).

For a description of the various systems, see reference [4]. Drawing RAD/0059970 shows the various sub-basement areas and components of the linac and LTB.

Surveys were taken in the Main Beamline Hall, elevator stairwell, elevator basement level, crane well and outside the main lobby. The survey location points are indicated in Drawing RAD/0059970.

The following list is a description of the various acronyms and abbreviations used in this report.

TRM	-	Transition Radiation Monitor
BST	-	Beam Stop
ST	-	Steering Coil
CLH/CLV	-	Horizontal/Vertical Collimator
TLD	-	Thermo-Luminescent Dosimeter
EPD	-	Electronic Personnel Dosimeter
BG	-	Background Levels
Pt1	-	Part 1 Levels
Pt2	-	Part 2 Levels
Cnt	-	Center on floor above beamline
1mS	-	1 meter South of Center
1mN	-	1 meter North of Center
TE	-	Tissue Equivalent
HPI	-	Health Physics Instruments
NMT	-	No Measurement Taken

5.1 EXPERIMENTAL METHOD

Each experiment is characterized by the beam configuration and beam loss scenario. Under each experiment, the beam parameters are well defined. Typical beam parameters are:

- Beam Pulse Repetition Rate – f (Hz),
- Beam Pulse Width - τ (ns),
- Beam Energy – E (MeV), and
- Beam Average Current in Pulse – I (mA).

Given the above parameters, the average beam power, P (W), can be determined.

For each beam setup, radiation levels were measured under various beam loss scenarios as described below.

5.2 PHASE I – PART 1

Part 1 was run under many different beam configurations. There were three beam destinations:

- Beam directed to beam stop BST0002-01,
- Beam directed to beam stop BST0003-02, and
- Beam directed to beam stop BST0004-01.

Under each beam configuration the radiation levels were measured in the occupied areas closest to the source of the radiation. Various beam loss scenarios that were investigated include the following:

- Full beam directed to a Beam Stop;
- Insert combinations of TRM0004-02, TRM0004-01, TRM0003-03, and TRM0003-04;
- Close slits CLH0003-02 to reduce current; and
- Misdirect the beam in the vertical and horizontal directions using combinations of ST0004-01, ST0003-01, ST0003-02, ST0003-05, ST0003-06, and ST0003-07.

5.3 PHASE I – PART 2

The beam was directed to beam stop BST0004-01.

Under this beam configuration the radiation levels were measured in the occupied areas closest to the source of the radiation. Various beam loss scenarios that were investigated include the following:

- Full beam directed to beam dump BST0004-01;
- Insert combinations of TRM0004-02, TRM0004-01 and TRM0003-04;
- Close slits CLV0002-01 to reduce the current; and
- Misdirect the beam in the vertical and horizontal directions using combinations of ST0004-01 and ST0003-07.

5.4 RADIATION MONITORING INSTRUMENTATION

Commissioning Team Personnel were monitored using TLDs, Siemens EPDs, and neutron bubble dosimeters.

Passive Area Radiation Monitoring (PARM) was done using K1, X9, I1 TLDs and neutron bubble dosimeters. K1 measures X-rays, gamma rays, and beta particles. X9 measures low energy gamma rays. I1 measures neutron particles. Passive area monitoring was also done using neutron bubble dosimeters.

Active Area Radiation Monitoring (AARM) was done using:

- HPI 2010 – serial #1032,
- HPI 2010 – serial #1033,
- HPI 2080 – serial #1121, and
- HPI 2080 – serial #1122.

The HPI 2010 is a TE Remote Area Ionization Detector and the HPI 2080 is a Pulse Neutron Survey Meter.

Radiological surveys were completed with:

- HPI 1030 – serial #120
- Exploranium GR130 – serial #9946

The HPI 1030 is a TE Pulse Radiation Detector and the Exploranium GR130 is a Gamma Ray Spectrometer.

6.0 ANALYSIS

As stated previously, given the appropriate parameters, the beam power can be calculated. If measurements of the appropriate parameters are taken at different sections along the beam path, then the beam power can be calculated at each section. The electron beam will lose power as it travels inside the beam pipe due to many different factors. If one knows the beam current at two different locations along the electron beamline, the power loss if any is proportional to difference of the currents, assuming the beam energy and the pulse width remain the same. This lost power contributes to ionizing radiation. Therefore, in order to theoretically calculate the radiation exposure rate, one must have an idea what the power losses are at certain locations. These calculations are all documented in [2]. The following tables display beam parameter information and calculated beam power for two days in both parts where most of the radiation measurements were taken on.

Table 1 Beam Power Losses for Part 1 Commissioning Measurements

Location	Part 1											
	Date											
	19-Sep-01						21-Sep-01					
	I (mA)	f (Hz)	W (ns)	E(MeV)	P (W)	%Loss	I (mA)	f (Hz)	W (ns)	E(MeV)	P (W)	%Loss
Gun (DC TOR)	144	2	360	180	18.66	0	142	2	280	180	14.31	0
SEC #0	89	2	360	180	11.53	38	90	2	280	180	9.07	37
SEC #6	85	2	360	180	11.02	4	84	2	280	180	8.47	7
ECS DUMP#1	65	2	360	180	8.42	24	69	2	280	180	6.96	18
ECS DUMP#2	74	2	360	180	9.59	14	67	2	280	180	6.75	3
SWYD DUMP#2	72	2	360	180	9.33	3	74	2	280	180	7.46	10
EA3 DUMP	65	2	360	180	8.42	10	60	2	280	180	6.05	19

Table 2 Beam Power Losses for Part 2 Commissioning Measurements

Location	Part 2											
	Date											
	24-Feb-02						2-Mar-02					
	I (mA)	f (Hz)	W (ns)	E(MeV)	P (W)	%Loss	I (mA)	f (Hz)	W (ns)	E(MeV)	P (W)	%Loss
Gun (DC TOR)	140	1	400	258	14.45	0	146	1	400	258	15.07	0
SEC #0	90	1	400	258	9.29	36	92.8	1	400	258	9.58	36
SEC #6	86	1	400	258	8.88	4	85.8	1	400	258	8.85	8
ECS DUMP#1	65	1	400	258	6.71	24	69	1	400	258	7.12	20
ECS DUMP#2	72	1	400	258	7.43	14	66.4	1	400	258	6.85	4
SWYD DUMP#2	NMT	NMT	NMT	NMT	NMT	NMT	75.2	1	400	258	7.76	13
EA3 DUMP	65	1	400	258	6.71	NMT	55	1	400	258	5.68	27

Radiation exposure rates were theoretically calculated using the source point model [3]. Shielding calculations were preformed at various points in occupied areas throughout the facility given the appropriate parameters such as electron energy, shielding thickness, angle from incident electron direction, beam power loss, and distance from source. These calculations also took into account the self-shielding of the beam stops, which are composed of a tungsten center and aluminum exterior. These values were then compared with the measured values obtained during commissioning. The following table has a comparison of these values. The values have been normalized for per Watt power loss for easier comparison. See the appendices for charts on radiation exposure rate measurements taken during commissioning. Refer to the attached drawing RAD/0059970 to locate the points listed in Table 3

Table 3 Comparison of theoretical calculations with measured values

Location	Point	Configuration (Beam directed to)	Experiment	Theoretical (µSv/hr*W)	Part 1 (µSv/hr*W)	Part 2 (µSv/hr*W)
Main Floor Above Room 0004	E5	BST0004-01	NORMAL	0.8011	0.0267	0.1788
Main Floor Above Room 0004	E7	BST0004-01	NORMAL	0.9503	0.0216	0.1788
Main Floor Above Room 0004	E9	BST0004-01	NORMAL	0.4227	0.0200	0.1788
Main Floor Above Room 0004	E3	BST0004-01	NORMAL	0.2176	0.0250	0.1788
Main Floor Above Room 0108	T4	BST0004-01	NORMAL	1.7713	NMT	0.1788
Main Floor Above Room 0108	T7	BST0004-01	NORMAL	0.4526	NMT	0.1788
Main Floor Above Room 0108	T9	BST0004-01	NORMAL	0.1682	NMT	0.1788
Elevator Basement Floor	EBL6	BST0004-01	NORMAL	5.7594	NMT	1.7883
Elevator Basement Floor	EBL7	BST0004-01	NORMAL	4.8154	NMT	1.6095
Elevator Basement Floor	EBL8	BST0004-01	NORMAL	3.5573	NMT	1.2519
Elevator Basement Floor	EBL9	BST0004-01	NORMAL	2.4166	NMT	1.0730

In Appendix 10.1,various charts were produced to compare radiation levels obtained during both parts of Phase I commissioning at various locations throughout the facility. In each area where points from part 1 and part 2 coincided, a chart was made to compare the levels with the background levels recorded at an earlier date. Under normal operating conditions, in this case when the beam was directed to BST0004-01, one can see that levels never exceeded 1.2 µSv/hr.

A chart was also produced to compare measured levels with theoretical calculations from Table 3 above. Refer to Figure 7. The measurements in part 2 were all taken with the HPI 1030 monitor. The monitor has a reproducibility of +/- 15%. Therefore the values measured are accurate to

15%. Also since the output is analog, the monitor can be read accurately to 0.1 mSv. This is a possible explanation why some values in Table 3 appear the same. As one can clearly see in the table, the measurements do not correspond to the calculated values. Since part 1 was preformed with a lower energy, the radiation levels should be lower, as is seen.

Comparative worst-case scenarios were also charted. In each situation, it was a different component that caused the higher radiation levels, such as a TRM or a steering coil. In most situations, it was TRM0004-01 that caused the high levels when it was inserted. These levels however never exceeded 4.0 µSv/hr. The worst situation occurred when ST0004-01 was misdirected using the driving current of the magnet (x = +5A, y = -4A). Levels of 108 µSv/hr were recorded above Room 0108. This is seen in Figure 8. An area of concern was the exit from the elevator at the basement level. The worst case and normal operating conditions are charted in Figure 11. Levels reached a high of 12.0 µSv/hr under normal operating conditions and 60.0 µSv/hr when ST0004-01 was misdirected (x = 5A, y = 5A).

All CLSI personnel were monitored using TLDs. The TLDs are sent to Landauer Inc. for analysis at the end of each quarter and the results are recorded in Radiation Exposure Reports provided by Landauer Inc. The values of all commissioning team personnel and non-commissioning personnel were averaged and charted. Also plotted along side the averages were the highest dose received by both commissioning and non-commissioning personnel during that particular monitoring period. This can be seen in Figure 12. The highest level seen on the chart was 0.4 mSv by non-commissioning personnel. This did seem a little unusual, but since the level was still below the CLS action level of 2 mSv per quarter, no formal investigation was made.

Passive area radiation monitors were placed throughout the facility and were analyzed by Landauer Inc. Locations of these monitors can be found on the attached drawing RAD/0061350. Different types of passive area radiation monitors were used to detect different types of ionizing radiation. These radiation monitors measure radiation exposure in mSv, not radiation exposure rate. Charts were produced to summarize the reports and where the highest levels were seen throughout the facility. Figure 14 summarizes the passive monitors in the interior of the building. The highest level detected was 41.9 mSv located in Room 0012, an interlocked area locked out during operation, in a fan casing. This badge was exposed for 99 days during the time frame of June 18, 2001 until September 25, 2001. Figure 15 summarizes the passive neutron monitors, I1s, inside the building, which were only used for part 1 of the commissioning. The highest level detected was 1.7 mSv accumulated over the same period as before. This badge was located between the elevator corridor 0005 and the sub-basement access 0006. Figure 13 summarizes the passive neutron monitors for part 2, which were the neutron bubble dosimeters. Radiation exposure rates were calculated with the neutron bubble dosimeters. The highest level detected was 5.86 µSv/hr located at the exit of the elevator basement level Point 6 when ST0004-01 was misdirected. Figure 16 summarizes the passive monitors placed on the exterior of the building or in the free access zones. The highest level recorded was 5.5 mSv located on the main lobby stairway during commissioning and 7.5 mSv located 2m outside the main doors to the lobby buried seven inches in the ground prior to commissioning.

Active area monitors were also used to take measurements where the levels were predicted to be high. Figure 17 and Figure 18 display an experiment preformed on ST0004-01. At different levels of current through the steering coil, radiation levels were measured. The highest levels of 1.0 mSv/hr occurred when ST0004-01 was set to x = 5.0A, y = -.88 A. This was for a monitor placed by Gate 18 just outside the lockup Zone 5.

7.0 SUMMARY

When the beam was directed to BST0002-01, surveys were taken in the lobby, the elevator stairwell and the crane well. Levels above background readings were recorded in the crane well with the highest level being 1.8 µSv/hr. Elsewhere in the occupied areas the levels were within background fluctuations.

The beam was directed to BST0003-02 and surveys in the occupied areas above BST0003-02 were carried out under different beam loss scenarios. Areas included the main lobby and the exterior of the building. The highest gamma readings found were 54 nSv/hr, consistent with background readings.

The beam was directed to BST0004-01 and radiation measurements were carried out under different beam loss scenarios. The various scenarios included inserting single TRMs, combinations of TRMs, reducing beam currents with slits and misdirecting steering coils.

- With the beam directed to BST0004-01, the gamma and neutron levels inside the booster tunnel at Gate 18 outside lockup Zone 5 were consistent with background. The levels in the basement areas at the exit of the elevator were 12 µSv/hr (gamma) and 3.5 µSv/hr (neutrons).
- Inserting various combinations of TRMs, the highest levels recorded were 27.0 µSv/hr above Room 0108 and 38.4 µSv/hr in the elevator basement level. This was found with TRM0004-01 inserted. With TRM0004-01 and TRM0004-02 inserted, readings for gamma were 1.08 mSv/hr in the storage ring. Shielding was placed at TRM 0004-02 and the readings dropped to 54 µSv/hr. Neutron levels of 4.7 µSv/hr were highest at the exit of the elevator at the basement level when TRM0004-01 was inserted along with CLV0002-01.
- Steering coil ST0004-01 was adjusted to different settings and the highest reading of 1.0 mSv/h was found at Gate 18 outside lockup Zone 5 when the setting was x = +5.0A, y = -0.88A. Readings were also taken outside the main lobby and the highest reading found was 117 nSv/hr when ST0003-06 was adjusted to y = –5.0A. Neutron levels of 5.68 µSv/hr were the highest in the exit of the elevator at the basement level

8.0 CONCLUSIONS

The Linac and subsequent systems up to BST0004-01 in the LTB transfer line were commissioned to the point where all systems can be said to run reliably. Beam suitable for making measurements of beam-induced radiation were delivered for several weeks and extensive radiation monitoring carried out.

When measurements were made under normal operating conditions, radiation levels were lower than the design levels of 5 µSv/hr in the Free Access Zone. The maximum gamma level in the occupied areas within the Free Access Zone was 1.2 µSv/hr while the maximum neutron level was 0.44 µSv/hr. The highest gamma level recorded in the Restricted Access Zone was 12 µSv/hr and the highest neutron level was 3.86 µSv/hr. The gamma levels within the Public Access Zone reached a maximum of 1.2 µSv/hr under normal operating conditions and neutron levels were with background radiation levels.

When measurements were made with various experiments described above, radiation levels were different throughout the facility. The levels however were still below the design levels of 5 µSv/hr in the Free Access Zone. The maximum gamma level in the occupied areas within the Free Access Zone was 4.8 µSv/hr while neutron levels reached a maximum of 1.29 µSv/hr. The highest gamma level in the Restricted Access Zone was 108 µSv/hr while the neutron level reached a maximum of 5.86 µSv/hr. The gamma levels in the Public Access Zone reached a maximum of 1.2 µSv/hr. Neutron levels never exceeded background levels in the Public Access Zone.

Electron beam power losses were theoretically calculated in [2]. When beam parameters were measured and power levels estimated, the power losses in each section proved to be correct with the model within experimental error. In each section, beam power was lost due to various factors as can be seen in Table 1 and Table 2. However the beam seemed to gain power between

BST0002-01 and BST0002-02. The reason for this is because not the entire beam was collected into BST0002-01 and therefore a lower current and hence lower power was seen. The inaccuracy of the power levels with the model lies in earlier measurements of the average current in the pulse, which could only be measured accurately to 5%.

The radiation measurements were compared with the radiation calculations based on a point source model as described in reference [3]. In general the dose rates are hard to calculate due to exact location of the source points and the power lost at that point. However, it is possible to estimate the dose rates under certain beam configuration. In this case, the calculated values tend to overestimate radiation dose rates in areas where calculations can be easily performed as illustrated in Table 3. The model predictions seem to be conservative.

During this phase I of beam commissioning, additional shielding was installed next to TRM0004-02 to reduce the radiation levels in the storage ring tunnel to acceptable levels. Without it the levels were reaching 1.08 mSv/hr. With the extra shielding the levels were lowered to 54 µSv/hr.

9.0 REFERENCES

1. M. Benmerrouche (2001) Canadian Light Source - Safety Report

2. M. Benmerrouche (2000) Canadian Light Source – CLS Source Parameters for Shielding Calculations. (0.2.35.1 Rev.0)

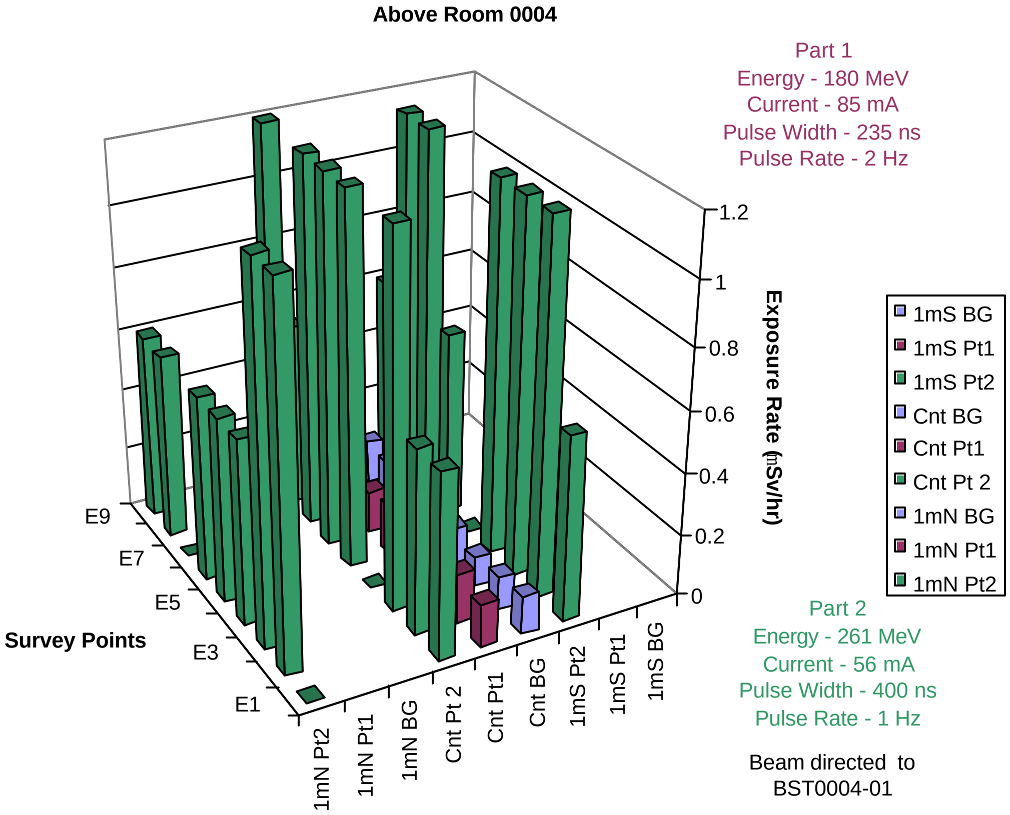
3. M. Benmerrouche (2001) Canadian Light Source – Shielding Requirements for the Canadian Light Source Accelerator Complex. (8.2.35.1 Rev. A)

4. L. Dallin (2001) Canadian Light Source – CLS Commissioning – Phase I Linac and LTB to OP2. (8.7.90.1 Rev. 1)

10.0 APPENDICES

10.1 APPENDIX A: RADIATION SURVEYS IN VARIOUS AREAS

The following figures show radiological exposure rates in various areas under normal operating conditions, in which the beam was directed to BST0004-01. These measurements were taken with the GR130 for part 1 and with the HPI 1030 for part 2. Therefore these charts display information for mostly gamma measurements.



Part 1
Energy - 180 MeV
Current - 85 mA
Pulse Width - 235 ns
Pulse Rate - 2 Hz

Part 2
Energy - 261 MeV
Current - 56 mA
Pulse Width - 400 ns
Pulse Rate - 1 Hz

Beam directed to
BST0004-01

Figure 1 Radiation Exposure Rate above Room 0004 under normal operating conditions

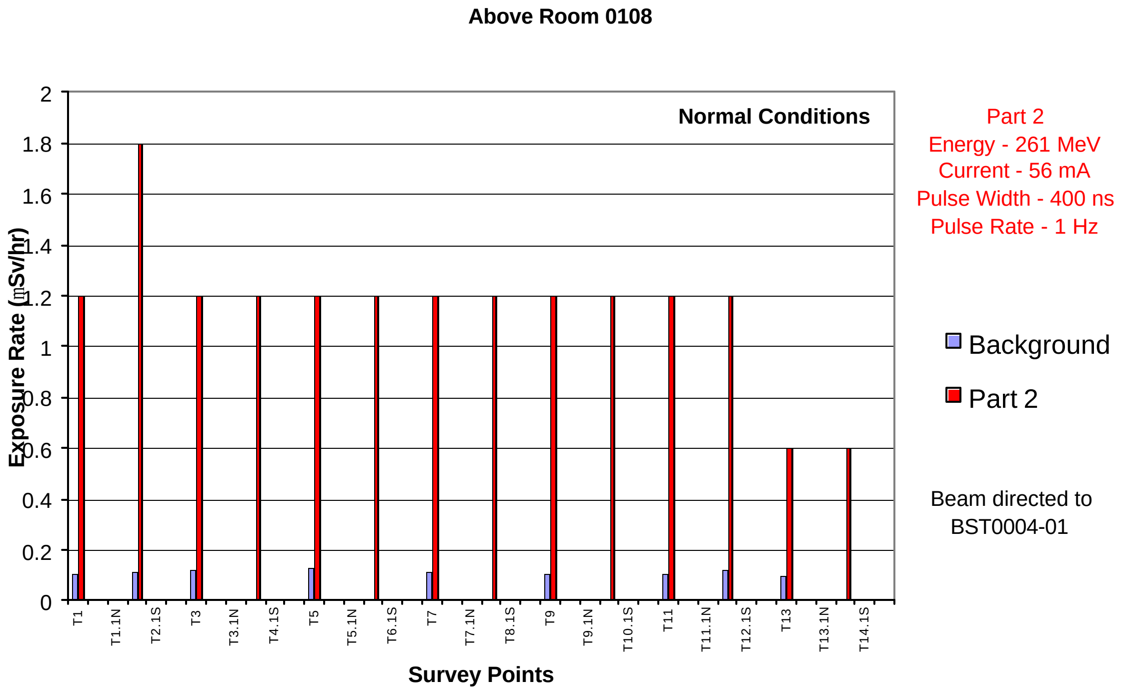


Figure 2 Radiation Exposure Rate above Room 0108 under normal operating conditions

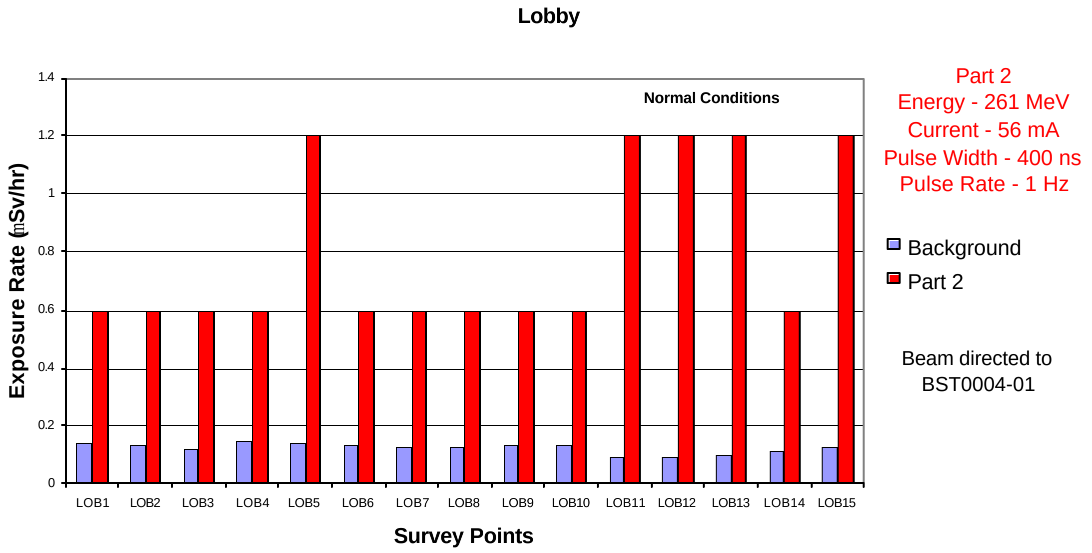


Figure 3 Radiation Exposure Rate above Main Lobby under normal operating conditions

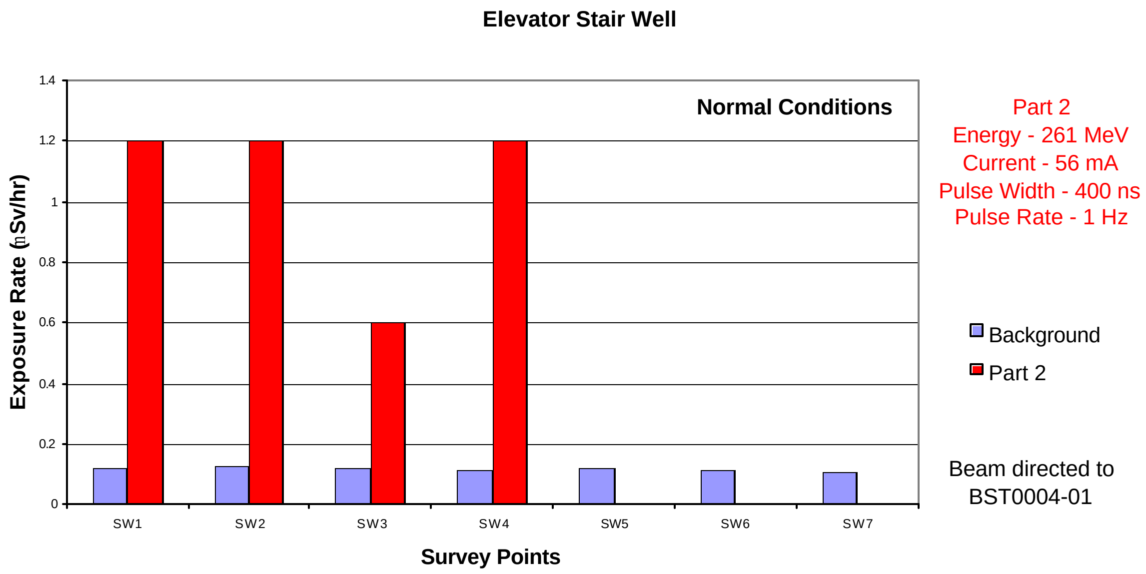


Figure 4 Radiation Exposure rate in Elevator Stair Well under normal operating conditions

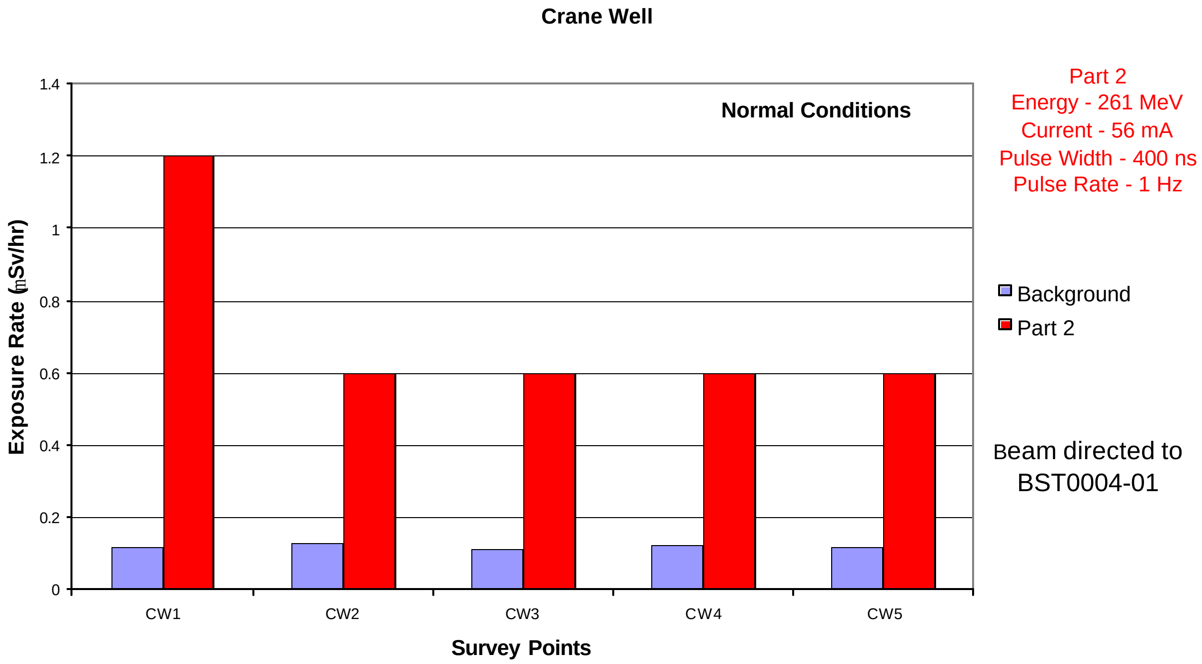


Figure 5 Radiation Exposure Rate in Crane Well under normal operating conditions

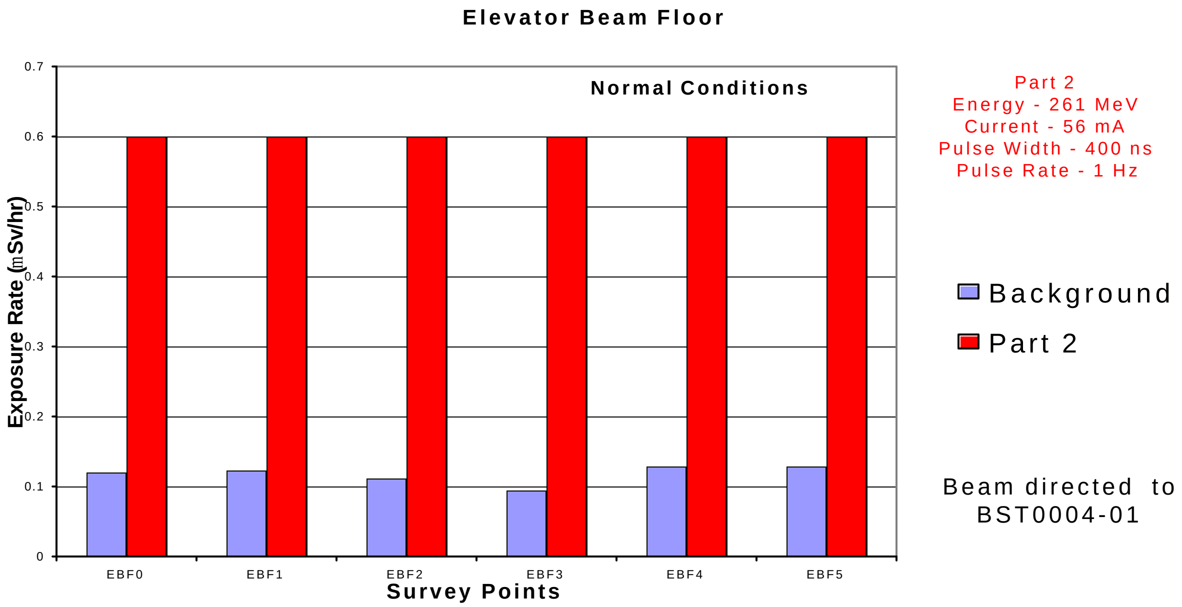


Figure 6 Radiation Exposure Rate on Elevator Beam Floor under normal operating conditions

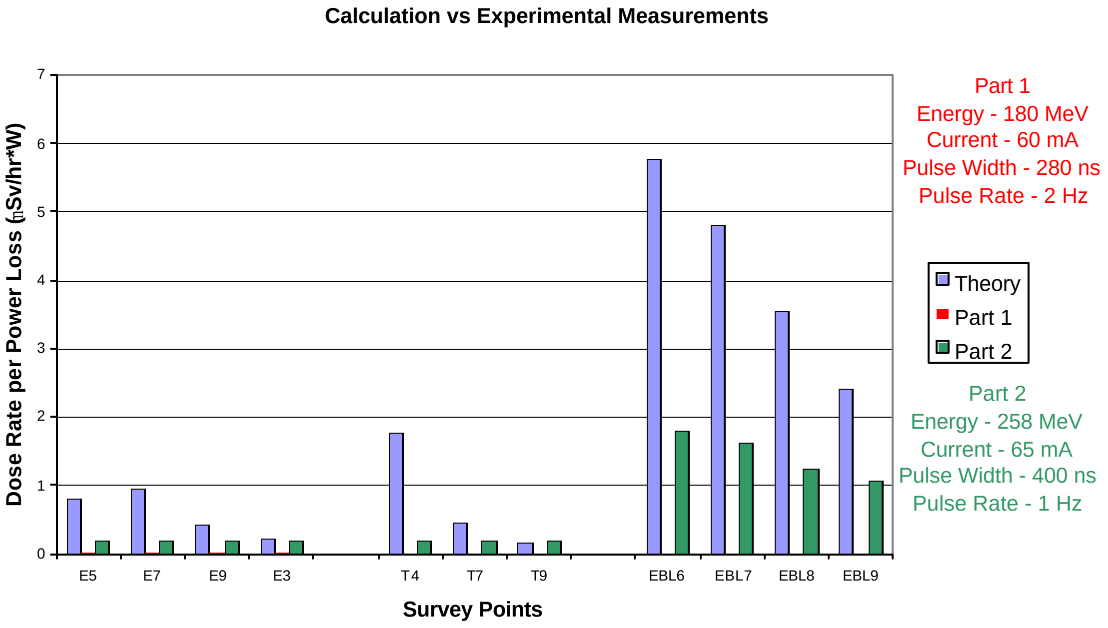


Figure 7 Comparison of the theoretical model with the actual measurements under normal operating conditions

The following charts show radiological exposure rates in various areas under extreme operating conditions. In each case, the beam was directed to BST0004-01 and then various experiments were preformed, such as inserting TRM0004-01 or misdirecting the beam with various steering coils.

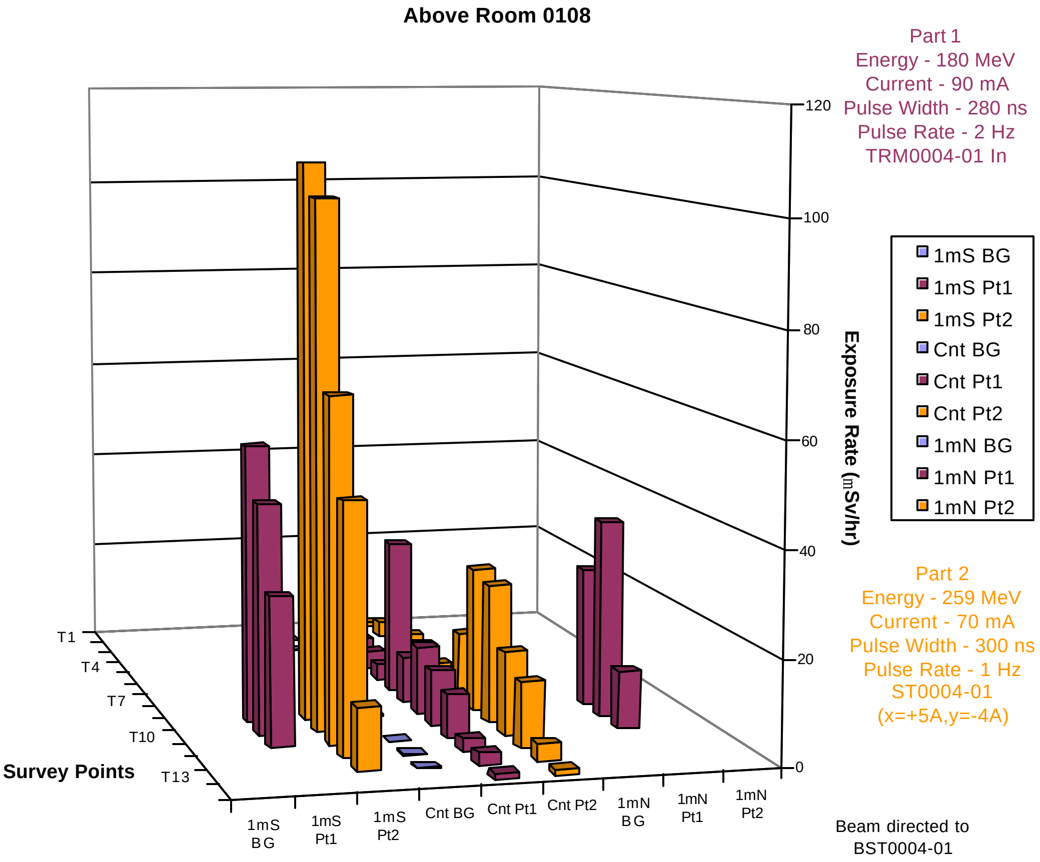


Figure 8 Radiation Exposure Rate above Room 0108 for different beam scenarios

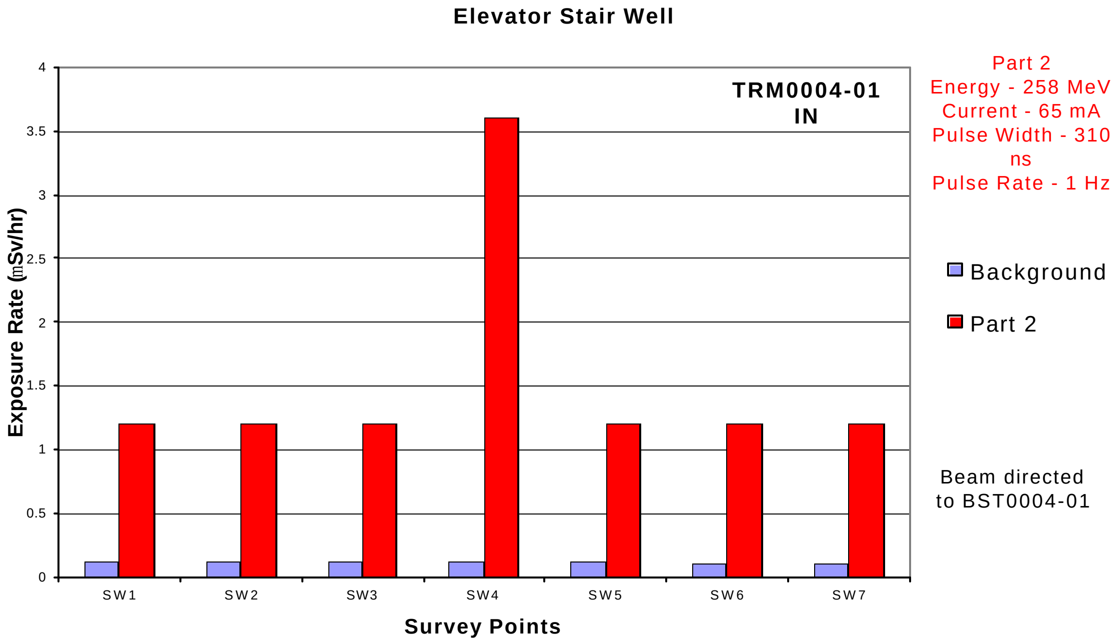


Figure 9 Radiation Exposure Rate in the Elevator Stair Well when TRM0004-01 was inserted

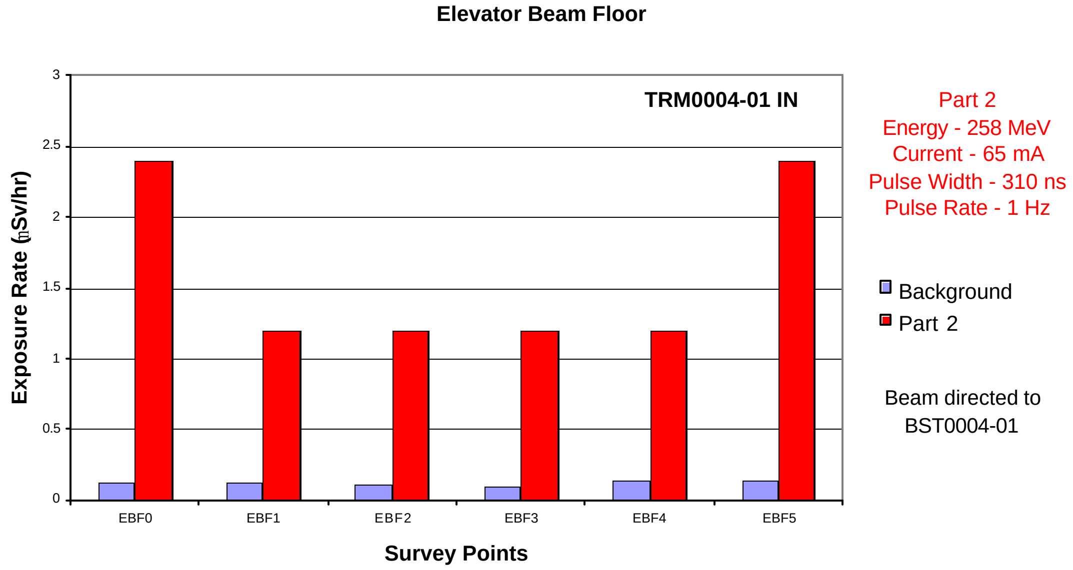


Figure 10 Radiation Exposure Rates on the Elevator Beam Floor when TRM0004-01 was inserted

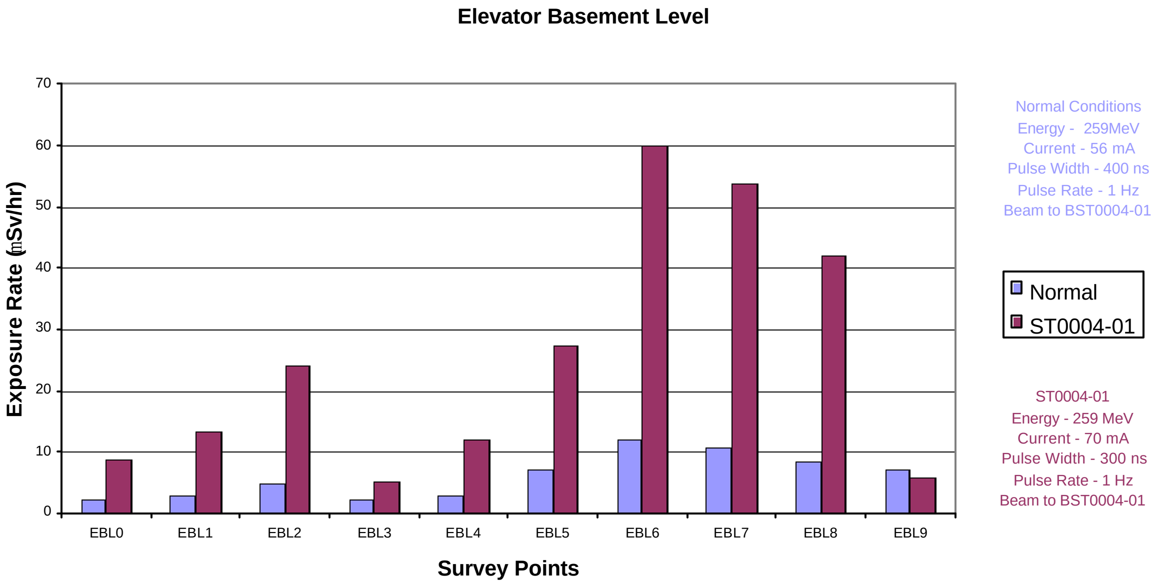


Figure 11 Radiation Exposure Rates on the Elevator Basement Level during normal operating conditions and when ST0004-01 was misdirected

10.1.1 Survey Point Locations

The drawing, RAD/0059970, outlining all the points in the CLS building where radiation surveys were performed during commissioning.

10.2 APPENDIX B: PERSONNEL DOSIMETRY RESULTS

All CLS personnel were monitored for radiation using various types of TLDs during the two parts of commissioning and also in between the two monitoring quarters. The results were tabulated and the following chart was produced. The lowest detectable level for these TLDs is 0.1 mSv. Anything below this level was recorded as an "M" on the Landauer Report. However each "M" was treated as the highest possible value it could receive which was 0.1 mSv to make the chart clearer. Therefore each value of 0.1 mSv actually was undetectable and appeared as an "M" on the Landauer Report.

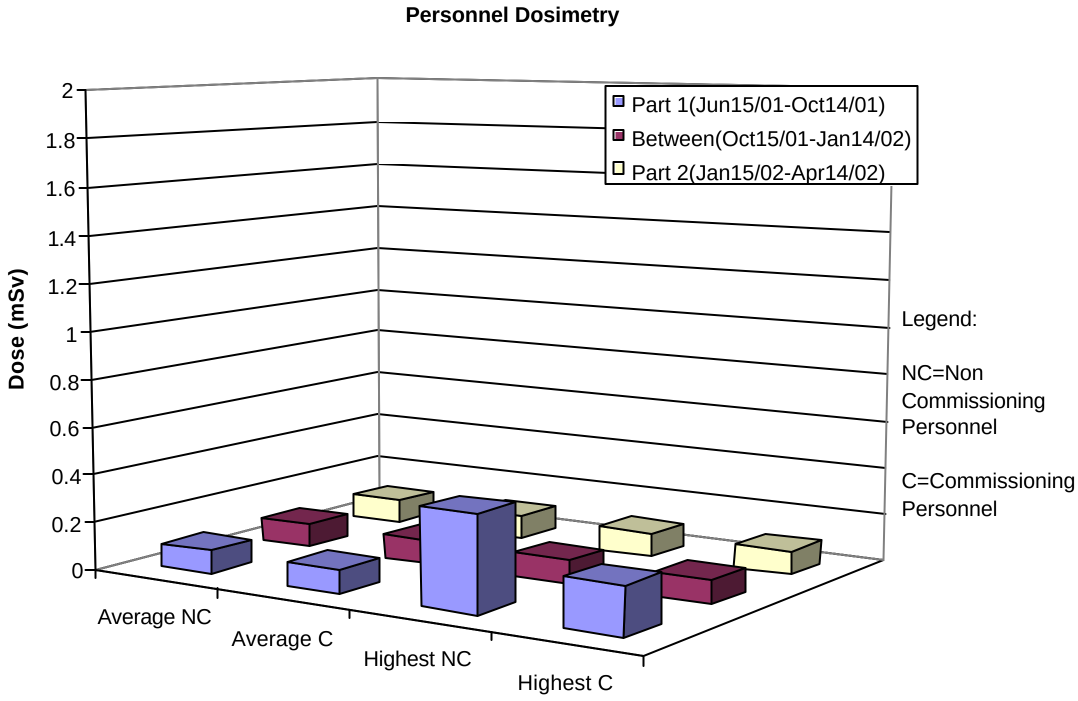


Figure 12 Personnel Dosimetry for the whole of Phase I Commissioning

10.2.1 Dosimetry Reports (Landauer Reports)

Attached are copies of the official dosimetry reports for the monitoring periods, which occurred during this phase of commissioning.

10.3 APPENDIX C: PASSIVE AREA RADIATION MONITORS

Neutron bubble dosimeters were placed at various locations around the building to detect neutrons when the beam was active. The following chart displays calculated exposure rates from the bubble dosimeters in various areas around the facility.

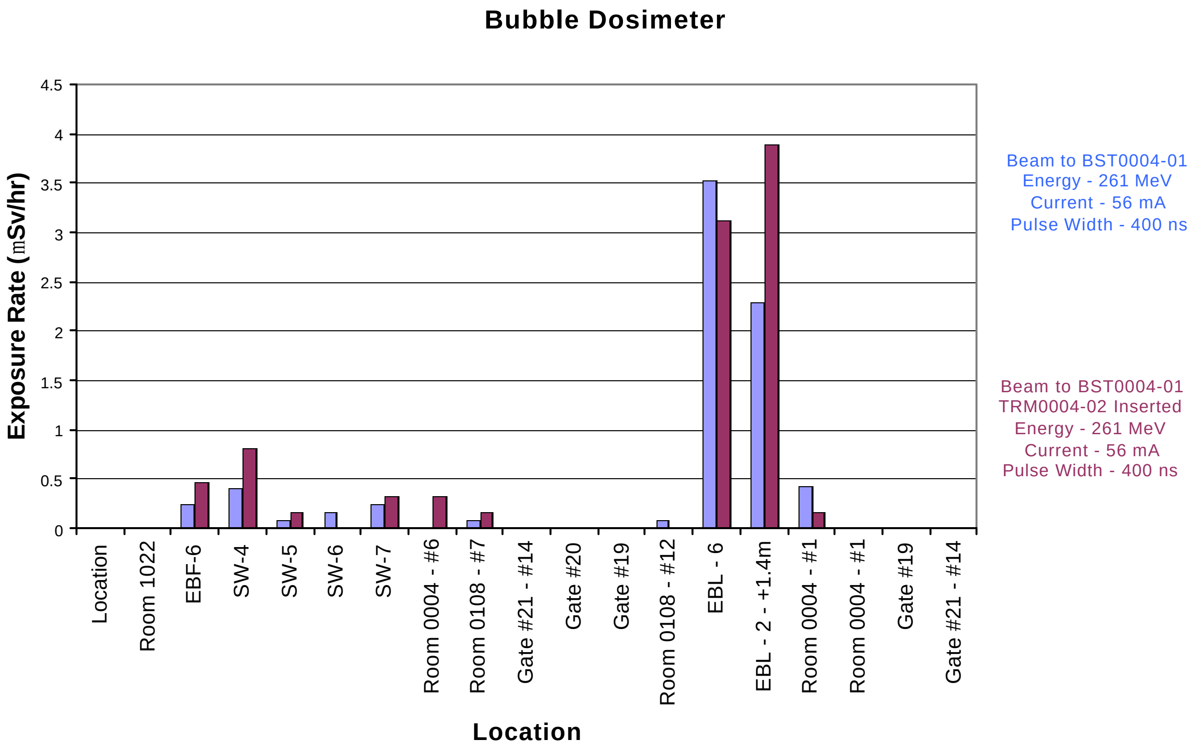


Figure 13 Radiation Exposure Rate in various areas measured by bubble dosimeters

TLDs were used for measurement of total accumulated radiation exposure in selected areas around the active accelerator sectors. The following charts display dose measurements in the given period of time. Measurements lower than 0.1 mSv are undetectable by the TLDs. Refer to RAD/0061350 for locations of these passive area monitors.

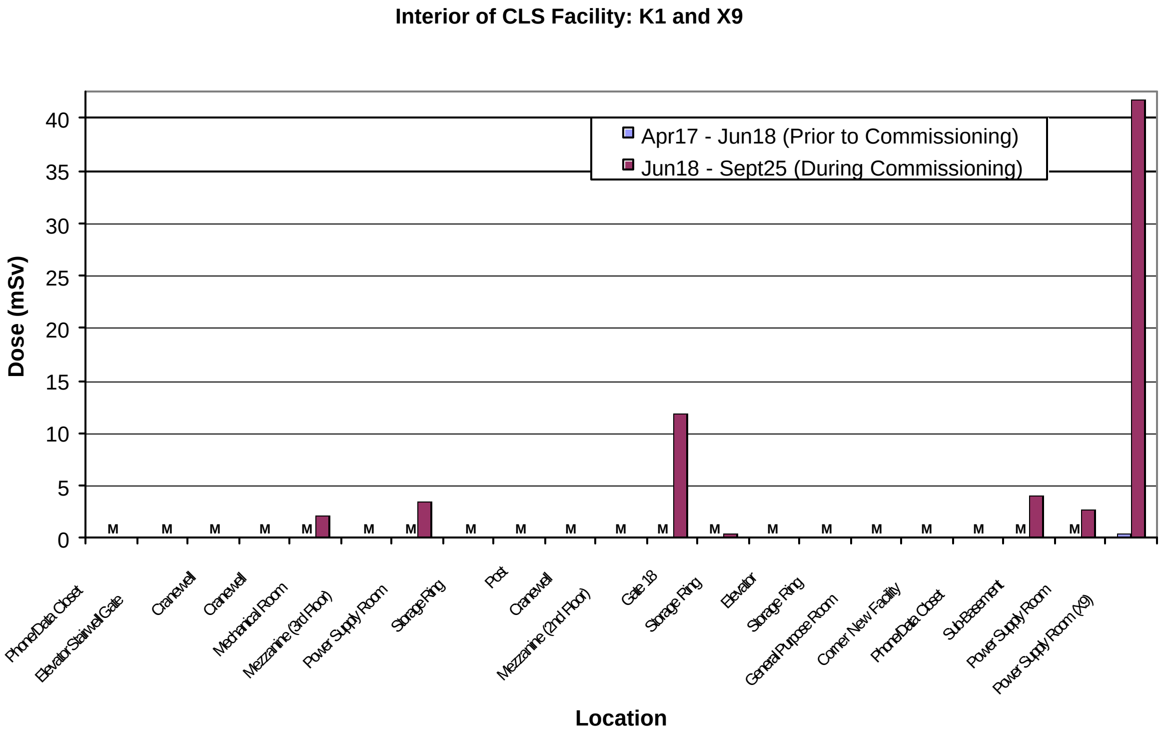


Figure 14 Radiation Dose at various locations inside the facility before and during the commissioning

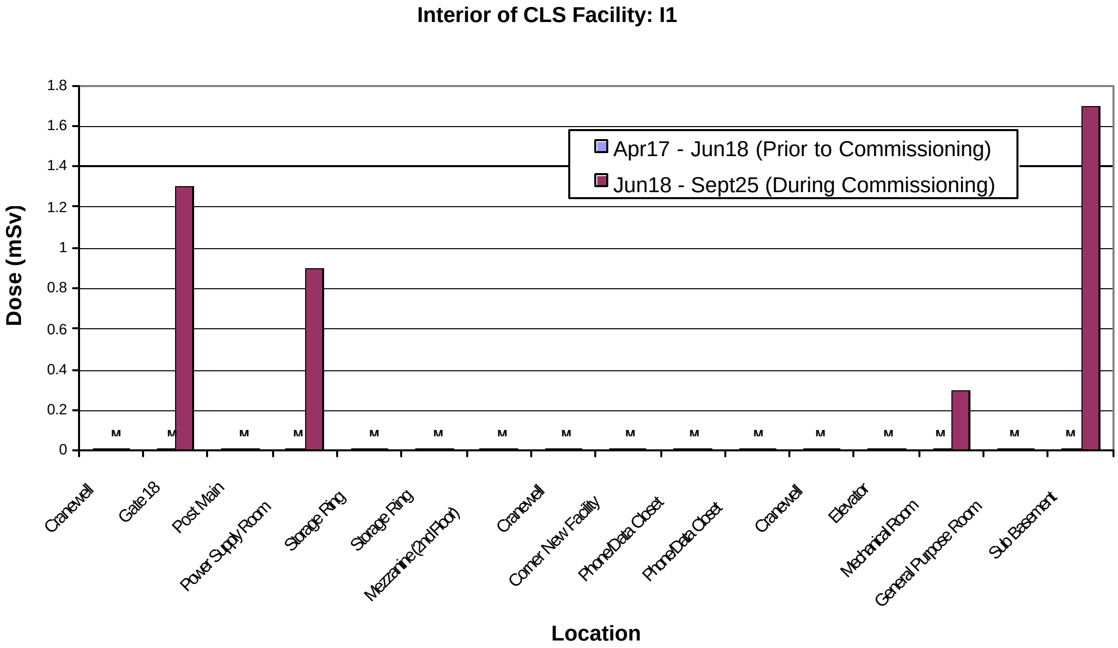


Figure 15 Radiation Dose of neutrons, as measured by I1 TLDs, at various locations inside the facility before and during the commissioning

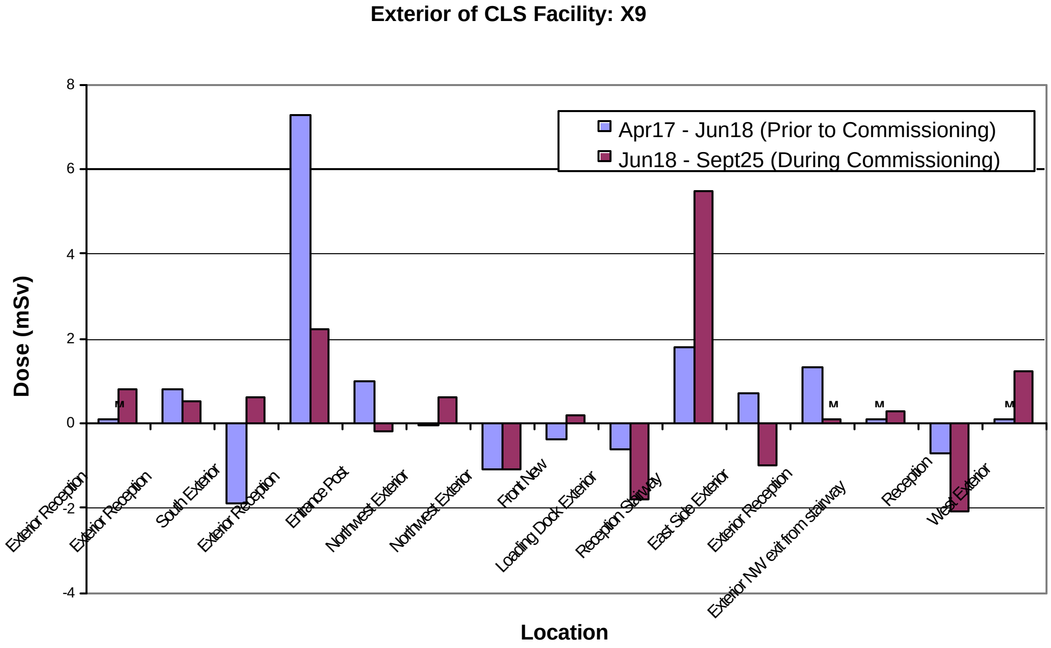


Figure 16 Radiation Dose at various locations outside the facility before and during the commissioning

The previous chart has values with negative dose measurements. This is possible since the level measured by the control badge, which measures the background radiation level, was subtracted off the measurements. Therefore if a badge measured a lower level than the control badge, the level would come back as negative.

10.4 APPENDIX D: ACTIVE AREA RADIATION MONITORS

Area radiation monitors were placed at different locations throughout the facility where high radiation levels were predicted to occur. This particular experiment was preformed on September 23, 2001. The area monitor GAM1 (HPI 2010 Serial# 1032) was located at the Zone #5 Gate. The other monitor, GAM2 (HPI 2010 Serial# 1033) was located in the elevator stairwell on the basement level.

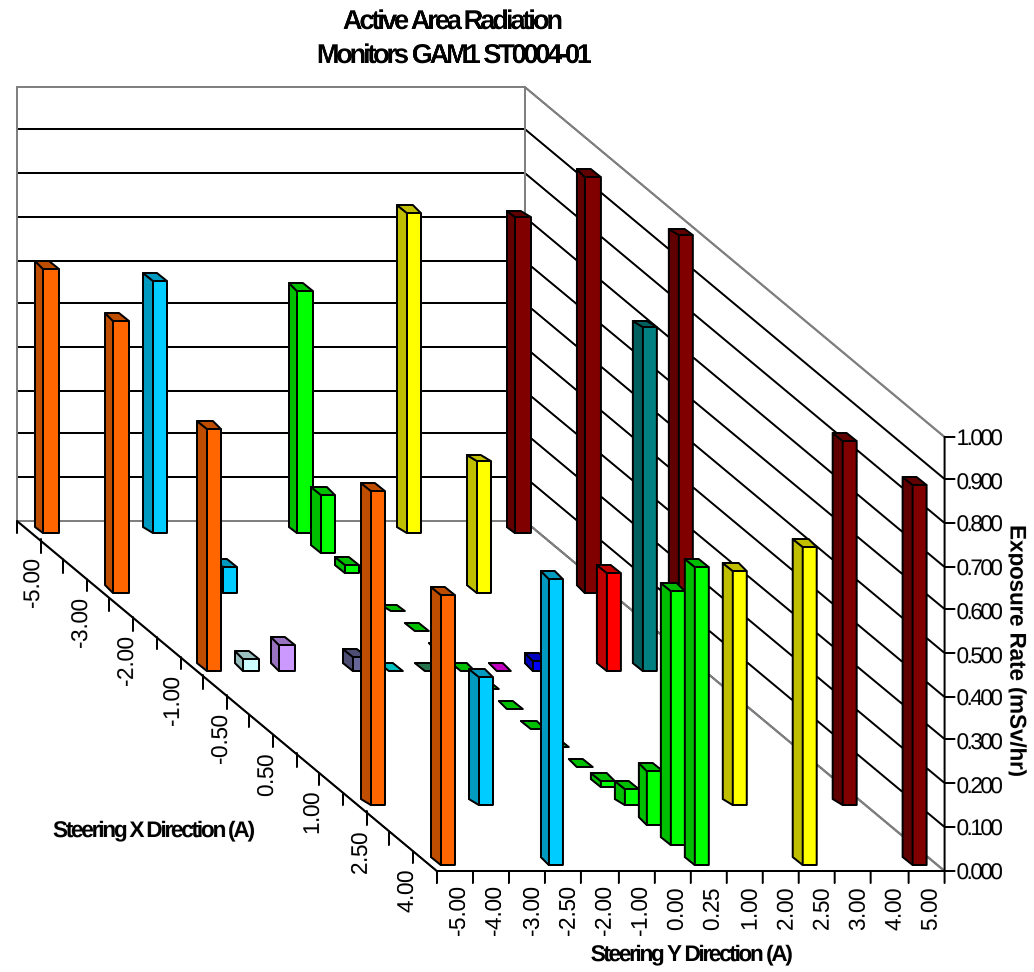


Figure 17 Area Monitor HPI 2010 #1032 during an experiment with the steering coil ST0004-01

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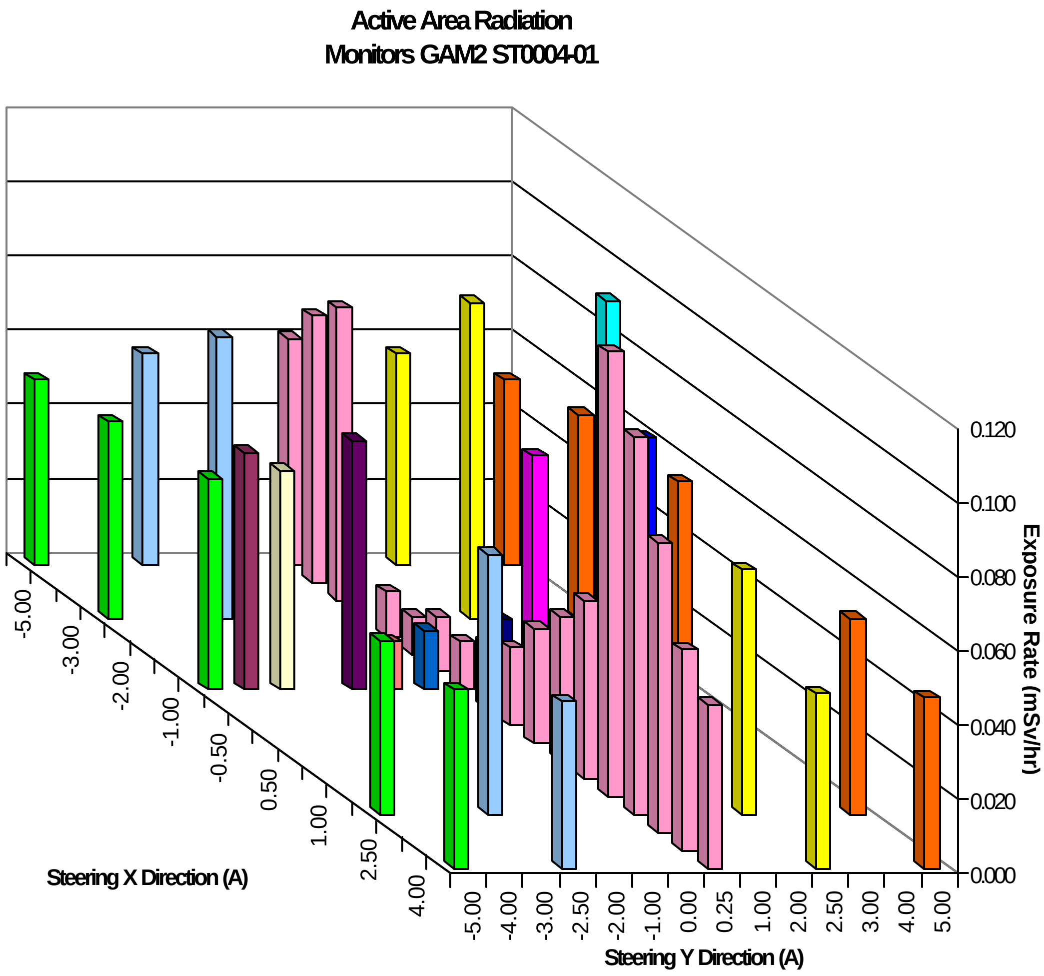

Figure 18 Area Monitor HPI 2010 #1033 during an experiment with the steering coil ST0004-01

10.5 APPENDIX E: BEAM PROFILE GRAPHS

Beam profile graphs taken on March 1, 2002. The sections where the beam was profiled on this day were BST0004-01, BST0003-02, BST0002-02, BST0002-01, Section #6 toroid, Section #2 toroid, Section #1 toroid, Section #0 toroid, and DC Toroid.