SUPERCONDUCTING CAVITY COMMISSIONING REPORT

11.18.53.3**- Rev. 0**

Date: 2004-06-25

Canadian Light Source Inc.
101 Perimeter Road
University of Saskatchewan
Saskatoon, Saskatchewan Canada
S7N 0X4

	Signature	Date
	Original on File – Signed by:	
Author	Grant Cubbon	
Reviewer #1	Mark de Jong	
Reviewer #2	Jonathan Stampe	
Approver	Mohamed Benmerrouche	

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1.0 INTRODUCTION

1.1 PURPOSE

Radiation measurements taken during the commissioning of the Super Conducting Cavity (SCC) in July and August of 2003 are presented and analyzed to determine if the existing bulk concrete shielding around the SCC is sufficient to meet the CLSI radiation exposure objectives outlined in the CLS Safety Report [1].

1.2 BACKGROUND

The 500 MHz superconducting cavity installed in the storage ring of the CLS will serve to replace the energy lost by electrons during the circulation of the stored electron beam. The nominal operating voltage of the cavity is 2.4 MV. A detailed technical description of the CLS Superconducting Cavity can be found in [2, 3, 4].

Field emission electrons are produced during normal operation of a superconducting cavity. Field emission sites, which are a result of impurities within the cavity, may be located anywhere within the cavity. These emission sites can be removed or 'burned off' during the commissioning process.

The maximum potential energy of these field emission electrons, and the resulting bremmstrahlung X-rays, is dependent upon the RF voltage applied across the cavity. The actual energy of each field emission electron is dependent upon the phase of the applied RF voltage that the electron is emitted into. The bremmstrahlung X-rays produced may therefore have an energy ranging from near 0 to a maximum of 2.4 MeV.

During conditioning of a superconducting cavity, the RF voltage and power are slowly increased to the nominal operating levels. While this process removes many of the emitter sites, it also creates significantly higher levels of bremmstrahlung radiation than is observed during normal operation. During acceptance testing, the cavity is set to nominal operating values.

This report presents the radiation levels measured at various points both within and outside of the Storage Ring (SR1) shielding enclosure near the Superconducting Cavity. The shielding enclosure walls are 46 cm thick while the roof is 60 cm thick. Both are constructed of normal density concrete. The measurements were taken during conditioning of the super conducting cavity as well as during acceptance testing when conditioning was complete.

1.3 ABBREVIATIONS

AARM	Active Area Radiation Monitor
ACIS	Access Control Interlock System
ADM	Area Display Monitor
BOW	Booster Ring Outer Wall
CLS	Canadian Light Source
CW	Continuous Wave
EPD	Electronic Personal Dosimeter
IBOW	Inside the Booster Ring Outer Wall
IP	Ion Chamber Probe

SC	Chicaned Opening on SR1 Roof
SCC	Superconducting Cavity
SIW	Storage Ring Inner Wall
SOW	Storage Ring Outer Wall
SR1	Storage Ring
SRF	Storage Ring Roof
TLD	Thermoluminescent Dosimeter

2.0 MATERIALS AND METHODS

2.1 EQUIPMENT

The following radiation monitoring equipment was used to measure the X-rays produced during commissioning of the superconducting cavity:

ThermoEberline FH40G-L!0	Gamma Survey Meter
Innovision 451 P	Gamma Survey Meter
Canberra ADM606M	Digital Display for Canberra Radiation Probes
Canberra IP100SI	Gas Filled Ionization Chamber Gamma Radiation Meter
Landauer Thermoluminescent Dosimeters	Personal radiation monitors sensitive to Gamma, X-rays, Beta, and Neutron radiation
Siemens Electronic Personal Dosimeters	Real time personnel radiation monitors sensitive to gamma, X-rays, and Beta radiation

2.2 EXPERIMENTAL DESIGN

Commissioning of the Superconducting Cavity took place in two stages. Stage 1 ran from July 1 to 7 2003 and Stage 2 ran from August 6 to 9, 2003.

During Stage 1, RF power levels were slowly raised. By the end of Stage 1, 80 KW of CW RF power was provided to the cavity, yielding the nominal cavity voltage of 2.4 MV. In Stage 2, high power conditioning continued and then the acceptance test was carried out when conditioning was complete.

Radiation measurements were taken during both stages using remote monitors directly around the SCC and outside the shielding enclosure. Radiation measurements were also taken using hand held survey meters outside the shielding enclosure. During Stage 2, TLDs were placed both inside and outside the shielding enclosure for a portion of the conditioning tests.

2.2.1 Active Area Radiation Monitoring

Canberra ADM606M display units coupled with Canberra IP100SI probes were used as a remote radiation monitoring system for the commissioning tests. The probes were strategically located in three areas:

1) One meter Upstream (1301-03), one meter downstream (1301-01), and on contact with SCC at 90^o to beam direction (1301-02), inside the SR1 shielding enclosure. An additional ADM606M (GP1400-01) permanently mounted on the wall near the SCC with an IP100 gamma probe was also used during conditioning.

2) Above the SCC, outside the SR1 shielding enclosure on top of chicaned openings for the SCC valve box

3) Beside the SCC, outside the SR1 shielding enclosure on the storage ring outer wall

See drawing DRW1 in Appendix 1 for exact locations of AARM probes during commissioning.

Real time radiation levels from all probes were collected and archived along with the operating parameters of the SCC during commissioning.

2.2.2 TLD Experiment

TLDs were placed inside and outside the SR1 shielding enclosure near the SCC for a 12 hour period during on August 9. The exact locations of the TLDs are shown in DRW 1.

2.2.3 Radiation Surveys

Radiation surveys with hand held instruments were taken periodically to confirm levels recorded by the AARM system and to provide some detail to the spatial extent of the X-ray fields produced during commissioning.

2.3 PERSONNEL SAFETY

During operation of the Superconducting Cavity, access to the cavity is restricted by using the storage ring Access Control Interlock System (ACIS). As a precaution, access to areas near the superconducting cavity was restricted to commissioning personnel during the commissioning tests. Signs were posted and barriers erected as necessary based on maintaining the potential radiation exposures to non-commissioning staff below 5 uSv/h.

All commissioning personnel were monitored for potential radiation exposures with both TLDs and electronic personal dosimeters (EPDs).

EPDs provided to commissioning staff included internal alarms for both exposure rate and cumulative exposure measured. The EPDs were set to provide an audible alarm to individuals if they entered an x-ray field greater than 10 uSv/h.

The TLDs provide the official dose record for each employee.

3.0 RESULTS AND DISCUSSION

3.1 ACTIVE AREA RADIATION MONITORS

3.1.1 Inside SR1 Shielding Walls

Figures 1-5 show the radiation measurements of the AARMs inside the shielding enclosure during conditioning plotted along with the RF Power supplied to the cavity.

In Figures 1-4, the x-ray radiation exposure dose rates near the cavity increase significantly as the RF power is increased. Initial low power conditioning on July 2, 2003 produced only a few hundred µSv/h of radiation downstream from the cavity. On August 8, conditioning at 80 KW CW produced a maximum of 2 Sv/h.

Figures 1 through 4 also show that radiation levels downstream from the cavity are greater than radiation levels upstream, which are in turn greater than radiation levels at 90^o to the cavity. Figures 1 through 4, and up until approximately 9:00 pm on August 9 (Figure 5), show fluctuations in radiation levels caused by the changing gas pressure inside the cavity. These changes are a consequence of the conditioning process.

Figure 5 also shows that once the cavity is conditioned, radiation levels are significantly reduced. The downstream radiation monitor recorded 33 mSv/h at 80 KW CW supplied RF power. As noted above, 2 Sv/h was observed on the same radiation monitor on August 8 when 80 KW CW RF power was supplied to the cavity.

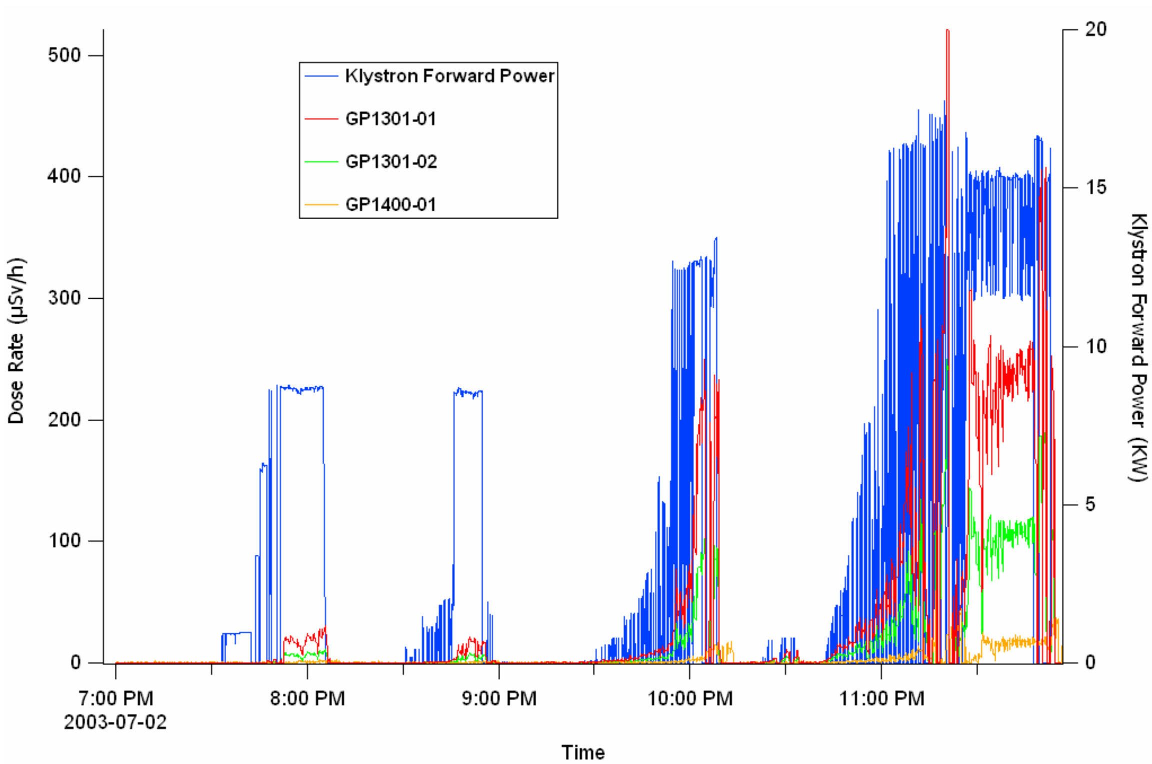


Figure 1 : X-ray radiation exposure levels inside SR1 tunnel and RF Power as a function of time. Data was taken on July 2, 2003.

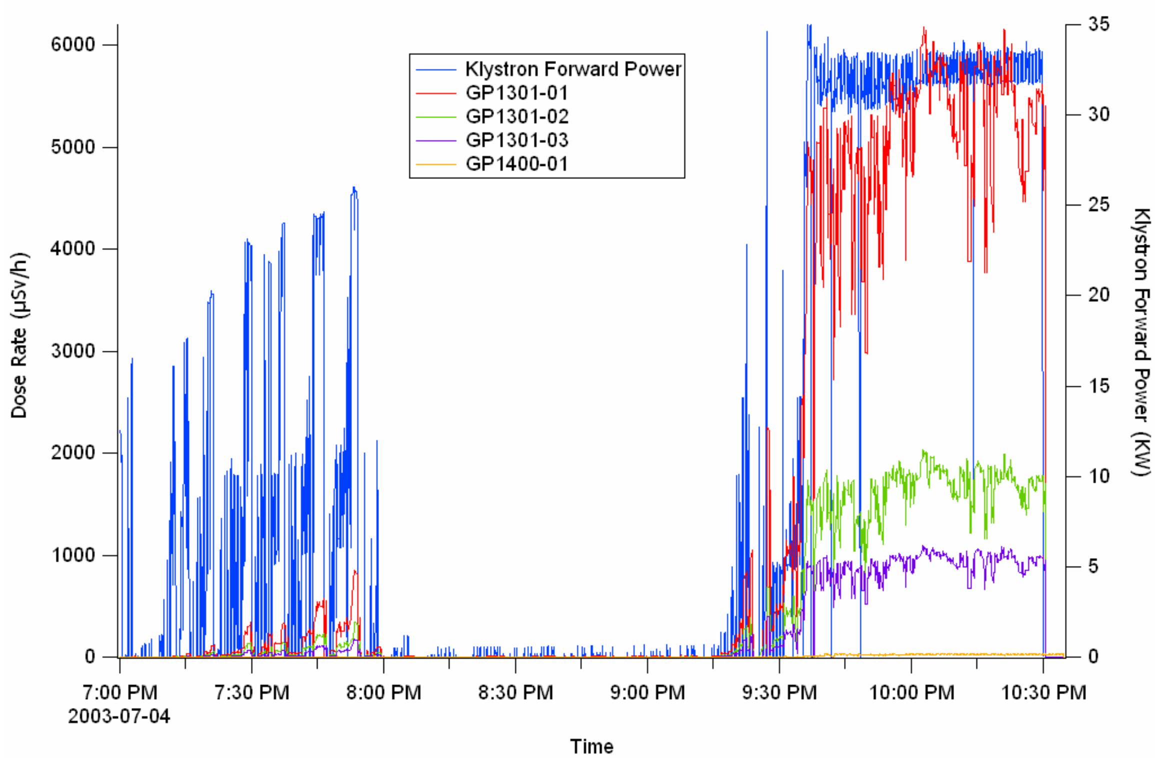


Figure 2: X-ray radiation exposure levels inside SR1 tunnel and RF Power as a function of time. Data was taken on July 4, 2003.

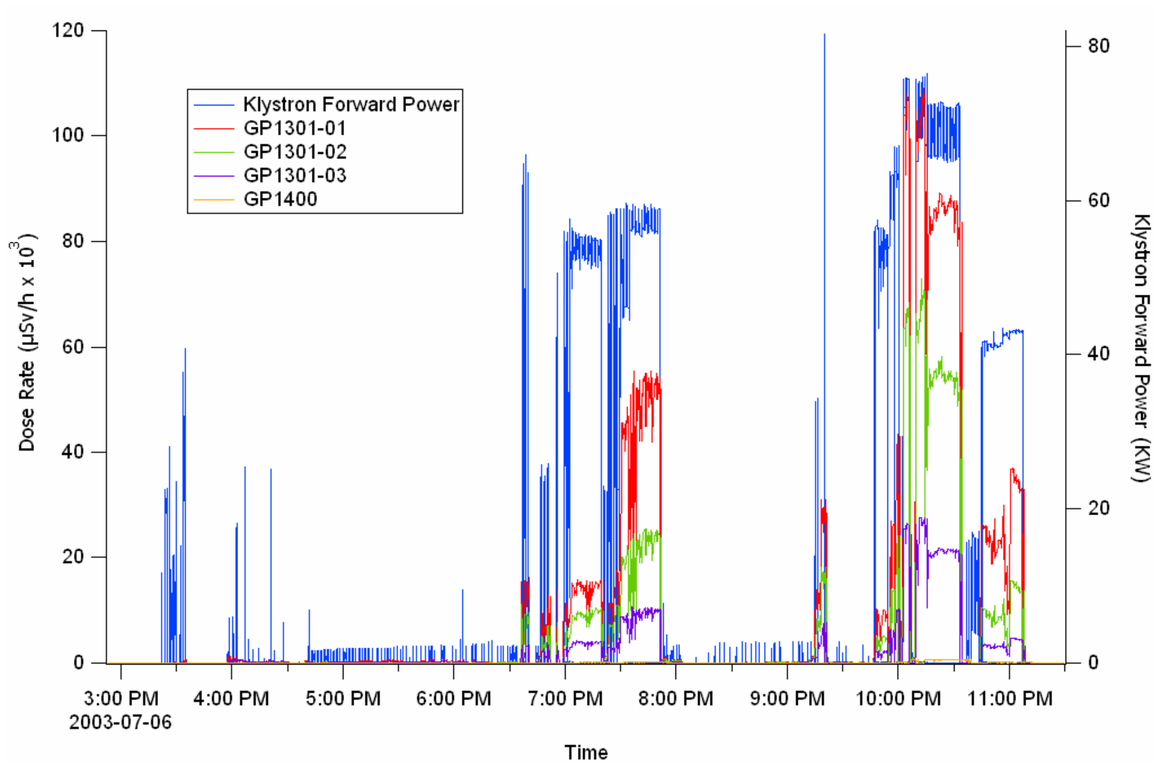


Figure 3: X-ray radiation exposure levels inside SR1 tunnel and RF Power as a function of time. Data was taken on July 6, 2003.

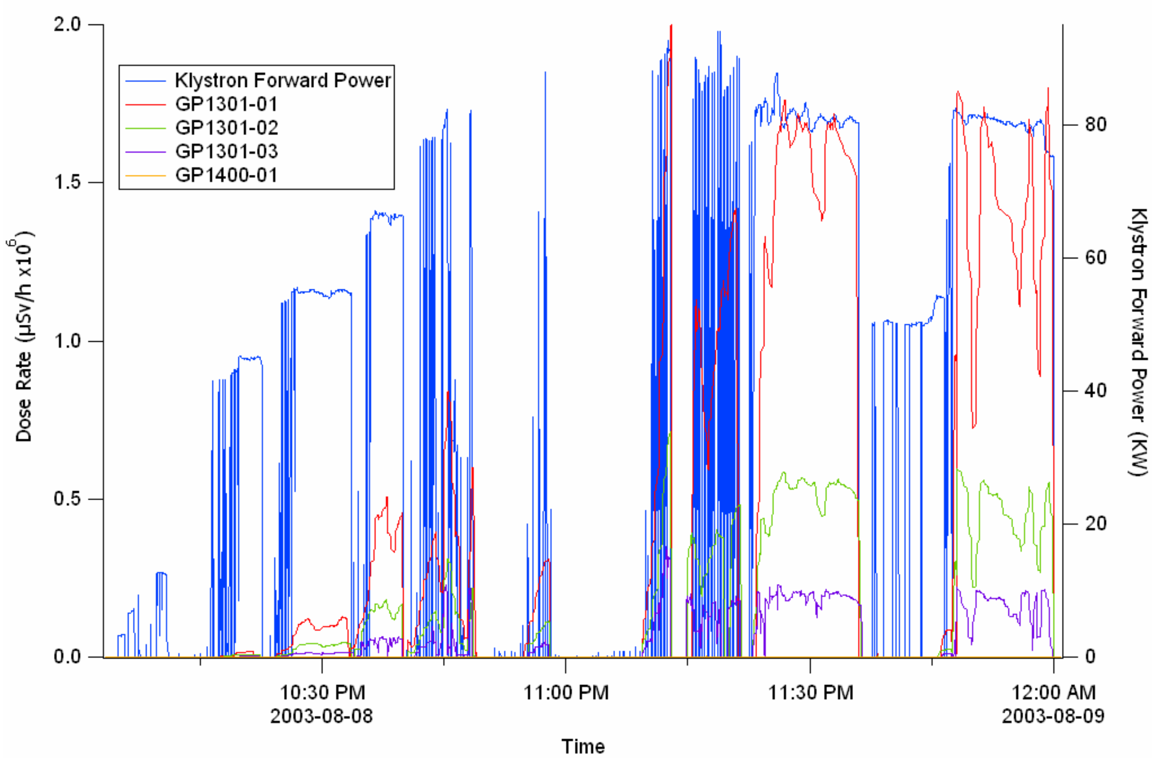


Figure 4: X-ray radiation exposure levels inside SR1 tunnel and RF Power as a function of time. Data was taken on August 8, 2003.

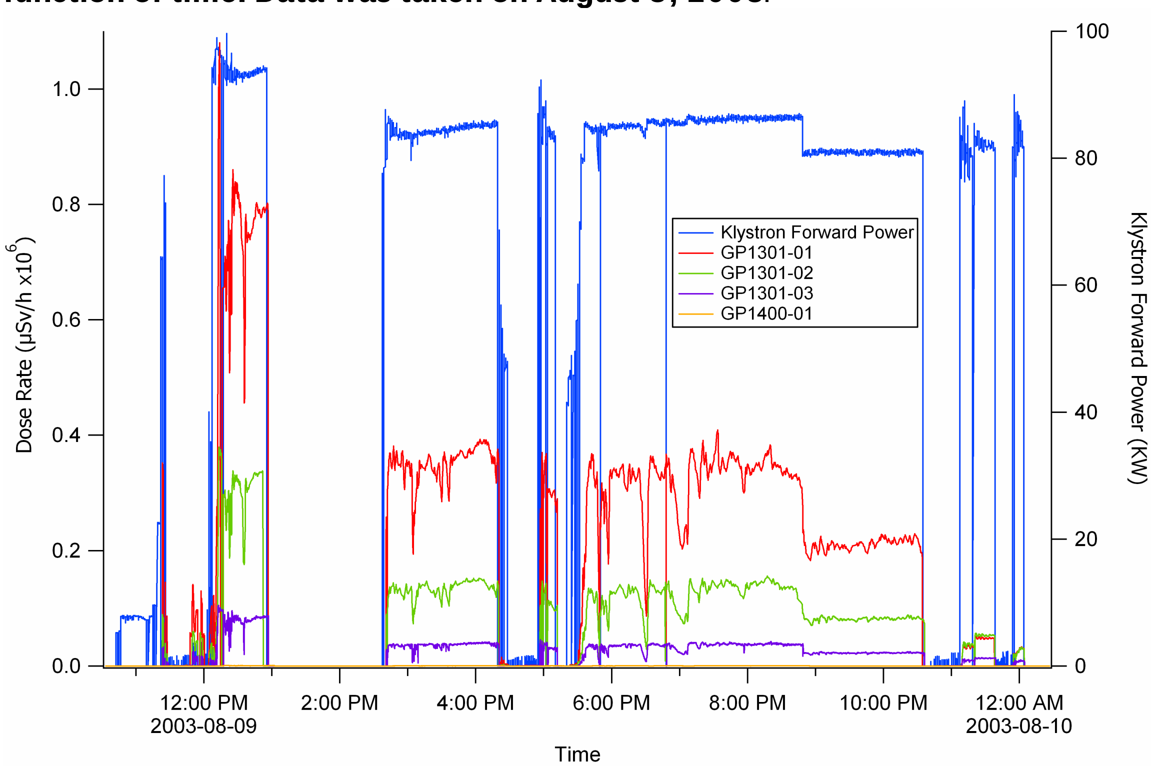


Figure 5: X-ray radiation exposure levels inside SR1 tunnel and RF Power as a function of time. Data was taken on August 9, 2003.

3.1.2 Outside SR1 Shielding – Above the Superconducting Cavity

The results for the two IP100SI probes placed across the chicaned openings below the SCC valve box are shown in figures 6-10. See DRW1 in Appendix 1 for exact locations of the probes.

Radiation levels increased as the power to the SCC was increased. The maximum measured by either probe on the SRF was 84.4 uSv/h and was recorded during conditioning on August 8 (Figure 9). On August 9, during the acceptance test, the maximum measured by either probe was 2.95 uSv/h (Figure 10).

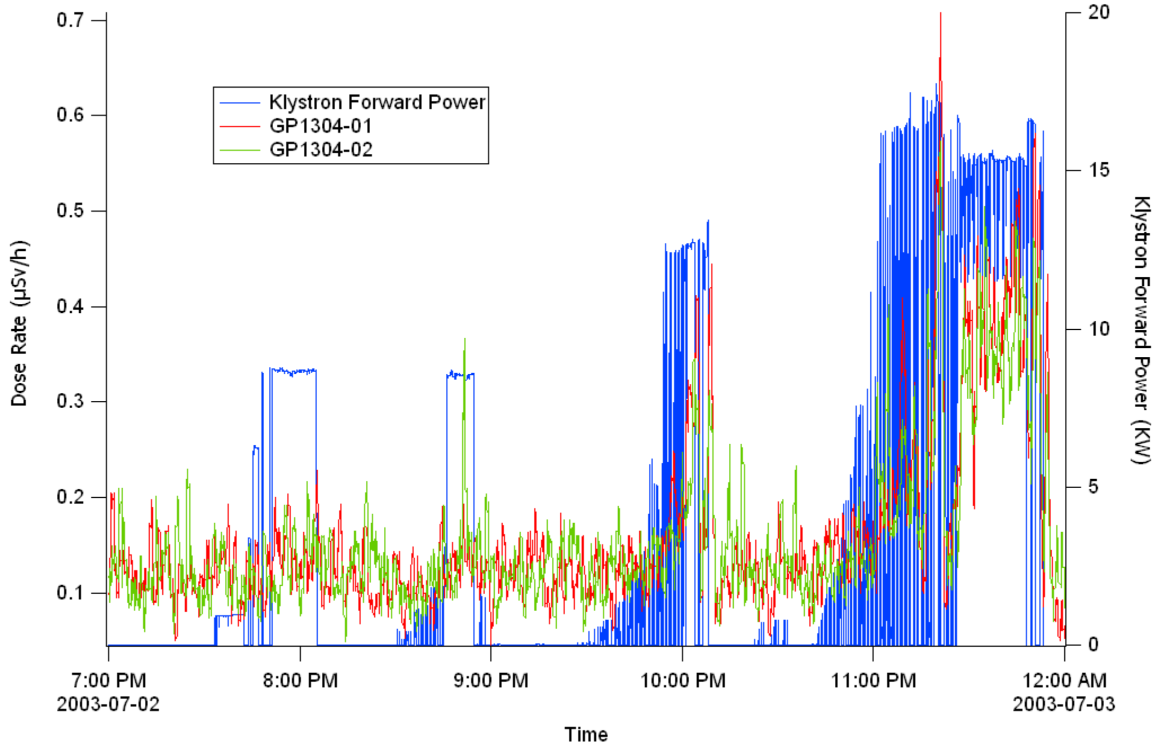


Figure 6: X-ray radiation exposure levels on roof outside SR1 tunnel and RF Power as a function of time. Data was taken on July 2, 2003.

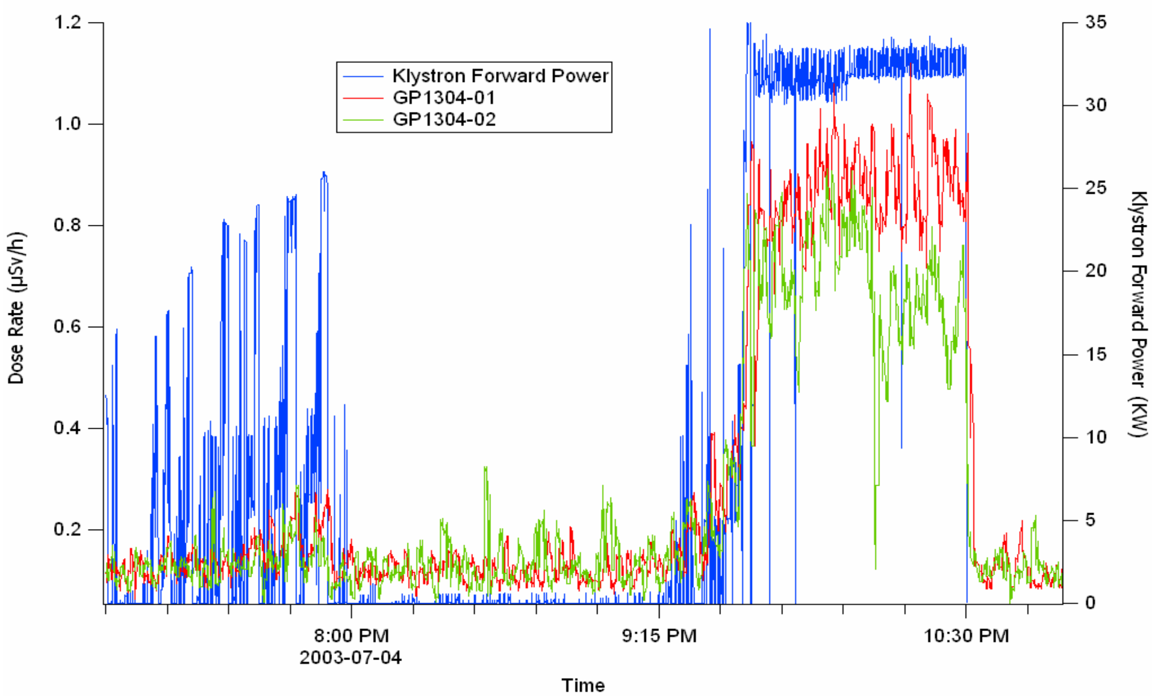


Figure 7: X-ray radiation exposure levels on roof outside SR1 tunnel and RF Power as a function of time. Data was taken on July 4, 2003.

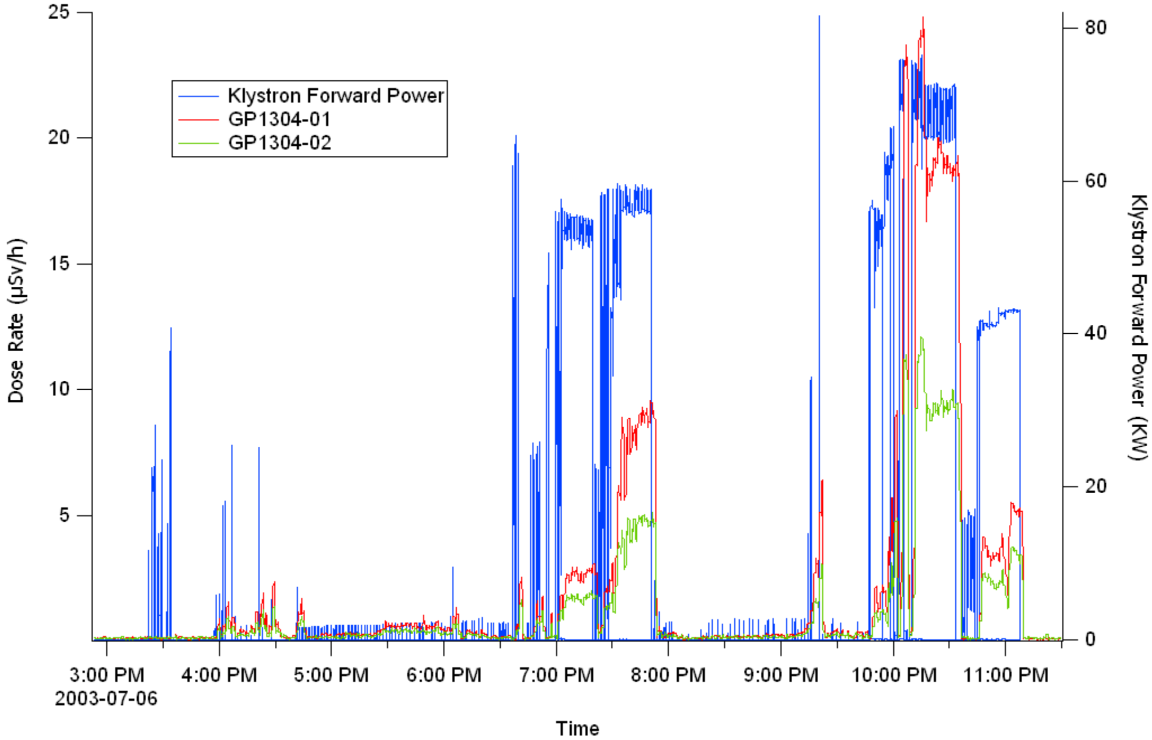


Figure 8: X-ray radiation exposure levels on roof outside SR1 tunnel and RF Power as a function of time. Data was taken on July 6, 2003.

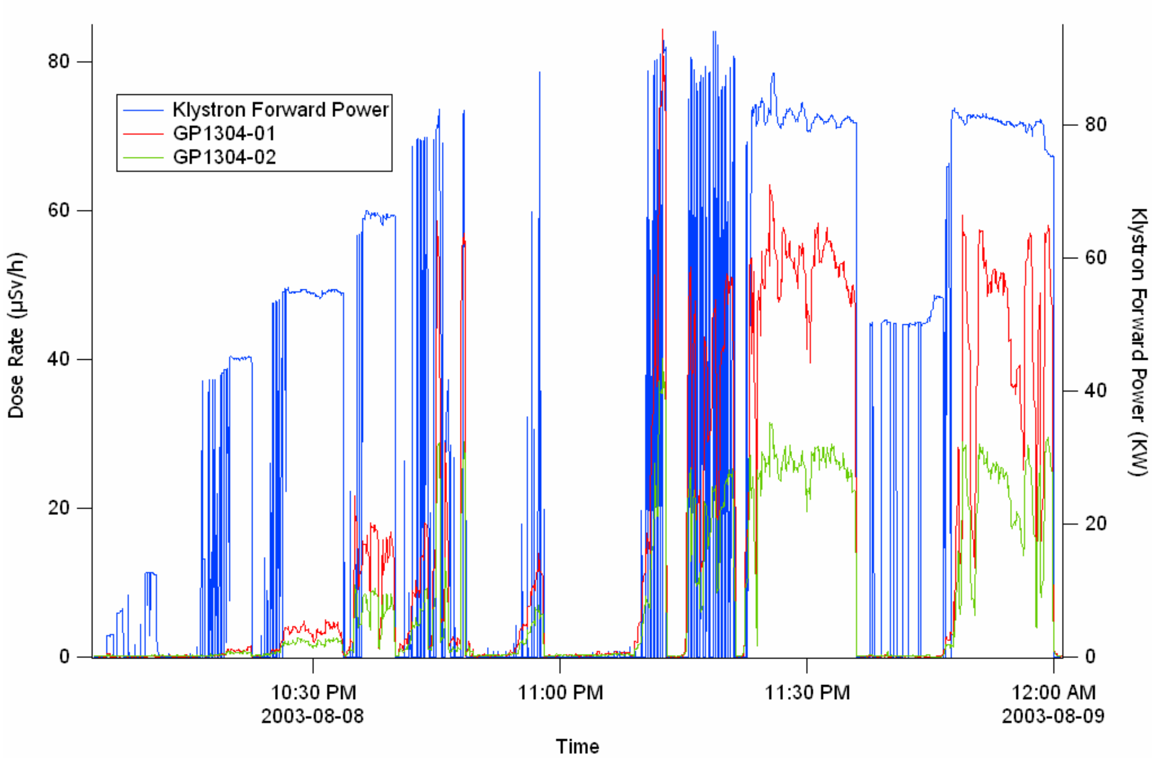


Figure 9: X-ray radiation exposure levels on roof outside SR1 tunnel and RF Power as a function of time. Data was taken on August 8, 2003.

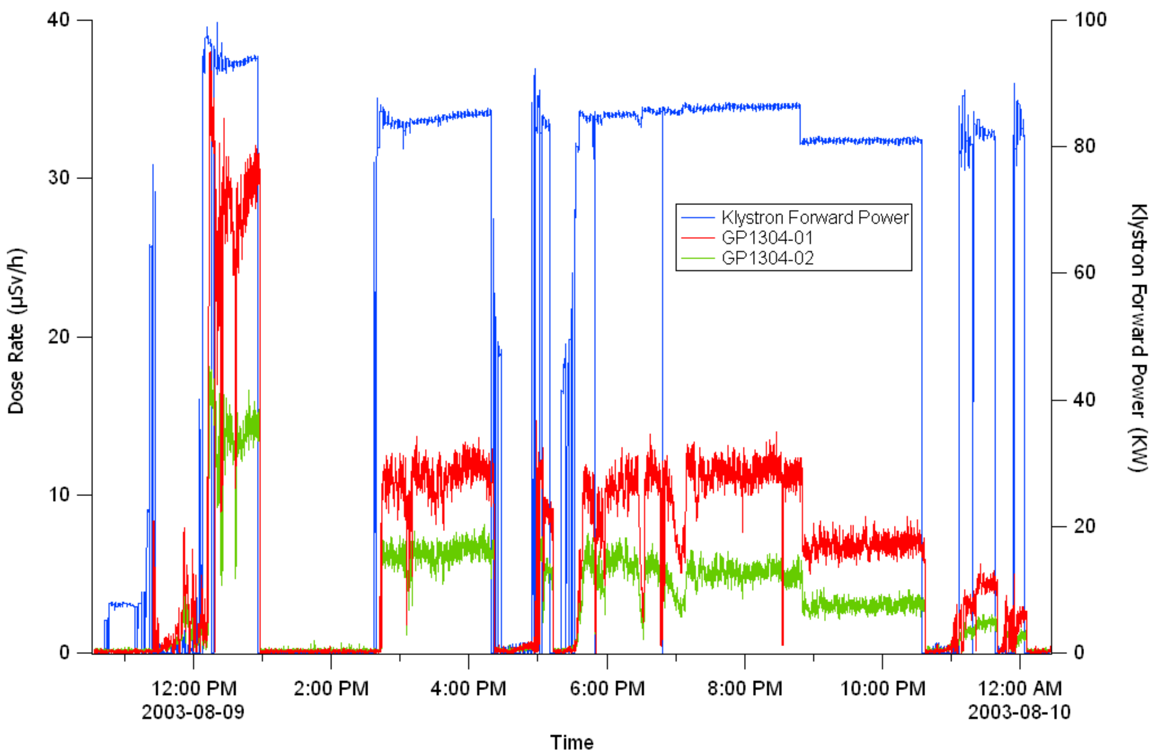


Figure 10: X-ray radiation exposure levels on roof outside SR1 tunnel and RF Power as a function of time. Data was taken on August 9, 2003.

3.1.3 Outside SR1 Shielding – Beside the Superconducting Cavity

Results for the 2 AARMs located on the storage ring outer wall are shown in figures 11-15 (See DRW1 in Appendix 1 for exact locations).

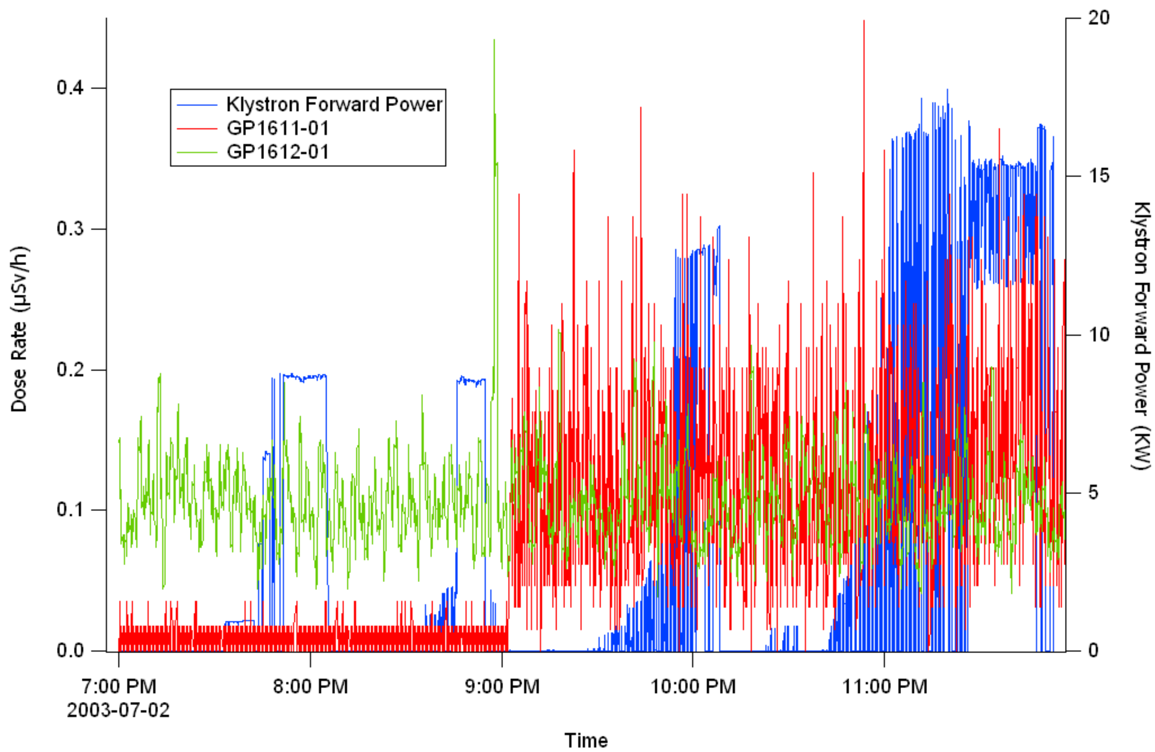


Figure 11: X-ray radiation exposure levels on wall outside SR1 tunnel and RF Power as a function of time. Data was taken on July 2, 2003.

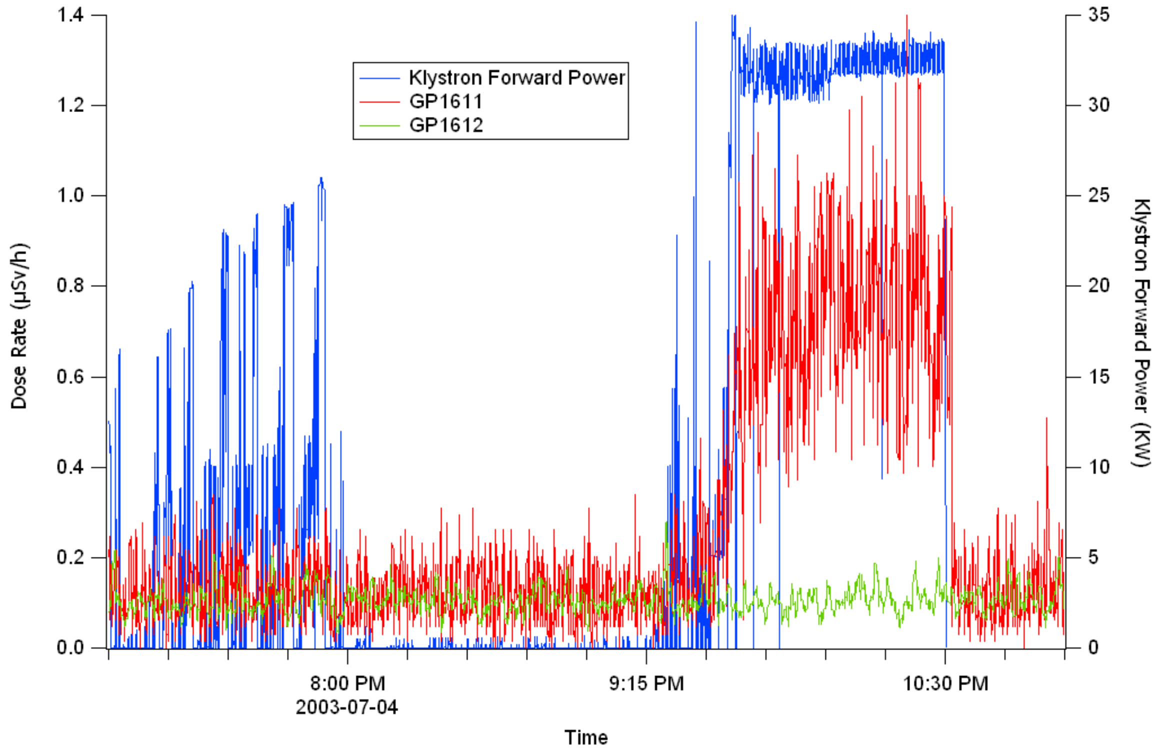


Figure 12: X-ray radiation exposure levels on wall outside SR1 tunnel and RF Power as a function of time. Data was taken on July 4, 2003.

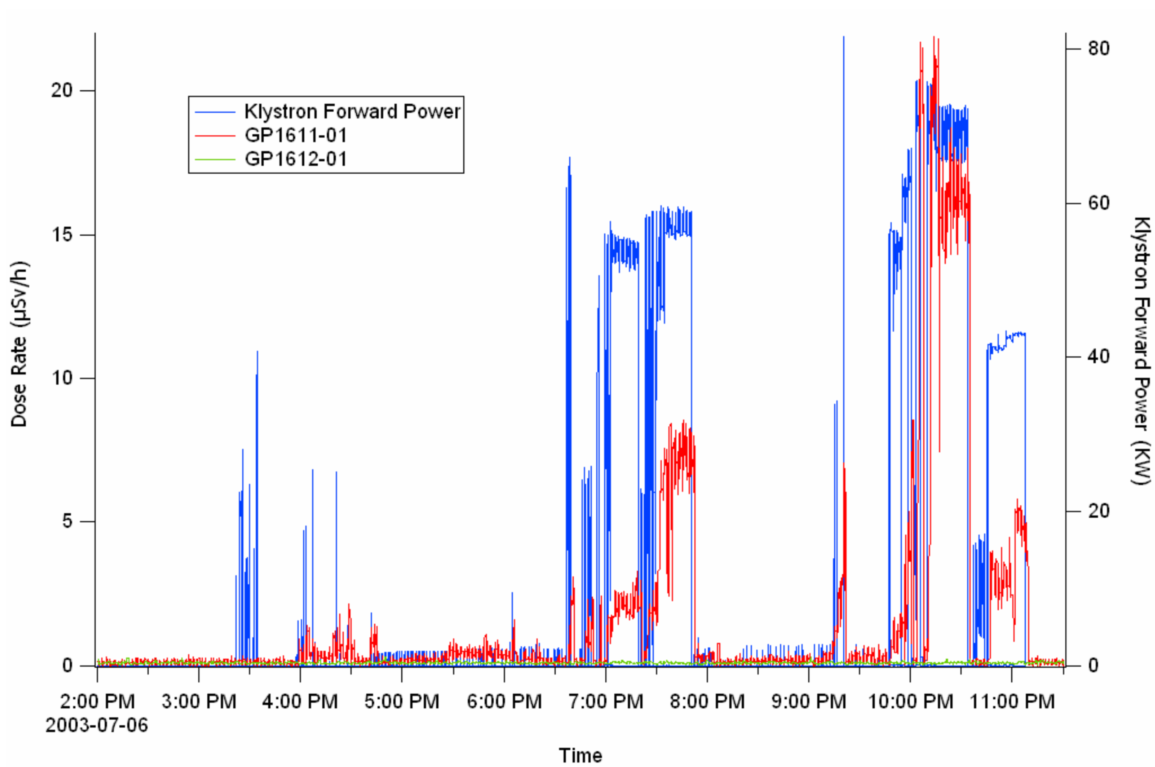


Figure 13: X-ray radiation exposure levels on wall outside SR1 tunnel and RF Power as a function of time. Data was taken on July 6, 2003.

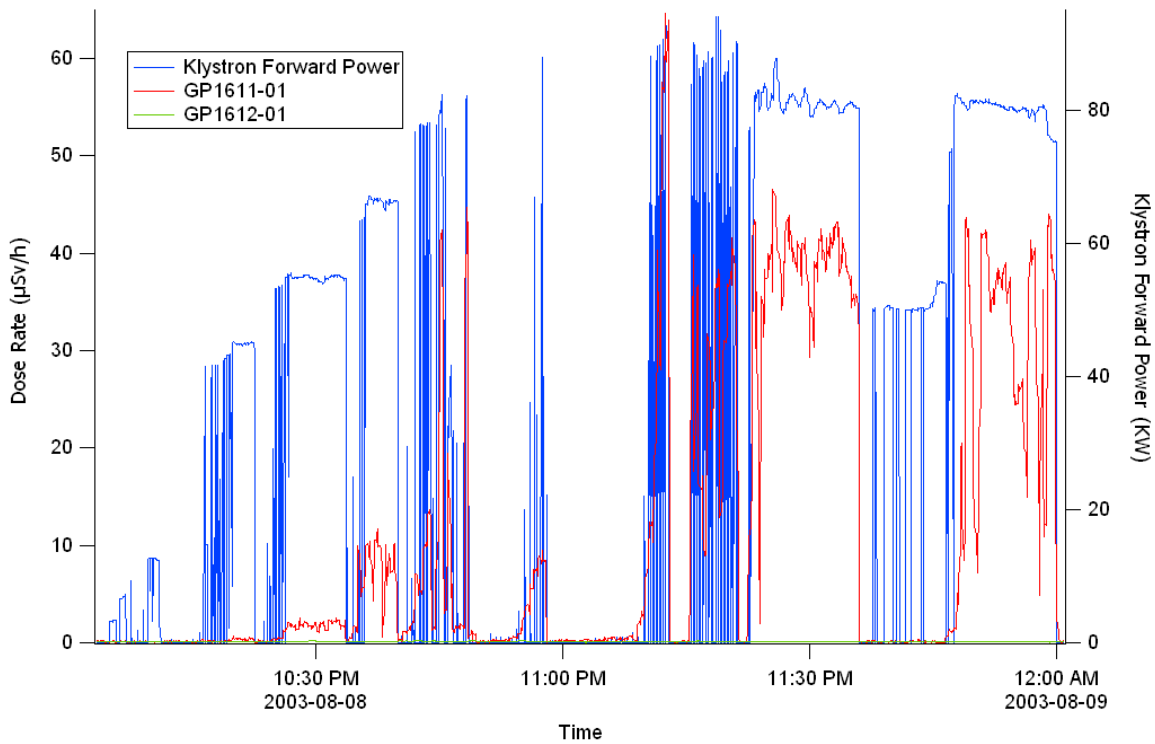


Figure 14: X-ray radiation exposure levels on wall outside SR1 tunnel and RF Power as a function of time. Data was taken on August 8, 2003.

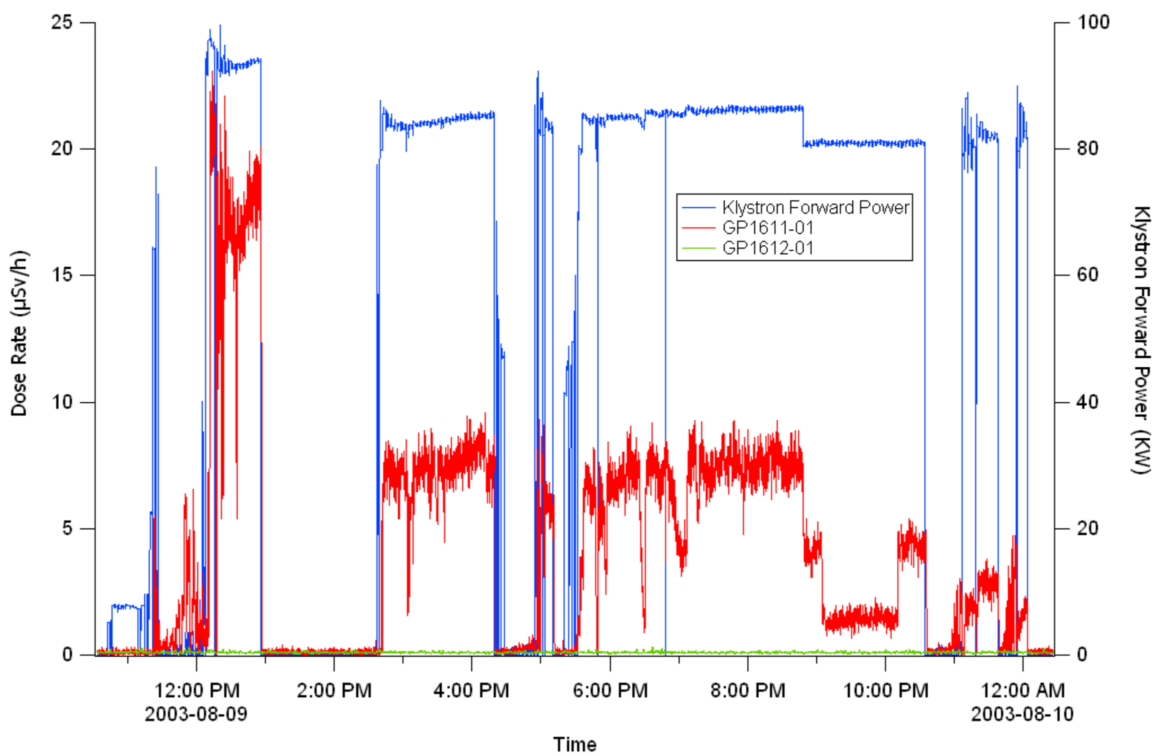


Figure 15: X-ray radiation exposure levels on wall outside SR1 tunnel and RF Power as a function of time. Data was taken on August 9, 2003.

AARM 1612-01, which is located downstream of beam direction, remained at background during all testing. AARM 1611-01, located at the closest point of the cavity to the storage ring outer wall, reached a maximum of 63.9 uSv/h on August 8. During the acceptance test on August 9, the maximum radiation level recorded was 2.33 uSv/h.

3.2 TLD EXPERIMENT

The results from the TLD experiment are presented in table 1 below.

Table 1: Exposure as recorded by TLD when exposed for a period of 12 hours on August 09, 2003. 'M' indicates that the exposure for that particular TLD is below the minimum detectable exposure of 0.1 mSv. All skin exposure reported are equal to whole body dose except as indicated.

Location	Description (See DRW#1)	Location Relative to Bulk Shielding	Whole Body Exposure (mSv)	Skin Exposure (mSv)
1	Cavity Front Left	Inside	161.6	
2	Cavity Front Right	Inside	169.7	
3	Beam Pipe Downstream	Inside	198.5	207.4
4	Cavity Facing BTS	Inside	195.5	
5	Cavity Top	Inside	319.8	
6	Cavity Facing SIW	Inside	436.3	
7	Cavity Bottom	Inside	284.2	
8	Beam Pipe Upstream	Inside	42.9	
9	SOW Inside	Inside	45.6	
10	SOW Outside	Outside	M	
11	SIW Inside	Inside	2.2	2.3
12	SIW Outside	Outside	M	
13	Waveguide Outside	Outside	M	
14	Zone 8.1 Gate 28	Inside	M	
15	SOW across from Zone 8	Inside	M	
16	Zone 8.1 Gate 27	Inside	M	
17	Zone 8.1 Across From Gate 27	Inside	M	
18	Ceiling Above Cavity	Inside	85.9	88.3
19	SR1 Roof	Outside	M	
20	Valve Box Chicane SRF 36	Outside	M	
21	Valve Box Chicane SRF 37	Outside	M	
22	Valve Box Chicane SRF 38	Outside	M	
23	Valve Box Chicane SRF 39	Outside	M	
24	Valve Box Chicane SRF 40	Outside	M	
25	SC25	Outside	M	
26	SC26	Outside	M	
27	SC27	Outside	M	
28	SC28	Outside	M	
29	SC29	Outside	M	
30	SOW 94	Outside	M	
31	Zone 8 Gate (SIW 004)	Outside	M	
32	SRF52	Outside	M	
33	SRF52 Downstream 0.5 m	Outside	M	
34	SRF52 Upstream 0.5 m	Outside	M	
35	SOW81 Upstream 0.5 m	Outside	M	
36	SOW81 Downstream 0.5 m	Outside	M	

Since the radiation levels during the TLD experiment were continually dropping during conditioning, and the cavity power was periodically at zero, the TLDs do not provide a meaningful indication of average exposure levels.

The TLD experiment does however demonstrate the effectiveness of the SR1 bulk shielding. All of the exposures reported, ranging from 2.3 mSv to 436.2 mSv, were recorded on TLDs placed inside of the SR1 bulk shielding. None of the TLDs located outside the SR1 shielding recorded an exposure above the detection limit (0.1 mSv) of the TLD.

The four TLDs located furthest away from the SCC but still inside the shielding enclosure also did not measure radiation above the detection limit of the TLDs. Radiation levels at the SCC were hundreds of mSv/h for much of the TLD experiment showing that radiation levels drop quickly with distance from the SCC as expected.

3.3 RADIATION SURVEYS

Radiation measurements were taken periodically during the conditioning. The points measured are shown in DRW 1. These measurements were often interrupted by trips in the cavity and were therefore not taken for all points listed for each measurement.

All measurements shown in tables 2 – 5 were taken at beam height on contact with the shielding walls, except for on the storage ring roof where measurements were taken on contact with the roof.

Table 2: Storage Ring Outer Wall Radiation Survey Measurements

Date:	July 4/03	July 6/03	Aug. 9/03	Aug. 9/03	Aug. 9/03	Aug. 9/03
Time:	21:48	22:10	14:43	18:15	20:06	23:27
Maximum RF Power (KW)	30	60	80	80	80	80
Point	**uSv/h**	**uSv/h**	**uSv/h**	**uSv/h**	**uSv/h**	**uSv/h**
85	0.1	0.11	0.11	0.16		
84	0.1	0.136	0.12	0.17	0.16	
83	0.11	0.47	0.16	0.25	0.183	0.33
82	0.12	6.9	2.53	2.8	2.7	1.2
81	0.48	16.4	7.16	7.6	8.7	3
80	0.41	6.5	3.43	3.7	3.3	0.62
79	0.27	3.6	2.27	2.1	2.2	0.07
78	0.18	2.1	0.21	0.3	0.19	
77	0.14	0.45		0.265	0.16	
76	0.14	0.83	0.23	0.27	0.16	
75	0.13	0.26	0.19	0.19	0.16	
74	0.14	0.24	0.13	0.18	0.16	

Radiation measurements taken with the survey meters near the AARM units showed good agreement. For example, AARM 1611-01 is located at SOW81. In table 2, on July 6 at 22:10, 16.4 uSv/h was measured with the survey meter while AARM1611-01 recorded 15.8 uSv/h at approximately the same time (Figure 15).

Table 3: Storage Ring Roof/Chicanes Radiation Survey Measurements

Date:	July 2/03	July 4/03	Aug 9/03	Aug 9/03
Time (approx.)	23:26	21:48	14:43	18:15
RF Power (KW)	15	30	80	80
Point	**uSv/h**	**uSv/h**	**uSv/h**	**uSv/h**
SC36	0.37	7.62	7.5	5.7
SC37	0.75	14.2	10.8	14.9
SC38	0.81	10.3	10.6	10.8
SC39	0.32	2.25	2.1	2.31
SC40	0.5	2.26	4	3.23
SRF50	1.8	0.31	0.13	0.13
SRF51	0.29	0.49	0.522	0.535
SRF52	0.17	2.58	2.26	2.18
SRF53	0.17	0.084	0.245	0.28
SRF54	0.31	0.071	0.21	0.25
SC35		0.15	0.2	0.24
SC41		0.25		0.559
SC42		0.31	0.91	0.965
SC43			0.2	0.24
SC44			7.8	10.1
SC45			7.4	8.3
SC46			0.3	
SC47			0.25	

Table 4: Storage Ring Inner Wall Radiation Survey Measurements

Zone 8 Gate Radiation Measurements

Date:	July 6/03	Aug 9/03	Aug 9/03	Aug 9/03
Time:	22:10	14:43	18:15	20:06
RF Power (KW)	60	80	80	80
Point	**uSv/h**	**uSv/h**	**uSv/h**	**uSv/h**
SIW1	0.1	0.084	0.19	0.1
SIW2	0.15	0.095	0.19	0.1
SIW3	0.15		0.19	0.1
SIW4	0.16	0.089	0.19	0.1
SIW5	0.1	0.081		0.1
SIW6	0.1	0.081		0.1
SIW7	0.1	0.086		0.1
SIW8	0.17	0.089	0.19	0.1

Table 5: Booster Ring Outer Wall Radiation Survey Measurements

Booster Ring Outer Wall Radiation Measurements				
Date:	July 4/03	Aug 9/03	Aug 9/03	Aug 9/03
Time:	21:48	14:43	18:15	20:06
RF Power (KW)	30	80	80	80
Point	**uSv/h**	**uSv/h**	**uSv/h**	**uSv/h**
IBOW27	0.1	0.084	0.11	0.17
IBOW28	0.1	0.082	0.11	0.17
IBOW29	0.1	0.073	0.15	0.17
IBOW30	0.11		0.21	0.16
Waveguide1	0.44	0.083	3.8	2.8
Waveguide2	0.89	0.082	9.8	10.5
IBOW31	0.11	0.079	0.72	0.16
IBOW32			0.12	0.16

Table 6: Storage Ring Outer Wall Radiation Survey Measurements

Grid Survey of Storage Ring Outer Wall										
Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
F	0.17	0.41	0.69	1.3	1.8	2	2.3	1.19	0.69	0.5
E	0.23	0.65	0.96	2	3	4	4.3	1.64	1.26	0.7
D	0.3	0.56	1.16	2.3	3.5	5	5.6	2.6	2.4	0.15
C	0.39	0.72	1.45	2.2	2.5	3.4	4.1	2.6	2.8	0.2
B	0.35	0.44	1.08	2.1	2.4	3.3	3	1.84	1.83	0.17
A	0.33	0.41	0.81	1.65	1.6	2.3	2.5	0.9	0.5	0.06

SOW81 = C7
ALL OTHER POINTS IN 0.5 METER INCREMENTS FROM SOW 81
ALL EXPOSURES IN uSv/H

Radiation measurements were also taken at various heights on the storage ring outer wall. Survey results shown in Table 6 represent a grid scan taken on the storage ring outer wall. Point C7 represents beam height at SOW81. All points are located in 0.5 meter intervals measured using C7 as the starting point.

A peak in the radiation levels can be seen 0.5 meters above beam height near SOW81. Radiation levels below beam height are below the values measured at the corresponding beam height. The radiation levels drop to near background levels at 3.0 meters away from SOW81 on the storage ring outer wall.

3.4 PERSONNEL SAFETY

EPD records indicate personnel radiation exposures were kept to near background levels for all involved in the commissioning process. TLD records indicate that all but three members of the

SCC commissioning team received no radiation exposure as a result of the commissioning of the super conducting cavity. Of the three members who did receive a radiation exposure, 2 are part of the CLS HSE department and most likely received exposures during beam commissioning. The TLD worn by an employee from the company that installed the cavity recorded an exposure of 0.2 mSv.

4.0 CONCLUSION

4.1 INSIDE SR1 SHIELDING ENCLOSURE

Radiation levels on contact with the superconducting cavity reached levels of almost 2 Sv/h during conditioning. When conditioning was complete, the radiation level on contact with the SCC with an applied CW RF power (nominal 2.4 MV cavity field) of 80 KW was 33 mSv/h.

4.2 OUSTSIDE SR1 SHIELDING ENCLOSURE

During conditioning, radiation levels above the cavity outside the storage ring shielding enclosure reached 84.4 uSv/h. Outside the storage ring outer wall, radiation levels reached 63.9 uSv/h. Both values exceeded the shielding design objective of 5 uSv/h for storage ring operation. After conditioning was complete, radiation levels on the SR1 roof and on the storage ring outer wall were 2.95 uSv/h and 2.33 uSv/h respectively.

The shielding design objective of the SR1 bulk shielding is to maintain radiation exposure rates below 5 uSv/h when all source terms (injected beam, stored beam, and SCC operation) are combined. The SR1 roof area is a restricted access zone with limited occupancy during normal operations. Shielding calculations were based on estimated radiation levels 1 meter from the surface of the roof.

The contribution of both stored and injected beam to the overall radiation exposure level is expected to be minimal on the SR1 roof. SCC radiation measurements were taken on contact with SR1 roof and drop off quickly with distance. As a result, the SR1 roof does not require additional shielding due to SCC operation.

The area outside the SR1 outer wall is a free access zone. Shielding calculations were based on estimated radiation levels 0.3 meter from the surface of the SOW. The contribution of the stored and injected beam to the overall exposure level is expected to be below 5 uSv/h, but not insignificant. When combined with the SCC contribution, it is possible the 5 uSv/h objective may be exceeded.

However, the area directly outside the SCC is between the SGM/PGM hutch and the SOW. This area will have very low occupancy during normal operation. Furthermore, access to the area could easily be restricted by erecting a barrier if future radiation measurements indicate that the 5 uSv/h objective is exceeded during normal operation.

Although precautions will be required during any future SCC conditioning tests, additional shielding near the superconducting cavity is not required for normal operation of the storage ring.

5.0 REFERENCES

[1] 11.18.40.2. Rev.3_Safety_Report-Benmerrouche

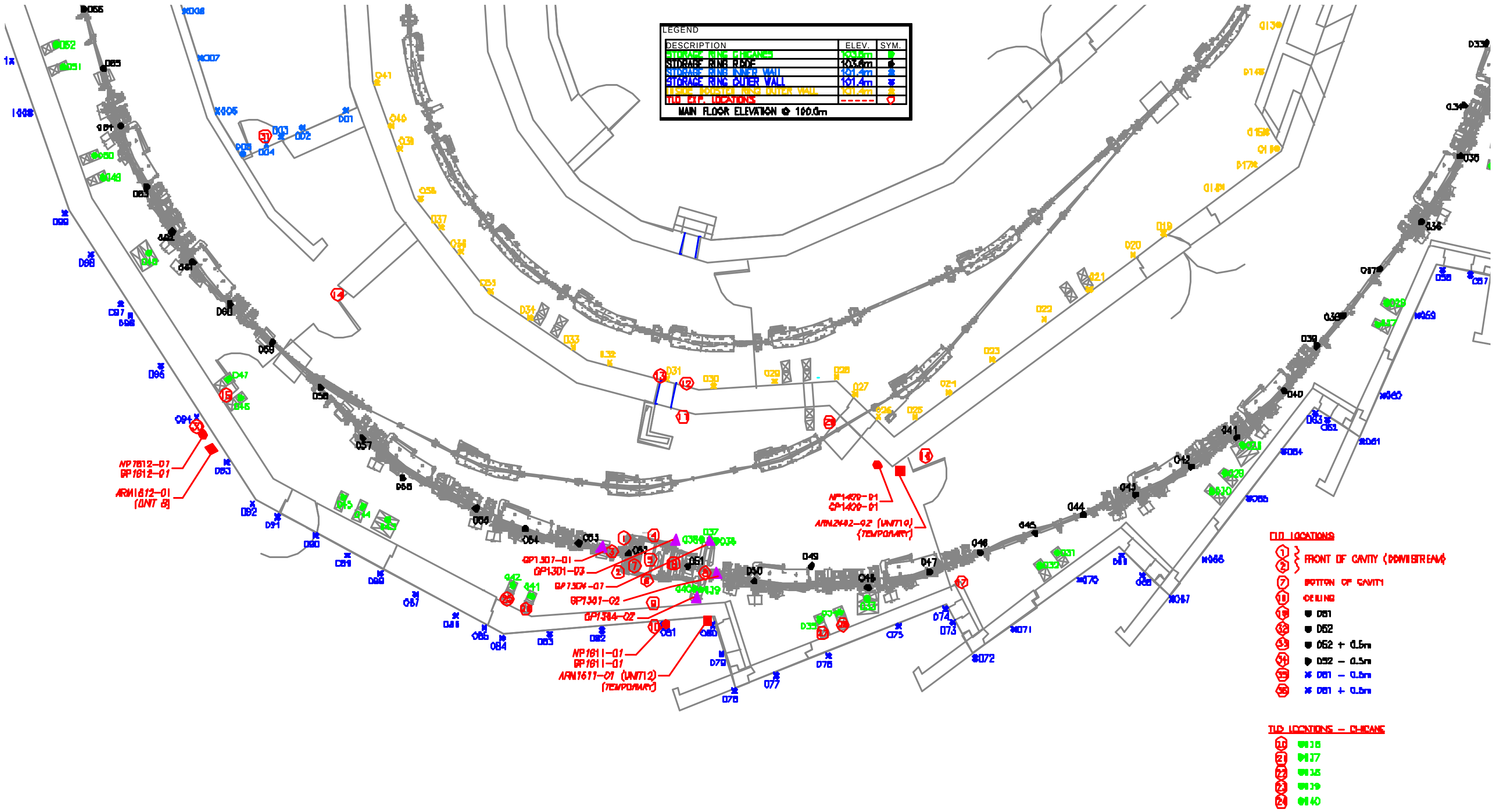
[2] 5.4.32.1.Rev.0-SC_RF_Acceleration_Module_Spec.-Silzer

[3] 5.4.32.2.Rev.0-CLS_Storage_Ring_Amplifier_System_Spec.-Silzer

[4] 5.4.32.3.Rev.0-CLS_Storage_Ring_Low-Level_RF_System_Preliminary_Design-deJong

6.0 APPENDIX 1

[1] DRW1 – Radiation Survey Point, TLD, and AARM Locations During Superconducting Cavity Commissioning.


LEGEND
DESCRIPTION | ELEV. | SYM.
STORAGE RING CHICANES | 103.6m
STORAGE RING RIDGE | 103.6m
STORAGE RING INNER WALL | 101.4m
STORAGE RING OUTER WALL | 101.4m
INSIDE BOOSTER RING OUTER WALL | 101.4m
TLD EXP. LOCATIONS
MAIN FLOOR ELEVATION @ 100.0m
TLD LOCATIONS
1, 2 FRONT OF CAVITY (DOWNSTREAM)
7 BOTTOM OF CAVITY
10 CEILING
D61
D52
D52 + 0.5m
D52 – 0.5m
D61 – 0.5m
D61 + 0.5m
TLD LOCATIONS – CHICANE