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A12.6

Trinity College Dublin Direct Current and Near Direct Current Field Simulation Testing Survey Report

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LIST OF ACRYNOMS

EM	Electromagnetic
EMF	Electromagnetic fields
EMR	Electromagnetic Radiation
EMI	Electromagnetic Interference
DC	Direct Current
AC	Alternating current
RF	Radiofrequency

1.0 Introduction

As part of stakeholder consultations, and with the intention of informing the Environmental Impact Assessment Report for MetroLink, CEI liaised with the University Departments, Institutes and groups from within Trinity College who had outlined concerns in relation to potential EMI with their equipment from the proposed MetroLink development.

An equipment list was obtained from Trinity College in which buildings and equipment potentially sensitive to EMI were outlined. Further equipment information was obtained in follow up visits to the Trinity campus in February and March 2019.

CEI conducted modelling of worst-case DC magnetic fields that would be generated by the proposed Metrolink at distances of 0 to 100 m from the alignment. These levels were compared with the technical specifications for the equipment that is installed at the various locations around the campus. The results of the findings are presented in detail in report 19E7900-1. In summary, the majority of electronic, mechanical and electromechanical equipment within the Trinity campus is inherently immune to DC magnetic perturbations with the exception of the specific equipment that was identified and will be addressed herein.

The table below outlines this equipment, their locations, sensitivities and the modelled DC magnetic field levels from the proposed development.

Table 1: Equipment sensitive to DC and near DC fields

Building Name	Equipment	Current DC Field fluctuations	Sensitivity	Modelled levels
SNIAM	SQUID machine	± 0.7 µT	0.01 µT	2.75 µT
Chemistry	Three NMRs	± 0.1 µT	0.5 µT (DC) 0.2 µT (AC)	10-14 µT (DC) 0.14-0.2 µT (AC)
Lloyd Institute	Two MRI Systems	± 0.2 µT	1 µT*	1.5 µT
Panoz (EE4)	Three SEMs	± 0.15 µT	0.1 µT	0.8 µT

It has been CEI's experience that despite manufacturer stated sensitivities certain equipment once installed may withstand field variations slightly above those specified depending on the nature of the equipment's use and the operator programmable parameters typically used during scans.

Therefore, it was proposed to simulate the modelled worst-case DC magnetic field levels depicted in Table 1 at these equipment locations to determine if the stated sensitivity was accurate. Although some scan setups may not be sensitive to interference (such as low-resolution scans for example), we requested that the most sensitive settings possible be used during the testing to ensure that we achieved as close to worst-case as possible.

After discussions with Trinity College, it was agreed to test one piece of equipment at the following locations –

Table 2: Equipment sensitive to DC and near DC fields

Building Name	**Equipment Type**
Panoz (EE4)	SEM
Lloyd Institute	MRI
Chemistry	NMR
CRANN	STM
SNIAM	SQUID

Note: The STMs at CRANN had previously been scoped out of this assessment as per report 19E7900-1 but were re-added to this test programme at the request of CRANN.

For illustration, the image below shows the proposed alignment with respect to the locations of the equipment listed in Table 2, along with some other equipment types that were previously scoped out by CEI.

Note: the circled locations being positions where CEI conducted baseline measurements which are again reported in 19E7900-1.

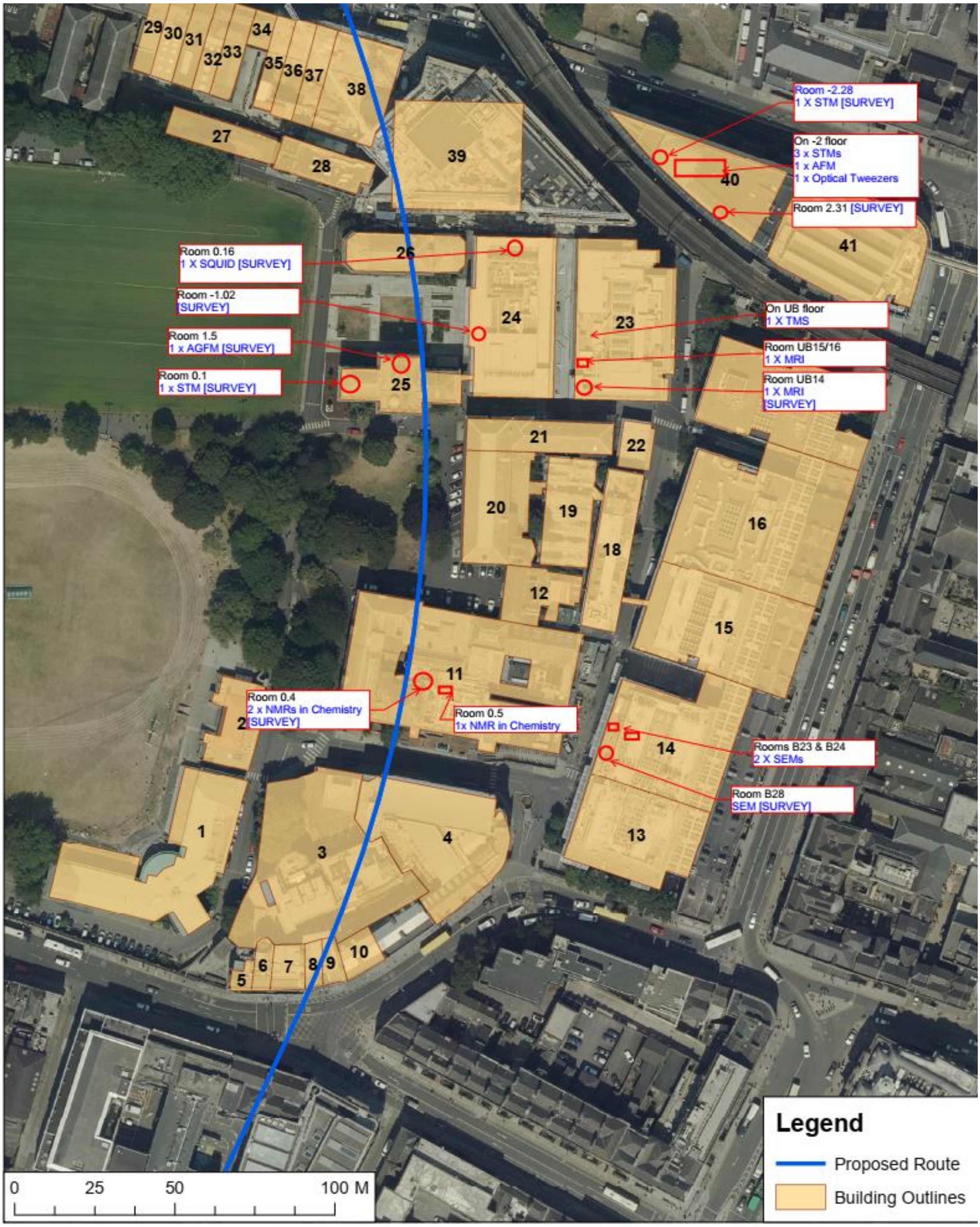

Figure 1: Equipment locations and measurement locations within Trinity College Dublin

2.0 Test Methodology

Varying DC magnetic fields were simulated at each of the test locations using a Helmholtz coil and variable DC current source with the transducers of the equipment under test located within the magnetic field region between the two coils.

A setup similar to the image below was typical, with the equipment under test located between the two loop antennas:

Figure 2: Helmholtz Coil

A static DC magnetic field could be created by applying a constant current; however, this would not truly reflect the profile of an electric train drawing current from an overhead line. The current (and therefore magnetic field) profile of such an event is quasi DC in nature in that it is a DC current but varies over time. A typical magnetic field profile from a Luas for example is shown in Figure 3 as it passed the measurement location.

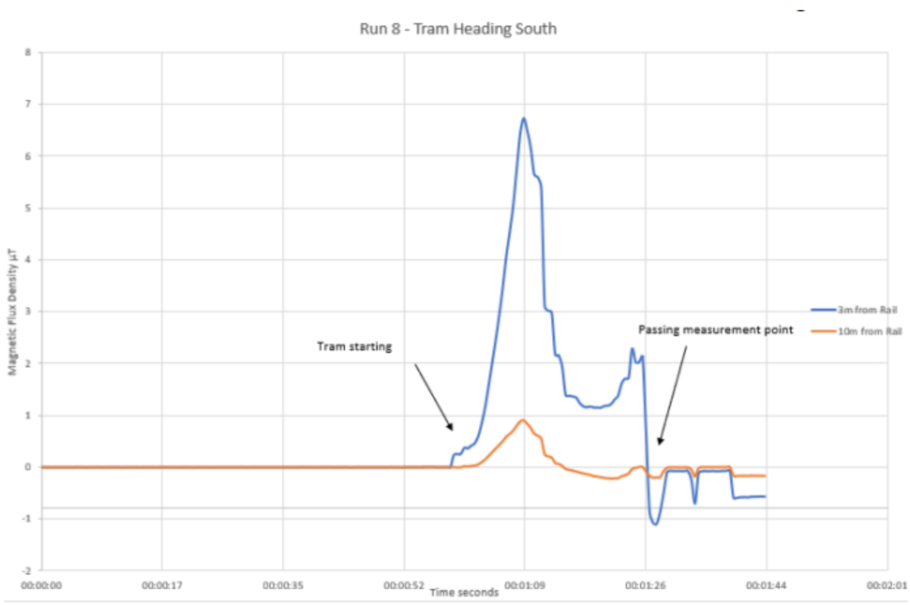

Figure 3: Magnetic flux profile of Luas passing measuring point at 3 m and 10 m distance

So, to simulate a profile similar to the above, the DC current source powering the Helmholtz coil was varied over a period of a few seconds while the equipment under test was operated normally.

The magnetic field was calibrated for each test location using a 3-axis magnetometer (Meda FM-300).

3.0 Field Simulation Results

3.1 PANOZ – Centre for Microscopy and Analysis

Equipment identified as having the potential for impact from the proposed development:

Equipment	Current DC Field fluctuations	Sensitivity	Modelled levels
Three SEMs	± 0.15 µT	0.1 µT	0.8 µT

The environmental specification for the TESCAN Mira3 SEM which was received from Trinity College stated the following: -

> 3) <u>The magnetic field:</u> to obtain the specified microscope performance, the magnetic field in the room must not exceed values below while the microscope is in operation:
> Synchronous magnetic field: <3 × 10^{-7} T
> Asynchronous magnetic field: <1 × 10^{-7} T

which equates to a magnetic field susceptibility of 0.1 µT. A similar sensitivity would be expected for the other SEMs within the CMA/iCRAG department.

DC magnetic field fluctuations of 0.1 to 0.15 µT were seen to occur during the previous baseline monitoring period. So, the equipment was already operating slightly outside the manufacturers recommended magnetic environmental specifications. However, modelling of the proposed MetroLink development suggested slightly higher levels of 0.8 µT could occur at this distance (63 m from the proposed alignment approximately). Therefore, it was necessary to apply this field level to the equipment to determine if any impact would be observed by the machine operators.

The setup at this location is depicted below, with the field applied to the Tescan S8000 Mira 4 in room B28.

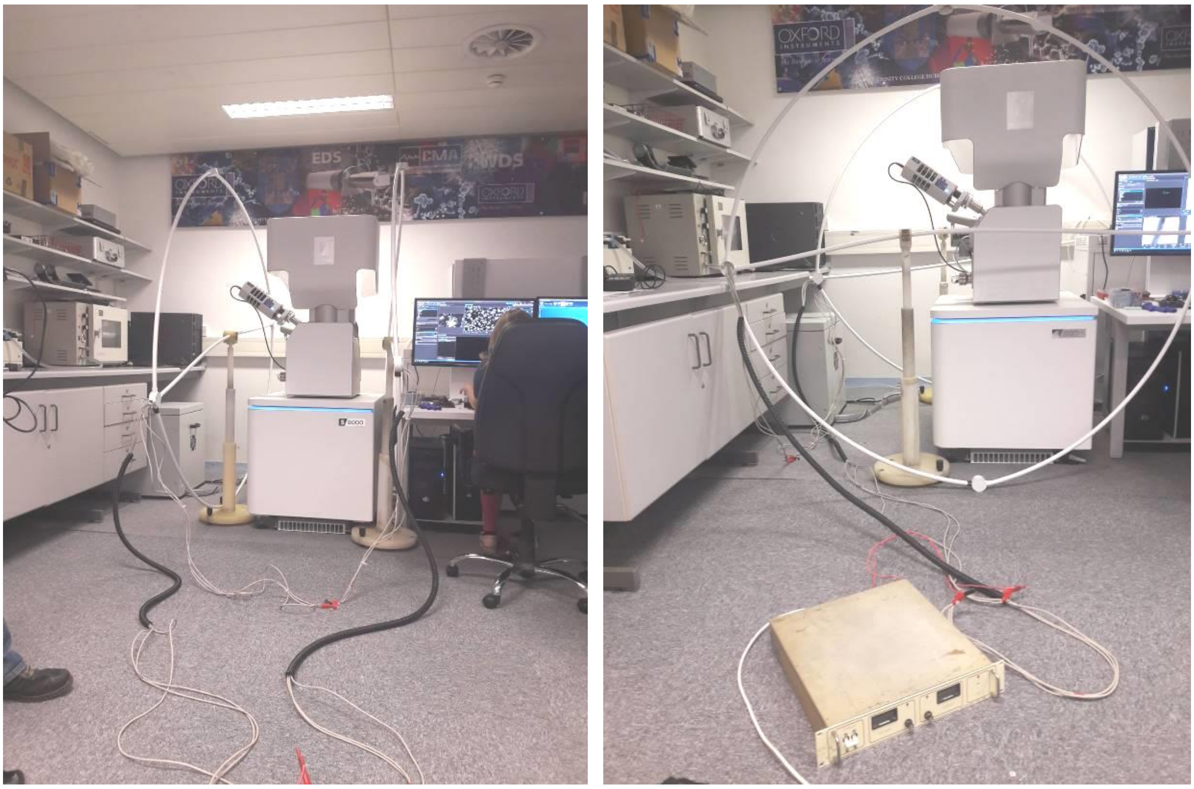

Figure 4: Test setup at SEM
Left - Loop orientation for perpendicular field application
Right - Loop orientation for parallel field application

As agreed with the equipment operators, a scan of a cobalt sample was setup at 200,000 times magnification. Figure 5 shows the baseline scan results without the field being applied while Figure 6 shows the result of applying a varying 0.8 µT field. Through discussions with the staff it was initially assumed that the orientation of the field would not have an impact on the type of affect expected. Initially, the field was applied perpendicularly to the modelled field lines as seen in the left image of Figure 4 above. A very noticeable effect was seen through varying the 0.8 µT field as depicted in the left-hand image of figure 6.

For accuracy however, it was decided to then apply the field in the correct orientation (i.e. parallel to the modelled magnetic lines of flux. Therefore, the loops depicted in figure 4 were moved though 90 ^{o} and the varying 0.8 µT field was re-applied. An effect was still seen, albeit less severe to the perpendicular field. Horizontal, scan lines were still seen, that were not present in the initial baseline image.

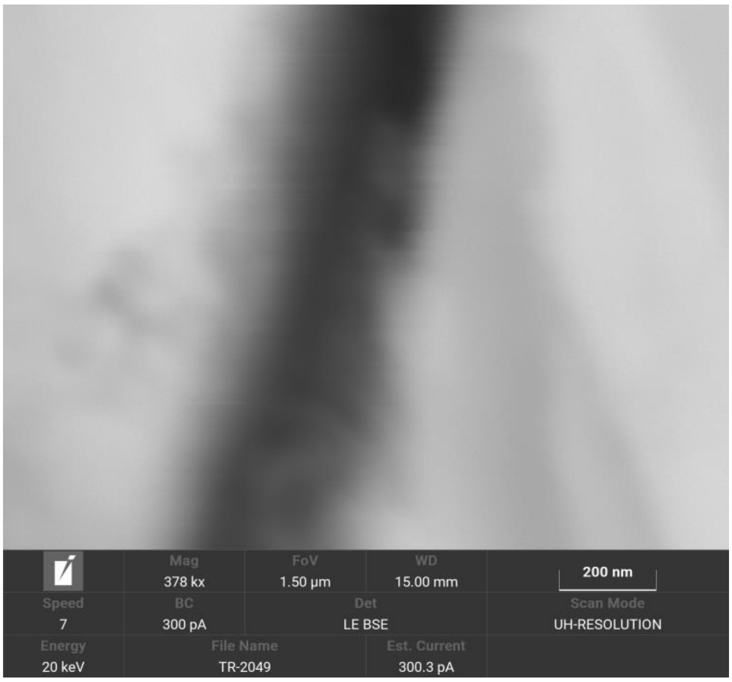

Figure 5: Baseline scan of Cobalt sample before application of field

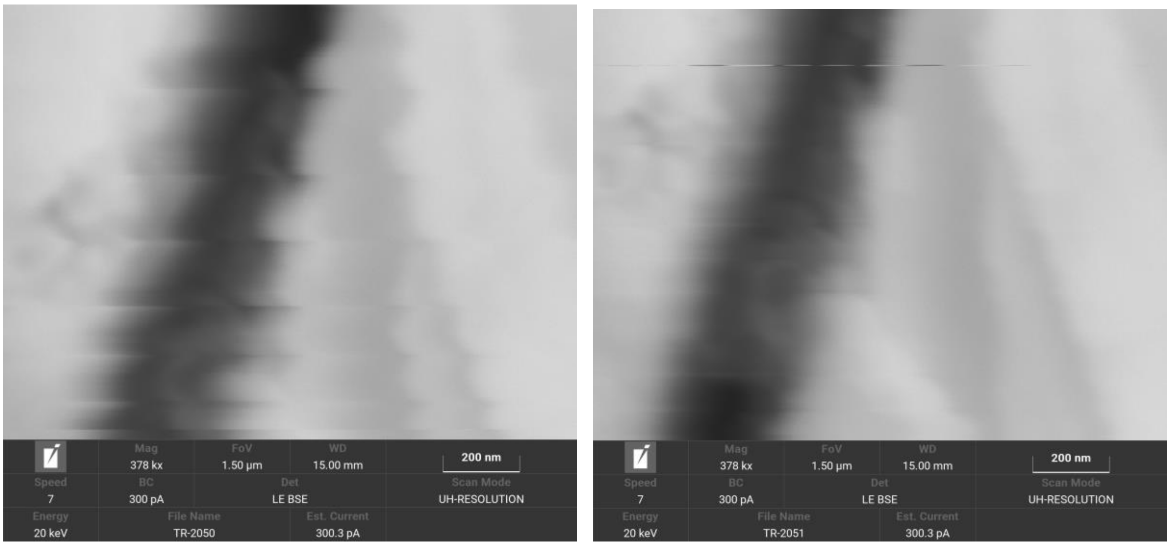

Figure 6 : Test result

Left: Varying field applied perpendicular to proposed alignment

Right: Varying field applied parallel to proposed alignment

3.2 Lloyd Building/TCIN - MRIs

Equipment identified as having the potential for impact from the proposed development:

Equipment	Current DC Field fluctuations	Sensitivity	Modelled levels
Two MRI Systems	± 0.2 µT	1 µT*	1.5 µT

No environmental specification was previously received in relation to the two MRIs but a typical sensitivity of 1 µT was assumed, which placed the modelled levels of 1.5 µT in excess of this. It was therefore deemed necessary to apply DC magnetic field fluctuations at this level to the equipment while in operation to determine if any impact would manifest itself.

The setup at this location is depicted below, with the field applied to the 3 Tesla MRI scanner as the 7 Tesla was out of commission on the day of our visit.

Figure 7: Test application at the 3 Tesla MRI

The operator performed a routine scan run of 5 minutes duration with 2 seconds per scan. A reference artefact was used for the scan.

It was noted that the operator was instructed to switch off the filtering of the machine for this testing. Due to time constraints around the availability of the machine, it was only possible to perform the test unfiltered to see what impact, if any it's disengagement would have had on the test results.

Figure 7 compares the baseline to the test scans. Although the contrast of the two images differs, that was not the actual impact of the varying field since the operator varied the image contrast post-scan to best view the results. The actual effect that can be seen in the right-side image where curved lines can be have appeared, most prominently in the lower section of the image.

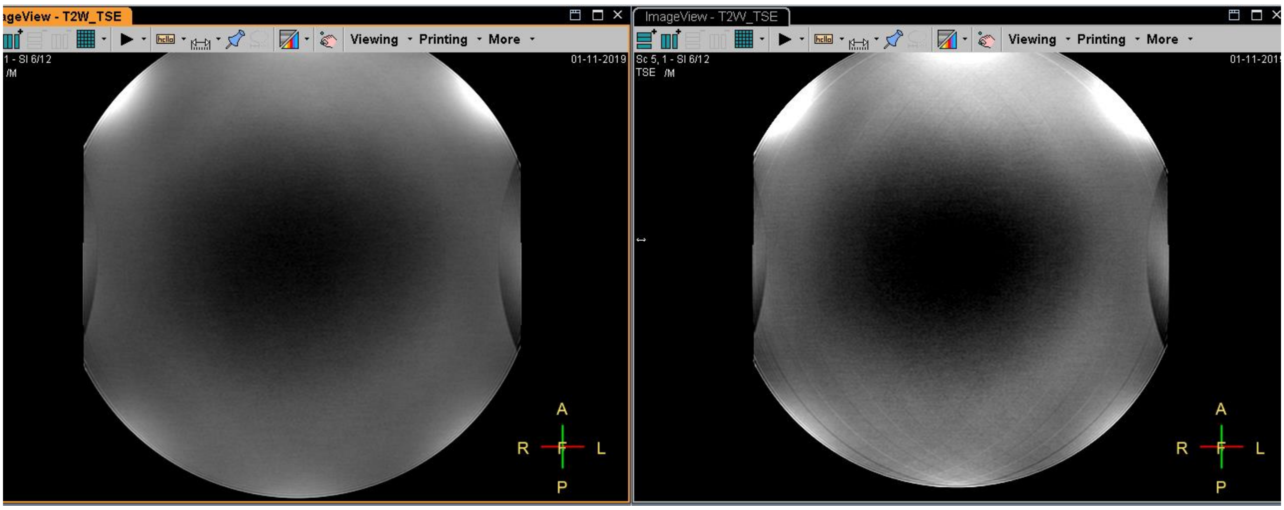

Figure 8: Baseline scan of test artefact (right) versus scan with varying DC field applied

3.3 Chemistry - NMR machines

Equipment identified as having the potential for impact from the proposed development:

Equipment	Current DC Field fluctuations	Sensitivity	Modelled levels
Three NMRs	± 0.1 µT	0.5 µT (DC) 0.2 µT (AC)	10-14 µT (DC) 0.14-0.2 µT (AC)

During CEI’s previous visit to the Chemistry department it was noted to house three Nuclear Magnetic Resonance (NMR) machines. Examination of the environmental specifications from one of the NMRs manufacturers established that it had a stated sensitivity to DC magnetic field levels of 5 mG which equates to 0.5 µT. This specification is illustrated below:

Guidelines: DC Interference **12.1.3**

When determining the effect of fluctuating magnetic fields, two parameters are important: the size of the fluctuation and the rate of change (gradient).

- **Field changes of between 0-5 mG**, regardless of the gradient, are generally considered harmless for standard NMR work. Likewise with UltraShield magnets (only), field changes up to 10 mG are considered harmless. The effect of such changes would be observable in only the most critical of experiments such as NOE difference experiments.
- For field changes **larger than 5 mG** the lock system will compensate the fluctuation, as long as the gradient is less than 5 mG/sec. (10 mG for UltraShield magnets, 50 mG for UltraShield Plus magnets).
- For field gradients **greater than 5 mG per second** (10 mG for UltraShield magnets, 50 mG for UltraShield Plus magnets), NMR performance may be affected.

Table 12.1. lists the minimum distances between the source of interference and the magnet center.

Table 12.1. Minimum Distances from Electromagnetic Interference Sources.

Source of Interference	Recommended Minimum Distance from UltraShield Magnet	Recommended Minimum Distance from UltraShield PLUS Magnet
DC Trams, subways*	100 m	80 m
Elevators, fork-lifts**	8 m	6 m
Mass spectrometer (slow ramp)	10 m	8 m
Mass spectrometer (sudden fly-back)	30 m	24 m

* **Trams and subways are also a source of vibrational interference** (refer to section *"Vibrations" on page 61*).
** Depends on the lift geometry and material. These specifications may vary.

Our previous baseline measurements determined that the equipment was working in a relatively quiescent environment with maximum DC magnetic field fluctuations of only 0.1 µT measured. Our modelling indicates that at this distance from the proposed alignment (3-9 metres) the different NMRs could experience field fluctuations of 10-14 µT. It was therefore necessary to simulate these field levels at the equipment locations to determine if the sensitivity was as stated. The testing was performed at the largest of the NMRs (the 14T Bruker 600/54 US), which was also the closest to the alignment and therefore the one that will be exposed to the highest DC field levels. The equipment contained a supercooled electromagnet that required the use of liquid helium. The operator was concerned about the test setup and its proximity to some of the cooling circuit joints for the liquid helium. He was very familiar with the equipment itself and knew the exact location of the internal magnet and scanning sensor, so instead of using the Heltholtz coil at this location a standalone loop antenna was utilised. This was calibrated remotely from the NMR due to the high static field emanating from the NMR itself. The test setup is depicted in Figure 9.

Figure 9: Test application at the NMR

The results of applying the time varying field application were noted to decrease the resolution of the scan being performed. Figure 10 shows the baseline scan on the top with the repeat scan under the influence of the time varying field below. The detail in the scan can be clearly be seen to have diminished with the side lobes of the baseline plot no longer evident. In effect the overall resolution of the scan was impacted by the application of the field.

Hydrogen NMR (nuclear magnetic resonance) spectrum taken from a Bruker 600 MHz AV II spectrometer in room 0.4 Chemistry Building Trinity College Dublin

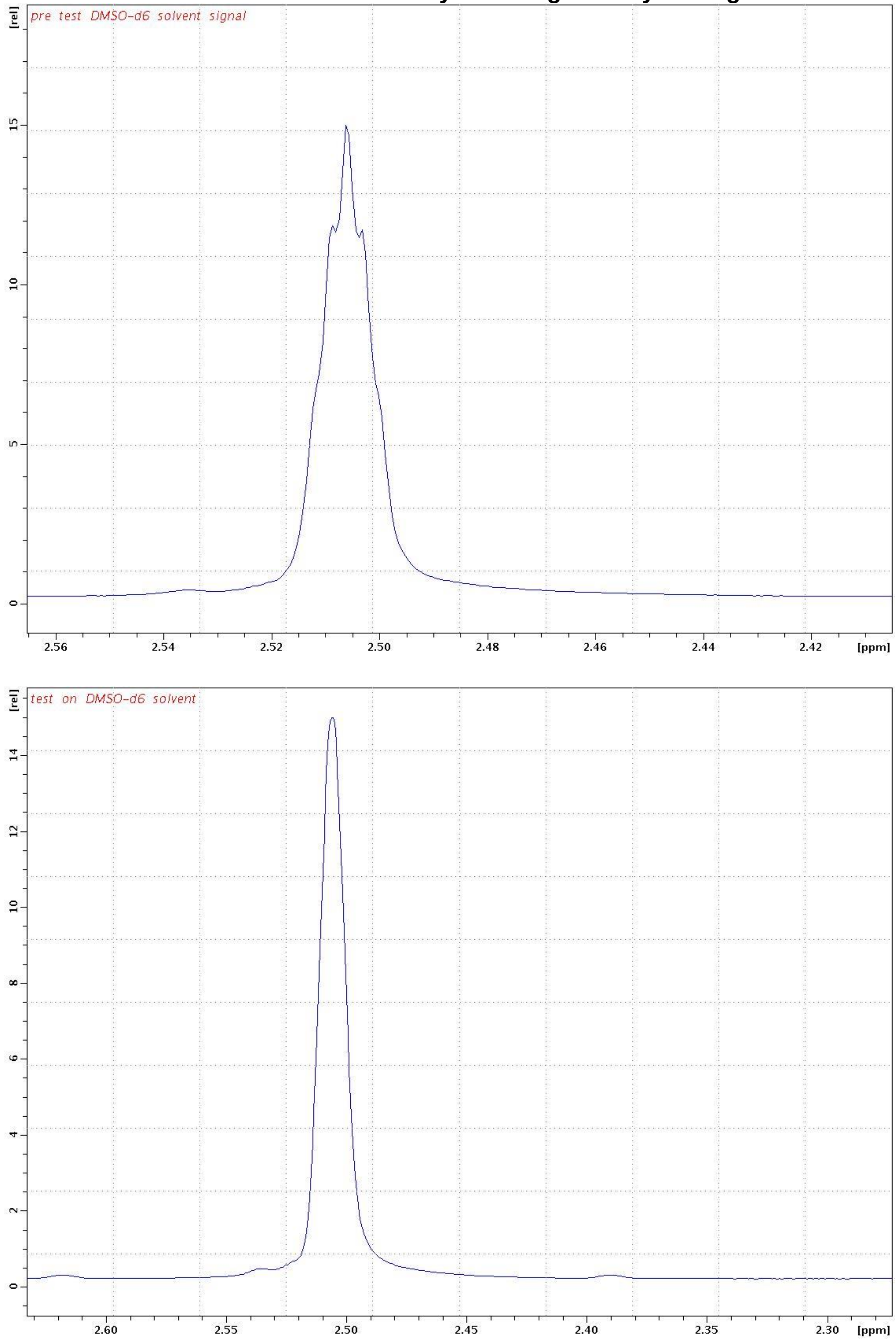

Figure 10: Results of test application to NMR

3.4 SNIAM Building - SQUID

Equipment identified as having the potential for impact from the proposed development:

Equipment	Current DC Field fluctuations	Sensitivity	Modelled levels
SQUID machine	± 0.7 µT	0.01 µT	2.75 µT

During CEI's previous visit to the SNIAM building the equipment identified with the highest likelihood of being impacted by magnetic fields arising from the proposed development was the Superconducting Quantum Interference Device (SQUID) in room -0.16. It had a specified sensitivity of 0.01 µT but was already operating to an acceptable level in its current environment, with DC fluctuations of 0.7 µT noted during our short baseline measurement period. However, the worst-case modelled levels indicated possible field levels of 2.75 µT so it was decided to simulate this field variation at the equipment to determine if it generated an impact on the SQUIDs performance. Figure 11 shows the setup.

Figure 11: Test application at the SQUID

A baseline scan had previously been performed with each datapoint taking approximately 30 seconds to generate. A full scan would have taken several hours with datapoints collected as the applied magnetic field of the SQUID cycled between 2 Tesla and -2 Tesla. After discussions with the equipment operators it was agreed that any impact would be seen immediately on any new datapoints generated so a test time of 10 minutes was applied and 30 datapoints were generated while applying the varying DC field. Figure 12 shows comparative plots of these datapoint sets for the baseline scan on the left and the tested scan on the right. The scan was run for 5 datapoints before the DC field began to be varied. No impact was seen by the equipment operators during the testing.

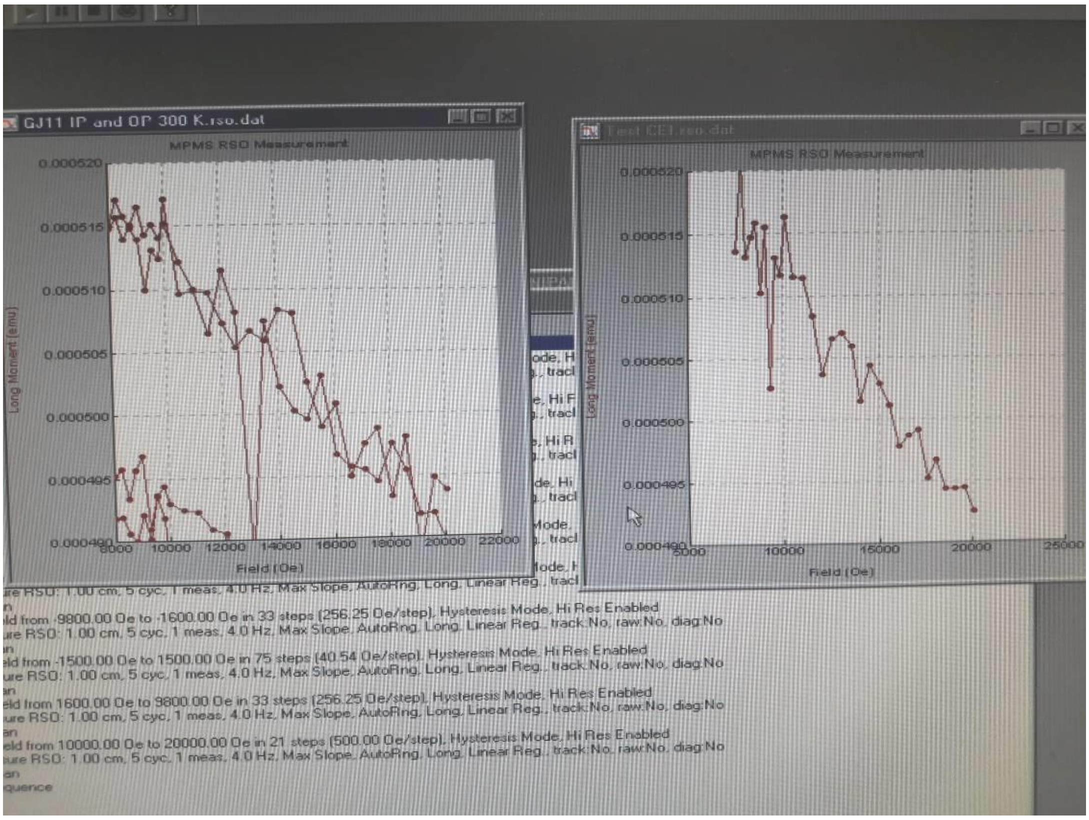

Figure 12: Results of test application to SQUID

Further discussions with the equipment operators determined that they would not have anticipated to see affects from the DC and quasi DC magnetic field application. Their primary concern centres around low frequency harmonics, which would be at multiples of the fundamental 50 Hz frequency for example harmonics at 100, 150, 200, 250 Hz etc.

3.5 CRANN Building

No equipment had been previously identified in the CRANN building that had the potential to be impacted by time varying DC magnetic fields from the proposed development. However, at the request of the CRANN it was agreed to apply the same field simulation testing as was being performed at the other locations on Campus to provide as a means of verifying that conclusion. The CRANN building houses several types of scanning equipment, the most sensitive of which would be their Scanning Tunnelling Microscopes. However, these would be more prone to interference from vibrations than DC magnetic fields. It was decided to apply the modelled magnetic field of 0.5 µT to one of the STMs installed in the basement of the building, floor -2, a Createc STM. The setup is shown in Figure 13.

Figure 13: Test application at Createc STM

A copper sample was analysed using a routine scan procedure lasting 10 minutes. A baseline scan was performed first followed by a scan during which the time vary DC magnetic field was applied. As anticipated, no impact was noted by the operator. The results of both scans are shown in Figure 14 with the baseline scan on the left-hand side and the comparable test scan on the right-hand side.

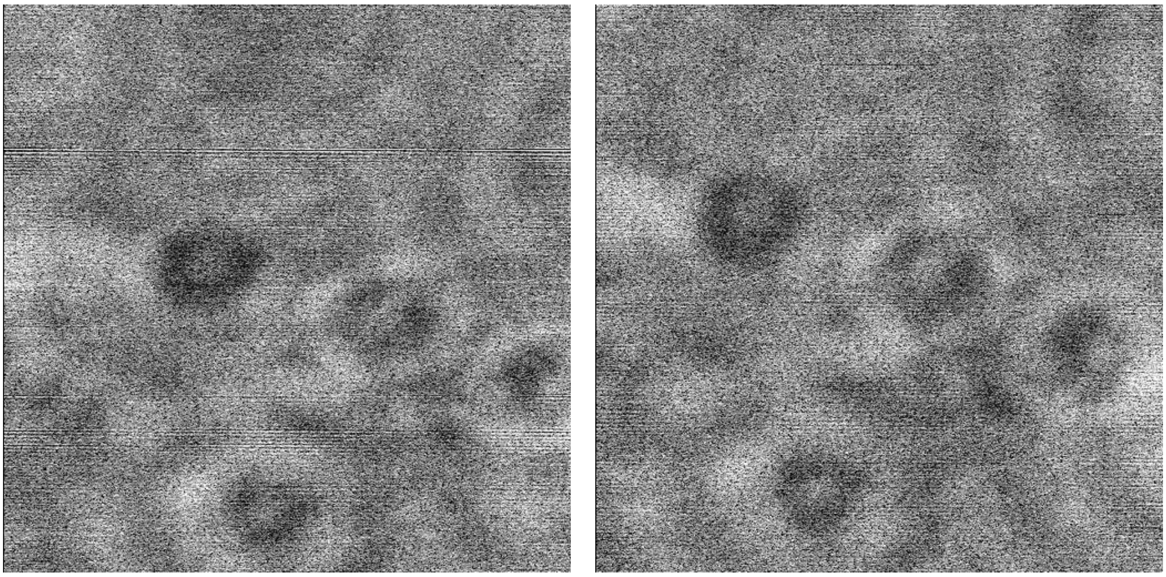

Figure 14: Results of test application to STM

4.0 Conclusions

Of the equipment tested impacts were noted at the following –

- SEMs in the Centre for Microscopy Analysis (PANOZ building)
- MRI machines in Lloyd building
- NMRs in Chemistry

No impact was noted at the STM in the CRANN building or the SQUID in SNIAM.

Mitigation will need to be employed to address the issues with the affected pieces of equipment. The following solutions are currently available:

1. Use of a compensation conductor
2. Active cancellation
3. Shielding

4.1 Compensation Conductor

The use of a compensation conductor (modelled here at 0.5 m from the overhead line) could have the following effect for these equipment locations

Table 3: Use of a compensation conductor

Equipment	Current DC Field fluctuations	Sensitivity	Modelled levels without compensation	Modelled levels with compensation
Three NMRs (3-9 m distance)	± 0.1 µT	0.5 µT (DC) 0.2 µT (AC)	**10-14 µT (DC)** **0.14-0.2 µT (AC)**	**1.2-1.8 µT (DC)** **0.018-0.026 µT (AC)**
Two MRIs (40 m distance)	± 0.2 µT	1 µT*	**1.5 µT**	**0.16 µT**
Three SEMs (63 m distance)	± 0.15 µT	0.1 µT	**0.8 µT**	**0.07 µT**
SQUID machine (34 m distance)	± 0.7 µT	0.01 µT	**2.75 µT**	**0.29 µT**

The proximity of the compensation conductor to the overhead line directly affects how successfully the counter magnetic field cancels the drive current from the system. A distance of 0.5 m between the overhead line and a theoretical compensation conductor is used here for demonstration purposes.

As can be seen, the flux density at the NMRs would still be above impact levels and thus additional mitigation would still be required. However, the MRIs and SEMs could be removed from the list of impacted equipment.

Meanwhile, although no impact was seen during testing of the SQUID both the modelled levels and the modelled impact levels are still above the sensitivity value used. As discussed in Section 3.4 a sensitivity of 0.01 µT was used. Also, discussion with the equipment operators revealed that they are more concerned with low frequency harmonics as opposed to quasi DC fields. Further information has been requested to establish the exact field intensity levels at which they would be concerned about for these frequencies. Reading some of the literature for the equipment obtained already, it states the following -

"*The second-derivative configuration strongly rejects interference from nearby magnetic sources and lets the MPMS function without a superconducting shield around the pickup coils.*"

The SQUID is almost equidistant from the DART and the proposed development. It is likely to already be experiencing levels from the DART that would exceed those emitted from the proposed development. Particularly if it were installed with a compensation conductor the risk of a potential impact on the SQUID at DC, quasi DC and low frequency levels could be greatly reduced, if not eliminated entirely. However, to make a definitive judgement on this the manufacturers declared susceptibility should be established.

The options of active cancellation and shielding will need to be explored in more detail for all the equipment in table 3 if a compensation conductor is not integrated into the track design beneath the Trinity campus.

It may still be necessary to apply further mitigation regardless of utilising a compensation conductor for the NMRs in Chemistry.

4.2 Active Cancellation and Shielding

Active cancellation systems operate on the basis of responding to a changing magnetic field, whereby the system generates a counter field to cancel out fluctuations as they occur. The response time of such a system has been cited as a cause of concern by some of the technical experts at Trinity, in previous meetings, so if such a system was decided to be adopted then the speed of cancellation versus the equipment acquisition rate would need to be scrutinised, to the point of field testing the application for effectiveness.

The final solution would be the installation of fixed shielding, a solution some of the departments and institutes at Trinity are already familiar with. The Scanning Transmission Microscope at the Advanced Microscopy Lab (AML), for example, has a sensitivity of 6 nT or 0.006 µT and has already been installed in a double shielded room constructed from Mu-metal.