# Survey of RF Test Facility During Cavity Conditioning

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Diamond Light Source is the UK's national synchrotron science facility, located at the Harwell Science and Innovation Campus in Oxfordshire. By accelerating electrons to near light-speed, Diamond generates brilliant beams of light from infra-red to X-rays which are used for academic and industrial research and development across a range of scientific disciplines including structural biology, physics, chemistry, materials science, engineering, earth and environmental sciences. As the electrons emit the synchrotron radiation, they need to have their energy replenished to keep them in orbit around the synchrotron at 3 GeV. Diamond uses two superconducting Radio Frequency (RF) cavities to replace the lost energy. In order for the cavities to work in a stable mode, they need to be vacuum conditioned – this needs to be done when the cavities are first used, or after any vacuum intervention. The conditioning process involves raising the applied voltage on the cavity to the maximum sustainable level, then applying more power until the vacuum conditions to a level where a higher voltage can be tolerated; the process then repeats. While the cavity is conditioning, it may generate bremsstrahlung photons at MeV energies, at dose rates of a few Grays per hour at contact. Cavity conditioning can take place within the synchrotron storage ring vault, which is already shielded for a higher radiation load than is produced by the adventitious radiation from the cavities. To provide more flexibility, and to allow cavities to be conditioned away from the storage ring, an RF test facility has been constructed. As a new facility being used to condition a new cavity, an extensive programme of radiation measurements was undertaken, both inside and outside the facility. This allowed not only the effectiveness of the shielding to be verified, but also allowed mapping of the field from the RF cavity as it conditioned. This report details the radiation output of the RF cavity, the effectiveness of the shielding of the RF test facility and the safety systems that have been employed. The conclusion includes some improvements to the shielding and safety systems of the RF test facility.

## 1. Introduction

Before RF Cavities can be used on the synchrotron, they need to be conditioned. This involves increasing the power, voltage and duty cycle in stages, starting with lowest power and voltage then slowly increasing the duty cycle from 0 to 100 %, or Continuous Wave (CW), then increase the power and raise the duty cycle from 0 to 100% again, and so on until power, voltage and duty cycle are at a maximum.

Conditioning can take weeks to complete and doing it in place in the synchrotron would result in a loss of beam time. An RF Test Facility (RFTF) has been built to condition RF cavities prior to being installed on the ring.

This process of conditioning causes particles of contamination to be liberated from the internal surface of the RF cavity. These particles are accelerated across the cavity by the RF field and impact on the internal surface of the cavity; this causes X-rays to be produced. Therefore the RFTF needs to provide adequate shielding of the RF cavity to keep dose rates on the outside As Low As Reasonably Practicable (ALARP).

## 2. Radio Frequency Test Facility (RFTF)

The RFTF is a cuboid surrounded by concrete walls (1.1m thick). Access to the RFTF is via a 40 Tonne concrete filled steel door placed on a track and rollers.

The roof provides a minimum of 1.1m of shielding. In order to accommodate services (power, cryogens) the overall thickness of the roof is as much as 2.8m in places, as can be seen below in figure 1. Two of the service chicanes are filled with pipes, the third chicane (far left) has very few services running through it and may be large enough for a person to access. Health Physics have recommended that a grille be fixed over this chicane. Part of the roof is constructed of 2 layers of interlaced concrete blocks. The blocks are movable, so they have been placed under configuration control.

The walls and door are all of the same thickness, however, while a cavity will emit radiation in all directions, it is expected that the intensity will be highest in the direction of the applied field, along the axis of the cavity. For this reason, the shielding at the ends of the cavity is enhanced with a 200mm thick lead wall. The lead wall allowed the overall footprint of the facility to be smaller, and reduced the required thickness of the door and rear wall.

Access to the RFTF through the sliding door is under Personnel Safety System (PSS) control. The PSS includes door interlocks, a room search system and cavity control keys.

### Figure 1: Side view of RFTF - section

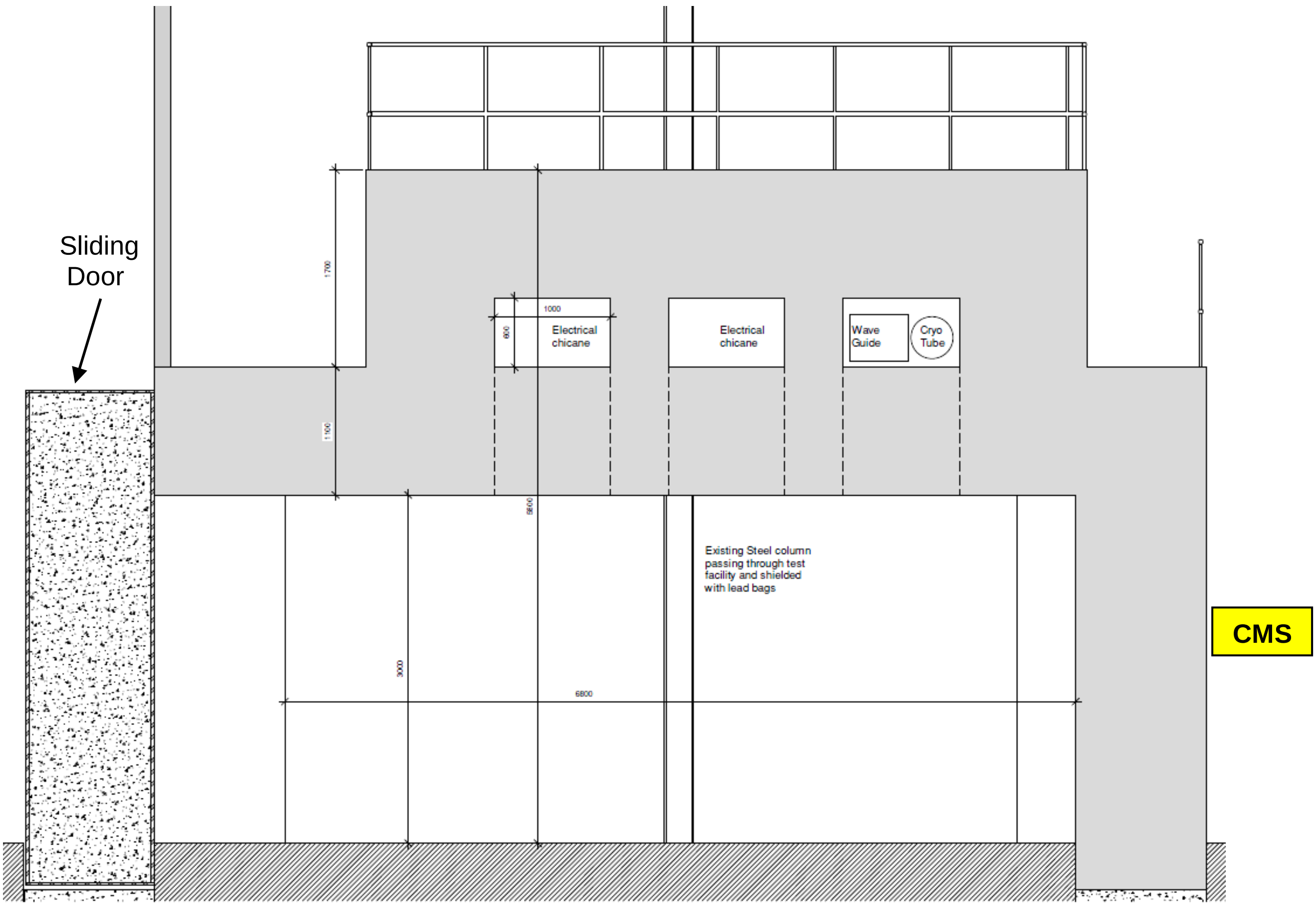
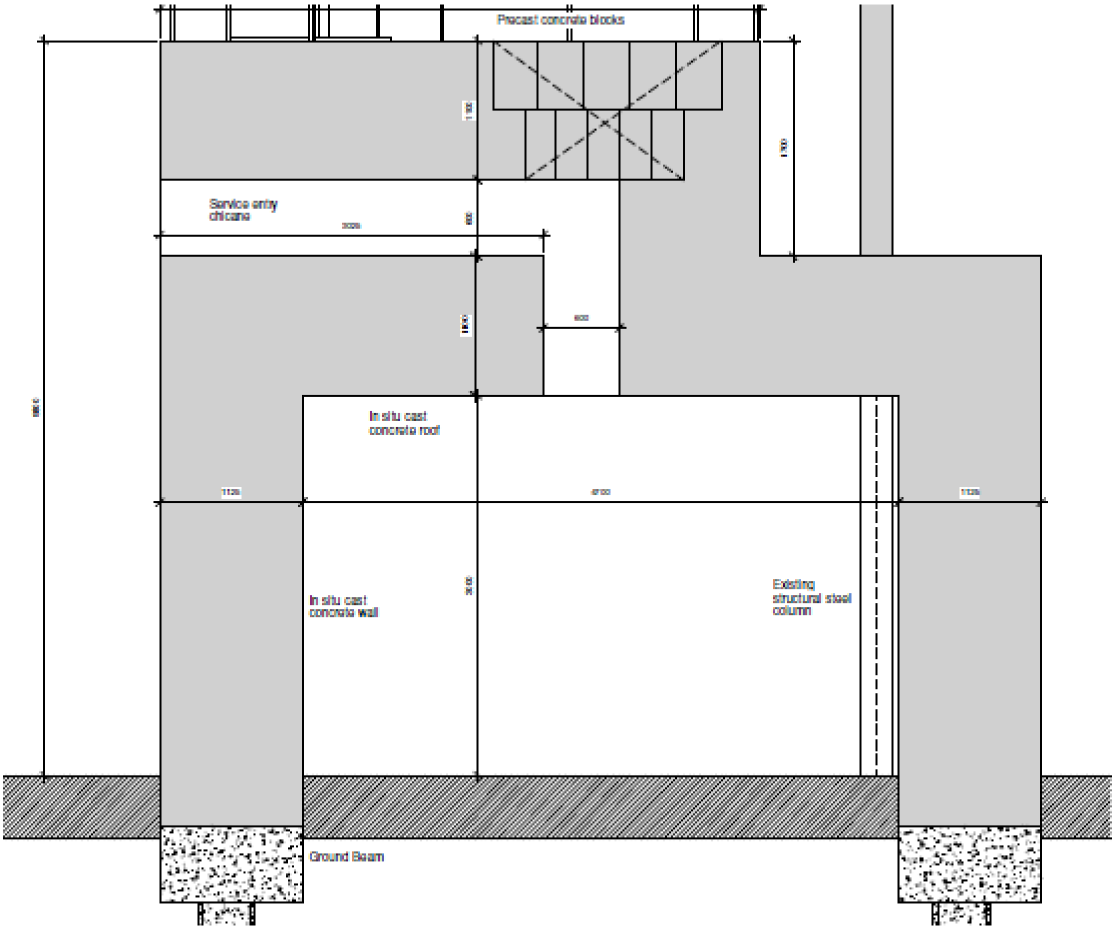


**Figure 2: End view of RFTF - section**




## 3. Overview

In order to confirm that the shielding of the RFTF is adequate, Health Physics carried out surveys of the shielding during the conditioning of Diamond Cavity 3, a new and previously unconditioned cavity.

Before starting, the area around the RFTF was cordoned off to prevent access to the area by unauthorised persons. A Canberra G64 area ionisation chamber was placed 65cm from the steel flange on the front of the cavity (where it is thought that the X-ray flux would be highest). The G64 was readout remotely, and was monitored to ensure that the cavity was producing radiation continuously during Health Physics surveys.

Continuous Monitoring Stations (CMS) measure and record doses/dose rates in areas occupied by personnel; they are linked to the PSS (in this case the PSS of the RFTF) and can turn off the cavity if the measured dose/dose rate exceeds a pre-set level, so they protect against high dose rates in working areas. A permanently installed CMS is on the outside rear wall of the RFTF, it is fitted with an IG1 ion chamber which measures high energy photon radiation; this was also monitored during the surveys.

A member of Health Physics was generally present during the conditioning to monitor progress. When Health Physics were not present the RF group were permitted to run the cavity up to the power level of the last survey. At every increase of power, voltage and duty cycle, Health Physics cordoned off the area and performed a survey.

Thermo Luminescent Dosimeters (TLDs) were placed at various points around the interior of the RFTF in order to assess the areas of highest dose.

# 4. Results

## 4.1 TLDs placed around inside of RFTF

TLDs were placed in the RFTF for 24 hours on 5 consecutive days (22/2/10 to 26/2/10).
Blue highlighted results are in front of the lead shields, green highlighted results are behind the lead shields.

### Tables 1-5

**Day 1**

| Pos No | Sv |
|---|---|
| 25 | 0.034 |
| 26 | 0.056 |
| 27 | 0.246 |
| 28 | 0.061 |
| 29 | 0.043 |
| 30 | 0.057 |
| 31 | 0.044 |
| 32 | 0.065 |
| 33 | 0.209 |
| 34 | 0.059 |
| 35 | 0.005 |
| 36 | 0.139 |
| 37 | 1.610 |
| 38 | 0.008 |

**Day 2**

| Pos No | Sv |
|---|---|
| 25 | 0.024 |
| 26 | 0.053 |
| 27 | 0.099 |
| 28 | 0.025 |
| 29 | 0.020 |
| 30 | 0.025 |
| 31 | 0.020 |
| 32 | 0.027 |
| 33 | 0.100 |
| 34 | 0.049 |
| 35 | 0.004 |
| 36 | 0.105 |
| 37 | 0.753 |
| 38 | 0.003 |

**Day 3**

| Pos No | Sv |
|---|---|
| 25 | 0.057 |
| 26 | 0.125 |
| 27 | 0.243 |
| 28 | 0.063 |
| 29 | 0.046 |
| 30 | 0.064 |
| 31 | 0.047 |
| 32 | 0.068 |
| 33 | 0.247 |
| 34 | 0.124 |
| 35 | 0.011 |
| 36 | 51.200 |
| 37 | 1.500 |
| 38 | 0.008 |

**Day 4**

| Pos No | Sv |
|---|---|
| 25 | 0.017 |
| 26 | 0.059 |
| 27 | 0.110 |
| 28 | 0.027 |
| 29 | 0.023 |
| 30 | 0.025 |
| 31 | 0.022 |
| 32 | 0.031 |
| 33 | 0.113 |
| 34 | 0.056 |
| 35 | 0.005 |
| 36 | 17.600 |
| 37 | 0.772 |
| 38 | 0.003 |

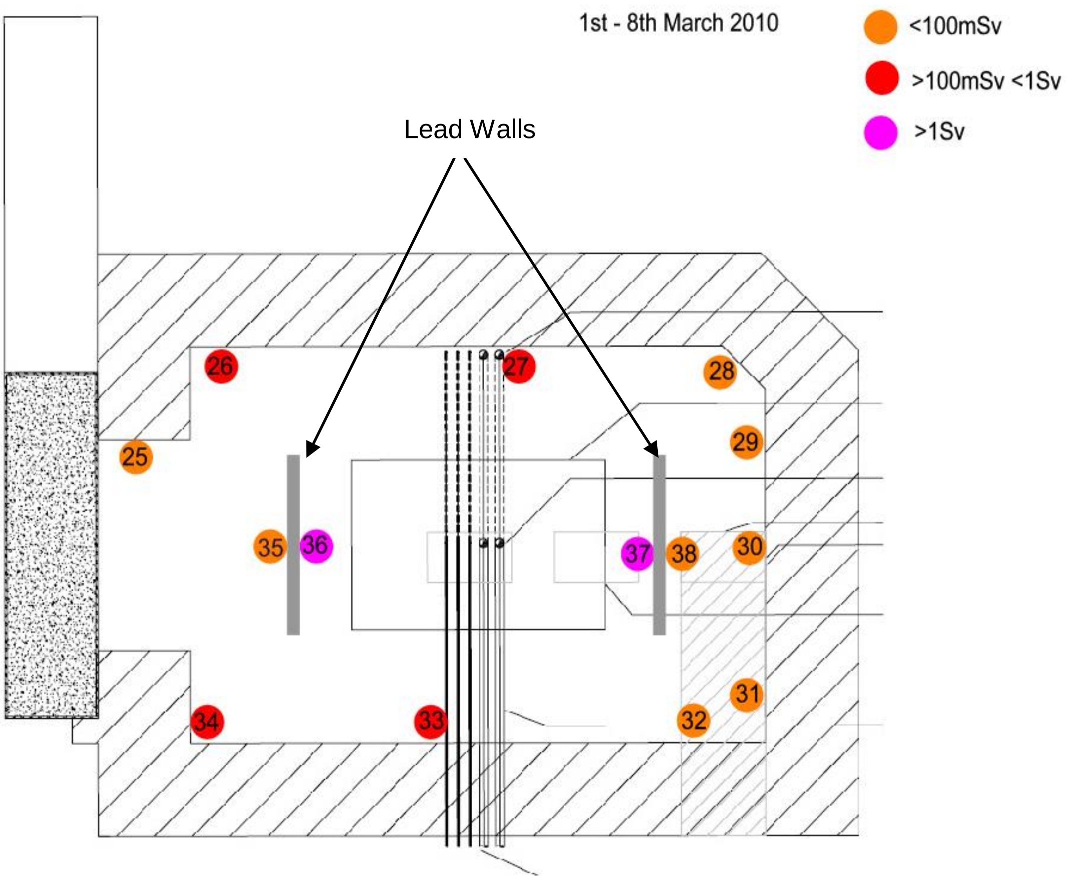
**Day 5**

| Pos No | Sv |
|---|---|
| 25 | 0.005 |
| 26 | 0.015 |
| 27 | 0.029 |
| 28 | 0.008 |
| 29 | 0.005 |
| 30 | 0.007 |
| 31 | 0.006 |
| 32 | 0.009 |
| 33 | 0.031 |
| 34 | 0.014 |
| 35 | 0.002 |
| 36 | 4.160 |
| 37 | 0.207 |
| 38 | 0.001 |

### Table 6 TLDs placed in RFTF for 7 days (1-8/3/10)

| Pos No | Sv |
|---|---|
| 25 | 0.030 |
| 26 | 0.112 |
| 27 | 0.198 |
| 28 | 0.050 |
| 29 | 0.040 |
| 30 | 0.045 |
| 31 | 0.041 |
| 32 | 0.061 |
| 33 | 0.210 |
| 34 | 0.109 |
| 35 | 0.009 |
| 36 | 85.900 |
| 37 | 1.220 |
| 38 | 0.006 |

**Figure 3: Plan view of RFTF and TLD positions**

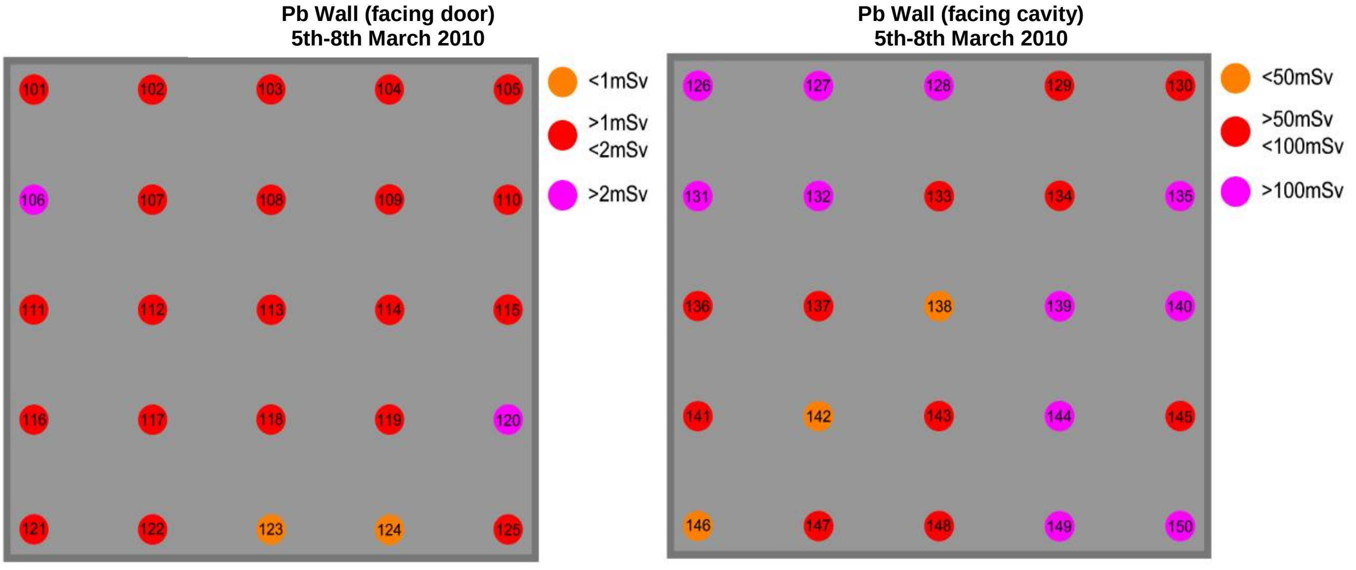


### 4.2 5 x 5 Matrix on lead wall at front of RFTF (front and back)

**Table 7**

| Pos No | Lead wall (facing door) mSv | Pos No | Lead wall (facing cavity) mSv | Reduction factor % |
|---|---|---|---|---|
| 101 | 1.35 | 130 | 87.50 | 6481 |
| 102 | 1.22 | 129 | 72.10 | 5910 |
| 103 | 1.32 | 128 | 112.00 | 8485 |
| 104 | 1.35 | 127 | 135.00 | 10000 |
| 105 | 1.49 | 126 | 100.00 | 6711 |
| 106 | 2.36 | 135 | 106.00 | 4492 |
| 107 | 1.36 | 134 | 91.80 | 6750 |
| 108 | 1.26 | 133 | 50.20 | 3984 |
| 109 | 1.21 | 132 | 110.00 | 9091 |
| 110 | 1.43 | 131 | 102.00 | 7133 |
| 111 | 1.31 | 140 | 119.00 | 9084 |
| 112 | 1.32 | 139 | 111.00 | 8409 |
| 113 | 1.19 | 138 | 39.20 | 3294 |
| 114 | 1.20 | 137 | 83.10 | 6925 |
| 115 | 1.42 | 136 | 90.60 | 6380 |
| 116 | 1.38 | 145 | 90.00 | 6522 |
| 117 | 1.07 | 144 | 102.00 | 9533 |
| 118 | 1.03 | 143 | 59.30 | 5757 |
| 119 | 1.08 | 142 | 48.80 | 4519 |
| 120 | 2.22 | 141 | 65.00 | 2928 |
| 121 | 1.04 | 150 | 103.00 | 9904 |
| 122 | 1.09 | 149 | 114.00 | 10459 |
| 123 | 0.89 | 148 | 76.20 | 8543 |
| 124 | 0.94 | 147 | 53.20 | 5636 |
| 125 | 1.06 | 146 | 41.10 | 3877 |

**Figure 4: Positions of TLDs on lead wall** (101 facing door corresponds to 130 facing cavity)



## 4.3 Dose surveys of outside of RFTF

**Table 8: Dose rate inside RFTF v Various areas outside RFTF.**

All measurements are in mSv/h (except CMS)

| Date | G64 | Under door/ service hatch | Door (front face) | Roof | Walls | CMS on rear wall μSv/h |
|---|---|---|---|---|---|---|
| 18/02/2010 | 30 | 0 | Bkgd | Bkgd | Bkgd | 0.67 |
| 19/02/2010 | 140 | 0.06 | Bkgd | Bkgd | Bkgd | 0.67 |
| 22/02/2010 | 1020 | 0.35 | Bkgd | Bkgd | Bkgd | 0.67 |
| 24/02/2010 | 2000 | 0.37 | Bkgd | Bkgd | Bkgd | 0.67 |
| 24/02/2010 | 3400 | 0.7 | 0.003 | Bkgd | Bkgd | 0.67 |
| 25/02/2010 | 6000 | 1.5 | 0.003 | Bkgd | Bkgd | 0.94 |

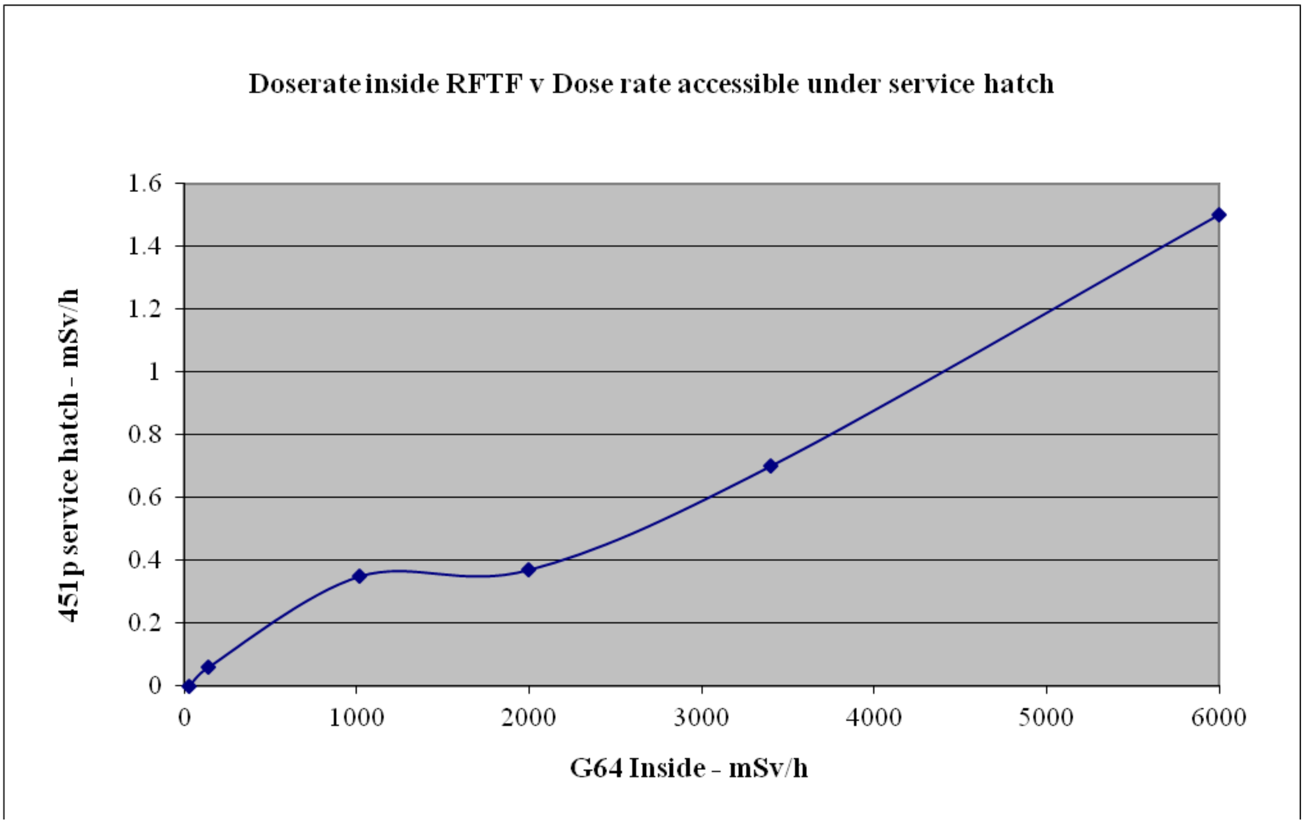



**Table 9 Dose rate inside RFTF v Dose rate at entrance to services chicane**

| Date | **G64** (mSv/h) | **Services chicane entrance** (mSv/h) | **Inside chicane (using Teletector)** (mSv/h) |
|---|---|---|---|
| 23/02/2010 | 1170 | 0.0095 | 19 |
| 24/02/2010 | 4170 | 0.01 | 19 |

All measurements (excluding the CMS, G64 and Teletector) were made using a Victoreen 451p ion chamber.

# 5. Analysis of results

## 5.1 TLDs placed around RFTF

These results confirm that the areas of highest flux (blue highlighted results) are at either end of the cavity. Positions 35 and 38 are on the other side of a lead wall (Indicated by the grey line). The results also show the doses experienced in other areas of the RFTF.

## 5.2 5 x 5 Matrix of lead wall at front of RFTF (Facing cavity and facing door)

These results show the importance of the lead wall in reducing the dose seen by the door and rear wall, this experiment was only carried out on the lead wall at the front of the cavity but it is reasonable to assume that similar results would seen for the lead wall at the rear of the cavity. It is important to stress that without the lead walls it is likely that unacceptably high dose rates would be seen outside the door and rear wall.

## 5.3 Dose surveys of outside of RFTF

The results show that the door, walls and roof give sufficient shielding at the highest dose rates measured.

The graph above shows an almost linear relationship between the dose rate in the service hatch under the door and the dose rate inside the RFTF. Normally these dose rates are not accessible but if someone was to remove the service hatch cover (which is outside the shielded area of the RFTF) while the RF cavity was in operation they could access dose rates in excess of 1mSv/h.

At dose rates >1 Sv/h (measured on the G64 at the cavity) the readings of the CMS show that there is some elevation in dose rate on the outside of the rear wall, the dose rate measured is not a cause for concern, however should the dose rate inside the RFTF rise considerably or the configuration of the shielding (especially the lead wall) change this could give rise to unacceptable dose rates. This again shows the importance of the lead walls at either end of the RF cavity.

Table 9 shows the dose rate at the entrance to the services chicane and where the chicane turns 90°. As the entrance to the services chicane is 4m above the ground, the dose rates at the entrance are not of great concern.

# 6. Conclusion/Actions

The surveys on the RFTF show that on the whole the shielding is sufficient provided the lead walls remain in place and the dose rates do not rise significantly. However there are several actions that need addressing.

It is understood that in order for the RF cavity to be removed from the RFTF (and a new cavity to enter) one of the lead walls will need to be removed, it is essential that this lead wall is replaced before conditioning of another cavity. It is recommended that the wall is placed under configuration control.

To reduce the dose rate under the service hatch a metal plate is going to be placed under the service hatch on which bags of lead shot will be placed, this should reduce the dose rate to an acceptable level. The plate, lead shot and service hatch cover will all be under configuration control. A survey of this area should be conducted when this has been completed.

The dose rates at the entrance to the service chicanes are not of great concern as they are 4m above the ground, however there are scissor lifts and mobile scaffolds in the area which could reach the entrance, because of this a permit to work system needs to be put in place if work at height around the service chicanes is to be carried out. Table 9 also shows the dose rates further down the chicane, this is not a problem for the two chicanes that are full of services but the chicane on the left could be entered, accessible dose rates of this level are unacceptable therefore a grille or similar obstruction under configuration control, must be placed at the entrance to the chicane as soon as possible.

## 7. Acknowledgments

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