Our Case Number: ABP-314724-22

Your Reference: Trinty College Dublin

An Bord Pleanála

Declan Brassil and Company Ltd.
Lincoln House
Phoenix Street
Smithfield
Dublin 7
D07 Y75P

Date Paid ....
Voucher No. ....
Cheque No. ....

Date Paid 15/12/2022
Voucher No. 1083/22
Cheque No. 40072

Date: 15 DEC 2022

Re: Railway (Metrolink - Estuary to Charlemont via Dublin Airport) Order [2022]
Metrolink. Estuary through Swords, Dublin Airport, Ballymun, Glasnevin and City Centre to Charlemont, Co. Dublin

Dear Sir / Madam,

An Bord Pleanála has received your recent submission and oral hearing request (including your fee of €100) in relation to the above-mentioned proposed Railway Order and will take it into consideration in its determination of the matter.

The Board will revert to you in due course with regard to the matter.

Please be advised, there is no fee for an affected landowner, listed on the schedule, to make an observation on this case. Further note, there is no fee required to request an oral hearing therefore, a cheque refund of €100 is enclosed.

The Board has absolute discretion to hold an oral hearing in respect of any application before it, in accordance with section 218 of the Planning and Development Act 2000, as amended. Accordingly, the Board will inform you on this matter in due course.

Please be advised that copies of all submissions/observations received in relation to the application will be made available for public inspection at the offices of the relevant County Council(s) and at the offices of An Bord Pleanála when they have been processed by the Board.

More detailed information in relation to strategic infrastructure development can be viewed on the Board's website: www.pleanala.ie.

If you have any queries in the meantime, please contact the undersigned. Please quote the above mentioned An Bord Pleanála reference number in any correspondence or telephone contact with the Board.

Yours faithfully,

Niamh Thornton
Executive Officer
Direct Line: 01-8737247

RA05

Declan Brassil + Company

Declan Brassil & Company Ltd.
Lincoln House
Phoenix Street
Smithfield
Dublin 7
D07 Y75P
Ireland

T: (01) 874 6153
W: dbcl.ie

An Bord Pleanála
64 Marlborough Street
Dublin 1
D01 V902

25 November 2022

Re: MetroLink – Railway (MetroLink – Estuary to Claremont via Dublin Airport) Order 2022

Submission made on behalf of Trinity College Dublin

ABP Ref.: NA29N.314724

Dear Sir/Madam,

Please find enclosed a submission on behalf of Trinity College Dublin, the University of Dublin ('Trinity') in respect of the application for approval made by TII for the MetroLink Project under the Transport (Railway Infrastructure) Act 2001, as amended.

This submission has been prepared on behalf of Trinity by Declan Brassil & Co., Lincoln House, Phoenix Street, Smithfield Dublin 7 in conjunction with Arup International Projects Ltd. and CECL Global.

Enclosed herewith is a cheque in the amount of €50 as the appropriate fee for making a submission in respect of a draft Railway Order.

We would also like to formally request that An Bord Pleanála holds an Oral Hearing in respect of the draft Railway Order. Accordingly, a separate cheque in the amount of €50 is submitted herewith as the appropriate fee for requesting an Oral Hearing.

An electronic copy of the submission has been enclosed for convenience.

We trust that the Board will afford due regard to the matters raised in the enclosed submission and we look forward to a favourable outcome.

Yours faithfully,

Declan Brassil
Declan Brassil & Co. Ltd

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List of Abbreviations

Acronym	Meaning
ACS	Active Cancellation System
AFM	Atomic Force Microscope
AGFM	Alternating Gradient Field Magnetometer
AMBER	Advanced Materials and Bio Engineering Research
CAMI	Centre for Advanced Medical Imaging
CRANN	Centre for Research on Adaptive Nanostructures and Nanodevices
CSET	Centre for Science, Engineering and Technology
EEG	Electroencephalogram
EIAR	Environmental Impact Assessment Report
EM	Electromagnetic
EMF	Electromagnetic Fields
EMI	Electromagnetic Interference
HRB	Health Research Board
iCRAG	Irish Centre for Research in Applied Geosciences
ITC	Information Communication Technology
MRI	Magnetic Resonance Imaging
NMR	Nuclear Magnetic Resonance
RAMS	Reliability, Availability, Maintainability and Safety
SEM	Scanning Electron Microscopes
SFI	Science Foundation Ireland
SNIAM	Sami Nasr Institute for Advanced Materials
SQUID	Superconducting Quantum Interference Device
STM	Scanning Tunnelling Microscope
TBM	Tunnel Boring Machine
TCD	Trinity College Dublin
TCIN	Trinity College Institute of Neuroscience
TII	Transport Infrastructure Ireland
TMS	Transcranial Magnetic Simulation
UHV AFM	Ultra High Vacuum Atomic Force Microscope
XPS	X-ray Photoelectron Spectroscopy

1.0 INTRODUCTION

This submission is made on behalf of Trinity College Dublin, the University of Dublin ('Trinity') in respect of the application for approval made by TII for the MetroLink Project under the Transport (Railway Infrastructure) Act 2001, as amended (the '2001 Act').

1.1 Background and Context

Trinity is a world-leading University and research centre. The University's CORE Mission is centred on Civic action, Organisation, Research and Education, expressed in its Vision Statement as follows:

'We are a globally connected community of learning, research, and scholarship, inspiring generations to meet the challenges of the future'.

The primary aims of the University's Strategic Plan 2020-2025 are to deliver its academic priorities as effectively and efficiently as it can and to continue to develop world-leading educational and research facilities to secure the status of the University among the top 100 globally ranked universities. Trinity's 'Living Research Excellence Strategy'[1] acknowledges the expansive nature of research undertaken at the University[2] and the role of all staff and students in striving for excellence in the future of research. The Strategy sets out the high-level actions to continue to promote and carry out research, stating:

> *"Research is an essential part of what we do in Trinity. We are driven by a passion for research and scholarship. Our research has a fundamental influence on our teaching. Research, along with teaching, forms our identity. It is one of the factors that makes Trinity the leading university in Ireland. And our standing in the research world contributes significantly to our international reputation. With the right supports and the freedom to act, we as researchers can continue to make enormous contributions to knowledge and significant breakthroughs that will have great impact upon the world and humanity."*

The Strategy states that *"Trinity is 427 years old. It has stood the test of time"*, and that *"[w]e work in a time of great opportunities, great threats, and great change. We need to ensure great research happens, no matter what."*

The Dublin City Development Plan acknowledges and supports the contribution and importance of Trinity to education, research and innovation at national and global levels; to the city and national economy; to the cultural life and heritage of the city; and, to the importance of protecting and promoting the international reputation and attractiveness of the University.

Trinity acknowledges the potential contribution of the MetroLink project to the civic and economic life of the city, to sustainable transportation, and to climate change and adaptation objectives. Trinity does not object to the principle of the MetroLink or an alignment of the MetroLink project beneath its campus, and supports the development of a rail link that eliminates all likely significant effects on sensitive receptors on Trinity's Campus by effective measures that are demonstrably practical and effective.

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[1] Attached as **Appendix A**

[2] Total research income has exceeded €100 million each year for the past 5 years and contributes over 25% of total income. Details of research projects and awards are presented in Table 2.1, below, and Section 2.1.

Given the significant importance of the project to the University and the city, Trinity engaged proactively with TII over the period commencing March 2018 to current date[3] to assist TII and its consultants in identifying likely significant negative effects, in particular, on sensitive equipment used in Trinity arising from Electromagnetic Interference (EMI) and ground-borne noise and vibration caused by the both the construction and operation of the MetroLink project. In this respect, and at its own expense, Trinity engaged Arup International Projects Limited (Arup) to assist in the process of identifying (a) all existing sensitive receptors; (b) the potential nature and magnitude of likely significant effects; and, (c) possible design and operational measures to avoid or mitigate those impacts (including alternative alignments, construction stage mitigation measures, and operational stage measures that include active-cancellation systems, relocation of affected University equipment where possible, and protection of the University's affected facilities 'in-situ').

For the reasons detailed in this Submission, the application for approval as submitted is materially deficient with regard to the identification and mitigation of likely significant impacts, which are matters of the utmost concern for Trinity.

Whilst the EIAR clearly identifies "significant" and "negative" impacts on Trinity's educational and research facilities, it is also acknowledged in the EIAR itself that the mitigation measures proposed in the design will not adequately protect the identified sensitive receptors. In this regard, the EIAR states, *inter alia* that:

> *"**TII will continue to work with Trinity** with respect to provision of appropriate mitigation to protect sensitive equipment at locations **that would still require some protection** based on this revised alignment."* (EIAR Section 7.7.9) [Emphasis added]

The Arup assessments of the proposed alignment and design have identified significant information gaps, omissions, errors, reliance on reference to mitigation measures that are asserted to have worked elsewhere without any reference to context or circumstance for comparison, and reference to future engagement with Trinity to design mitigation measures in respect of which the EIAR and submitted documents provide no certainty, or even an acceptable level of confidence, can be effective. In the latter respect, it is well-established that it is impermissible to devise mitigation measures after development consent is granted.

The EIAR is materially inadequate and qualitatively deficient in this regard, and those inadequacies and deficiencies have significant consequences for Trinity's existing teaching and research and development facilities and thus the application documentation fails to adequately identify, describe and assess the likely direct and indirect significant effects of the MetroLink project on Trinity.

The significant uncertainty in respect of the availability and efficacy of potential mitigation measures also has significant implications for the future provision, upgrade and enhancement of equipment and research programmes in the affected buildings. In this regard, the proposed alignment, together with the wholly inadequate mitigation measures identified, have significant potential to constrain or sterilise Trinity's existing and future core academic and research activities on the eastern part of its campus.

Based on Arup's assessment of the proposed alignment, and the ineffective nature of the mitigation measures proposed in the EIAR to protect the performance requirements of the affected equipment, the only effective mitigation strategy is based on the following elements:

- **Trinity's Proposed Mitigation Strategy**:

[3] A record of the interactions between Trinity and TII is attached as **Appendix B**.

- Mitigation by design with a localised realignment of the line beneath the Campus, identified on Figure 1.1 below as 'Alignment Option 5', moving the alignment 61.5 m westward of the current proposed alignment; and
- Further detail and assessment provided by the Applicant, by way of response to a Request for Further Information issued by the Board, in respect of the Mitigation Measures proposed in the EIAR, as supplemented in this submission by Trinity's experts, to demonstrate to the satisfaction of the Board (and Trinity) the efficacy and practicality of those measures based on robust survey data, monitoring, assessment, and evidence of successful comparators, **based on the Option 5 Alignment.**

The relevant information in respect of the proposed localised realignment of the line beneath the Campus, (Alignment Option 5), is set out in Section 4.1, below.

The further detail, information and assessment required to properly assess likely significant impacts and the efficacy of mitigation measures is set out in Section 5 below.

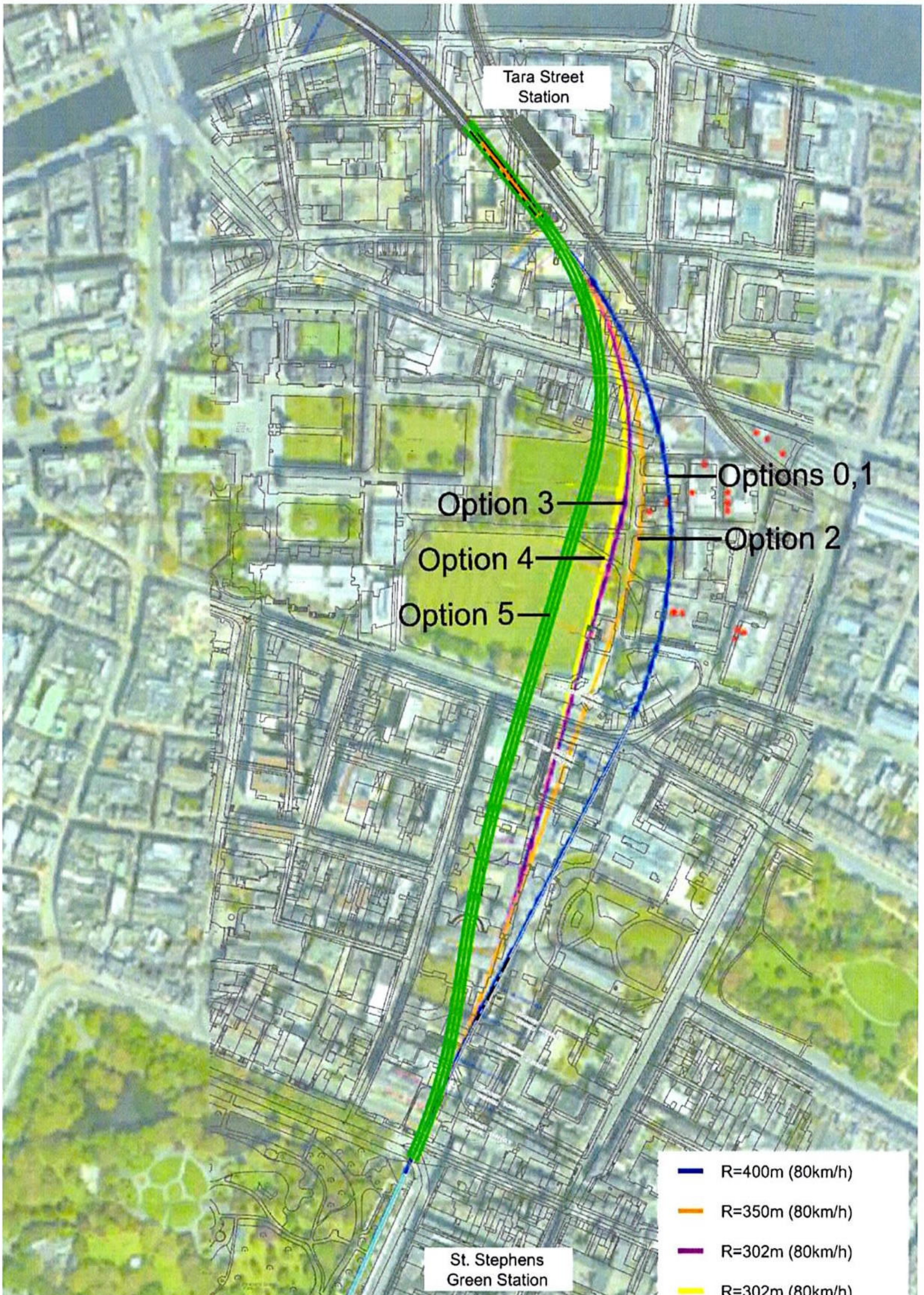
A spreadsheet is attached at **Appendix C** to assist the Board in understanding the interactions between the sensitive equipment and receptors, the route alignment options and the proposed mitigation measures. The spreadsheet identifies all sensitive equipment, the 'as submitted' route alignment with EIAR mitigation, the alternative route alignment options with mitigation, and alignment Option 5 with EIAR mitigation. The spreadsheet uses a colour coded system to identify the predicted EMI and vibration impacts on all elements of sensitive equipment. The colour coding demonstrates the increasing confidence in the efficacy of mitigation the further west the alignment is moved. In this regard, Trinity's Proposed Mitigation Strategy is the only approach that provides an acceptable level of confidence that significant impacts will be alleviated.

Based on the information submitted with the application, it is the opinion of Trinity's technical experts that the Applicant has failed to demonstrate that it is proposed mitigation measures are capable of effective implementation. In particular, the mitigation measures proposed in the EIAR are qualitatively deficient in that they lack substantive validation by robust survey data, monitoring, assessment and evidence of successful comparators.

In the event that the Applicant fails to demonstrate that effective, proven mitigation measures can be implemented, then Trinity will be left in the position where it requests that the Board should refuse consent, or decide to terminate the MetroLink at a point north of Trinity's Campus[4], having regard to the likely significant adverse, permanent and unacceptable impacts on the University's sensitive equipment, its established and future research facilities, its students, researchers and staff, and its global status and funding.

[4] It is noted that the termination of the MetroLink further north echoes one of the observations made by the Major Projects Advisory Group of the Department of Public Expenditure & Reform (Jul-22) which provides that *'the rationale for extending the preferred scheme to Charlemont is seen as being strategically weak, given the additional costs involved and the duplication of the LUAS Green line which also provides a public transport service to these areas of the city'*;

Figure 1.1 Route Alignment: EIAR Options 1 to 4, and Proposed Alternative Option 5



(Source: EIAR Diagram 7.17: Option Alignments Tara Street to St. Stephen's Green as annotated by CECL Global)

1.1.1 Objectives of this Submission

Given its support for the principle of the MetroLink project and in order for the Applicant to be given a further opportunity to properly consider the likely significant direct and indirect effects on Trinity and, in particular, adequate mitigation measures (including mitigation by design), this submission is intended to provide a basis for the Board to issue a Request for Further Information inviting the applicant to submit a revised EIAR, revised plans and all necessary assessments, in respect Trinity's Proposed Mitigation Strategy.

The submitted Arup Reports provide detailed assessments of the impact of the proposed alignment and the EIAR mitigation measures on Trinity's equipment and faculties. Indeed, it should be noted that the Arup assessments are based on information supplied by Trinity to the Applicant at the pre-application consultation stage. That information includes details of the location and type of all affected equipment and facilities and information in respect of the applicant's assessment of likely and significant impacts and the proposed mitigation measures.

As noted, the Arup assessments conclude that there are significant omissions and errors in the assessment of potential impacts, that the potential efficacy of the proposed mitigation measures are inadequate and/or have not been demonstrated by reference to monitoring, data and relevant comparators.

It is imperative that the Applicant provides the significant additional information in respect of proposed mitigation measures identified in this submission for the following reasons:

1. To enable an assessment by the Board of the efficacy of proposed mitigation measures that are reasonable, feasible and that can be implemented.
2. To clearly detail and articulate in the EIAR the proposed mitigation measures to which the Applicant is committing and will be obliged to implement at its own cost in the event that the project proceeds.
3. To clearly detail monitoring that will be undertaken by the Applicant for the duration of construction and operation phases, and further mitigation measures that may be necessary in the event that the mitigation measures are not effective.

This submission and the accompanying reports provide the technical evidence base for the Board to invite the applicant to submit a revised EIAR, plans and assessments in respect of the Trinity's Proposed Mitigation Strategy. This submission also itemises the information that the Board is invited to request from the Applicant for the purpose of satisfying items 1 to 3 above.

Trinity's Proposed Mitigation Strategy presented in this submission identifies possible mitigation measures, in addition to the measures identified in the EIAR, that are necessary to protect the equipment and to avoid unacceptable impacts on the University's educational and research facilities, its students, researchers and staff, and its global status and funding. It is requested that TII is invited to assess these mitigation measures, based on the information available and supplied by the University and Arup, and to incorporate those mitigation measures into the EIAR so that they are legally binding, in the event that the Board grants development consent. The revised EIAR and design details must demonstrate to the satisfaction of the Board that the mitigation measures are reasonable, feasible, will be effective, and will be the responsibility of TII to implement.

As noted, this submission presents evidence for Option 5 as a reasonable alternative to reduce significant impacts that should be considered. Option 5 has been considered by Trinity's experts and there is no apparent planning, technical or engineering reason which would preclude the Board from considering this route option. In order to do so, however, the Board should request TII to provide all necessary information to enable a complete assessment of this route alignment. This is further addressed in Section 4.1.

As noted, in the event that the Applicant does not demonstrate to the satisfaction of the Board that effective mitigation measures can be implemented at its expense, Trinity reluctantly requests the Board to refuse consent, or to terminate the MetroLink at a point North of Trinity's Campus, having regard to the likely significant adverse, permanent and unacceptable impacts on the University.

1.2 Structure of this Submission

This submission is structured to provide the Board with the necessary information to fully understand the nature and magnitude of the impacts on sensitive equipment and receptors in Trinity, the efficacy of the mitigation measures proposed in the EIAR and the design of the proposed development based on the information provided in the EIAR, and the necessary additional information required to undertake an informed assessment of potential mitigation to protect the ongoing safe and effective operation of Trinity's equipment and its research and development facilities.

Section 2 provides an overview of the faculties, facilities and equipment identified by Arup and Trinity that will be impacted by the construction and operational phases of the project; the nature and magnitude of the potential impacts of the construction and/or operational phases on specific items of equipment; and, consequential impacts on the faculties' educational and research activities and programmes. A full schedule of all faculties, facilities and equipment affected by the project is provided in Table 2.1 below.

Section 3 provides a summary of the assessments undertaken of the information contained in the EIAR in respect of sensitive receptors, likely significant impacts and proposed mitigation measures. The detailed assessments undertaken by Arup and CECL Global are included at **Appendices C to E**.

Section 4 provides an overview of Trinity's Proposed Mitigation Strategy, identifying an alternative route and the additional information necessary to establish and assess the magnitude of likely impacts on sensitive receptors, the mitigation measures that are necessary to effectively avoid or appropriately mitigate potential impacts, and the basis for the identification of clear, implementable measures to mitigate to the greatest extent possible potential impacts on sensitive equipment.

Section 5 sets out the detail of the information which Trinity respectfully requests the Board to invite the Applicant to submit as Further Information including a revised EIAR, and revised plans and assessments in respect of Trinity's Proposed Mitigation Strategy, namely: revised plans and assessments in respect of Alignment Option 5, and further detail and assessment in respect of the Mitigation Measures proposed in the EIAR as supplemented in this submission by Trinity's experts, to demonstrate to the satisfaction of the Board (and Trinity) the efficacy and practicality of those measures based on robust survey data, monitoring, assessment, and evidence of successful comparators.

1.3 Contributors to this Submission

This Submission has been prepared by Declan Brassil and Associates in conjunction with Arup and CECL Global.

This submission has been informed by the following Reports, which are referenced throughout this document and are attached as appendices:

- A Review of Alignment and Associated Tunnelling Matters prepared by CECL Global (Appendix D)
- MetroLink Impacts – Electromagnetic Interference (EMI) prepared by Arup (Appendix E)

- MetroLink Impacts – Vibration Assessment prepared by Arup (Appendix F)

These documents form part of this Submission and should be read in conjunction with this document.

2.0 LOCATION, NATURE AND STATUS OF SENSITIVE RECEPTORS

2.1 Details of Buildings, Departments, Faculties and Equipment Impacted

Approximately 312m of the alignment as presented in the Draft Railway Order documentation (Option 2) passes directly under the eastern side of the Trinity Campus.

As noted previously, Trinity engaged proactively with TII from March 2018 to November 2022, in order to assist the Applicant in identifying all existing sensitive receptors, the potential nature and magnitude of likely significant impacts, and possible design and operational measures to avoid or mitigate those impacts. This Section identifies the sensitive receptors include buildings, Departments, Faculties and equipment of critical importance to the teaching, research and commercial activities of Trinity that will be impacted by vibration and EMI during the construction and operational phases of the proposed development.

The Departments, Faculties and buildings impacted by the construction and operation of the proposed alignment are listed below and identified on Figure 2.1 overleaf.

Table 2.1 on the following pages itemises and details the affected equipment located in those buildings, and its purpose and importance to the relevant Departments', Faculties' or Institutes' teaching and research activities.

The affected buildings identified on Figure 2.1 overleaf are:

- The Option 2 alignment passes directly under the Simon Perry Building and The Pavilion and Moyne Institute of Preventative Medicine.
- The Botany Building and Fitzgerald Building are located immediately east of the Option 2 alignment.
- The Sami Nasr Institute of Advance Materials and the Lloyd Institute are immediately east of the Botany and Fitzgerald buildings. The closest element of sensitive equipment is 58 m from the Option 2 alignment.
- The Chemistry Building is to the east of the Option 2 alignment. The closest element of sensitive equipment is 45 m from the alignment.
- The Panoz Institute is immediately east of that building. The closest element of sensitive equipment is 115 m from the Option 2 alignment.
- The Centre for Research on Adaptive Nanostructures and Nanodevices (CRANN) is approximately 98 m to the north-west of the Option 2 alignment.

Figure 2.1: Approximate location of the MetroLink Proposed Alignment on the Eastern Portion of the Trinity Campus

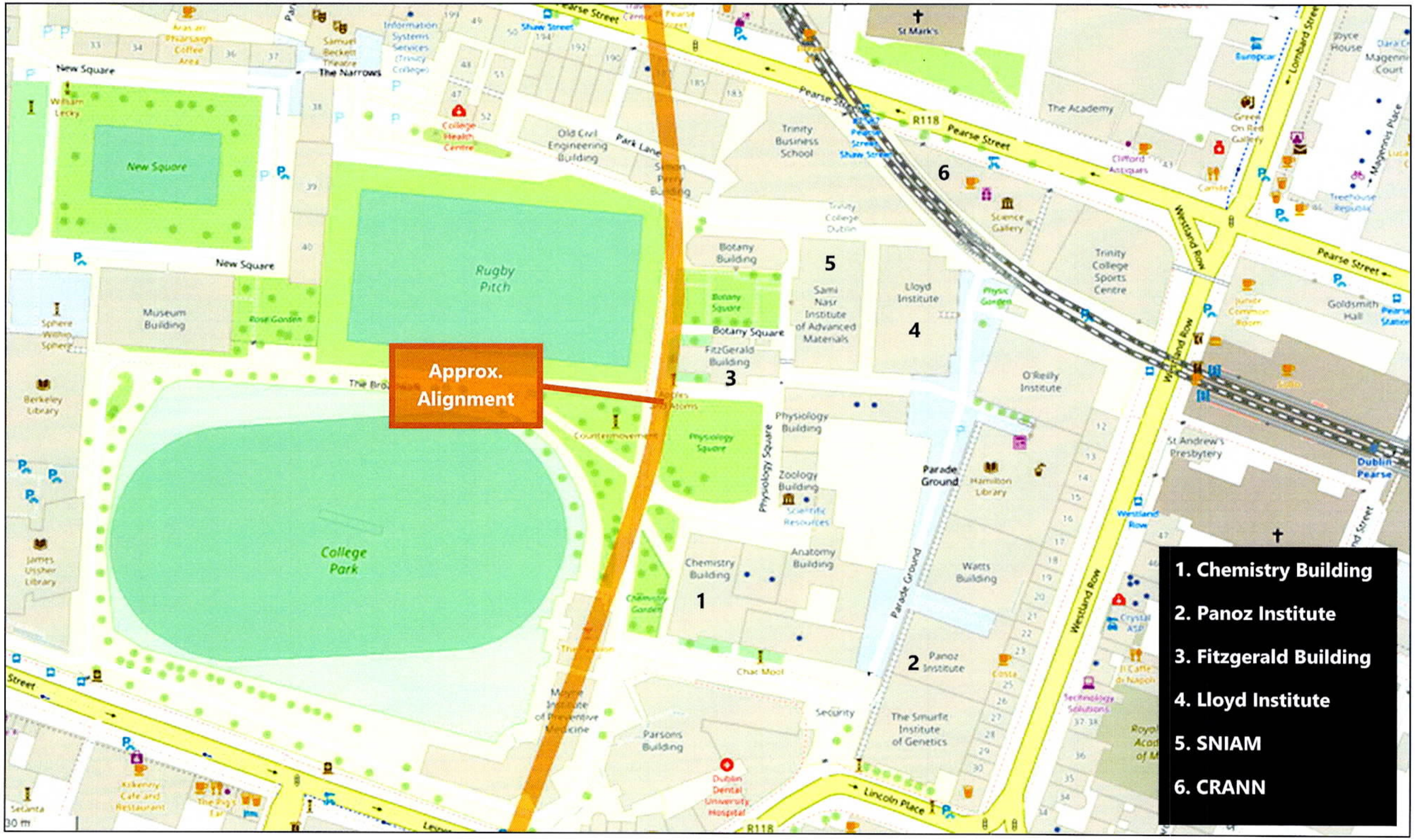


Table 2.1: Sensitive Receptors

Location	Overview of Department	Critical Sensitive Equipment
Lloyd Institute	The Lloyd Institute houses the Institutes of Information Technology and Advanced Communications; Neurosciences; and Statistics, which focus on research into real and artificial intelligence. It includes space for undergraduate teaching, postgraduate research, academic offices and associated support services. The Trinity College Institute of Neuroscience (TCIN) is a Trinity Research Institute with 50 Principal Investigators (PIs) and 250 researchers from a wide range of disciplines. The administrative and scientific hub of TCIN is based in the Lloyd Building. The Institute provides a gateway for internal and external connectivity between basic and applied Neuroscience. TCIN facilitates access to advanced research and diagnostic technologies as well as to patient populations, bio samples, and genotyping required for translational Neuroscience, which prominently and deeply involves clinical PIs based in St James', St Patrick's and Tallaght Hospitals. St James additionally houses CAMI, a clinical Neuroimaging facility as well as the Wellcome-Trust HRB Clinical Research Facility for clinical trials. TCIN houses strong research programmes funded by the Science Foundation Ireland, the Wellcome Trust, the Health Research Board, the European Research Commission/ Horizon 2020 Framework Programmes, and multiple Philanthropic and Industrial Sponsors. The Lloyd building houses several TCIN-managed advanced research technologies, including two high-field human and small animal Magnetic Resonance Imaging (MRI) systems. TCIN PI's develop and utilise preclinical cell and animal models, as well as molecular, cellular, biological, biochemical, behavioural, physiological and genetic technologies to study both humans and model organisms.	1x MRI (Bruker BioSpec 70/30 AVANCE III 7T) 1x MRI (Siemens Magnetom Prisma 3T) 2x TMS machine (DuoMag) 3x EEG machine (TruScan) 1x Confocal Microscope (Zeiss LSM 501) 1x Confocal Microscope (Zeiss LSM 880)

SNIAM	Sami Nasr Institute for Advanced Materials (SNIAM) accommodates a multi-disciplinary department involving Physics, Chemistry and Electronic Engineering, which focus on postgraduate research into advanced materials. The School of Physics has a well-established international reputation for innovative research in Magnetic, Electronic and Photonic Materials, Nanoscience, Computational Physics and Astrophysics. Researchers in the School collaborate with groups from academia and industry across the world, funded through a broad range of national and international source. The SNIAM building, together with the original Physics Laboratory (The Fitzgerald Building), provides exceptional modern facilities for teaching and research for a community of over 200 physicists, technical and support staff, including 27 full-time academic staff, approximately 50 postdoctoral fellows and over 100 graduate students. In research, the School has a worldwide reputation and several staff members are recognised as leaders in their fields. Much of this research is funded by Science Foundation Ireland. Inventions and technical developments arising from the Schools research have led to the foundation of several spin-off companies in recent years. The SNIAM building also houses some of the School of Chemistry academic staff, together with six purpose-built research laboratories with associated instrument rooms which underpin the Schools undergraduate teaching and postgraduate research work	1x SQUID (Quantum Design MPMS-XL)
CRANN	The Centre for Research on Adaptive Nanostructures and Nanodevices (CRANN) is Trinity's largest research institute, and a Science Foundation Ireland (SFI) funded Centre for Science, Engineering and Technology (CSET). CRANN is Ireland's leading nanoscience institute. CRANN brings together over 300 researchers including 37 leading Investigators based across multiple disciplines including Trinity's Schools of Physics, Chemistry, Medicine, Engineering and Pharmacology. In October 2013, a Science Foundation Ireland funded research centre, AMBER (Advanced Materials and BioEngineering Research) was launched. AMBER is jointly	1x AFM (Bruker Multimode 8) 2x UHV AFM (Omicron VT and RT) 2x Nanoindenter (KLA XP and DCM), 1x 3DContact Mechanics Tester (Fast Forward Devices) 1x Stylus Profileometer (Bruker Dektak)

	hosted in Trinity by CRANN and the Trinity Centre for BioEngineering, and works in collaboration with the Royal College of Surgeons in Ireland and University College Cork. The centre provides a partnership between leading researchers in material science and industry to develop new materials and devices for a range of sectors, particularly the information communications technology (ICT), medical devices and industrial technology sectors. The Naughton Institute, which forms a principal part of CRANN, is a state of the art, custom designed and constructed research facility located to the northeast of the campus immediately east of the DART line. CRANN is working with over 50 companies, including the major ICT companies such as Intel and Hewlett-Packard, and indigenous and multinationals within the medical devices sector. CRANN researchers have generated 42 invention disclosures, 40 patent applications across international territories and five patents, with three licenses. Three companies have been spun out by CRANN PIs in recent years – Cellix, Glantreo and Miravex. Nanotechnology is a key enabling technology which underpins the ICT, medical device, and pharmaceutical sectors. A Thomson-Reuters report in late 2010 placed Ireland 8th globally for materials science research (a branch of nanotechnology) based on citations per publication for the decade 2000—2010. CRANN researchers were responsible for >70% of the outputs leading to this national ranking. In Nanotechnology, Ireland's global ranking is sixth in terms of both the quality of its publications and the volume output per capita. The total value of research awards house in CRANN is €123M. These are multiyear programmes which span the current date to 2027 and include the current AMBER award and associated industry programmes which expire in 2025. AMBER is currently preparing for its phase III renewal which will target at least €40m of exchequer funding for the period 2025-2031.	2x Optical Tweezer Instruments 1x XPS 4x STM (Omicron Variable Temperature STM, 2x Omicron Cryogenic STM, Empa designed AFM/STM) 1x STM 1x STM 1x STM 1x SEM (proposed in future)

Fitzgerald Building	The Fitzgerald Building is the main laboratory for the School of Physics in Trinity for both undergraduate and postgraduate activities. As outlined above, the Fitzgerald Building, together with SNIAM, provide exceptional modern facilities for teaching and research for a community of over 200 physicists, technical and support staff, including 27 full-time academic staff, approximately 50 postdoctoral fellows and over 100 graduate students. In research, the School has a worldwide reputation and several staff members are recognised as leaders in their fields. Much of this research is funded by Science Foundation Ireland. Inventions and technical developments arising from the Schools research have led to the foundation of several spin-off companies in recent years.	2 x STM 1 x STM 1 x AGFM 1x optical telescope 1 x radio telescope
Chemistry Building	The Chemistry Building is the main headquarters of the School of Chemistry for both undergraduate and postgraduate activities and accommodates a multi-disciplinary department involving Physics, Chemistry and Electronic Engineering. The School is research intensive and has an active research programme that spans all sub-disciplines of Chemistry. Its members are involved in a great many inter-departmental, national and international research programmes. Research income (approx. €5 million per year) is earned from national, international and commercial sources, and several groups are involved in networks of European laboratories. The School of Chemistry currently spearheads Trinity activity in Raw Materials and significant funding has been obtained in this area in recent times in collaboration with European and International partners, both academic and industrial. The instrumental analysis facility for the School of Chemistry is located within the basement of the Chemistry Building. The Chemistry Building is located directly above the proposed tunnel alignment. The most sensitive instruments are the NMR (Nuclear Magnetic Resonance) spectrometers of which three are located at basement level of the Chemistry Building. The NMR and other analytical instruments located at basement level are routine analytical instruments essential for teaching and research.	1 x NMR (Bruker Advance II 400MHz) 1 x NMR (Brucker Advance II 600MHz) 1 x NMR (Bruker Advance HD 400MHz)

Panoz Institute	The Panoz Institute includes the School of Pharmacy & Pharmaceutical Sciences research laboratories and the Centre for Microscopy and Analysis (CMA) which forms part of Department of Geology. The main building was completed in the 1800s. It has had a number of extensions added, the most recent being opened in 2005. The School of Pharmacy and Pharmaceutical Sciences aims to improve the lives of people through insights and discoveries that relate to medications and health. Pharmacy Practitioners offering a multi-disciplinary approach to basic and translational research, substantial critical mass of internationally trained researchers bringing experience from the clinic, academia and industry, with a proven track record of successfully collaborating with small indigenous companies, scanning electron microscopes (SMEs) and big Pharma. The CMA offers a wide range of expert quality accredited commercial and research analytical testing. CMA's analytical capabilities are utilised by industry nationally and internationally for forensic failure analysis, foreign material identification/classification analysis, etc. CMA comprises state-of-the-art electron and laser beam equipment for the characterisation of geoscience material. These facilities have ushered in a new era in geo-analysis in Ireland with the first dedicated SEM funded by Science Foundation Ireland using the latest in detector technology for the characterisation of minerals. The instrument is a Pan-European collaboration of three leading manufacturers giving Irish researchers a cutting edge in applied and fundamental research.	1x SEM (Tecsan S8000) 1x SEM (Tecsan Mira3 Tiger) 1x SEM (Zeiss Sigma 300)

The equipment listed in Table 2.1 comprises sophisticated analytical instruments that are essential and routinely used for teaching and current and future research carried out by Trinity. The assessments undertaken by Arup (and to a lesser extent, the assessments in the EIAR) establish that there is a high probability of significant impacts on the operation of the equipment during the construction and operational phases of the proposed MetroLink development.

Damage to, or the inability to reliably use, the equipment would result in severe disruption to, and (in a worst case scenario) a complete shutdown of, many current teaching and research activities, including world leading research being undertaken by PhD students and post-Doctoral researchers. Furthermore, negative impacts on the ability to reliably use equipment would result in the discontinuation of grants and an inability to secure new grants for further research and development. The loss or revenue from external sources would seriously impact the viability of many of the University's research activities[5].

The EIAR does not adequately reflect the range and extent of vibration sensitive locations and facilities that would potentially be affected, both by construction and operation of MetroLink; only a small sample of the impacts are described in Chapter 14 of the EIAR.

With regard to the construction phase of the project, in particular, the disruption impacts are anticipated to be widespread and more difficult to mitigate than operational stage impacts. Construction impacts will arise from the tunnel boring machine (TBM) and from any temporary construction railway. Vibration from the TBM is predicted to impact all facilities and may also cause adverse ground borne noise impacts in some spaces. Vibration from any temporary construction railway would be at least as high as that from the unmitigated operational railway, although there would be fewer movements per day. During construction, disruption to Trinity's activities would occur for several months. The only mitigation proposed in the EIAR is for Trinity to "work around" the tunnelling programme, which would significantly disrupt Trinity's activities. Furthermore, the risks from blasting works for Tara Station have not been reported or assessed.

There will be limited impact from an EMI, EMF or stray current perspective likely during the Construction Phase of the proposed Project. However, sensitive equipment assessed by Arup would be affected by vibration during the construction phase and impacts require to be properly assessed and demonstrably effective and feasible mitigation measures proposed.

The operational phase of MetroLink, as currently proposed, is predicted to impact the performance of sensitive equipment within the Departments and Institutes identified in Table 2.1, above.

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[5] Examples:

- CRANN is part of the AMBER programme, which runs from 2020-2026 with €40m funding from industry and €40m EU funding. The program funds 50 no. PhD students jointly with ICL. CRANN also has income from European Council Awards of €1-2m each year CRANN also has a collaboration with Intel worth several million Euros each year that enables the Institute to employ graduates, fund bursaries and is an essential relationship/funding stream.
- The NMRs are essential to the economic viability of the Chemistry Department. They provide troubleshooting for a number of a pharmaceutical companies including for cancer treatments and commercially in materials identification for forensic science. NMRs are also used by other departments including Physics, Biology and Materials Science.
- In the Panoz Institute, the iCRAG labs are the main geo-analysis labs and are critical for Science Foundation Ireland 2015-2020 which has been renewed from 2021 onwards, a €70-80m program spanning 7 academic institutions. Phase 1 is heavily SFI funded; phase 2will be split 50:50 between industry and SFI funding. A further €300k comes from rapid turnaround commercially funded analyses.

During operation, with the track system proposed for other locations, the EIAR identifies that there would be significant risk to Trinity's equipment from vibration. EIAR Chapter 14 states that the impacts at Trinity will be fully mitigated by track design and by additional local mitigation where needed. A complex track support system is proposed by TII that Arup's analysis indicates could address the majority of significant effects, however, there are uncertainties about the viability of the proposal.

The predictions of vibration impacts at low frequencies are uncertain due to uncertainties in the input parameters. Furthermore, the track support system proposed would result in track deflections much greater than normal or proven for floating slab track, which has not been described or assessed in the EIAR.

The proposal in the EIAR to mitigate residual significant effects at the receptor (sensitive equipment) through the use of base-isolated foundation slabs would not be practicable for all equipment and buildings, especially for locations where equipment is not on a ground floor or basement level slab. It cannot, therefore, be concluded that all vibration risks to Trinity's equipment would be addressed. Furthermore, provision of sufficient and adequate mitigation at any affected items of equipment would be disruptive and/or impracticable.

Trinity has considered an alternative potential mitigation option that would involve the relocation of sensitive equipment. This option is not viable or practical for the reasons identified below:

- There is no current viable relocation option available on the Campus, in terms of the areas required to accommodate the relocated activities.
- The damage to Trinity's reputation as one of Ireland and Europe's leading research universities and the consequential damage to Ireland's overall reputation within the European research community which would arise from such disruption and uncertainty
- The prohibitive cost of relocating equipment, particularly equipment currently accommodated in specially designed and purpose-built structures, buildings and parts of buildings.
- The time and cost of securing suitable alternative premises and the associated costs in their renovation and fit-out to provide acceptable facilities.
- The time required to decommission and recommission would be long and disruptive.

3.0 ASSESSMENT OF THE PROPOSED ALIGNMENT (OPTION 2) AND EIAR

This section provides an overview of the proposed alignment (Option 2) and the information contained in the EIAR with regard to the likely significant impacts on the sensitive receptors identified in Section 2, and the mitigation measures proposed to avoid or ameliorate those impacts.

This section should be read in conjunction with the Arup and CECL Reports attached to this Report at Appendices D to F.

3.1 Omissions and Errors in the EIAR Assessments

The assessments included in the EIAR have failed to identify, describe and assess the range and nature of sensitive equipment likely to be impacted.

With regard to ground borne noise, the EIAR identifies only three sensitive receptors on the Trinity campus for assessment – the Chemistry Building Extension, SNIAM and the Moyne Institute (see EIAR Ch 14, Section 14.3.1.4 and Table 14.18). The EIAR does not accurately identify or describe the range and extent of locations and facilities that would potentially be affected by ground borne noise during both the construction and operation of MetroLink.

Section 14.4.1.7 of the EIAR states: *"with regard to vibration effects on sensitive equipment, Criterion VC-E will occur within a distance of 250m either side of the tunnel centreline, and during the passage of the TBM there is a potential significant effect on the operation of sensitive equipment"*. However, no predictions are provided for the many other facilities within the 250m wide corridor and in particular those identified in Table 2.1.

The EIAR assessment of predicted impacts during the passage of the TBM only tabulates predictions for the three buildings identified in Table 14.18 [Chemistry Building Extension, SNIAM and the Moyne Institute]. EIAR Table 14.21 provides a much more extensive list of buildings and facilities within the 250 m corridor. EIAR Appendix A14.5 provides a table of all vibration modelling results and shows the whole of the Trinity campus to be exposed to vibration above VC-A, which is above the criteria for all Trinity's sensitive equipment. As such, there are significant omissions, gaps and internal inconsistencies in the information presented and the assessments undertaken in the EIAR.

Having regard to operational groundborne noise and vibration, EIAR Section 14.2.5.4.3 states: *"at Trinity College Dublin examples of the most sensitive cases were fully modelled in three dimensions"*. Details of the modelling for each building have not been included in the EIAR and Table 14.44 provides predicted groundborne noise levels for only three buildings (Chemistry Building, Sami Nasr Institute and Moyne Institute).

In terms of sensitivity to EMI, the refined list of equipment identified in EIAR Section 12.8.4.9 is generally consistent with the sensitive receptors identified by Arup and is considered to be adequate for the purpose of assessment.

In addition to the above omissions and deficiencies, the following further omissions and deficiencies in the EIAR have significantly constrained an assessment of the magnitude of likely significant impacts and the need for or efficacy of proposed mitigation measures:

- Appendix A7.10, Trinity Alignment Options Report, should contain detailed Horizontal / Vertical Alignment Detail drawings for each of the 4 no. alternative alignment options considered (Appendix E of that Report). These have been omitted contributing to the difficulty in assessing the relative merits of each of the alternatives considered.
- EIAR Appendix A14.2 provides insufficient detail on rolling stock to facilitate a rigorous swept path analysis for the purpose of determining the potential for a slightly tighter radius curve enabling the alignment to move further westward from the sensitive receptors.
- EIAR Section 14.3.2.2, considering vibration surveys at Trinity Buildings, refers to EIAR Appendix A13.5 and states that *"full details of survey location, methodologies, parameter definitions and results of the baseline surveys at Trinity"* are provided. A summary rather than the full results is provided in EIAR Appendix A13.5.
- Vibration from tunnel boring has been predicted using the FINDWAVE® numerical modelling method (EIAR Section 14.2.5.2.1), with details of the methodology stated to be presented in EIAR Appendix A14.4. The Appendix only describes the software application to operation of MetroLink and not the construction.
- EIAR Chapter 5 provides a detailed description of equipment needed to support the TBM but does not include any detail how personnel and materials such as tunnel lining segments would be transported through the tunnel to the TBM. Assumptions relied upon in EIAR Chapter 14 (Groundborne Noise & Vibration) include that *"the TBM will not be serviced by a temporary construction railway, but instead conveyors will be used for the transfer of materials from the TBM and out of the tunnel Rubber tyred vehicles will also be used for the transportation of material and people"'*. Certainty regarding the nature of transport to the TBM is critical to determine the likely impacts on the operation of sensitive impacts and the duration of potential disruptions due to such movements.
- There are significant deficiencies in the numerical modelling presented in the EIAR. The vibration modelling demonstrated that the predictions are very heavily dependent on the assumed ground stiffness parameters and the track isolation assumptions. Using the parameter values assumed in the EIAR, the modelling predicted vibration to be low. However, there is uncertainty in the ground properties assumptions, for which small differences in the assumed values have a large effect on the predicted vibration, particularly at low frequencies.
- The floating slab track proposed as mitigation in the EIAR assumed a very low spring stiffness, which leads to an unsuitable track design solution due to the deflection that would occur under the static loading of the train. To control the static track deflection, springs with higher stiffness would be more typically used. Modelling with higher spring stiffness, leads to higher predicted vibration and hence greater risk to Trinity's equipment. Furthermore, modelling by Arup indicates that the combination of booted sleepers and a floating slab track may make the vibration impacts on Trinity's sensitive equipment worse than an optimised floating slab design alone.
- Having regard to EMI, EIAR Table 12.14 assumes that all SEMs have same performance requirement of 0.1µT p-p. However, the Zeiss Sigma Installation Requirements (2019) supplied by Panoz technical lead on 5 August 2020, state a requirement of 0.05µT p-p. There are also differences in the performance requirements for the SQUID.
- Significantly, the operational phase assessment of EMI carried out does not take into account the cumulative impact of the MetroLink and the baseline environment which will mean that conditions are likely to be worse than that assumed (so it is not a worst-case).

3.2 Nature and Magnitude of Potential Impacts on Trinity Sensitive Receptors

3.2.1 Vibration

Groundborne Noise and Vibration impacts are only reported in the EIAR for a small number of Trinity's buildings, as noted above. The results presented in the EIAR do not reflect the range and extent of vibration sensitive locations and facilities that would potentially be affected by both construction and operation of MetroLink. In particular, no consideration is given to the Panoz Institute, the Lloyd Institute, CRANN or the Fitzgerald Building, all of which were identified to TII as sensitive receptors by Trinity.

With regard to the **Construction Phase**, EIAR Table 14.32 identifies significant impacts in terms of predicted vibration at the Trinity buildings identified [Chemistry Building, SNIAM and the Moyne Institute] associated with the passage of the TBM.

There is inconsistency in the reported extent of the corridor potentially adversely impacted by vibration during construction of the tunnel. In one section it is stated that the corridor would be 100m either side of the tunnel and elsewhere 250m is stated. Furthermore, the 100m corridor is the same as that stated for the operational impacts. It is submitted that a wider corridor would be expected for tunnelling than from operation of the railway.

As outlined above, the description of the construction works (EIAR Chapter 5 MetroLink Construction Phase) does not describe how personnel and materials such as tunnel lining segments would be transported through the tunnel to the TBM. The EIAR vibration assessment, however, is based on the assumption that there would not be a temporary construction railway, but rubber tyre vehicles will be used instead. It is critical that clarity is provided on the manner by which personnel and materials will be transported as the provision of a temporary construction railway would result in significant potential impacts for an extended duration during the construction period.

Furthermore, there is a risk that groundborne vibration from blasting works for Tara Street Station could exceed the vibration criteria for some sensitive equipment. This has not been reported in the EIAR and would need to be assessed before any such works to determine the impacts on Trinity's activities.

Based on the foregoing it is considered that insufficient clarity has been provided to appropriately quantify potential construction phase impacts and the duration and magnitude of such impacts.

In respect of the **Operational Phase**, with the track system proposed elsewhere on the MetroLink, the EIAR identifies that there would be significant risk to Trinity's equipment from vibration.

As outlined, the EIAR only considers groundborne vibration at three locations [Chemistry Building, SNIAM and Moyne Institute]. EIAR Table 14.46 predicts that the effect of groundborne vibration at these three locations will be 'significant'. However, assessments carried out by Arup determine that the extent of significant impacts will be much wider that reported in the EIAR. It is submitted that the EIAR does not adequately report on the full extent of potential impacts to sensitive receptors within Trinity.

The Arup assessment concludes that there is significant risk that vibration will exceed assessment criteria for equipment located within the Panoz Institute, the Lloyd Institute, CRANN and the Fitzgerald Building, in addition to those identified in the EIAR. In particular, **unacceptable risk** was identified for equipment located within the Panoz Institute (2x Confocal Microscopes), CRANN (1x Stylus Profileometer) and the Fitzgerald Building (3x STM, 1x STM, 1x AGFM and 1x Optial Telescope).

Notwithstanding the deficiencies identified in the EIAR with regard to the identification of affected buildings and equipment, and the assessment of vibration impacts, the EIAR vibration assessment concludes that the identified impacts will be fully mitigated by track design and by local mitigation at the sensitive equipment, where needed.

3.2.2 EMI

The EIAR and the Arup assessment identify significant negative impact on the operation of sensitive due to EMI. Trinity is the only listed receptor along the entire MetroLink route which has 'significant', 'negative' effects as a consequence of EM emissions from MetroLink.

The following equipment in Trinity has been identified as being at risk of negative impact from the MetroLink:

- 3 no. Scanning Electron Microscopes (SEM) in the Panoz Institute
- 3 no. Nuclear Magnetic Resonance (NMR) machines in Chemistry
- 2 no. Magnetic Resonance Imaging (MRI) machines in the Lloyd Institute
- 1 no. SQUID machine in Sami Nasr Institute of Advanced Materials (SNIAMS)

During the **construction phase** the impact from EMI on this sensitive equipment will be minimal. The EIAR proposes that Trinity's equipment that is also vibration sensitive will be turned off as the Tunnel Boring Machine (TBM) passes near to Trinity.

During the **operational phase** the EIAR predictions of emissions from the MetroLink are broadly consistent with Arup's assessment. However, the EIAR does not assess the cumulative effect of existing baseline environment and the additional emissions from MetroLink. In this regard, baseline fields (from survey) and MetroLink emissions (from modelling) considered together generate more EMI than the MetroLink emissions considered on their own:

- The EIAR assessed MetroLink emissions only. On the basis of the modelled emissions, the SEMs and NMRs are at risk from interference and are predicted to not meet equipment performance requirements.
- Arup's assessment of Baseline + MetroLink emissions concludes that MRIs, SEMs and NMRs are at risk from interference and are predicted to not meet equipment performance requirements.
- Arup's assessment also concludes that the predicted EM fields at the location of the sensitive equipment will not meet the performance requirements for some of the equipment under the Trinity proposed Option 5 alignment, and additional mitigation will be required.

Accordingly, it is clear that significant additional information is necessary from the Applicant for the purpose of identifying and assessing the efficacy and practicality of proposed mitigation measures to protect sensitive equipment from EMI emissions accurately predicted on the basis of Baseline + MetroLink sources.

3.3 Effectiveness of Proposed EIAR Mitigation Measures

Table 3.1 below sets out the EIAR migration measures (EIAR Chapter 31) in respect of EMI and Vibration at Trinity. Understanding the nature, type and detail of the mitigation measures presented in the EIAR is necessary to frame the assessments presented in the Arup Reports and summarised below in respect of the information required to properly assess the efficacy and practicality of proposed mitigation measures, and to properly understand the material deficiencies present in the EIAR.

Table 3.1: Extract of EMI & Vibration Mitigation Measure taken from EIAR Tables 31.5 & 31.7

Impact	Description	Stage of Impact
EMI	With regard to DC magnetic field impacts on sensitive medical and scanning equipment such as those located in Trinity, the Rotunda and the Mater the following mitigation measures are available: - Relocation of affected equipment; - Installation of an active-cancellation system; and - Shielding of the labs/rooms using specialised material design to attenuate magnetic fields.	Operational
EMI	A final solution would be the installation of fixed shielding, a solution some of the departments and institutes at Trinity are already familiar with. Any unexpected impacts in relation to AC fields should be addressed in a number of ways if necessary, including Shielding and Filtering.	Operational
Vibration	Tunnel Boring Impacts: The principal mitigation measures aimed at minimising impacts are as follows: • Advance public consultation and stakeholder engagement can greatly reduce the significance of groundborne noise effects, as building occupants would be prepared for the passage of the TBM and resultant elevated noise and vibration levels. • TII will accept and consider applications for additional measures on a case-by case basis, in accordance with its Noise and Vibration Mitigation Policy (see Appendix A14.6: Airborne Noise and Groundborne). • With regard to vibration effects on the use of sensitive equipment, there is potential to plan the passage of the TBM during weeks when critical use of the equipment can be avoided. The programme for the TBM will be planned by the contractor. Consultation will be undertaken with Trinity as soon as this programme is available to ensure that sensitive research operations on the campus do not coincide with the passage of the TBM.	Construction

Vibration	• With regard to all but a limited number of sensitive receptors, no significant effects are predicted during the Operational Phase. There are some locations where an enhanced track support system will be required. • In the case of buildings that are sensitive to groundborne noise, including buildings containing particularly sensitive equipment as well as large auditoria and studios, mitigation in the form of floating slab track will be incorporated into the design to remove any significant effects during the operational phase. • With regard to sensitive laboratory equipment, detailed building-specific numerical modelling will be required to establish the likely exceedance of equipment specifications, and to find the optimum specification for the track support system to minimise exceedances. Mitigation at the receptor for specific rooms within sensitive buildings in the form of the installation of base-isolated foundation slabs to support the equipment may also be required. As the specific sensitive equipment in use at Trinity is expected to change between the time of this assessment and the opening of the proposed Project. close consultation should be undertaken between TII and Trinity in relation to the specifically sensitive rooms. • The sections of the tunnel where mitigation in the form of floating slab track, or other track support measures are required are summarised in Chapter 14 (Groundborne Noise & Vibration) Table 14 .47.	Operational
	• In the case of buildings that are sensitive to groundborne noise, including buildings containing particularly sensitive equipment as well as large auditoria and studios, mitigation in the form of floating slab track will be incorporated into the design to remove any significant effects during the operational phase. • With regard to sensitive laboratory equipment at Trinity, detailed building-specific numerical modelling will be required to establish the likely exceedance of equipment specifications, and to find the optimum specification for the track support system to minimise exceedances.	

3.3.1 Vibration

EIAR Section 14.5.1.1 addresses **construction stage** mitigation measures and states *"there are no effective methods are [sic] available to reduce groundborne noise or vibration from TBMs at source"*. Mitigation measures for groundborne noise and vibration are proposed as public consultation and stakeholder engagement: *"additional measures on a case-by-case basis"* in accordance with the Noise and Vibration Mitigation Policy (EIAR Appendix A14.6). No practical ways to reduce TMB vibration impacts have been identified. The EIAR concludes:

'With regard to vibration effects on the use of sensitive equipment, there is potential to plan the passage of the TBM during weeks when critical use of the equipment can be avoided. The programme for the TBM will be planned by the contractor. Consultation will be undertaken with Trinity as soon as this programme is available to ensure that sensitive research operations on the campus do not coincide with the passage of the TBM'.

For the TBM, assuming a tunnelling rate of 7m per day and that the effects on sensitive equipment would be apparent up to 100m from the tunnel face as reported in the EIAR, disruption could be 29 no. days continuously (including both before and after the TBM passes). However, the EIAR also states that the affected corridor could extend to some 250m around the TBM which would increase the period during which the requirement for sensitive equipment is exceeded to 71 no. days. Slower rates of tunnelling would further extend the duration of the disruption.

No programme is available but disturbance to Trinity could be expected for several months in the absence of any system to mitigate construction phase mitigation measures. To fully quantify the level of disruption to Trinity's activities clarification is required in respect of potential impacts on blasting, the manner by which personnel and equipment are transported to the TBM and the construction programme.

To mitigate **operational phase** vibration impacts, a complex track support system is proposed in the EIAR. EIAR Section 14.5.2 describes mitigation of vibration at source (in the track system design) and at receptors and provides:

"With regard to all but a limited number of sensitive receptors, no significant effects are predicted during the Operational Phase. There are some locations where an enhanced track support system will be required.

"In the case of buildings that are sensitive to groundborne noise, including buildings containing particularly sensitive equipment as well as large auditoria and studios, mitigation in the form of floating slab track will be incorporated into the design to remove any significant effects during the Operational Phase."

Arup's analysis indicates that the proposed track support system would assist in addressing some of the significant effects. However, there are several items of equipment generally not identified or assessed in the EIAR for which the relevant criteria would be exceeded, even with the implementation of the proposed track support system.

Allied to this, there remains a significant level of uncertainty about the predictions at low frequencies due to uncertainties and sensitivity of numerical modelling to assumptions about the ground properties. Furthermore, the track support system properties stated would result in a system for which deflection of the rails under the static load imposed by the train is likely to be considerably greater than what is normal or proven for floating slab track. No confirmation of the practicability of the proposed system is provided.

EIAR Section 14.5.2 acknowledges that there are facilities within Trinity that will require detailed consideration in the design to comply with the equipment requirements. Furthermore, it acknowledges that there may be changes in equipment between the present and the opening of MetroLink that need to be considered and mitigated:

"With regard to sensitive laboratory equipment, detailed building-specific numerical modelling will be required to establish the likely exceedance of equipment specifications, and to find the optimum specification for the track support system to minimise exceedances. Mitigation at the receptor for specific rooms within sensitive buildings in the form of the installation of base-isolated foundation slabs to support the equipment may also be required. As the specific sensitive equipment in use at Trinity is expected to change between the time of this assessment and the opening of the proposed Project close consultation should be undertaken between TII and Trinity in relation to the specifically sensitive rooms." [Emphasis added]

The proposal in the EIAR to mitigate residual significant effects at the receptor (sensitive equipment) through the use of base-isolated foundation slabs is not practicable for all equipment and buildings, especially for locations where equipment is not on a ground floor or basement level slab. Even where this solution could be possible, construction would cause significant disruption to Trinity's activities. Furthermore, any future requirements for vibration sensitive equipment to be installed in the same facilities could also be compromised.

3.3.2 EMI

EIAR Section 12.10.1 addresses construction phase mitigation for EMI and states:

"As part of mitigation measures for noise and vibration some of these (particularly in Trinity) will not be in operation as the TBM passes, reducing the likelihood of DC magnetic field interference to nil for those equipment types".

While it is understood that such measures are dictated by vibration mitigation requirements rather than EMI, it is considered that the practicality of such measures, given the size of the TBM and the duration it will take to pass, would be seriously detrimental to Trinity's activities.

Section 12.11 of the EIAR states:

"With regards to DC magnetic field impacts on sensitive medical and scanning equipment such as those located in Trinity, the Rotunda and the Mater the following mitigation measures are available:

- *Relocation of effected [sic] equipment;*
- *Installation of an active-cancellation system; and*
- *Shielding of the labs/rooms using specialised material designed to attenuate magnetic fields.*

"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 were 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. A final solution would be the installation of fixed shielding, a solution with which some of the departments and institutes at Trinity are already familiar." [Emphasis added]

It is noted that relocation of sensitive equipment has been suggested as a mitigation option in the EIAR, but not examined in any detail. This mitigation approach is unacceptable given the level of disruption involved to Trinity, the absence of any alternative suitable on-campus locations, and the effective sterilisation of eastern portion of the Campus for future research opportunities.

The Active Cancellation Systems (ACS) system referenced as a potential EIAR mitigation measure consists of a number of orthogonal coils typically located around the room where the sensitive equipment is located, with a magnetic field sensor placed beside the sensitive equipment. The coils are used to create varying magnetic fields which oppose any magnetic field fluctuations at the sensor location. This is the mitigation option preferred in the EIAR at the location of the sensitive equipment. For the proposed alignment the sensitive equipment performance requirements are exceeded at the location of the NMRs (Chemistry Building) and SEMs (Panoz Institute) when the emissions from the MetroLink are considered on their own. The assessment of baseline and MetroLink emission is consistent with the EIAR methodology set out in the EIAR Guidelines, and the omission of the baseline levels from the assessment of impacts gives rise to significant deficiencies in the assessment of predicted impacts and proposed mitigation measures.

The EIAR presents ACS as a viable mitigation option at the location of the SEMs and the NMRs. There is no assessment provided in the EIAR of how the ACS systems would work with 3 no. SEMs located in close proximity to one another (in the same room), nor is there any consideration of the practicality of using an ACS with NMRs. Arup has been unable to find precedents, comparators or indeed proven manufacturer ACS products for mitigation of EMI for NMRs. In addition, the coils of the active cancellation system cannot be placed close to reinforcement bars or other large ferrous masses as this will reduce its effectiveness, this may be challenging in an existing building.

The final EIAR mitigation measures considered, which appears to be a last resort if ACS is not effective, is passive shielding. This mitigation option involves installing a high permeability material such as mumetal on all 6 sides of the room or laboratory. Compared with ACS passive shielding is highly disruptive and very costly. This option is partially explored as a solution for the NMRs. However, the budget of €90,000 proposed in EIAR Appendix A7.10 is considered to be unrealistic.

3.4 Residual Risk Associated with Proposed Alignment

Notwithstanding the EIAR mitigation measures identified, the EIAR concludes that **residual risk, for both vibration and EMI, remains 'significant'** for the three Trinity buildings assessed.

EIAR Section 14.6 sets out the expected residual significant effects of groundborne noise and vibration. Section 14.6.1.1 states:

> *"There will be effects during the passage of the TBM which can be mitigated by an early stakeholder engagement programme, so that building occupants would be prepared for the passage of the TBM and resultant temporary elevated noise and vibration levels. Nonetheless, in certain circumstances some residents may find the effect intolerable. TII will accept and consider applications for additional measures on a case-by case basis, in accordance with the Airborne Noise and Vibration Mitigation & Groundborne Noise Mitigation Policy (Refer to Appendix A14.6)."*

EIAR Table 14.49 provides that residual impacts associated with construction phase vibration remain significant at the three Trinity buildings considered.

EIAR Section 14.6.2.2 addresses operational stage vibration and states:

> *"Only in the case of highly sensitive laboratory equipment is it likely to prove difficult to avoid exceeding manufacturers' specification for ambient vibration, which will necessitate receptor-specific mitigation."*

EIAR Table 14.54 also concludes that residual impacts associated with operational phase vibration remains "significant" at the three Trinity buildings considered.

The headway between trains is generally only around two minutes. If vibration from operation was to compromise the working environment, the time between trains would be insufficient for it to be practicable to carry out vibration sensitive activities during these short quiescent periods. As noted in Section 3.3.1, the practicality and the effectiveness of the EIAR outline mitigation measures do not provide an acceptable level of certainty that there will not be unacceptable vibration impacts.

With regard to residual EMI impacts, EIAR Section 12.12 states:

> *"Locations within the Trinity, Rotunda and Mater Campuses where DC and quasi-DC magnetic field perturbations are at elevated levels from the operation of the proposed Project may not be suitable for the installation or relocation of equipment with sensitivities to these types of fields'.*

Section 12.12 goes on to state:

> *"Despite applied mitigation measures to minimise the magnitude of stray current, it is an inevitable phenomenon associated with DC rail systems. Continued monitoring of the performance of the traction circuit with respect to current returns to the substation will be required."*

As outlined, it is acknowledged that ACS systems are widely used with SEMs) and they have also been used with MRIs. However, it is Arup's understanding that ACS systems are not established technology for NMRs. Furthermore, it is considered that the location of multiple SEMs in the same room and installation in existing buildings may restrict the effectiveness and practicality of such systems.

Given the level of uncertainty in the suitability and effectiveness of the mitigation measures proposed it is necessary that a trial of an ACS system is conducted at the location of the SEMs and that this informs the proposed EIAR mitigation strategy.

3.5 Inadequate Assessment of Alternative Alignments

Section 4.1 below presents a robust technical assessment of the Option 5 Alignment utilising the same criteria used in the EIAR consideration of alternative alignments under the Trinity Campus. The alternatives considered all pass beneath the sensitive buildings on the eastern side of Trinity's campus and represent minor variations on the alignment applied for. As illustrated on the table in **Appendix C**, even with comprehensive mitigation, none of these alignments can demonstrably and fully mitigate the likely significant impacts on Trinity's sensitive equipment. The EIAR is materially inadequate and qualitatively deficient in this regard.

4.0 MITIGATION OF LIKELY SIGNIFICANT EFFECTS

Based on Arup's assessment of the proposed alignment, and the ineffectual nature of the mitigation measures proposed in the EIAR to protect the performance requirements of the affected equipment, the only effective mitigation strategy is based on the following elements:

- **Trinity's Proposed Mitigation Strategy**:
  - Mitigation by design with a localised realignment of the line beneath the Campus, identified on Figure 1.1 as 'Alignment Option 5', moving the alignment 61.5 m westward of the current proposed alignment; and
  - Further detail and assessment provided by the Applicant, by way of response to a Request for Further Information, in respect of the Mitigation Measures proposed in the EIAR as supplemented in this submission by Trinity's experts, to demonstrate to the satisfaction of the Board (and Trinity) the efficacy and practicality of those measures based on robust survey data, monitoring, assessment, and evidence of successful comparators, **based on the Option 5 Alignment.**

The relevant information in respect of the proposed localised realignment of the line beneath the Campus, (Alignment Option 5), is set out in Section 4.1, below.

4.1 Alternative Route Alignment (Option 5)

As referenced earlier, Trinity engaged proactively with TII over the period commencing March 2018 to November 2022 to assist the Applicant in identifying and avoiding or appropriately mitigating the potential for likely significant negative impacts arising primarily from EMI and vibration (see **Appendix B**). This engagement included the assessment by the Applicant of potential amendments to the tunnel alignment with a view to mitigating and reducing reliance on mitigation measures. EIAR Appendix A7.10 addresses the consideration of 4 no. alternative alignment (Options 1 to 4) together with the then preferred route (Option 0).

The Assessment recommended that the then preferred alignment (Option 0) be amended to Option 2. Option 2 does offer some improvement over the original alignment (Option 0). However, the EIAR itself clearly states that this option still results in "significant" "negative" impacts on Trinity's educational and research facilities.

The EIAR preferred route (Option 2) incorporates a design radius of 350m and assumes a maximum running speed of 80kmh. As detailed in EIAR Appendix A7.10, Options 0 and 1 also assumed a maximum operating speed of 80kmh, while Options 3 and 4 have an assumed maximum operating speed of 60 kmh.

As detailed in the Arup EMI and Vibrations Studies, the current proposed alignment, together with the significant uncertainty in respect of the effectiveness of the proposed mitigation measures, will result in significant adverse effects on Trinity's educational and research activities. The EIAR Consideration of Alternatives and the Arup assessments undertaken clearly establish that the movement of the proposed alignment westwards, which increases the separation between the MetroLink and the highly sensitive equipment research equipment, will assist in reducing the magnitude of impact during both the construction and operational phases.

The EIAR identifies two more westerly alternatives (Options 3 and 4) and states that these were not feasible and, accordingly, these options were dismissed without presenting any detailed assessment[6]. The stated reasons are provided in EIAR Appendix A7.10 and are summarised as follows:

- Inadequate space proofing of the tunnel to accommodate the dynamic kinematic envelope of the train operating on a tighter radius
- TBM steering difficulties operating on a tighter radius
- Operational Speed restrictions leading to increased journey times
- Non-compliance with MetroLink's Design Parameters
- Wheel-Rail Interference

The CECL Global Report submitted herewith (**Appendix D**) disagrees with the findings of the options study and considers that a more westerly route could be designed which would have negligible impact on the construction, functionality or operation of the railway.

The Report presents an alternative feasible alignment (Option 5) which would increase the separation between the MetroLink and the highly sensitive research equipment without having consequential impacts to the alignment beyond Tara Street and St. Stephen's Green stations. Option 5 requires the following changes to the preferred alignment proposed in the Draft Railway Order:

- One-degree clockwise rotation of Tara St Station
- Reducing the minimum design radius to 260m
- Reducing the operational speed to 60 km/h

This alternative alignment is not a unique solution and other permutations of these types of changes may be used to achieve the same goal.

The Applicant has rejected similar solutions in its options assessment based on a number of assumptions. The Report prepared by CECL Global includes the following summary which addresses these concerns and demonstrates that Option 5 as presented is a feasible alternative and which the Board is requested to require the Applicant to assess as part of a Request for Further Information:

[6] It appears that TII has made a deliberate choice to prioritise the performance of the railway over the needs of TCD.

Table 4.1: Extract from CECL Global Report Addressing Specific Concerns with a more Westerly Alignment

Concern Raised by MetroLink	Assessment
Inadequate space proofing of the tunnel to accommodate the dynamic kinematic envelope of the train operating on a tighter radius	The dynamic kinematic envelope design for the tunnel considers the worst coexistent combination of horizontal and vertical curvature. The proposed horizontal alignment immediately South of Tara St. Station is relatively flat and therefore would not generate the same envelope. We therefore contend that sufficient space exists to accommodate the Trinity Westerly alignment.
TBM steering difficulties operating on a tighter radius	We have assessed that a tunnel radius as small as 225m (i.e. significantly smaller than we propose) would have no impact on the ability to steer the tunnelling machine or to maintain efficient logistical backup. The tunnel ring, TBM and logistics would simply be designed for this minimum radius. In the zone beneath Trinity, a full face of homogeneous competent Argillaceous Limestone rock is expected which should provide excellent conditions for steering the tunnelling machine. A significant length of tunnel will have already been built by the time the TBM drives beneath Trinity and issues relating to learning curve will therefore have long since passed.
Operational Speed restrictions leading to increased journey times	The new proposed alignment would require a modest reduction in operational speed which will result in a negligible increase in journey time. This however needs to be offset against an overall reduction in the length between the two stations which will reduce journey time. We calculate the net increase in journey time to be less than 1 second
Non-compliance with MetroLink's Design Parameters	Inspection of the values used by the Designer reveals an exceptionally conservative approach to the design when compared with recognised European and international best practice. We therefore do not accept that compliance with MetroLink's *"gold plated"* design parameters should be viewed as a fixed constraint.
Wheel-Rail Interference	Wheel-rail interference would not normally be expected to be encountered on a properly maintained system above the minimum radius of 150m as recommended in the European Standard. We therefore also reject this argument against the Westerly alignment.

The proposed Option 5 alignment constitutes a reasonable alternative that should be addressed in a substantive manner by the Applicant by way of a Request for Further Information. It is acknowledged that scope to move the alignment westwards, without consequential changes to the alignment north and south of Tara Street and St. Stephen's Green stations, is limited[7]. Accordingly, while movement westwards by itself may not fully mitigate EMI and Vibration impacts, it can materially reduce and minimise the magnitude of such impact and to reduce the reliance on untested mitigation measures.

Significantly, Option 5 also has the benefit of substantially reducing the impact on Trinity's future research and development activities within the College Green campus, providing scope for new or upgraded equipment to be located within the currently affected buildings on the eastern part of the campus.

The EIAR identifies significant construction phase vibration impact associated with the TBM. Due to the rate of movement of the machine, and the distances at which impacts will be felt, while the proposed Option 5 is unlikely to fully mitigate the impacts associated with the TBM, it would assist in creating a greater separation distance and therefore considerably reduce the duration and magnitude of the construction phase impacts.

With regard to operational vibration impacts, the Arup Vibration Report identifies an improvement in the vibration risk associated with Option 5, compared to the EIAR preferred Option 2, as locating the tunnels as far west as practicable would, in conjunction with optimised floating slab track design, reduce the risks and need for additional local mitigation at Trinity's facilities. It is submitted to the Board that it is necessary for the EIAR to assess the potential of this proposed mitigation by design, coupled with verified in situ mitigation measures to be identified in the EIAR.

The Arup EMI Report assesses the potential of the Option 5 alignment to mitigate the negative impacts on sensitive equipment locations. The NMRs in Chemistry dictate the separation distance as they are predicted to be exposed to high emissions from MetroLink and also are relatively sensitive to EMI (compared to the MRIs and the SQUID) and that equipment doesn't have established mitigation. The additional monitoring proposed in Section 5.0 below is required to properly understand and establish the baseline conditions. This will inform the distance that the alignment needs to move westwards to meet the performance requirements.

The Arup EMI Report concludes that *"it is only by further increasing the separation between the MetroLink and sensitive equipment that the performance of the research activities at TCD can be assured."*

The Report states that to meet the performance requirements for the NMRs:

- Using the EIAR survey and predicted emissions, the alignment would need to move an additional 65m (Option 5) west of alignment Option 2, and
- Using Arup survey and predicted emissions, the alignment would need to move an additional 175m west of alignment Option 2.

This emphasises the magnitude of the challenge to effectively mitigate EMI impacts under the Option 2 as applied for.

[7] The consequences of the proposed Option 5 Alignment on lands beyond the Trinity Campus are considered to be limited and of a low order of magnitude, and can be assessed in a revised EIAR.

In this regard, Option 5 as presented in the CECL Global Report moves the alignment approximately 61.5m westward of Option 2. Based on the information available, this is the extent the alignment can be moved without giving rise to more substantial design changes to the balance of the alignment.

A spreadsheet is attached at **Appendix C** (and summarised at Table 4.2 below) to assist the Board in understanding the interactions between the sensitive equipment and receptors, the route alignment options and the proposed mitigation measures (subject to demonstrating efficacy). The Appendix identifies all sensitive equipment, the 'as submitted' route alignment with EIAR mitigation, the alternative route alignment options with mitigation, and alignment Option 5 with comprehensive and updated EIAR mitigation (subject to demonstrating efficacy).

Table 4.2 below identifies all sensitive equipment, the 'as submitted' route alignment with EIAR mitigation, and alignment Option 5 with EIAR mitigation (subject to demonstrating efficacy by way of a Request for Further Information).

The Table uses a colour coded system to identify the predicted EMI and vibration impact on all elements of sensitive equipment. The colour coding clearly demonstrates the increasing confidence in the efficacy of mitigation by design associated with the westward realignment, coupled with additional mitigation measures. In this regard, there is a demonstrable difference in respect of vibration impacts between the two options. This significant potential of this mitigation by design option clearly warrants its consideration by TII by way of a Request for Further Information. There is also a demonstrable improvement in the sensitive equipment impacted by EMI, noting that significant additional mitigation measures that are demonstrated to be effective and viable will be required for the NMR machines in Chemistry.

Table 4.2 Extract from Overview of Predicted Impacts (Full Table included at Appendix 3)

Location	Equipment	EIAR Mitigation (Alignment Option 2)		Option 5 + Comprehensive Mitigation*	
		Vib.	EMI	Vib.	EMI
Chemistry	1x NMR (Bruker 400MHz)	Green	Red	Green	Yellow
	1 x NMR (Brucker 600MHz)	Green	Red	Green	Yellow
	1x NMR (Bruker 400MHz)	Green	Red	Green	Yellow
Panoz	1x SEM (Tecsan S8000)	Green	Yellow	Green	Green
	1x SEM (Tecsan Mira3 Tiger)	Green	Yellow	Green	Green
	1x SEM (Zeiss Sigma 300)	Yellow	Yellow	Green	Green
Lloyd	1x MRI (Bruker BioSpec 70/30 AVANCE III 7T)	Green	Yellow	Green	Green
	1x MRI (Siemens Magnetom Prisma 3T)	Green	Yellow	Green	Green
	2x TMS machine (DuoMag)	Yellow		Green	
	3x EEG machine (TruScan)	Yellow		Green	
	1x Confocal Microscope (Zeiss LSM 501)	Red		Green	
	1x Confocal Microscope (Zeiss LSM 880)	Red		Green	
SNIAMs	1x SQUID (Quantum Design MPMS-XL)	Red	Green	Green	Green
CRANN	1x AFM (Bruker Multimode 8)	Red		Green	
	2x UHV AFM (Omicron VT and RT)	Red		Green	
	2x Nanoindenter (KLA XP and DCM),	Red		Green	
	1x 3D Contact Mechanics Tester (Fast Forward Devices)	Red		Green	
	1x Stylus Profileometer (Bruker Dektak)	Red		Green	
	2x Optical Tweezer Instruments	Red		Green	
	1x XPS	Red		Green	
	4x STM (Omicron Variable Temperature STM,	Yellow		Green	
	2x Omicron Cryogenic STM, Empa designed AFM/STM)	Yellow		Green	
	1x STM	Yellow		Green	
	1x STM	Red		Green	
	1x STM	Red		Green	
	1x SEM (proposed in future)	Green		Green	
Fitzgerald	2x STM	Red		Green	
	1x STM	Red		Green	
	1x AGFM	Red		Green	
	1x optical telescope	Red		Green	
	1x radio telescope	Red		Green	

Green: Low Risk/Meet Criteria

Yellow: Risk of Exceedance of Criteria

Red: Unacceptable Risk of Exceedance

On the basis of the foregoing, it is submitted that the only mitigation strategy that can provide an acceptable level of confidence is:

1. Alignment Option 5, and
2. Further detail/corroboration on the EIAR Mitigation Measures, and:
3. Arup's recommendations, subject to:
   - The Applicant demonstrating to the satisfaction of the Board that the combined realignment and mitigation measures will be effective and practicable in mitigating impacts and residual impacts to an acceptable level.

Section 5 below sets out the necessary detail and assessments required to demonstrate the adequacy of the mitigation measures proposed.

5.0 MITIGATION MEASURES – INADEQUACY OF INFORMATION

On the basis of the information presented above, it is evident that significant additional information is required in order to identify, describe and assess all likely significant direct and indirect impacts on all elements of sensitive equipment identified in this submission, that presents an evidence-based assessment of the magnitude of those impacts having regard to the baseline context, and includes proposals to mitigate those impacts to acceptable levels substantiated by appropriate data and analysis, and evidence of their successful use in comparable contexts.

Accordingly, it is imperative that the Applicant is requested to provide significant further information for the following reasons:

- To enable an assessment by the Board of the efficacy of proposed mitigation measures that are reasonable, feasible and can be implemented.
- To clearly detail and articulate in the EIAR the proposed mitigation measures to which the Applicant is committing and will be obliged to implement at its own cost in the event that the project proceeds.
- To clearly detail monitoring that will be undertaken by the Applicant for the duration of construction and operation, and further mitigation measures that may be necessary in the event that the mitigation measures are not effective.

Accordingly, the Board is respectfully requested to issue a Request for Further Information.

5.1 Detail of Further Information Required

The Board is respectfully requested to issue a Request for Further Information that requires the applicant to submit the following information in respect of:

A. All elements of sensitive equipment identified in Table 2.1 this submission.

B. Route Option 2 (as submitted), and Route Option 5 (Alternative Alignment) as presented in this submission.

The information required to undertake the necessary assessments, to specify mitigation measures and to demonstrate the efficacy and practicality of those measures, is summarised as follows:

1. Confirmation and evidence that the track support system design is viable in terms of railway engineering design. In particular, detail is required in respect of the deflection of the track under the proposed design, and evidence as to how the proposed deflection is acceptable in terms of RAMS (reliability, availability, maintainability and safety).
2. Confirmation and evidence of the predicted vibration levels and spectra at each item of sensitive equipment at Trinity as identified on Table 2.1 of this submission. Details must include the modelling input data used, including assumptions about the building structure.
3. Confirmation and evidence that the predicted vibration levels and spectra at each item of sensitive equipment at Trinity as identified on Table 2.1 of this submission can be achieved by a track support system that is acceptable in terms of RAMS. Details must include the modelling input data used, including assumptions about the building structure
4. Appendix A14.4 provides details of the FINDWAVE software used for the vibration predictions. It does not, however, provide spectral results and information relating to the level of uncertainty or error in the predicted vibration that would occur at the receptors. Due to uncertainties particularly related to the dynamic properties of the ground and the response of the various buildings, there are inevitably limitations in the accuracy of any prediction method, particularly related to low frequency vibration. Accordingly, further information on the uncertainty/margins of error in the predictions is necessary to substantiate the assessments contained in the EIAR, and to provide a better understanding of the risk implications.
5. Modelling evidence is required to demonstrate that the proposed combination of floating slab track and booted sleepers is the best solution and would successfully mitigate vibration in the full range of frequencies relevant to vibration sensitive equipment identified on Table 2.1. A sensitivity study is required to compare the outcomes of viable mitigation solutions, using a variety of combinations of floating slab track and sleeper isolation.
6. Where impacts cannot be demonstrated to be fully mitigated at source, further details are required to demonstrate how equipment can be isolated locally by the installation of isolated plinths or, for smaller items, isolation tables or resilient mounts. Each isolation system should be individually specified, with evidence presented to demonstrate effectiveness. Alternatively, it may be possible to combine insertion gain required for the track and equipment isolation.
7. Details of specific measures proposed, for all items of equipment which require local mitigation, should be provided, including evidence that the proposed solutions are effective and practicable.
8. Details as to how the existing vibration conditions will be protected such that the MetroLink would not compromise Trinity's ability to expand and develop their facilities in the future.
9. Additional detail on monitoring to demonstrate that the baseline environment will not be made worse than that currently enjoyed by Trinity, and detail on the manner in which agreed baselines are measured over an extended period of time, and at locations to be agreed between TII and Trinity.
10. Assessment of EMI monitoring is required to be undertaken. Three weeks of monitoring is required for EMI at the location of the NMRs identified on Table 2.1 of this submission.
11. Proposals for a monitoring system (see example *link*) for longer term readings of the baseline EM fields are also required [state purpose].

12. Details of proposed mitigation proposals and evidence of their successful use in comparable contexts to demonstrate that EMI risks to all equipment identified on Table 2.1 of this submission can be minimised to an acceptable level. This should include evidence of ACS being successfully used for NMRs, SEMs (multiple SEMs in close proximity) and MRIs.
13. Trinity is agreeable in principle to the Applicant undertaking a trial of an ACS at the location of the SEMs in Panoz, and for the results to be submitted to the Board.
14. Additional detail and clarification of the type of ACS's proposed and an assessment of efficacy of the system for the purpose of mitigating effects on all sensitive equipment identified on Table 2.1 of this submission.

6.0 CONCLUSION

Trinity is a world-leading University and research centre. MetroLink is an important project for the city and climate objectives. Trinity engaged with TII at the design stage of the project with the objective of supporting a MetroLink project that incorporated design and mitigation measures that provided the necessary level of confidence that that the construction and operation stages of MetroLink would protect its research and teaching facilities.

The EIAR clearly identifies "significant" and "negative" impacts on Trinity's educational and research facilities. The EIAR acknowledges that the mitigation measures proposed in the design will not adequately protect the identified sensitive receptors.

It is the opinion of Trinity's technical experts that the application fails to adequately identify, describe and assess the likely direct and indirect significant effects of the MetroLink project on Trinity. The EIAR has failed to assess and consider feasible alternatives to reduce the level of unacceptable impacts and the EIAR mitigation measures lack substantive validation by robust survey data, monitoring, assessment and evidence of successful comparators. The EIAR is materially inadequate and qualitatively deficient in this regard, with significant consequences for Trinity.

The significant uncertainty in respect of the availability and efficacy of potential mitigation measures also has significant implications for the future provision, upgrade and enhancement of equipment and research programmes in the affected buildings. In this regard, the proposed alignment, together with the wholly inadequate mitigation measures identified, have significant potential to constrain or sterilise Trinity's existing and future core academic and research activities on the eastern part of its campus.

Based on Arup's assessment of the proposed alignment, and the ineffective nature of the mitigation measures proposed in the EIAR to protect the performance requirements of the affected equipment, the only effective mitigation strategy is based on the following elements:

- Mitigation by design with a localised realignment of the line beneath the Campus, identified on Figure 1.1 as 'Alignment Option 5', moving the alignment 61.5 m westward of the current proposed alignment; and
- Further detail and assessment provided by the Applicant, by way of response to a Request for Further Information, in respect of the Mitigation Measures proposed in the EIAR as supplemented in this submission by Trinity's experts, to demonstrate to the satisfaction of the Board (and Trinity) the efficacy and practicality of those measures based on robust survey data, monitoring, assessment, and evidence of successful comparators, based on the Option 5 Alignment.

It is submitted that it is imperative that the Applicant provides the significant additional information in respect of proposed mitigation measures identified in this submission for the following reasons:

1. To enable an assessment by the Board of the efficacy of proposed mitigation measures that are reasonable, feasible and that can be implemented.
2. To clearly detail and articulate in the EIAR the proposed mitigation measures to which the Applicant is committing and will be obliged to implement at its own cost in the event that the project proceeds.
3. To clearly detail monitoring that will be undertaken by the Applicant for the duration of construction and operation phases, and further mitigation measures that may be necessary in the event that the mitigation measures are not effective.

In the event that the Applicant fails to demonstrate that effective, proven mitigation measures can be implemented, then Trinity is left in the position where it requests that the Board refuses consent, or terminates the MetroLink at a point north of Trinity's Campus having regard to the likely significant adverse, permanent and unacceptable impacts on the University's sensitive equipment, its established and future research facilities, its students, researchers and staff, and its global status and funding.

Given its support for the principle of the MetroLink project, Trinity respectfully requests that the Board presents the Applicant with a further opportunity to properly consider the likely significant direct and indirect effects on Trinity, and in particular adequate mitigation measures (including mitigation by design). Section 5 of this submission provides a basis for the Board to issue a Request for Further Information inviting the applicant to submit a revised EIAR, revised plans and all necessary assessments, in respect Trinity's Proposed Mitigation Strategy.

We trust that the Board will afford due regard to the matters raised in this submission and we look forward to a favourable outcome.

APPENDIX A

TCD LIVING RESEARCH EXCELLENCE STRATEGY

A LIVING RESEARCH EXCELLENCE STRATEGY

Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

FOREWORD

Research is at the heart of what we do in Trinity. It is part of our core mission along with teaching. In preparing this Research Excellence Strategy the passion of our staff and students for their work has been evident in the huge input that has been made to this document, and to the accompanying Research Charter. The wealth of ideas and suggestions that were forthcoming speak to the real desire to be research leaders and to continue to build and improve our research culture.

We do live in challenging times, and they are no less challenging for research. In one sense, research always involves a struggle – a struggle on the individual level to uncover new knowledge, make the breakthroughs, or create something new, and a struggle at the system level to defend the value of research and to fight for its full support.

This research excellence strategy seeks to address both the opportunities and the challenges we face and build on the great strengths and talents of the people in Trinity. Sincere thanks go to the many colleagues who helped shape this plan.

Linda Doyle

Prof. Linda Doyle
Dean and Vice President for Research

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THE ESSENCE OF THE RESEARCH EXCELLENCE STRATEGY

With the right supports and the freedom to act, we as researchers can continue to make enormous contributions to knowledge and significant breakthroughs.

Introduction

Research is an essential part of what we do in Trinity. We are driven by a passion for research and scholarship. Our research has a fundamental influence on our teaching. Research, along with teaching, forms our identity. It is one of the factors that makes Trinity the leading university in Ireland. And our standing in the research world contributes significantly to our international reputation.

With the right supports and the freedom to act, we as researchers can continue to make enormous contributions to knowledge and significant breakthroughs that will have great impact upon the world and humanity. However, we operate in a country in which investment in the Third Level sector, and in research even more so, has suffered significantly over the last decade. We are working at a time when political threats such as Brexit dominate for our economy and society. We also live in a world in which the demands on each individual researcher, and on all staff in the university as a whole, continue to grow. Yet despite the constraints and challenges, it is our desire always to do better, to continue to address burning questions that advance knowledge for its own sake and for the sake of society.

It is against this backdrop that this Research Excellence Strategy is written. It recognises the challenges we face but aims to be a document that inspires a way forward, encourages us to further excel, and carry out the very best research in Trinity.

A Living Research Excellence Strategy

The research world is a dynamic one that is frequently challenging and often changing. This Research Excellence Strategy echoes that. The strategy described here aims to provide a clear and strong framework to drive our ambitions while at the same time allowing a dynamic approach to its implementation. The idea of a 'living' Research Excellence Strategy recognizes the expansive nature of research. All parts of Trinity, and all staff and students, have a role to play in the future of our research, and the ownership of the actions contained within this plan need to be taken on by many. It is about giving a strong voice to research and keeping the conversations around research alive and vibrant. It is about learning by doing and updating and refining our actions as we do. It is about constantly striving for excellence together.

The Foundations of the Strategy – the Research Charter

This plan is built on our Research Charter. Over the first half of 2018, a Research Charter that listed key principles underpinning our approach to research was created. The Charter was the result of a highly consultative process that engaged people from different disciplines and divisions across Trinity. Over 60 different meetings took place.

In the Charter our vision is set out as one that is about engaging in research with the quality, intensity, depth, diversity, and openness that leads to fundamental breakthroughs, new understandings, key insights, and that can make translational and transformative advances – so that we can build a world in which we want to live.

The seven principles that emerged are seen as a means of developing the kind of research environment that will allow us to deliver on this vision. The Charter describes each principle in turn and sets out a high-level goal associated with each.

Principles from the Research Charter and the High-level Goals

Principle	High-Level Goal
Cherish academic freedom, diversity of scholarship and pursuit of truth	*To be synonymous with a culture of academic freedom, diversity of scholarship, the pursuit of truth, and the highest level of academic standards.*
Position research at the heart of Trinity	*To fully reflect the research intensity of the institution in our governance, structures, and operational practices.*
Foster and grow research talent and leadership	*To develop the kind of research environment that attracts and nourishes the very best research talent, and allows our researchers to excel at all stages of their career.*
Harness our collective expertise for the greater good	*To be bold in defining and taking the lead in multidisciplinary initiatives or emerging fields of research that leverage our expertise, for the long-term benefit of humanity.*
Broaden our local and global impact	*To identify and deliver opportunities for local and global impact that exemplify the diverse forms of scholarship that are part of the Trinity research landscape and drive impact to new heights.*
Engage profoundly with our publics	*To be a world leader in how we communicate our research to our multiple audiences.*
Stand up for research	*To be a champion for a balanced research ecosystem in Ireland and Europe, one that has excellence as a foundation, and influence how research policy is developed to achieve this.*

The table above captures those principles and goals. The Charter is our public commitment to the values that underpin our research and is the starting point for the Research Excellence Strategy. This Research Excellence Strategy is the internal document that provides a framework to guide our actions.

From High-Level Charter Goals to Detailed Actions

The Research Excellence Strategy is about actions we need to take to make the Charter a reality. To move from that starting point, a detailed process of mapping the principles and high-level goals to actions was undertaken. Many of the ideas and recommendations that arose during the consultation phase for the Charter played a role at this stage of the process as well.

The mapping process led to the identification of a whole range of actions that we need to undertake. The Research Excellence strategy is written from the perspective of the resulting actions that stem from our analysis. These actions break down as follows:

1 *Stimulate and build strategic research collaborations*
2 *Make it easier to do research*
3 *Generate the funding and resources we need*
4 *Radically revise how we do research communications*
5 *Join the dots on all policies relating to our research*
6 *Be bold in planning our long-term research future*

A chapter will be devoted to each type of action. More detailed action plans will be mapped out in implementation plans and these will be updated as needed to reflect the dynamic nature of the strategy.

The Wider Strategic Landscape in Trinity

Before proceeding, it is important to recognise that this Research Excellence Strategy does not operate in a vacuum. There are many other areas in Trinity which have worked on their own strategic plans. It makes sense that any resonances and linkages with those plans should be leveraged.

Currently there are three existing strategies which have implications for this Research Excellence Strategy and vice-versa. The Trinity Education Project is the first of those. The graduate attributes in TEP are ones that are very much the kind of attributes that our PhD candidates, and indeed all involved in research, should have: namely to act responsibly, to think independently, to develop continuously and to communicate effectively. While research always informs our teaching, TEP explicitly recognises this to the benefit of all undergraduates in the TEP electives.

The newly launched Estates and Facilities Strategy is of huge importance when it comes to thinking about how we use space in this university. A number of plans within that strategy are directly related to research expansion. More broadly, being able to use the space we have more efficiently is crucial. The Global Relations Strategy 3, GRS3, also resonates as we aim to further build our global reach and develop strong networks that can work in harmony with research goals.

There are also strategies in the making. The future Digital Trinity strategy will have implications for research, both in terms of general support for research administration as well as support for learning and development. Over 2019 a new Strategic Plan for the university is being developed and the Research Excellence Strategy will inform that. In fact, the new Trinity Strategic Plan is very explicitly building on the ongoing work in all of the areas mentioned above. It can, therefore, also provide an opportunity for linking between areas, such as in the area of the integration of research and teaching. It is worth emphasising that research-led teaching is and will remain a central principle of our activities.

The Wider Cultural Landscape in Trinity

Finally, Trinity also has a unique cultural landscape in which our research takes place, and this should not be overlooked when working on our research future. These institutions offer us many opportunities for differentiation and growth.

Our Library dates back to the establishment of the College in 1592 and it is the largest library in Ireland. It has over 6 million printed volumes with extensive collections of journals, manuscripts, maps and music reflecting over 400 years of academic development. The Library is central to much of the research we do in Trinity and will continue to play a major role.

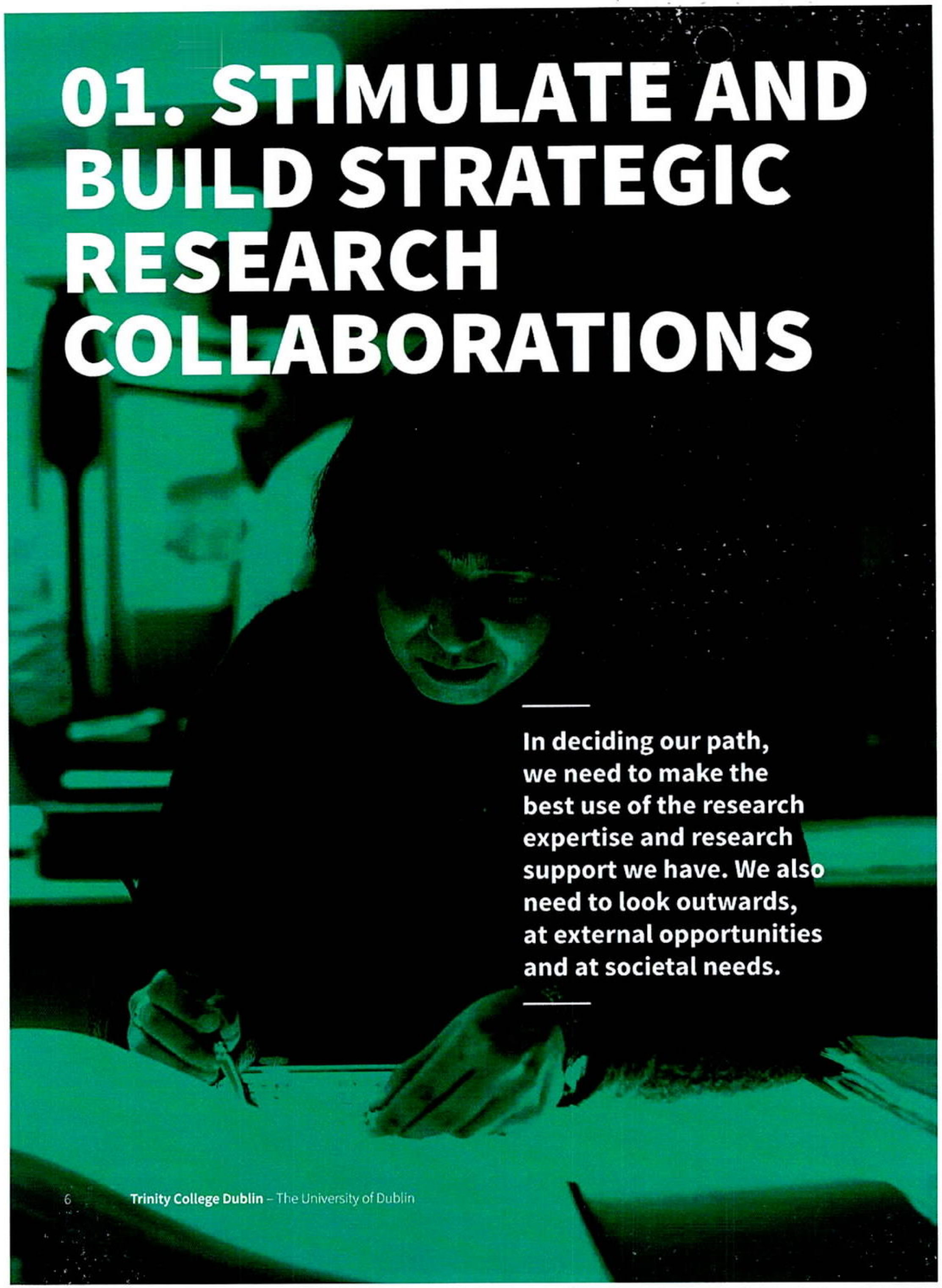
We also have newer cultural institutions that play a part and are growing on the research front. The Douglas Hyde Gallery is renowned for excellence and has a 40 year history of first class exhibitions. On the opposite corner of the main campus is the Science Gallery that has carried out cutting-edge programmes for over ten years, and draws audiences in huge numbers. The Science Gallery is growing its research activities and is also at the heart of Science Gallery International – a global network that grew from the efforts here in Trinity.

Conclusion

This living Research Excellence Strategy will contain a number of already well-defined actions which sit within the different categories. More importantly it will also consist of emerging actions that will require more research and discussion to pin down. Ideally, it will also grow to contain new ideas that push us to do things very differently.

There are objectives that need to be balanced. In a research world of increased complexity and demands we need to find more ways to allow staff and students to simply get on with their research and to excel. But we also need to make sure, to use a well-worn but useful phrase, that the whole of our activities is greater than the sum of the parts. The latter is especially important in a highly competitive research environment.

01. STIMULATE AND BUILD STRATEGIC RESEARCH COLLABORATIONS



In deciding our path, we need to make the best use of the research expertise and research support we have. We also need to look outwards, at external opportunities and at societal needs.

CONTEXT

Research in Trinity is based on individual curiosity-driven endeavour as well as on collective effort. As individuals, we have academic freedom to pursue our own research paths. We trust our staff and students in their individual endeavours. Much of the excellent research that has emerged in Trinity is driven by individuals.

The set of actions in this part of the Research Excellence strategy focus on collaborations. Increasingly, we face research challenges that either require critical mass to make progress, or are of a nature that cannot be solved from one perspective alone. These call for collective effort. We also work together because by bringing together different researchers and diverse forms of research we open up the possibility of identifying new research questions, new opportunities, and new fields of study.

As an institution, we need to decide what opportunities make most sense for us. It goes without saying that any collaborative endeavour requires individuals who are themselves excellent. In deciding our path, we need to make the best use of the research expertise and research support we have. We also need to look outwards, at external opportunities and at societal needs. We need to be responsive, and we need to be ready for change. We need to take risks in going in bold new directions that can lead the way in research internationally.

This section of the strategy focuses on the collective efforts that draw us together. The actions address our desire to be at the forefront of new disciplines, and to work with each other on larger-scale initiatives that seek to build critical mass in specific areas, and revolve around multidisciplinary research challenges. The actions help us set out the direction for our university.

Link to the Charter Principles

The key principle to which these actions apply is Principle 4, to harness our collective expertise for the greater good. The actions described are also part of Principle 3, fostering and growing research talent as the collaborative initiatives described here both provide environments which can be supportive of staff and also attract new staff. Moreover, large-scale and highly visible initiatives, as well as initiatives that focus on societal challenges, contribute to Principle 5 of expanding impact locally and globally.

Key Actions

The main actions are described here with more fine detail in implementation plans that will drive the execution of the strategy.

1.1 Systematically develop, advance and refresh our collaborative research initiatives within Trinity

Trinity already has a strong and long history of research collaborations within and across disciplines in the university and is well known for interdisciplinary research. In planning where we go next it is important to stand back and look at all of our Trinity-based collaborations. While of course collaborative work happens in many guises, for example, within Schools, what is of relevance here are the more formal structures we have created in Trinity to support collaboration. To plan effectively, we need to look collectively at these initiatives and understand their reach.

Trinity research centres, of which there are more than 50, are the smallest formal scale at which collaborations occur. There are 19 themes which bring researchers together at a larger scale. The five Trinity Research Institutes (CRANN, TBSI, TCIN, TLRH and TTMI) are more formal structures for focusing on areas of great strength in the university. Trinity also currently hosts three SFI Research Centres in Trinity (AMBER, ADAPT, and CONNECT), and is a participant in many others. The figure overleaf attempts to capture the range and breadth of scales of how we currently collaborate. There are also other collaborative initiatives beyond these groupings.

Different modes of Collaborative Initiatives in Trinity

01 **Trinity Research Centres** →

- Ageing and Intellectual Disability (TCAID)
- Asian Studies
- Beckett Studies
- Biblical Studies
- Biodiversity Research (TCBR)
- Bioengineering (TCBE)
- Computing and Language Studies
- Contemporary Irish History
- Creative Technologies and Media Engineering
- Digital Business
- Digital Humanities
- Early Modern History
- Environmental Humanities
- Gender Equality and Leadership
- Gender and Women's Studies
- High Performance Computing (TCHPC)
- Literary and Cultural Translation
- Maternity Care Research
- Medieval and Renaissance Studies
- Mediterranean and Near Eastern Studies (MNES)
- New Irish Studies
- Non-profit Management
- People with Intellectual Disabilities (TCPID)
- Post-Conflict Justice
- Practice and Healthcare Innovation
- Psychological Health
- Social Innovation
- Environment (TCE)
- Study of Immunology (TCI)
- Urban and Regional Studies
- War Studies
- Advanced Medical Imaging (CAMI)
- Global Health
- Innovative Human Systems
- Research in IT in Education (CRITE)
- Transport Research and Innovation for People (TRIP)
- Hamilton Mathematics Institute
- Haughton Institute
- Institute of Population Health
- Irish Centre for European Law
- Centre for Health Policy and Management
- Trinity Plato Centre
- Academic Gastroenterology Group Research Centre (TAGG)
- Cancer Research Centre (TCRC)
- EngAGE - Centre for Research in Ageing
- Trinity Future Cities: Centre for Smart and Sustainable Cities
- TrinityHaus Research Centre
- Trinity Health Kidney Centre
- Trinity Impact Evaluation Unit (TIME)
- Trinity Institute of Cardiovascular Science
- Trinity Irish Art Research Centre (TRIARC)
- Trinity Medieval History Research Centre
- Trinity Migration and Employment Research Centre
- Trinity Oscar Wilde Centre for Irish Writing
- Trinity Research Centre for Cultures, Academic Values and Education (CAVE)
- Trinity Research in Childhood Centre (TRiCC)

02 **Trinity Themes** →

- Ageing
- Cancer
- Creative Arts Practices
- Creative Technologies
- Digital Engagement
- Digital Humanities
- Genes & Society
- Identities in Transformation
- Immunology Inflammation & Infection
- Inclusive Societies
- International Development
- International Integration
- Making Ireland
- Manuscript, Book & Print Cultures
- Nanoscience
- Neuroscience
- Next Generation Medical Devices
- Smart Sustainable Planet
- Telecommunications

03 **Trinity Research Institutes** →

- Crann
- Trinity Biomedical Sciences Institute
- Trinity College Institute for Neuroscience
- Trinity Long Room Hub
- Trinity Translational Medicine Institute

04 **Multi-Institutional**

SFI Research Centres & Spokes Led by Trinity

- Adapt
- Amber
- Connect
- Fintech
- J&J
- Enable

National Initiatives Co-Funded by Trinity

- *The Irish Longitudinal Study on Ageing (Tilda)*
- *IDS-Tilda*
- *Growing Up in Ireland*

Other Significant Initiatives

- Mercer's Institute for successful ageing
- Trinity St James Cancer Institute
- Nature +
- Trinity Research in Social Sciences
- Trinity International Development Initiative

Armed with this knowledge, we can look at the university from a big picture perspective, build on the firm foundations of what we have already created, and seek to understand gaps, trends, connections and opportunities.

1 We can understand existing plans and commitments to future endeavours (e.g. E3, TTEC, Cancer) and see where they fit.

2 We can, from a top-down perspective, identify further gaps and areas that are primed for expansion and growth. The areas that are ripe for this are ones in which we already have expertise, have people willing to take on leadership, and in which there are opportunities for supporting growth. This combination is very important.

3 We can use existing entities as foundations for building initiatives at greater scale. For example, it may be useful to explore how existing Trinity Research Centres which resonate with each other might form some kind of cluster and, over time, develop into a theme or an institute as appropriate.

4 We can use other approaches[1] that encourage out of the box thinking to bring research domains in Trinity together. We can continue the pairing of researchers from different fields to spark new ideas. We can define clear mechanisms that allow ideas to percolate upwards, and that support all interested staff and students to make suggestions and take the lead.

5 We can regularly challenge and refresh existing initiatives. Collaborative initiatives take time to establish and grow. They require commitment and dedication. It is, however, important that we stand back at intervals and look at the ongoing initiatives to ensure they are still relevant, excellent and cutting-edge. It is important that we do not rest on our laurels. We also need to close down activities that are not functioning, and look for new opportunities: for example, for Trinity Research Centres to reinvent themselves. A quick view of all the collaborative platforms above, will quickly lead to the conclusion that a certain amount of triage is needed. Actions here include light touch reviews of all Trinity Research Centres, an analysis of the status of the themes with a view to closing down inactive themes or expanding in new areas if appropriate, and regularly questioning the role, fitness for purpose, trajectory and identity of our Trinity Research Institutes.

[1] Schrödinger at 75 – The Future of Biology was a major gathering in Sept 2018 and brought leading experts from around the world together to consider the future of biology. It was followed up by seminars for Trinity postdocs who gave their responses to the event to tease out directions of study for their work. www.tcd.ie/biosciences/whatislife/

1.2 Bring the identified initiatives to fruition in an open and collaborative manner

Once initiatives are identified, through whatever mechanism (top-down/bottom-up), the work begins in making those initiatives thrive and excel. We should be transparent with our plans so that all in the university can see the overall direction of travel and can get involved where appropriate. The different initiatives themselves will require different actions in order to bear fruit. Depending on the state of development, they call for actions which range from building buy-in, identifying participants, developing the research ideas, identifying mechanisms for funding, matching hiring strategies to the initiative, and other more specific actions that depend on the exact type of initiative.

The tables that follow show the current direction of travel. The tables include initiatives that are already firmly on the agenda, as well as really strong elements of Trinity research that could be harnessed much more systematically and at scale.

The latter are the result of an initial scanning exercise that has coincided with the development of this strategic plan and should be read in that context. Much more work needs to be carried out to collectively flesh out target areas. Undoubtedly, there are other areas in which we have expertise, we have people willing to take on leadership, and in which there are opportunities for supporting growth. The table below will also be updated as initiatives are delivered and new opportunities arise.

1.3 Build the wider collaborative networks we need to do our research

Trinity is a very outward facing university, engaging nationally and globally, and our collaborations go beyond the walls of the university. We collaborate on research with colleagues across Ireland and with colleagues all over the world. The research networks in which we operate are important in establishing us as significant global research players. It is important we continue to build research networks that help us to deliver our research goals.

We can be strategic in deciding the new key institutional networks with which we engage at an institutional level.[2] These can be driven by the key areas of interest previously identified above, as well as other concerns such as Brexit. In creating and building networks for collaboration at an institutional level, we need to be more strategic in planning how we go forward, and how we make best use of the limited resources we have. Actions here include mapping current networks and identifying gaps, working more closely with Global Relations and others to get a better sense of all of the concerns for Trinity in building networks, and creating mechanisms for systematically choosing where to collaborate.

We need to make more strategic use of the networks we already have built. These include, for example, our EIT Knowledge and Innovation Community (KIC)[3] networks which facilitate collaboration that is particularly useful for how we translate research into wider impacts, and how we create opportunities for innovation and entrepreneurship. The newly emerging EU University Networks also affords us the opportunity to build our research collaborations, as well as make further strong connections between research and joint degrees that could be offered across the network. The EU University Network may have increased importance in a post-Brexit context.

[2] Academic freedom allows our researchers to pursue the kinds of research networks that support their work and allow them to contribute to the wider body of research, and this will always be the case

[3] A Knowledge and Innovation Community (KIC), is a highly autonomous partnership of leading higher education institutions, research organisations, companies and other stakeholders in the innovation process that tackles societal challenges through the development of products, services and processes and by nurturing innovative entrepreneurial people

Planned Initiatives (with much opportunity for shaping and development)

Initiative	Comment
The E3 Research Institute will follow on from the coming together of Engineering, Computer Science and Statistics and Natural Sciences in the E3 Learning Foundry. At the heart of E3 is a desire to solve the world's challenges through designing technical solutions that can work in harmony with the planet. The E3 tag line 'balanced solutions for a better world' encapsulates this. Rather than setting technology in tension with the planet, we are working together to create the balance that will create a better world.	*The E3 Research Institute will be a highly interdisciplinary institute. It will draw on research expertise of the three schools involved in E3. It will also draw on our SFI Research centres, ADAPT, CONNECT, AMBER and ICRAG. Currently, there are broad themes to guide the research - resources, production, environment, data, well-being and cities. This up-ending of disciplines allows us to tackle the mega trends that are shaping our world, such as changing demographics, urbanisation, depletion of resources, or shifting global powers.*
The Grand Canal Innovation District will be Ireland's Innovation District. It will see the emergence of a new Trinity campus on the TTEC site. It will be a mixed development focused on academic and industry endeavours. It will be constructed to encourage and facilitate wide spread collaboration between academia, industry, start-ups, and the community. It will also retain its strong cultural elements (e.g. The Lir)	*From a research perspective the GCID will open up many opportunities for Trinity and will draw on relevant research initiatives across three faculties. The E3 Research Institute will be an anchor tenant but the opportunities beyond that are huge. While the GCID is at an early stage, it is imperative we start to think about the research principles on which GCID will be built as well as the type of research that will happen in that location.*
The Trinity St James's Cancer Institute aims to be the first comprehensive cancer care centre in Ireland and will focus on cutting-edge cancer research, extensive clinical trials, and first-class cancer education. It will be located on the St James's Hospital campus.	*The Cancer Institute will open opportunities for bringing the cancer research we do together and growing it strategically. There are opportunities here for researchers in Health Science and in the Life Sciences more generally. There is potential here as well to build on our strengths in Immunology.*

Key Emerging Opportunities (which will require much input)

Trends	Comment
The Whole Life (Lifecourse)	*Trinity is already well established in the area of ageing research (TILDA, Mercer Institute for Successful Ageing, Global Brain Health Initiative, IDS TILDA etc.). We also have substantial research in the area of children. As with the case of ageing, it is highly interdisciplinary and brings together researchers from across AHSS, HS and EMS. We, in fact, take a very distinctive holistic approach that spans children's literature and their cultural well-being to health, education, policy and more. Many of the researchers involved across these different domains are already actively collaborating with each other.* *The building of the Children's Hospital at St James's offers further opportunities.* *The arc of our research essentially extends from birth to death. It is one that we can build on substantially and that lends itself exceptionally well to a multi-disciplinary perspective. What form such a joined-up endeavour may take is yet to be explored.*

Key Emerging Opportunities (which will require much input) *Continued from previous page*

Trends	Comment
United Nations Sustainable Development Goals	*We already have expertise in Trinity focusing on the Sustainable Development Goals. That expertise is deep and world class. However, our collective work on SDGs is not as visible as it should be and there is potential to deepen and add scale. A Sustainable Development Goal Hub is needed to, in the first instance, draw attention to the SDG related work we do, and in the second instance really push our SDG work forward. We already know of the huge opportunities that will exist in Horizon Europe and elsewhere. Even more importantly, SDGs represent a desire to make the world a better place and are aligned with our vision and mission.* *In driving the SDG agenda forward, there is opportunity across all faculties and disciplines. However, the SDG Hub will not be about re-badging research activity under SDG headings. Our aim will be to make parts of the SDG initiatives distinctly Trinity.* *There are many potential areas for growth. One such example is at the intersection of Gender, Climate Justice and Conflict. Here we can draw on a rich range of research from AHSS, through HS to EMS. We can resist with memory, understand through current conditions, work towards a different future. We already have a number of Trinity Research Centres that resonate with this concept, such as the Centre for Environmental Humanities and Cultural Trauma, and could work together to further these ideas. In addition, we have powerful international collaborators that we can work with should we go in this direction. This is the kind of collaborative endeavour that brings a unique opportunity for Trinity. Another example is the work of Nature+ which aims to understand the feedbacks between natural capital and climate systems, to design future-proof solutions to ensure economic growth.*
Social Change/ Improving Lives/ Making Policy	*Social science research is a large part of our research focus in Trinity, exemplified by the very active Trinity Research in Social Sciences (TRISS) initiative. There is significant involvement from many schools and there is much to build on here.* *We have many more staff throughout the university whose research is about effecting change through policy or drawing on their expertise to influence policy development. In terms of the latter the role of Arts and Humanities colleagues in influencing state policy towards the Decade of Commemorations comes to mind. Both of the categories mentioned above (Lifecourse and SDG), also have significant policy related aspects. We certainly need to capture all of the broader work in Trinity that is responsible for driving policy, locally and internationally.* *We also have opportunities to build on Trinity's strong relationship with the Institute of European and International Affairs (IIEA). We already have rich and varied ongoing activities including those coordinated through TRISS, TLRH, and the Business School with potential for wider engagement.* *Influencing and making policy through research is a hugely impactful activity. We have the potential to focus on the 'RESEARCH-POLICY interface' and take a leadership role. We see LERU and other leading universities driving this kind of agenda and there is a real opportunity for Trinity to excel.*

Potential Externally Driven Large-Scale Opportunities

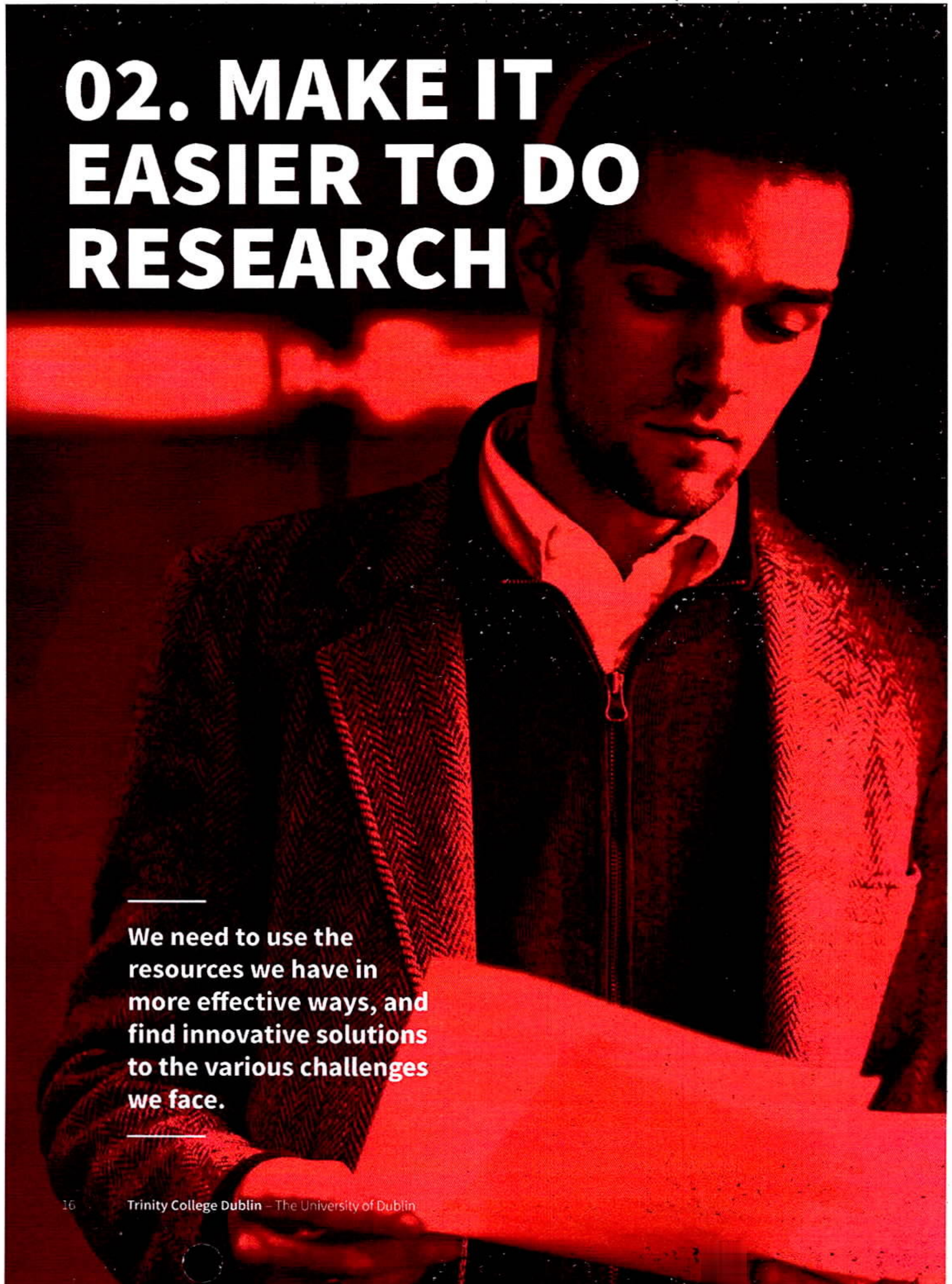
Initiative	Comment
Scaled Doctoral Initiatives There is an increasing trend in the research funding ecosystem to support PhD education at scale. These initiatives typically call for a cohort of PhD students to be hired loosely or tightly based on a topic or area, depending on the funding call. These kinds of initiatives allow us to further build collaborations across the university.	*The SFI call for Centres for Research Training (CRT) will see an additional 700 PhD students come into the Irish system. The growth of the role of data science/machine learning/artificial intelligence in all areas of research was addressed through this call.* *Six Centres for Research Training have been funded. Trinity leads the 'Digitally Empowered Human Engagement in the Real World' CRT and has strong involvement in the others.* *Other funding bodies have opportunities which we will also aim to leverage if suited to our research goals.*
Scaled Postdoctoral Initiatives There are also opportunities to fund large-scale postdoctoral initiatives – as in the PhD case. These types of initiatives can support postdoctoral researchers from all areas but typically require matched funding.	*Currently we have a number of these in operation through the MCSA Cofund programme. Our existing programmes support researchers across the faculties. We will seek to leverage more of these types of opportunities. There is increasing scope to leverage advances in Arts and Humanities linkages with industry in this context as well.*
SFI Centres and Spokes A future call for additional SFI Research Centres is currently still on the agenda. If that call is forthcoming, Trinity needs to be prepared for it. We also need to continue to exploit opportunities for spokes (large scale initiatives that are attached to one or more centres).	*There are a number of areas which could build on existing exceptional research strengths in Trinity and which could fill gaps in the Irish landscape. Potential candidates include Creative Technologies, Nature+, Personalised Medicine/ Cancer + and next generation Neuroscience, Future Biology. An exploration of these options will get underway in 2019.* *There is also an option for leading on new spokes. Spokes are mechanisms for growing existing centres. Currently we have a number of spokes led out of Trinity with room for identifying additional ones.*

1.4 Recruit to match our ambitions

As we grow existing and new research initiatives, we need to recruit the very highest calibre academics to strengthen them. We need to ensure that research excellence is at the heart of all our academic hires. We will need to continue to innovate in hiring practices to achieve this.

We can use our collaborative initiatives as part of the process of attracting the best. When it comes to hiring staff, we have a great university as an incentive. However, we compete in an ever-growing global market, from a country that needs much more investment in research, and from a city that is expensive and has issues around housing that make these challenges all the greater. Initiatives like E3 and the Trinity St James's Cancer Institute are already affording us the opportunity to collectively advertise posts across all the schools involved. In so doing, we can signal to prospective candidates the array of opportunities that come with the post, and that there is room for growth and leadership. This type of approach that signals opportunity for leadership needs to be embedded in our practices.

The Ussher Programme has been successful in recruiting high calibre Assistant Professors. We should now review existing hiring practices at Chair level to ensure we are doing everything to attract the best field of candidates. We must look at starting packages for new Chairs and explore how we offer supports such as temporary accommodation when first moving here, and also consider post-recruitment support for all new academic hires. We must open up new recruitment possibilities. The Ussher Programme was a strategic, centrally-driven programme that led to large-scale hiring of highly-motivated individuals and was linked to major initiatives across the university. It is important for us to look at how we might run a similar centrally-driven programme at Chair level. A centrally-driven programme is not there to usurp the role of the schools in their own hiring plans. Rather, the aim of any centrally run hiring scheme is to recruit in ways that brings additional value and leadership, and can have significant impact on our collaborative initiatives. The challenge here, of course, is 'with what funds?' The answer is that funds will have to be sourced. A connected answer is that opportunities for sourcing funds will tend to be linked to the types of large initiatives laid out here. We should aim to source funding for 25 Chair positions over the next decade that can respond to the call for research leadership, and that will ensure we stay at the forefront of research.



02. MAKE IT EASIER TO DO RESEARCH

We need to use the resources we have in more effective ways, and find innovative solutions to the various challenges we face.

Context

The challenges of the research environment grow yearly. In the face of growing demands on time, greater expectations on individuals, and tightening resources we need to find ways to make it easier to 'just get on' with research. To make this happen we need to come together across the university.

Working together to make research happen more effectively and with greater ease involves providing access to all of the training and upskilling researchers and research support staff need over the lifetime of their careers. It means making the research processes as streamlined as possible. It means providing the time, space and infrastructure needed to do research. As a research-led university we are also interested in sowing the seeds of research at an early stage. For us, the research career begins with the undergraduate – every student has potential to be a researcher – so it means making it easier to do research at this level too.

These are no small goals in a world in which the demands on individuals are ever-increasing and in which time and space for research become increasingly scarce. We need to use the resources we have in more effective ways, and find innovative solutions to the various challenges we face.

Link to the Charter Principles

The key principle to which these actions apply is Principle 3, to foster and grow research talent, and Principle 2, putting research at the heart of Trinity. However, many of the actions described are also part of cherishing academic freedom, diversity of research and the pursuit of truth, and developing the skills to communicate with our publics, among others.

Key Actions

The main actions are described here with more fine detail in implementation plans that will drive the execution of the strategy.

2.1 Drive a major college wide initiative that delivers a single point of access to all research related training and upskilling

There have been ongoing demands in Trinity for dedicated support for Early Career Researchers (ECR). This must be addressed with urgency. The ECR, especially at postdoctoral level, is particularly exposed to many challenges given the precarious nature of their employment, and the lack of academic career opportunities. We as a community need to do much more in supporting their wellbeing. We can do this through finding a better way of supporting all staff to develop all of the skills needed over the lifetime of their research careers in Trinity.

The challenge for us is to do this in a way that makes it easy for staff to upskill for research purposes. Various worthy initiatives do already exist across college to support researchers at different stages in their careers. While there are examples of great practice, in general the initiatives are disjointed and the support that exists tends to be patchy and inconsistent. There is no single location from which to get all information relating to career support. There is much reinventing of the wheel as individuals, driven by laudable aims, provide courses for specific cohorts of researchers. There are different and confusing pathways to creating content for career support. There is limited use of various career support tools in which the college has invested. The resource issues that arise in delivering support are exacerbated by this highly fragmented approach.

The key initiative recommended here is that a complete reorganization of all career support takes place so that it is managed by one entity and is accessible in one location.

There are many sub-actions which fall under this action. The most important is to explore where that single point should be. Previous initiatives need to be re-examined with this in mind (e.g. The Teaching, Learning and Research Academy which would see an expansion of CAPSL). There is a need to map out existing research career offerings, map out the needs of researchers, consolidate the different entities which offer support into one, create a mechanism for deciding what new career supports need to be added to the offerings centrally provided, provide mechanisms for better leveraging many of the highly creative research supports that are dispersed around college, provide ways for all to navigate what is on offer, and more. While these actions will be for the benefit of all staff, priority will be given to modules that are specifically relevant for ECRs.

While this action is demanding and calls for much work, it offers us an opportunity to really begin to differentiate ourselves in terms of how we support all our staff in the university. The same imagination and creativity that has been applied to thinking about the qualities of our graduates can be applied to that of our staff.

2.2 Build a deeper culture of support for research career development

The formalizing of career support through one single venue can be complimented with initiatives taken and led by staff. There is a huge opportunity for building a more collegiate environment through these kinds of initiatives, and more importantly building a culture in which self-development is encouraged. There are a range of actions which are relevant here.

The first set of actions revolve around recognising the increasing burden on staff that comes with an increased focus on research ethics, research integrity, GDPR, data management more generally, the role of gender in research etc. and the need to upskill as a result. It is important that upskilling is seen as a means to becoming a better researcher and not just a box-ticking exercise, and that the culture we foster here is one in which the various training requirements are seen as valuable. The actions here very much lie across the university, especially among more senior staff who can lead by example.

The second set of actions revolve around the creation of more informal networks that can be focal points of support. These actions are motivated by the success of the ERC Club which was set up by staff members to support each other in fulfilling the demands of their ERC award, as well as to help others wishing to win an ERC award. There is potential for clubs that focus on issues such as getting started in research, researching with industry, reinventing your research career, as well as a retired researchers' network among others. The latter, for example, gives us the opportunity to keep connected to a community of researchers who have much to offer Trinity post-retirement and who can continue to contribute to building our culture of research.

The third set of actions revolve around valuing the strengths of the individual researcher. Research is a very competitive endeavour and can lead to imposter syndrome. It important that all staff are encouraged to be ambitious and to strive for new goals. The more systematic nominating of colleagues for different research awards is one way of promoting our colleagues' careers, and of course we need to celebrate all individual and group wins.

2.3 Bolster mechanisms for providing pre- and post- award support

The Research Development Office (RDO) provides critical support for researchers applying for funding. The addition of a number of Research Programme Officers (RPOs) assigned to different areas, but working in tight collaboration with the RDO, added greatly to this capacity. The current RPO programme is nearing an end and a number of positions have already been mainstreamed. We need to look at new areas that could benefit from this approach. We also need to think about post-award support. Exploring how a post-award Research Programme Officer programme might be created, resourced, put in place and ultimately mainstreamed are key actions here.

2.4 Simplify practices around research administration

All of the practices around research (research project management, financial management, data management, recruitment, performance management etc.) have become more complex in the past decade. While we fully respect the requirements for proper oversight and the necessity to take a completely professional approach to our research, many have become very onerous. It is, therefore, timely that we would look at all the practices involved in research with a view to simplifying where possible. This will require us to work as a community and call for strong engagement across different areas of college. It will require us to look at all administration around research much more collectively. The actions here resonate with other parts of this Research Excellence Strategy, in particular the sections on 'joining the dots' on policies relating to research as well as the #ResearchMatters communication campaign.

2.5 Make it easier for large-scale research initiatives to work within our structures

Our university is organised into faculties and schools, and this structure works well. However, it can be the case that large-scale collaborative research efforts that sit across schools do not always sit in perfect harmony with the college structures. We need to completely eliminate any friction that occurs so that our collaborative research initiatives, our schools, and faculties can all thrive. Actions here include identifying issues and creating structures so that all relevant parties can work through any issues that might arise.

2.6 Rethink time, space and infrastructure

In creating this plan one of the prevailing issues that arises is the lack of time for research. Simplifying administration and upskilling staff can help in this regard. However, we need to do more. As a starting point, it is important to take stock of where we are across the university, to look at how work-load models across the schools are designed and put into action, to compare sabbatical policy and how it is executed, and to bring a bigger picture perspective to bear.

Space is also an issue. It is an issue for current staff and plays a significant role in our ability to attract new staff. The recent Estates and Facilities Strategy launched by the Bursar will provide a starting point for how we might better manage space. The Bursar and Dean of Research need to work together to more systematically address research space issues. There are two broad categories under which we need to operate. Firstly, we need to think about research space needs for now and secondly, we need to think about how differently we might do things in the future. The development of the Grand Canal Innovation District, for example, affords us the opportunity to not repeat the same mistakes about research space and to plan for the future in different ways.

We also have challenges when it comes to infrastructure. We face particular problems when it comes to equipment that needs replacing and for which no research grants exist. There are again no easy solutions to this. We can, however, seek to optimise the use of the equipment and infrastructure we have, as well as find new means of sharing or redistributing existing equipment. The longer-term solution, of course, involves #StandingUpForResearch and increasing investment in research.

Ultimately, what is needed from colleagues across all of these domains is leadership of the kind that can build a research culture that provides for the time, space, and wider environment that is conducive to excellent research.

2.7 Increase opportunities for undergraduates to engage in research

It is never too early to start people on the research path. Opportunities for undergraduates to engage in research are already in existence in college, such as the Laidlaw Scholarships. These kinds of initiatives need to better publicized. Different disciplines include research projects at undergraduate level. The TEP initiative calls for all undergraduates to engage in a research project and actions to deliver on this are necessary. Initiatives such as the Laidlaw Scholars open up opportunities for undergraduates to apply for and secure research funding. Actions that focus on identifying wider opportunities and communicating these to undergraduates are needed. The TEP electives need to be harnessed as exemplary showcases of research-led teaching.

03. GENERATE THE RESEARCH FUNDING AND RESOURCES WE NEED

We need to unlock existing resources within Trinity and refocus them on research activities which are important for driving the research agenda forward.

Context

While it is the case that there are areas of research in which we are engaged where funding does not play a major role, a significant proportion of the research we do is dependent on funding. We need to unlock existing resources within Trinity and refocus them on research activities which are important for driving the research agenda forward. We need funding to continue for existing work and we need funding for new ideas. We must bear in mind that we are judged internationally and rated by our ability to attract competitive research funding and, therefore, a significant effort needs to be spent generating the resources we need to do our work.

The task of generating the research funding and resources we need is made more challenging by the constraints of the research investment environment in which we operate. Consequently, we also need to continue striving to unlock funding resources nationally and internationally. In Ireland, in particular, we need to work with others to achieve change.

The actions here relate to how we organise ourselves internally in relation to funding and how we set our funding goals, as well as how we can work to change the funding landscape from a policy perspective into the more balanced system we desire.

Link to the Charter Principles

The actions here have implications for all seven of the principles and high-level goals in the Charter.

Key Actions

The main actions are described here with more fine detail in implementation plans that will drive the execution of the strategy.

3.1 Work with Trinity Research & Innovation to stress test funding scenarios, set targets for research funding and maximise our ability to deliver

Trinity has a strong track record in securing research funding and has performed exceptionally well in recent years and as can be seen from the table on page 22.

We are, however, currently at a moment in which the state of the research funding system is of great concern. As mentioned in the introduction to this document, the State invests 1.2% of GDP in research, well below the 2.4% average of the OECD. This lack of investment has been ongoing for some time and effects all universities. There are additional issues for Trinity:

1. SFI funding has typically accounted for almost 50% of Trinity research income. In 2018, and most likely in 2019, calls such as the SFI IvP will not be held. The typical level of income from such a call for Trinity is in the region of €16 million. The fact that this and other calls will not take place has a significant impact on our income, not to mention the academics whose research depends on this type of income.

2. While Trinity has performed exceptionally in Horizon 2020, out-performing all of the other Irish institutions by tens of millions, the challenge for Trinity is capacity. This manifests itself in two ways. Firstly, it is important to note that a large part of that success is due to ERC activity, including incoming ERCs. While ERC award holders come with research funds, it ultimately remains the case that the school needs to support them and there is only a certain amount of capacity in the system. Our success more widely in H2020 is dependent on many researchers who are already at maximum capacity and do not have scope for new projects.

Research Income Per Source over the Past Five Years

*European Commission

Year ending	EC*	Irish State	Industry	Other	Total
2010/11	11,454,262	66,584,928	3,847,386	9,862,771	91,749,347
2011/12	12,737,313	56,327,763	2,184,526	6,225,934	77,475,536
2012/13	17,873,325	66,332,145	2,024,109	7,344,332	93,573,911
2013/14	14,102,052	47,511,862	2,159,531	7,262,445	71,035,890
2014/15	18,053,207	60,610,257	2,276,037	10,150,494	91,089,995
2015/16	15,845,722	67,163,907	4,653,126	9,264,453	96,927,208
2016/17	19,737,679	66,324,063	4,609,476	11,527,358	102,198,576

We also need to keep a focus on generating full costs for the research we carry out. While we will always compete for prestigious funding – an essential activity for a leading research university – we also need to pay attention to how overheads can be maximised.

The actions here are actions that must be carried out closely in collaboration with Trinity Research and Innovation (TR&I) as we collectively develop funding diversification plans. Actions include stress testing research income through mapping the changing patterns of funders, looking at academic retirements and the impact on funding income, exploring new sources of funding (non H2020 EU opportunities, industry, foundations etc.). We need to make sure that our structures within TR&I best reflect our targets and needs, and that staff in TR&I are supported in their endeavours. This may call for a remapping of functions or sourcing of new resources. It is crucial that these actions be carried out in close collaboration with TR&I.

3.2 Expand the base of eligible researchers applying for funding through external hires as well as from within

Of great importance is the need to expand the base of applicants for research funding. The caveat here, of course, is the areas and domains in which no funding exists or funding is not needed for the work. This section should be read as calling for a focus on researchers that would benefit from this approach and not as a set of actions that force a solution on those not looking for it. There are, broadly speaking, two approaches to expanding the base of researchers involved in attracting funding.

The first approach is about growing the academic staff through the continued recruitment of world-class researchers. We have made great progress to date, especially in the context of ERC holders moving to Trinity. Expertise for supporting this kind of activity has been built into the system and the number of incoming academics has increased significantly. Between incoming candidates and home-grown success, currently we have almost 50% of all ERC awardees in Ireland. Based on our learnings to date, much more refining and streamlining of the process is needed. There are issues on the ground in terms of capacity, as previously mentioned, and these must to be addressed. The approach we take to ERC awards also needs to be expanded to include other prestigious awards. We have had less success in bringing in SFI Professorships for example, and we need to re-examine the issues here and weigh up efforts versus success.

The second approach is about making sure that every member of staff in Trinity who has the kind of research that lends itself to attracting funding is engaged in this kind of activity. Actions here include proactively encouraging staff to apply for funding and working with them to this end. These activities are already ongoing but there is room for further expansion. We also need to work much more proactively on the H2020 front. There is also scope for postdoctoral researchers to engage more widely. Mechanisms for ensuring proper and official recognition of the role of the postdoctoral researchers in securing grants are also needed. More generally, however, where it is relevant for their research we need to get all staff actively pursuing research grants.

3.3 Identify mechanisms for growing internal research funding

We also need to find ways to provide more funds internally in Trinity for research. While it is unlikely that any internal funds will address all of the many needs we have, these funds can be used wisely to make progress. The following actions are possible:

1. We can create a strategic Dean of Research fund for seeding and supporting research. Over the last decade, different holders of the DoR office have argued for such a strategic fund. Previous DoRs have made much progress in providing evidence for the requirement of this fund and have garnered support. The main actions here revolve around specifying the details of such a fund and identifying a source. The main recommendation is that the fund come from the overheads that are directed to the central divisions of the university rather than from those returning to the academic units. This makes sense in that the Office of the Dean of Research is a central service in Trinity. It signals that research is at the heart of Trinity, in line with Principle 2 of the Charter, and it also does not de-incentivise research activity through reducing overheads set aside to support research at academic unit level. To roll out the fund, mechanisms will need to be put in place that optimise its use. No fund will be large enough to address all of what is needed in Trinity. The core principles of how the fund should be spent will need to be developed with a focus on how the fund can be used to seed new initiatives, and leverage or bridge between opportunities. Oversight of expenditure will be carried out by the Finance Committee.

2. We can look to grow central schemes such as the Provost's PhD awards.

3. We can explore options for applying for funding at a central level – there is potential on the MCSA co-fund front for example.

4. We can work more closely with the Trinity Campaign to look at philanthropic options.

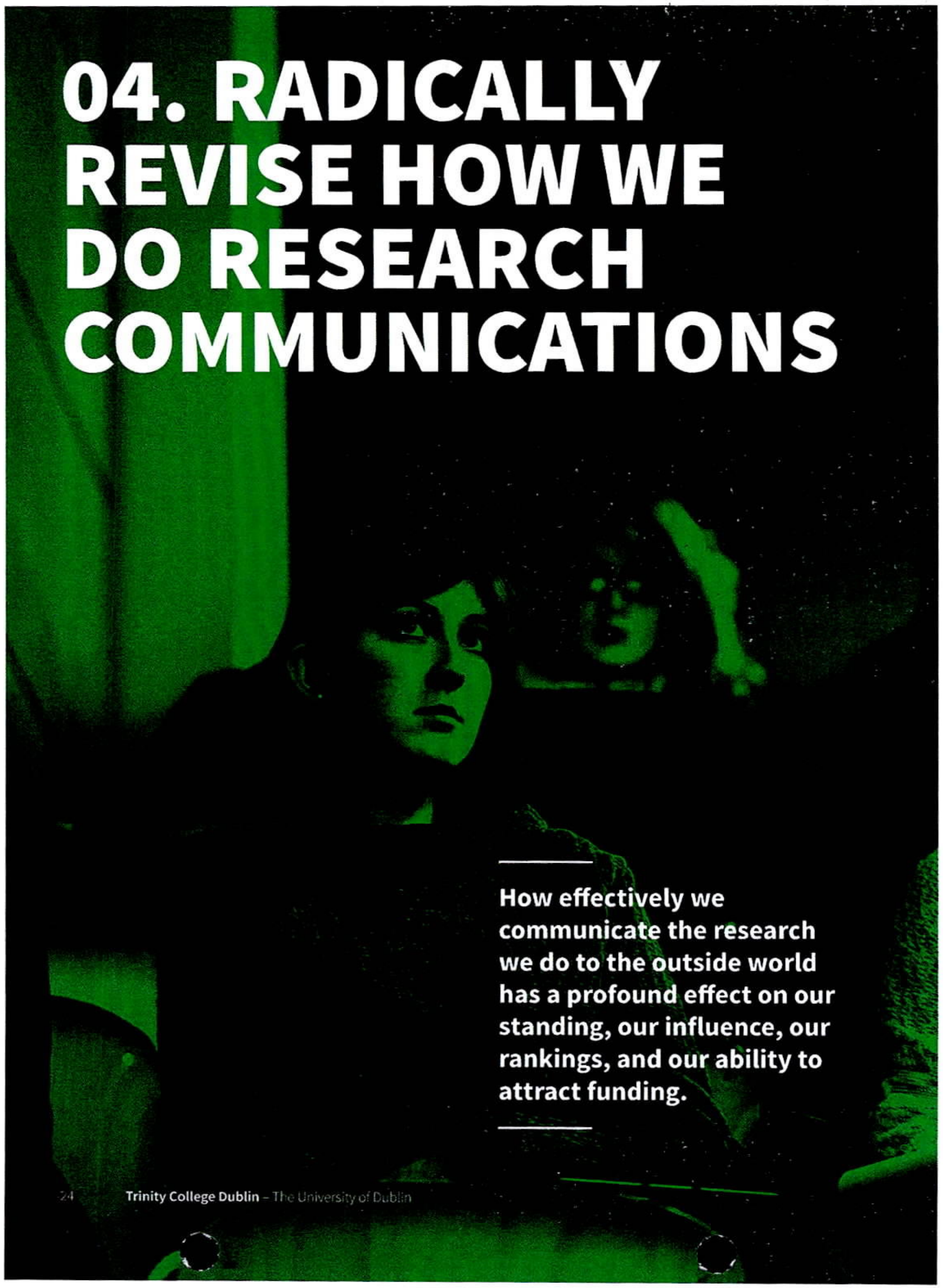
3.4 Work to increase available resources in the research system in Ireland

This is all about standing up for research and maintaining pressure to increase the funding in the research system in Ireland. Not only must we keep up the pressure to increase the pot of funding, but we must also ensure that investigator-led research becomes a significant part of the landscape, and make certain that research funding is available across disciplines. In other words, we must strive for a balanced research eco-system.

The actions here are varied. In the first instance we must continue to develop our own voice on these issues. Secondly, and most importantly, we must work with colleagues in the third-level sector and with collaborators from other sectors who realise the importance of open-ended and non-directed research to the long-term sustainability of Ireland. Thirdly, we must build networks with industry, academia, agencies, civil society, alumni, visiting researchers and other groups who matter to us and can inform as well as help with our research objectives. The actions here relate to building and maintaining these networks. The actions also include developing better understanding of how we can, through these networks, better influence research policy and better set research agendas.

We also have work to do internally in explaining why research matters. If we want freedom to work on research topics that we see as important we have an obligation to explain to the tax-payer why funds should be spent on our work. One way we do this is through becoming much more adept at showcasing our research impact. We are at a very good time to do this as the understanding of what impact means has become increasingly sophisticated. There is a greater understanding of the types of impact that can be made across all disciplines, and the different and varied time scales involved. There is also an increased focus on how we get research out beyond the journal article to the wider world. We need to work on systematically harvesting all of our impact, and we need to better build this type of activity into career progression to ensure it becomes embedded in the system.

04. RADICALLY REVISE HOW WE DO RESEARCH COMMUNICATIONS



How effectively we communicate the research we do to the outside world has a profound effect on our standing, our influence, our rankings, and our ability to attract funding.

Context

Communication of research ideals, research goals and research achievements are key aspects of every principle in our Charter. How effectively we communicate the research we do to the outside world has a profound effect on our standing, our influence, our rankings, and our ability to attract funding. How we communicate research successes matters to the individuals we seek to recognize. How we communicate our research and research goals to each other has a significant effect on our ability to collaborate and engage and build communities.

Link to the Charter Principles

The main principle of focus here is Principle 6, to engage profoundly with our publics. However, all of the other principles call for better communications, whether that be in reflecting the diversity of our research, positioning research at the heart of Trinity, and more. Our goal here is ambitious – to be a world leader in how we communicate our research to our multiple audiences.

Key Actions

The main actions are described here with more fine detail in implementation plans that will drive the execution of the strategy.

4.1 Overhaul our digital research presence

One of the basic actions is to address our central online research presence through updating the website and social media platforms. In the longer-term a content-based management system is essential for Trinity to more effectively manage our online profile with ease, speed, and in a manner that provides the kind of metrics needed to properly analyse engagement. The absence of such a system has to be considered a very high risk. However, in the medium-term work will need to be carried out within the limits of the existing structures. As a result, a number of the actions here focus on improving our website and evolving our social media presence for research. We will draw on the expertise in Public Relations and Communications (PAC) for this.

Updating our digital presence will make no difference unless there is a consistent flow of material that can be used. We aim to develop more sophisticated ways of telling our research stories, to provide material about any one research topic in different styles and formats for different types of audiences, to better draw on the diversity of research that happens in Trinity, and to feature work from every researcher in the university.

To aid in this process we will put in place a Research Story Curation Team. This team will draw on expertise in Public Relations and Communications (PAC) and others interested in communications in Trinity. The team will plan research communications for the year ahead. Each quarter will be dedicated to a broad theme that can be widely interpreted and that will be used to guide the creation of content for that quarter. The Research Story Curation Team will also set out the parameters for selecting material to ensure a spread of research stories, a diversity of research modes, and a variety of established, upcoming and student researchers are included. Actions will need to be taken to secure any necessary funds for content creation.

The themes for each quarter will be chosen in consultation with different groups in Trinity. However, this approach will be piloted with Trinity Brain Power as the first theme.

4.2 Harness the power of the wider community to communicate research

The online research presence of course is not just the one that is centrally managed. Throughout the university we have a host of excellent communicators who are in the best position to disseminate their own research.

There are a number of key actions here. Firstly, we need to harness much more effectively the skills of our community. Secondly, we need to provide information and training for those wishing to enhance their own skills. This has benefits for the university as a whole as well as the individual researcher. There are now far more opportunities for dissemination in new fora that are suited to academic discourse that we can exploit.[4] The focus on altmetrics[5] is driving some of these methods of dissemination. We can also consider rewarding individuals who contribute significantly to research communication, and draw in the undergraduate body to write about research through writing competitions and more.

A very important area in research these days is the area of co-creation of research with the wider public. While this does not impact all areas of research, it is of growing interest across the university. In Trinity, we have a number of projects focused on Public and Patient Involvement (PPI) which are leading the way internationally in research. We should learn from these. We also have Campus Engage initiatives that are building expertise in reflexivity and more so that we can become more skilled in two-way communications around research.

During the creation of this strategy there have been many suggestions by individuals for events and mechanisms through which we can communicate our research. We must do a much better job of collecting these and acting on those suggestions that make most strategic sense.

4.3 Ensure that face-to-face communications remains part of how we work

While a significant part of this section of the research strategic plan has been dedicated to digital communications, it is important to stress that face-to-face communications are essential. We need to ensure that there are more opportunities for colleagues to come together around research. We must hold more research events that allow our researchers to get together. We must celebrate all wins. We must regularly talk about research concerns. We must improve how we talk to each other across academic and administrative divides, so we can ensure that everyone is behind our research goals. Face-to-face communication is not just important for internal purposes but also in an external context. It is essential we spend time with our different audiences and stakeholders, and continue to hold regular events that allow participation and engagement.

4.4 Design and deliver strategic communications campaigns as required

In addition to improving how we communicate research more generally, it is also the case that we need to initiate more specific research campaigns. These campaigns will be aimed at different audiences, some for the general public and others more targeted. There are a number that already have been identified and undoubtedly more will materialise as needs require and resources permit, and we will work with PAC closely on these.

[4] www.timeshighereducation.com/a-z-social-media

[5] Altmetrics are non-traditional bibliometrics proposed as an alternative or complement to more traditional citation impact metrics

4.5 Initiate a series of flagship communications projects

The overall aim of the actions in this section of the plan is to become a world leader in research communications. Improving how we communicate and better harnessing the talents of our students and staff will no doubt do that. However, we need to go further and work on very big and bold initiatives. Any initiative will, of course, need resourcing and part of the challenge will be to secure resources to deliver these goals. The actions here involve exploring options, weighing up opportunities, finding resources as well as planning and delivering.

The current candidate for focus is a specific Trinity Citizen Scholarship platform. This would allow Trinity to develop a very specific engagement brand around research. Two-way engagement with the public is of increasing importance in research. This remains for the moment as a suggestion and others are welcome. A business plan for any suggestions would need to be developed for any to progress.

4.6 Secure an additional resource for the Office of the Dean of Research

The overall aim of the actions in this section of the plan is to become a world leader in how we communicate our research. It is an ambitious aim, but one we can deliver. We already have great foundations in place with many excellent researchers who are world class communicators.

To succeed in our goal, a first step in the right direction is to have a resource whose focus is research communication. This will involve coordination of the Research Story Curation Team, and the wider harnessing of communication capabilities in the university. The individual will pay special attention to modes of engagement suited for dissemination of research, and how staff and students can play a role in attaining our goals. The individual will work closely with PAC.

Suggested Initial Campaigns

Campaign	Description
The Standing Up for Research Campaign #StandingUpForResearch #LoveTrinityResearch #LoveIrishResearch	*This campaign is about working together to ensure research remains a priority area of investment for Ireland, and that investment is made in ways that lead to a thriving research ecosystem. It is all about rebalancing the research landscape, across basic and applied research, across individual endeavour and group collaboration, across all stages of research career, across different disciplines, as well as across maintenance of existing infrastructure and investment in the new. This communications campaign is a very targeted one – targeted at stakeholders and decision-makers in the research space.*
The Research Impact Campaign #TCDResearchImpact	*This campaign will address the fact that many researchers across Trinity are making huge impact, but we do not always capture that impact. This campaign will focus on capturing impact for the purposes of making researchers themselves more aware of the impact they create as well as for wider dissemination. We will draw on the definitions of impact developed by the Campus Engage initiative, as well as on concepts which allow for thinking through impact from a long-term perspective more suited to basic and fundamental research (e.g. take pathways to impact approach).*
The Research at the Heart of Trinity Campaign #ResearchMatters	*This campaign seeks to make sure that both academic (teaching & research) and administrative sectors in Trinity understand and are part of the drive for research excellence. This campaign will be very focused on face-to-face communications to better communicate how different choices we make as a university impact our ability to excel in research. The emphasis will be on building relationships, exchanging concerns, and getting everyone behind the same goals. It is envisaged that this type of communication needs to be a constant part of how we do business.*

Aspirational Flagship Project

Suggested Flagship	Description
The Trinity Citizen Scholarship Platform	*The concept here is to inspire the public through a Trinity Citizen Scholarship platform that allows the public to engage in Trinity research projects. Citizen Scholarship is about research conducted in whole or in part by amateurs or non-professionals. Citizen scholarship platforms already exist (see Zooniverse as one example) but the purpose of creating our own platform is to focus on research relevant to Trinity, and to make Trinity-specific material available on that platform. There are a number of reasons why this could be a flagship project:* 1 *At the heart of this is research. There are whole areas of research that are very suited to a citizen engagement approach and which, in fact, cannot be carried out without significant resources spent on database analytics. Citizen Scholarship is about crowdsourcing this kind of help and, in so doing, educating and involving large groups of people.* 2 *We have unique content that can be made available through such a platform. One obvious source is the Trinity Library; we could base projects on internationally unique material.* 3 *There is a huge branding opportunity. Trinity can lead the way in Ireland and beyond with this approach.*

05. JOIN THE DOTS ON ALL POLICIES RELATING TO OUR RESEARCH

The major question we need to ask of every policy we create is how does this policy enable or block research?

Context

In recent years, research has become much more professional and more regulated. Hence there are myriad policies in place that are directly related to the research we do. There are also policies related to the general running of the university which greatly impact research.

The major question we need to ask of every policies we create is how does this policy enable or block research? A follow-on question which is equally important is how can we evaluate if the different policies we have work together for research or if instead they produce counterproductive effects? Additionally, the operationalization of policy is key. It is all too often the case that policies are made but never put in practice.

Link to the Charter Principles

The actions in this section have implications for many principles. They are related to the type of professional supports needed for Principle 1 of cherishing academic freedom, diversity of research and the pursuit of truth. They also very much relate to positioning research at the heart of Trinity, and they have implications for Principle 3, to foster and grow research talent.

Key Actions

The main actions are described here with more fine detail in implementation plans that will drive the execution of the strategy.

5.1 Develop a system for oversight of all research policy

One of the most interesting and exciting aspects of research is that it affects, and is affected by, all areas of the university. This is also what makes it a hugely complex domain. There are, therefore, a huge number of policies that relate to research. Broadly speaking they fall under two categories.

The first are policies that directly relate to research and for which there are many external drivers. These policies are driven by new laws such as GDPR or movements such as Open Scholarship. Not only do they affect how we carry out research in the university, they also increasingly impact on our eligibility to apply for funding.

The second set of policies are those related to the more general running of the university such as hiring, promotions, school budget models and overheads etc. Again, these all have implications for how we do our research. They can enable or block research happening.

As the external drivers for new policies grow in tandem with the requirement for streamlining existing policies, we need to find a much better way of looking across the policy landscape. Firstly, we need to develop some kind of policy mapping tool that allows us to look at all the research-related policies in Trinity and their interdependencies. The oversight does not stop at making the policy, however. We need to have better assurances around how the policies are operationalized and get feedback on their effectiveness. We need to better interface with the College risk register around policy challenges. We also need to work towards making research related policies more accessible and navigable, through the right kind of documentation.

5.2 Initiate new or update existing research policies to align with external drivers

The oversight system will help us more systematically identify new policies that need to be created and those which need to be updated. There are a huge amount of external policy drivers on the horizon. The actions here involve monitoring changes coming down the line, creating policy as needed, and also taking the opportunity to be leaders in how policy might be created where necessary. Currently, we have work to do on policies relating to research ethics, research integrity, GDPR, Athena Swan, open recruitment, and open scholarship among others. It is envisaged that there will be different external policy drivers that need attention over time. As these arise, we will have to initiate new projects and actions.

5.3 Overhaul existing policies to better align with a research-intensive university

The whole purpose of this section of the Research Excellence Strategy is to ensure that we do not create policies that are counter-productive to the carrying out of research. To this end we need to revisit the different policies in operation within the university. Many policy issues were identified in the consultation phase of this Research Excellence Strategy, indicating that this is a big task and not easily resolved. The actions in section 5.1 which seek to better show dependencies between policies can potentially help in this process. More specifically, the operationalisation of policy deserves greater attention. Those which come to the fore time and time again include hiring for research, school funding models and incentivisation of research, and local policies related to teaching-buyout among others. It is not yet clear how best to approach this task in a strategic fashion. As a result, early actions here revolve around scoping exercises as well as more widespread research on how this might best be approached.

06. BE BOLD IN PLANNING OUR LONG-TERM RESEARCH FUTURE

Trinity is 427 years old. It has stood the test of time. However, we need to be able to step back and ask whether we can and should do things differently.

Context

The actions in this strategy are systematic actions that build on what we have grown in Trinity in the past decades and use mechanisms that we understand. We also need to think outside the box, however, and look at new ideas and concepts and how they might affect us, and to think about the future of research.

We also need to allow for new ways of thinking and doing things. Trinity is 427 years old. It has stood the test of time. However, we need to be able to step back and ask whether we can and should do things differently.

As stated at the beginning, this is a living Research Excellence Strategy. This final section acts as a way of constantly questioning all that is involved in strategy. It encourages us to think beyond where we are now and to plan for the long-term future. The spirit of this chapter is to set up some questions we might consider as well as structures through which they could be addressed.

Link to the Charter Principles

All of the principles in the Research Charter are connected with this section, hence the actions here are relevant for all principles.

Key Actions

The main actions are described here with more fine detail in implementation plans that will drive the execution of the strategy.

6.1 Create a Trinity Research Foresight Initiative

We need a better way to think about the longer-term research future. To this end, we propose the establishment of the Trinity Research Foresight Initiative which will operate as an internal think-tank, 'researching research' so to speak. We do not often use our own research capabilities and research methodologies for the purposes of researching our research plans and the Foresight Initiative will do just that. Foresight teams exist in agencies and industry. This will be the first foresight team of its kind in a university. This initiative is not intended in any way to displace the efforts of the individual researcher in forging their path. Rather it is intended to better leverage that talent and to push the university in bold new directions across all areas of research. There is a wealth of expertise in Trinity that can be harnessed to this effect. The Trinity Research Foresight Initiative should also allow us to be a leading international voice in developing thinking about the future of research. In addition, the Research Foresight Initiative can be used as a means of reaching out to thought-leaders around the world, inviting them to engage with us in looking to the future, and further establishing Trinity at the forefront of research thinking.

The Foresight Initiative can look at topics of its own choosing and act as a means of bringing together input from the different actions that follow.

6.2 Understand what Trinity wants from an Open Scholarship future

Open Scholarship is an enormous area. It ranges from everything to do with open access to published research to a fundamental change of the academic system. Funders all over the world are reacting to the Open Scholarship agenda and we have greater obligations as a result. There are also enormous cost issues for how we do research business. We as a community need to consider what we want from the Open Scholarship world and how we want research to operate in an era of Open Scholarship.

We firstly need to understand our obligations under Open Scholarship: what are the areas over which we have no choice, and which need to be embedded in Trinity research activities. We need to identify areas in which we should be a follower: for example, Ireland is a small market and we may need to follow the lead of other countries around journal access. But most importantly we need to identify areas in which Trinity should be a world leader. We also, of course, need to understand the cost implications. Open Scholarship is by its nature a collective endeavour and we need to work closely with LERU, Coimbra, colleagues in Ireland and other networks.

Actions here include the setting up of an ad hoc committee to begin the work of looking at where Trinity stands; mapping all that is happening globally and nationally; the creation of the Unboxing Open Scholarship series as part of the process of more widely socialising ideas in the Open Scholarship domain. All of this work is happening in tight collaboration with the Library.

6.3 Understand how new forms of engaged research and research co-creation can drive discovery

Engaged research describes a wide range of rigorous research approaches and methodologies that share a common interest in collaborative engagement with the community. The research typically aims to improve, understand, or investigate an issue of public interest or concern. The research questions are co-created with the community and the research is advanced with that community. The term community is used liberally and tends to include public or professional service and product users, policy makers, civil and civic society organisations and actors. Trinity is already engaged in a pilot that focuses specifically on Public Patient Involvement (PPI) and is leading the way in thinking on what is seen as a paradigm shift in how research is conducted. Though the term engaged-research is already much in use by funders and other bodies, it has not really penetrated how we go about our work beyond pilot studies. The actions here are about understanding based on learning from the pilot and international best practice how this paradigm shift in approaches could and should impact our research, and how we would like this to work in Trinity.

6.4 Explore how new ideas around impact can be embedded in the university

Impact is a contested term in research. It can often make researchers uncomfortable or feel that only research with economic impact matters. In recent years, however, much wider definitions and more nuanced understanding of impact is emerging. There is an increased comprehension of the types of impact that can be made across all disciplines, and the different and varied times scales involved. There is a deeper understanding that in some cases impact can take decades to emerge, as well as the fact that research without any specific intention to make impact often does. This more nuanced and enlightened way of thinking offers much opportunity for our university. Currently we do not account for nor systematically deal with impact from this wider perspective. The actions here relate to further developing this nuanced take, learning from other countries, engaging with our key networks (e.g. LERU and Coimbra) on these topics and understanding how we leverage these approaches.

6.5 Understand how the future of work may change how we do research

The future of work is a very current topic, with conflicting information from various experts on the impact automation and technology such as artificial intelligence (AI) and robotics might have on jobs, skills, and wages. The question for us is to understand how that might affect how research is carried out and supported in a university. It may be the case that certain research functions are made easier or certain research activities may disappear.

The future of work may also have implications for laboratories. Today we struggle to invest in and maintain laboratories. Many researchers are under strain in making equipment last. Investment in new equipment is rarely for replacements. While we have made some suggestions for helping equipment go further in sections of this strategy, we might need to deal with the question of how we manage in a world of diminishing public funding – a world in which a centralised laboratory no longer exists. Or we may need to look at how we work from a climate change perspective.

The comments here are just examples, and none of the issues mentioned may prove to be a problem. However, it is important for us to begin to discuss this with the view to understanding the kind of future research world we would like to cultivate as well as to make plans.

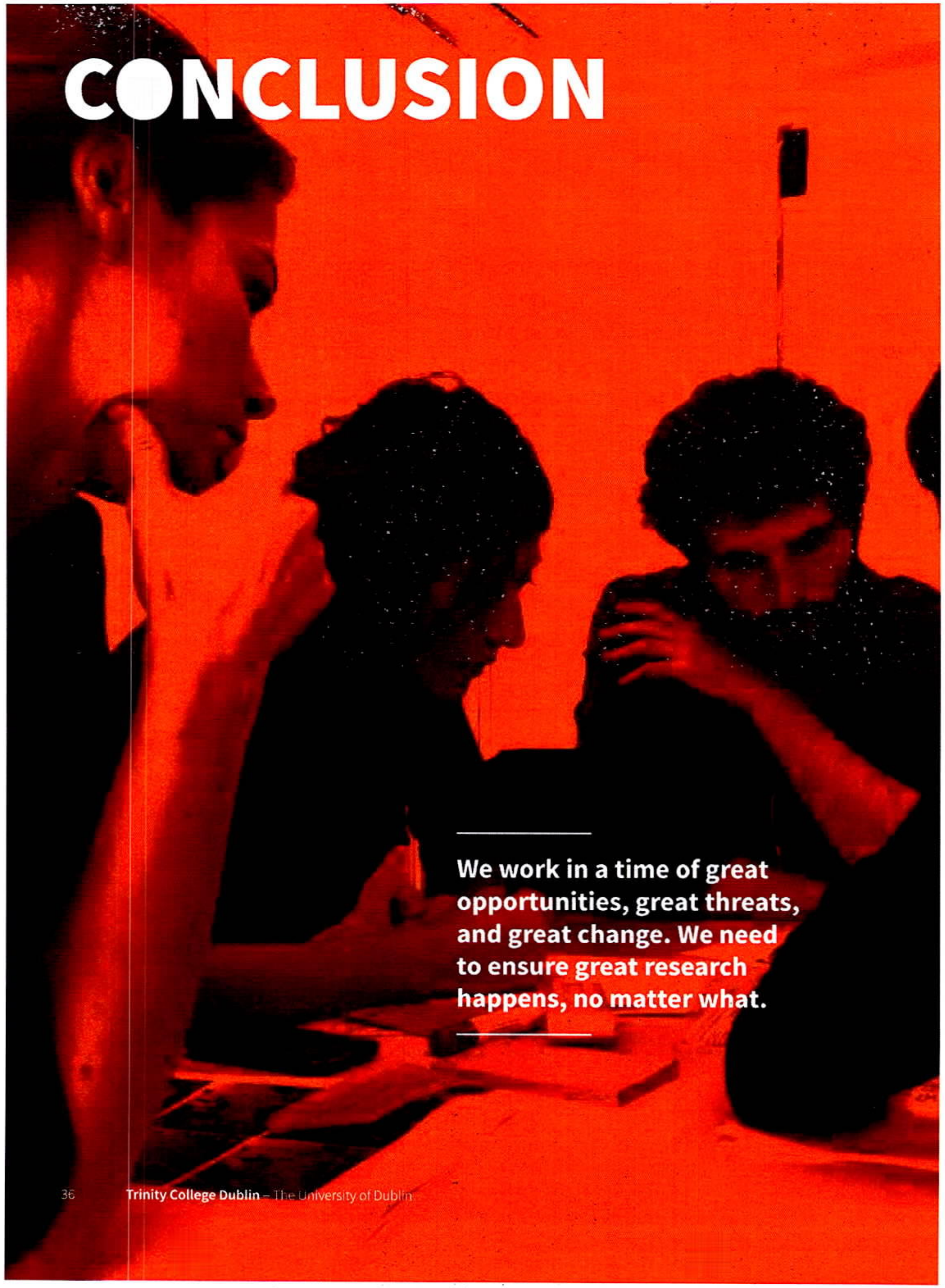
6.6 Analyse and plan in better ways

To be able to analyse and plan we need access to data. Today data is often needed for making returns to various bodies (e.g. rankings agencies, HEA etc.). Data is also needed more generally to talk about and make the case for our research to different audiences. However, it is the case that more and more data is needed to explain trends, give insights on performance, and make decisions. Some of that data involves numbers, while more of it increasingly relates to richer forms of data. Some data is required at institutional level and other data is for the individual researcher to aid with their decisions. The next diagram shows all of the kinds of qualitative and quantitative data that is potentially needed.

To look at the present, let alone the future, we need to find better ways of automatically capturing the data we need. It remains difficult, for example, to determine the basic breakdown of how PhD candidates are funded, let alone get more sophisticated data. While it may not be possible to make it as easy as we would like to gather all the data we need, we cannot move away from the need to make informed decisions, and the role data plays in strategic planning. Actions here involve classifying data in terms of whether it is currently available or not, how easy it is to collect, exploring options for automatic collection through our systems, using new types of technology to collect data etc. Actions here also include looking at various dashboards that exist now, such as the HR dashboard, and exploring what other types of dashboards can be created. To be bold in our thinking about the future and to push boundaries we need to understand the data of the past.

	Qualitative	Quantitative
Internal	Policies Hr Processes Decision Making Pathways Research Integrity Training Opportunities College Committees Space Strategy	KPIs from relevant Strategies College Data Tools Research Data Rankings Data Innovation Data Engagement Data Networks Data and Mapping
External	LERU Position Papers National Policies EU Policies External Audiences Impact Stories National Funding Strategies EU and International Strategies	Comparator Data National Targets EU Targets Rankings Data for Comparators Open Scholarship Goals Impact Metrics LERU Analytics

CONCLUSION



Conclusion

This living Research Excellence Strategy is a result of significant consultation in Trinity. However, while some detail is given here, the text in no way reflects fully the range of ideas and suggestions that have come forward. It could never do so. Instead it captures the different kinds of high-level actions that are essential for our ambition to excel in the research we do. It does this as a starting point and the many suggestions and ideas that have been proposed will systematically feed in to how the strategy is implemented and put into action.

In some cases, we have well-defined goals and solutions. In others, we need to explore different avenues and try out different ideas. In all cases we need to work together.

We work in a time of great opportunities, great threats, and great change. We need to ensure great research happens, no matter what.

APPENDIX B

RECORD OF THE INTERACTIONS BETWEEN TRINITY AND TII

Timeline of engagement with TII

DATE	COMMUNICATION
26th March 2018	Contact made by Murphy Surveys to Sandra Kenny (SK) of Trinity in relation to carrying out a topographical survey for what was then Metro North.
4th April 2018	SK attended Public Consultation at Wood Quay and queried the proposed route with TII as previous route had been shown under Westland Row, not under Trinity campus. Also brought up the MRI's in the Lloyd and vibration free plinths in CRANN
31st August 2018	Contact made by TII/Jacobs Engineering to SK about identifying "sensitive receptors" on campus.
12th September 2018	SK met with Jacobs and TII. Jacobs presented a brief slide show after which SK conducted a brief site walk
20th September 2018	Jacobs emailed SK a comprehensive list of details required for the production of their Environmental Impact Assessment Report (EIAR) including equipment sensitive to EMC/EMI and vibration
24th September 2018	SK made contact with a number of Chief Technicians (KC, CC, MF, MR, SMcN) in the East End and spoke through TII/Jacobs requirements for the EIAR
15th November 2018	Trinity E&F Meeting with TII and Jacobs. Trinity express grave concerns about operational phase and its effect on research and specialised equipment. Trinity sought clarity on the criteria used for route selection.
29th November 2018	CEI carry out an initial baseline vibration survey at Zoology and SNIAMS
8th January 2019	TM of Trinity PAC receives an email noting Trinity's concerns about the "worst possible route" via a 3rd party
15th January 2019	SK met with TII in relation to sensitive equipment and building surveys
17th January 2019	Information gathered from Chief Technicians start to indicate that there could be an enormous impact on sensitive equipment
22nd January 2019	SK sends initial information to TII re sensitive equipment in particular buildings for review
14th February 2019	Trinity E&F meets with TII and Jacobs. Dean of FEMS was contacted so Trinity could have some SME 's on hand. TII gave presentations on Settlement, Vibration and EMI/EMC.
25th February	Trinity agrees to let CEI, on behalf of TII to conduct more in-depth electromagnetic baseline surveys in the presence of the relevant SME (CRANN, Fitzgerald, SNIAMS)
19th March 2019	Trinity agrees to let CEI, on behalf of TII to conduct more in-depth vibration and electromagnetic baseline surveys in the presence of the relevant SME (Panoz, Chemistry, and Lloyd)
22nd March 2019	CEI requests magnetic environmental specs for some equipment. Chief Technicians (SME's) voicing concerns that their equipment and research will be seriously impacted, not only by the tunnel boring, but also the operation of Metrolink
17th April 2019	Metrolink Public Consultation attended by MC, SK, CC, JO'R, PMcD. Concerns were again raised with TII about route selection without any consultation with Trinity and the consequences of this
18th April 2020	Meeting with TII re MetroLink updates. Reports presented on EMI and Vibration

5th October 2020	TII ICE Public Presentation re MetroLink
8th October 2020	Letter from Trinity to TII outlining concerns and seeking clarification on what mitigation measures would be used.
23rd November 2020	Letter from TII to Trinity enclosing Jacobs technical report dated 20 November 2020
14th December 2020	Letter from Trinity to TII acknowledging report which is to be reviewed by Trinity experts, but expressing concern it did not address vibration.
18th December 2020	Letter from TII to Trinity proposing a meeting
22nd January 2021	Letter from Trinity to TII agreeing to meet to discuss mitigation measures
10th February 2021	Meeting between TII and Trinity
3rd March 2021	TII Follow up workshop re EMI
25th March 2021	TII Follow up workshop re Vibration
30th March 2021	TII Follow up coordination workshop TII re alignment
18th May 2021	Letter from Trinity to TII referring to the meeting and outlining Trinity's expert analysis on the alternative alignment proposals
2nd June 2021	TII Meeting re Track Alignment + Vibration model assumptions + Active Cancellation
23rd June 2021	TII Track Alignment Discussion
21st July 2021	TII Meeting with experts to discuss alternative alignment options
3rd August 2021	Letter from Trinity to TII
6th August 2021	Response from TII and subsequent amended letter issued
10th September 2021	Letter from Trinity to TII requesting a meeting for Jacobs to present alternative alignment of 302 M alignment.
29th September 2021	Response from TII re Jacobs undertaking further analysis on alignment
20th December 2021	Letter from TII to Trinity confirming Jacobs had not finalised analysis.
20th December 2021	Letter from Trinity to TII acknowledging analysis would not be provided until the new year and advising of EMI analysis conducted by Trinity's advisors on the 302m alignment
22nd February 2022	Letter from Trinity to TII following up on Jacob's analysis of alignment options
7th March 2022	Letter from TII to Trinity confirming analysis not yet complete.
22nd April 2022	Jacobs/Idom Report received
12th May 2022	Letter apologising for errors and issuing an Amended Jacobs/ Idom report provided
13th May 2022	Email from Trinity expressing concern on the inaccuracy in the report
1st June 2022	Letter from Trinity to TII enclosing list from Arup on assessment details previously requested
8th September 2022	TII presentation of alignment
30th September 2022	Railway Order Application lodged at an Bord Pleanála
14th November 2022	MetroLink Project Director visits Trinity campus
22nd November 2022	TII carry out a winter bird survey on Trinity Campus

APPENDIX C

OVERVIEW OF PREDICTED IMPACTS

Overview of Predicted Impacts (as per ARUP Assessment)

- [Green] Low Risk/Meet Criteria
- [Yellow] Risk of Exceedance of Criteria
- [Red] Unacceptable Risk of Exceedance

Location	Equipment	EIAR Mitigation (Alignment Option 2)		Alignment Option 3		Alignment Option 4		Option 5 + EIAR Mitigation		Option 5 + Comprehensive Mitigation*	
		Vib.	EMI	Vib.	EMI	Vib.	EMI	Vib.	EMI	Vib.	EMI
Chemistry	1x NMR (Bruker 400MHz)	Green	Red	Green	Red	Green	Red	Green	Yellow	Green	Yellow
	1 x NMR (Brucker 600MHz)	Green	Red	Green	Red	Green	Red	Green	Yellow	Green	Yellow
	1x NMR (Bruker 400MHz)	Green	Red	Green	Red	Green	Red	Green	Yellow	Green	Yellow
Panoz	1x SEM (Tecsan S8000)	Green	Yellow	Green	Yellow	Green	Yellow	Green	Yellow	Green	Green
	1x SEM (Tecsan Mira3 Tiger)	Green	Yellow	Green	Yellow	Green	Yellow	Green	Yellow	Green	Green
	1x SEM (Zeiss Sigma 300)	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Green
Lloyd	1x MRI (Bruker BioSpec 70/30 AVANCE III 7T)	Green	Yellow	Green	Yellow	Green	Yellow	Green	Green	Green	Green
	1x MRI (Siemens Magnetom Prisma 3T)	Green	Yellow	Green	Yellow	Green	Yellow	Green	Green	Green	Green
	2x TMS machine (DuoMag)	Yellow	Black	Yellow	Black	Yellow	Black	Green	Black	Green	Black
	3x EEG machine (TruScan)	Yellow	Black	Yellow	Black	Yellow	Black	Green	Black	Green	Black
	1x Confocal Microscope (Zeiss LSM 501)	Red	Black	Yellow	Black	Yellow	Black	Yellow	Black	Green	Black
	1x Confocal Microscope (Zeiss LSM 880)	Red	Black	Yellow	Black	Yellow	Black	Yellow	Black	Green	Black
SNIAMs	1x SQUID (Quantum Design MPMS-XL)	Red	Green	Yellow	Green	Yellow	Green	Yellow	Green	Green	Green

CRANN	1x AFM (Bruker Multimode 8)		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]
	2x UHV AFM (Omicron VT and RT)		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]
	2x Nanoindenter (KLA XP and DCM),		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]
	1x 3D Contact Mechanics Tester (Fast Forward Devices)		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]
	1x Stylus Profileometer (Bruker Dektak)		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]
	2x Optical Tweezer Instruments		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]
	1x XPS		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]
	4x STM (Omicron Variable Temperature STM,		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]
	2x Omicron Cryogenic STM, Empa designed AFM/STM)		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]
	1x STM		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]
	1x STM		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]
	1x STM		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]
	1x SEM (proposed in future)		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]
Fitzgerald	2x STM		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]
	1x STM		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]
	1x AGFM		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]
	1x optical telescope		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]
	1x radio telescope		[redacted]		[redacted]		[redacted]		[redacted]		[redacted]

* Subject to verification by the Applicant of the efficacy of the proposed mitigation measures

APPENDIX D

METROLINK DRAFT RAILWAY ORDER – A REVIEW OF ALIGNMENT AND ASSOCIATED TUNNELLING MATTERS PREPARED BY CECL GLOBAL

METROLINK DRAFT RAILWAY ORDER – A REVIEW OF ALIGNMENT AND ASSOCIATED TUNNELLING MATTERS

A report produced for Trinity College Dublin

CECL / 0037 / RT / 0003 / B

23/11/2022

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DOCUMENT CONTROL

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Prepared by	Checked by	Approved by
Colin Eddie Managing Director	Eyre Hover Principal Engineering Consultant	Colin Eddie Managing Director

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A	01/11/2022	First Issue
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1 Introduction

We have been instructed by Mike Clarke, Director of Campus Infrastructure, Trinity College Dublin to provide tunnelling expertise in relation to the proposed construction of the Metrolink in proximity to its campus assets.

An initial brief was received 11 Feb 2021, and this was followed by a formal order 10 March 2021.

Since this time CECL have reviewed and reported on information as it has become available and following the recent publication of the Draft Railway Order have undertaken a detailed review of the proposed alignment and associated tunnel construction matters. We have been assisted in this task by rail alignment experts from Arup.

2 Review of Current Design

The proposed alignment of the tunnel at Trinity College Dublin (TCD) is provided at Section 4 - Railway Order Plans and Drawings - Alignment Details Book 2 of 2 Dublin City Council. The alignment at TCD is included in what the order describes as Area 306. Figure 1 is extracted from Book 2 and shows that we need to consult four of the drawing sheets to understand the proposed alignment at TCD which runs between Tara St Station and St. Stephen's Green Station. The alignment of the Tara St Station is shown on sheet ML-RO 306 O-A and St, Stephen's Green is shown on sheet ML-RO-306 C-D.

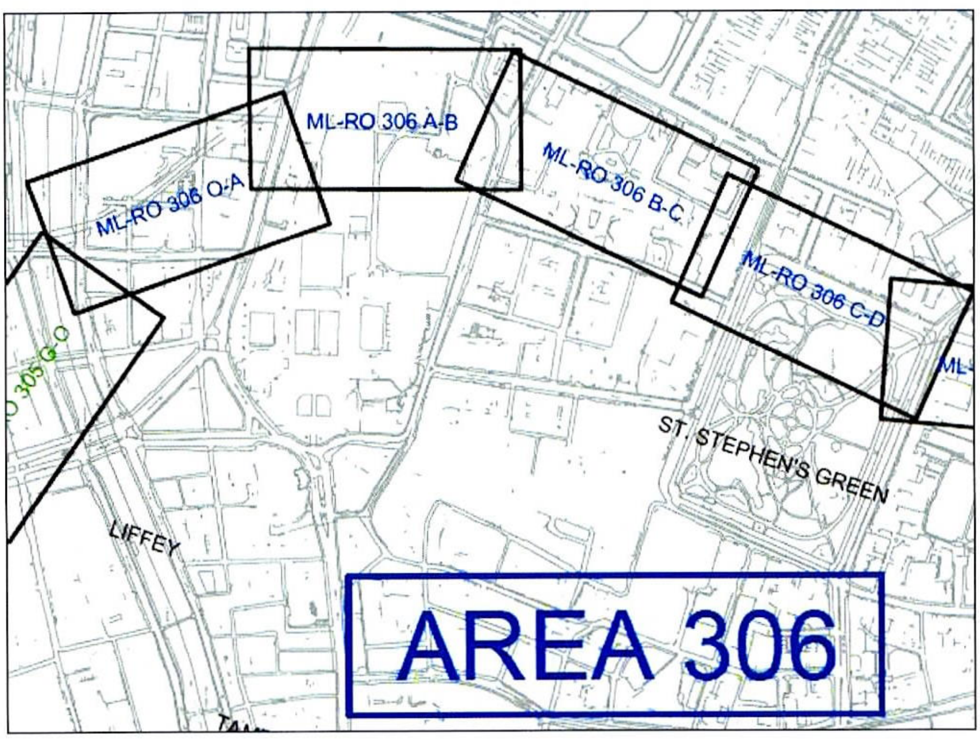


Figure 1 - Area 306 Proposed Alignment Drawings at TCD

Also contained within the Draft Order is a report which details the alignment options considered by Metrolink. This can be found in section 5 - Environmental Impact Assessment Report (EIAR) - Volume

2 Introduction and Project Description - Chapter 07 Consideration of Alternatives - A7.10 Trinity College - Alignment Options Assessment.

The five Options considered by Metrolink are described in Figure 2 and shown in Figure 4.

- **Option 0 Preliminary Design Alignment (R=400m):** This is the original alignment from the emerging preferred route (EPR), retained as the current Preliminary Design alignment, with a 400m curve radius (R= 400) past the TCD campus and under Government Buildings to the south.
- **Option 1** (R=400m) **:** Modified PD **–** this retains the same horizontal alignment as Option 0 but with an adjusted vertical profile to increase rail depth below Leinster House and TCD buildings. (i.e., essentially the PDR Option 0 mitigated to reduce currently assessed impacts on the buildings above). No change to the Tara and St Stephen's Green station locations.
- **Option 2** (R=350m) **:** An alternative horizontal alignment running to the west of Option 1 and with the same adjusted vertical profile (increased depth) as per Option 1. Taking advantage of the proximity of Tara Station and the fact that all commercial trains will be stopping there, the transition curve south of and next to the station is shortened to 30m to assist the westward movement of this alignment option.
- **Option 3** (R=302m)**:** An alternative horizontal alignment running to the west of Option 2 and with the same adjusted vertical profile (increased depth) as per Option 1.
- **Option 4 (R=302m + 1 degree rotation):** New 302m Alignment including a 1-degree rotation of Tara station in order to further increase the westwards movement of the metro alignment past the TCD campus.

Figure 2 - Alignment Options considered by Metrolink

Options 0, 1 & 2 assume a maximum operating speed of 80km/h. Options 3 & 4 have an assumed maximum operating speed of 60 km/h.

The Alignment Options Report Appendix E (see Figure 3) should contain the detailed alignment drawings for the options considered. Unfortunately, these drawings have not be made available and it is therefore not possible to undertake a detailed review of each option.

Appendix E. Horizontal / Vertical Alignment Design Drawings

Option 1 ML1-JAI-CPS-ROUT_XX-DR-Y-00011

Option 2 ML1-JAI-CPS-ROUT_XX-DR-Y-00012

Option 3 ML1-JAI-CPS-ROUT_XX-DR-Y-00013

Option 4 ML1-JAI-CPS-ROUT_XX-DR-Y-00014

Figure 3 - Extract from Report A7.10 - Alignment Options Assessment Report

Metrolink's conclusion from this options assessment exercise was to select the Option 2 route as their preferred option. As discussed above, these drawings (albeit in PDF format) have been made available in Section 4 of the Order. We have converted these PDF drawings to vector files and imported them into CAD, and have produced a sketch of an overlay of the stitched together detailed alignment drawings with the image contained within Metrolink's Options Assessment Report (Figure 5). This confirms that the selected alignment corresponds with the orange line of Option 2.

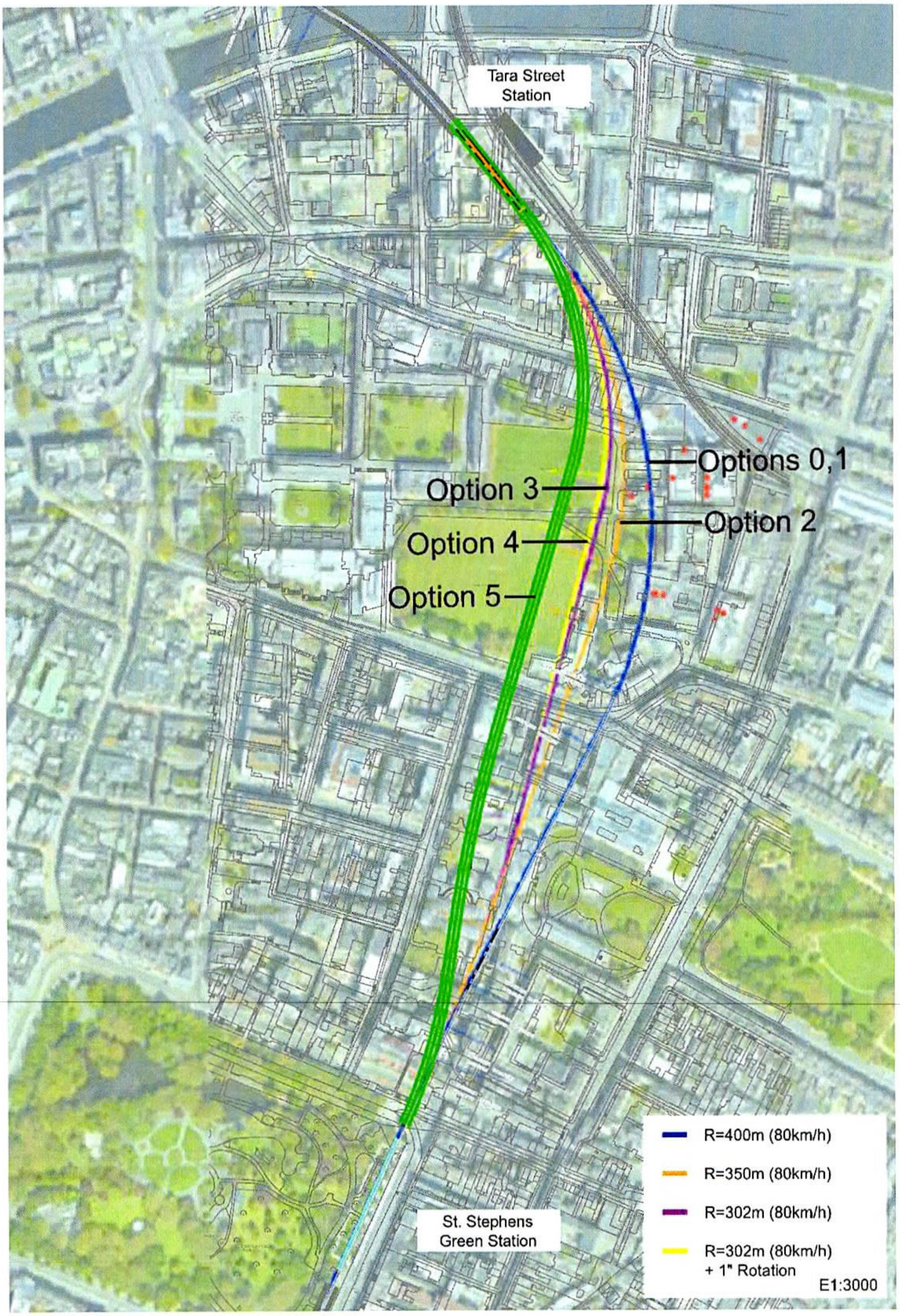


Figure 4 - Extract of Figure 2.1 from Alignment Options Assessment Report (Option 5 added)

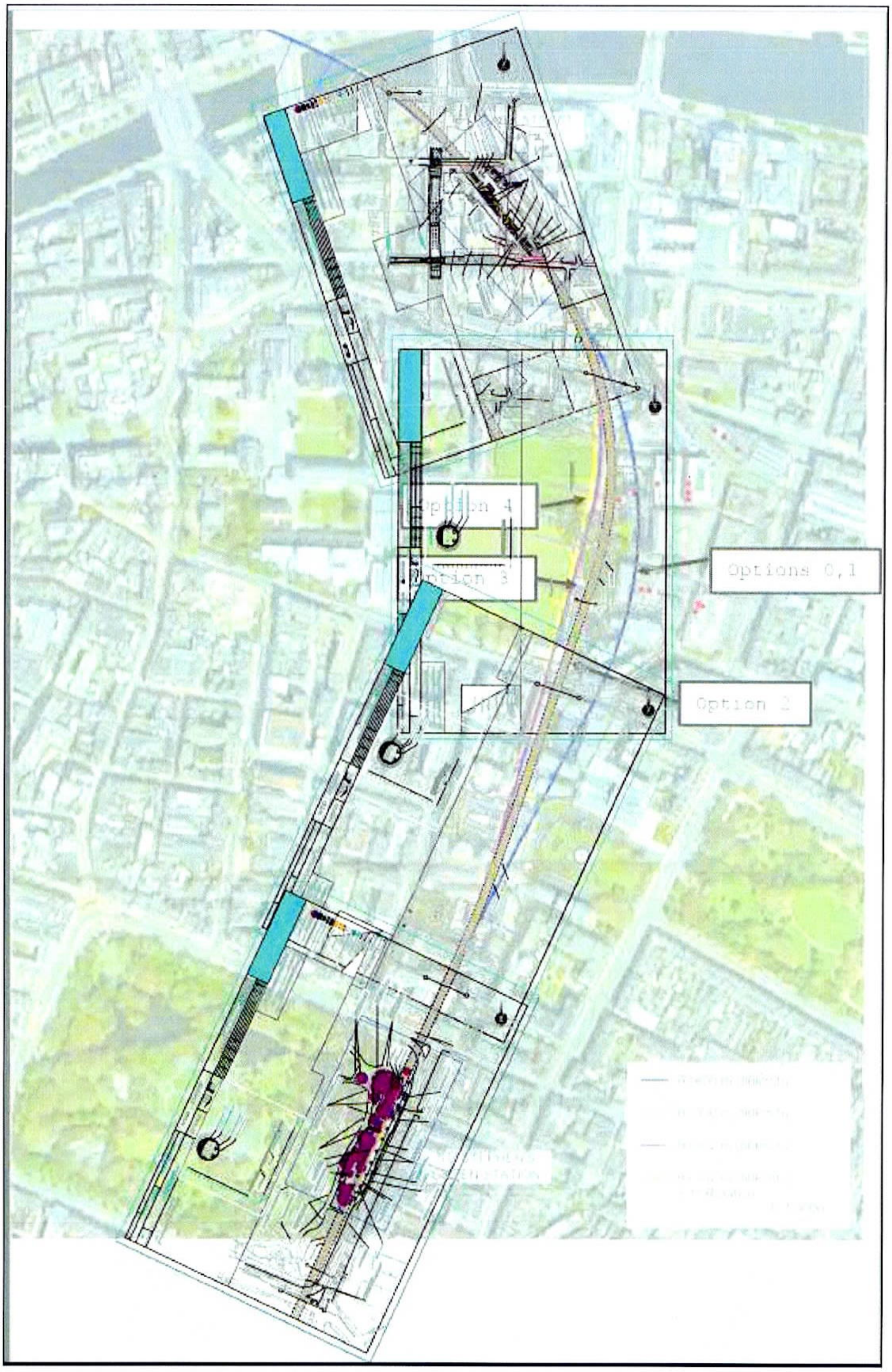


Figure 5 - Overlay Sketch of Preferred Alignment with Metrolink's Option 2

The preferred route incorporates a design radius of 350m and assumes a maximum running speed of 80km/h. As detailed in the Arup EMI and Vibrations Studies, the current proposed alignment will have a significant detrimental effect on the research activities of TCD. We therefore conclude that a more Westerly alignment must be found which increases the separation between the Metrolink and the highly sensitive equipment research equipment.

Metrolink has previously explored such alternatives but unfortunately concluded that a more Westerly route was not feasible. This work is documented in Volume 2, Chapter 7, 7.7.9.4 Alignment under Trinity College Dublin of the Environmental Impact Assessment submitted with the Draft Order. The more Westerly Options 3 and 4 were dismissed. The reasons for rejection have been extracted (Figure 6 for Option 3, and Figure 7 for Option 4).

Option 3 - incorporates a further reduction to 302m for the horizontal curve radius and maintains the lowered vertical alignment. This option would provide a further westward movement of the alignment and our assessment indicates that no Active Cancellation measures would be required at known TCD equipment locations under this Option and no additional damping required for the track. However, this alignment has particular disadvantages:

- It would reduce or remove current design tolerance between train and tunnel furniture, limiting future construction and operator design options and which will remain a constraint on the system for its operational life. Such restrictions at this design stage are not considered desirable due to the future construction/operation risks introduced.
- There would be additional risk during the TBM drive of potential further speed limitations if the tunnel drive deviated from the design alignment and needed correction through tighter curves.
- It would have a permanent speed restriction due to the tighter radius curve south of Tara Station, impacting journey time and incurring an ongoing economic cost incurred over the life of the system.
- An exceptional element would be introduced within the overall alignment, outside the proposed design parameters for MetroLink.
- The risk of wheel rail interface issues arising during the Operational Phase is considered to significantly increase on curves down to 300m radius or less, with a 350m radius recommended as the minimum radius.

Figure 6 - Reasons for rejecting Option 3

Option 4 - incorporating 302m radius curves both north and south of Tara station, with an associated 1-degree rotation of the station, was shown to provide only around a 5m additional westward movement of the alignment compared to Option 3 at sensitive TCD equipment locations. It would have the same concerns and constraints as Option 3 and was not considered to provide any additional benefit to the EMI mitigation whilst increasing the construction and operational impacts associated with the two tighter 302m curves required compared to the minimum 350m curve adopted elsewhere.

Figure 7 - Reasons for rejecting Option 4

The reasons (which would also apply to our Option 5 alternative alignment proposal) can be summarised as follows:

- Inadequate spaceproofing of the tunnel to accommodate the dynamic kinematic envelope of the train operating on a tighter radius
- TBM steering difficulties operating on a tighter radius
- Operational Speed restrictions leading to increased journey times

- Non-compliance with Metrolink's Design Parameters
- Wheel-Rail Interference

In addition to the above objections, Metrolink have also previously expressed concerns about excessive ground settlement and practical logistical issues of tunnel construction on a tighter radius. We shall therefore also respond to these concerns.

We fundamentally do not agree with the findings of this options study and believe that a more Westerly route could be designed which would have negligible impact on the construction, functionality and operation of the railway. We shall therefore address each of the concerns individually.

Spaceproofing within the tunnel

Metrolink contend in Appendix A7.10 Trinity College - Alignment Options Assessment that any reduction in tunnel radius *"will reduce or remove current design tolerance between train DKE and tunnel furniture, limiting future construction and Operator design options"*. We have therefore undertaken our own assessment of the Dynamic Kinematic Envelope (DKE) and Structure Gauge using the proposed Option 5 alignment (min 260m radius) and the proposed local reduction in speed (60km/hr).

Whilst no detailed alignment calculations were provided in the Draft Order, Metrolink have previously shared with TCD the following documents:

- Jacobs IDOM Report ML1-JAI-RTA-ROUT_XX-RP-Y-00602 | P01 - 2020/12/18 – Alignment Calculations
- Jacobs IDOM Report ML1-JAI-PLD-ROUT_XX-RP-Y-00403 | P02 - 18/12/2020 - Volume 4 - Chapter 3 - Alignment & Cross Sections
- Jacobs IDOM alignment presentation ML1-JAI-EIA-SC14_ZZ-PP-Y-00001 – 2021/06/02).

From these documents we understand that the maximum desirable applied design cant, will be set at 120mm. Figure 8 shows the tunnel cross section for this condition. It should be noted that the **Structure Gauge Envelope** does not encroach upon the construction tolerances for the tunnel which, according to the British Tunnelling Society Specification for Tunnelling, would normally be ±50mm for a tunnel of this size and this is consistent with the tolerance allowance of 100mm shown on the Metrolink drawings. The allowance however between the **Dynamic Envelope** and the **Structure Gauge** appears conservative when compared with the recommendations of the relevant European Standard EN 15273-1/2/3 - Railway applications - Gauges - Parts 1, 2 and 3 and industry best practice. In particular we note the M3 allowance (Infrastructure Manager Reserve) is 200mm. We consider this excessive for this type of system.

Metrolink explain that this cautiousness relates to uncertainty surrounding the selection of the rolling stock. In their alignment calculations they state *"the method applied by the MetroLink team is valid for the objective of determining a structure gauge compatible with rolling stock potentially provided by a wide and competitive range of rolling stock suppliers"*. Appendix A.14.2 – Train Characteristics however states *"The trains assumed for the MetroLink are based on the design of those used on the Metro in Madrid, which are CAF 6000 units"*. As the dimensions of the rolling stock are clearly essential for this exercise, we do not accept that the design can be based upon a specific vehicle type and then an arbitrary additional allowance is then made to accommodate any other potential design of vehicle that may be selected in the future. If a range of vehicles needed to be considered the gauging exercise should have been done for each on a standalone basis.

As further described in Section 3, to maximise the distance between the new railway and the sensitive receptors at TCD, it would be beneficial to introduce a slightly tighter radius curve (260m) immediately South of Tara St. Station. This is referred to as Option 5.

When considering the swept path of a railway carriage to determine the **Dynamic Kinematic Envelope**, it is necessary to consider, amongst other things, the combined influence of both the horizontal and vertical alignment. The **Structure Gauge Envelope** appears to consider the worst theoretical coexistent combination of horizontal and vertical curvature along with a number of other conservative assumptions. The proposed horizontal alignment immediately South of Tara St. Station is relatively flat and therefore would not generate the same envelope as shown in Figure 8 or the documents listed above.

We are therefore of the option that with additional thought and elimination of several layers of conservatism that Metrolink could safely accommodate the tighter radius we propose.

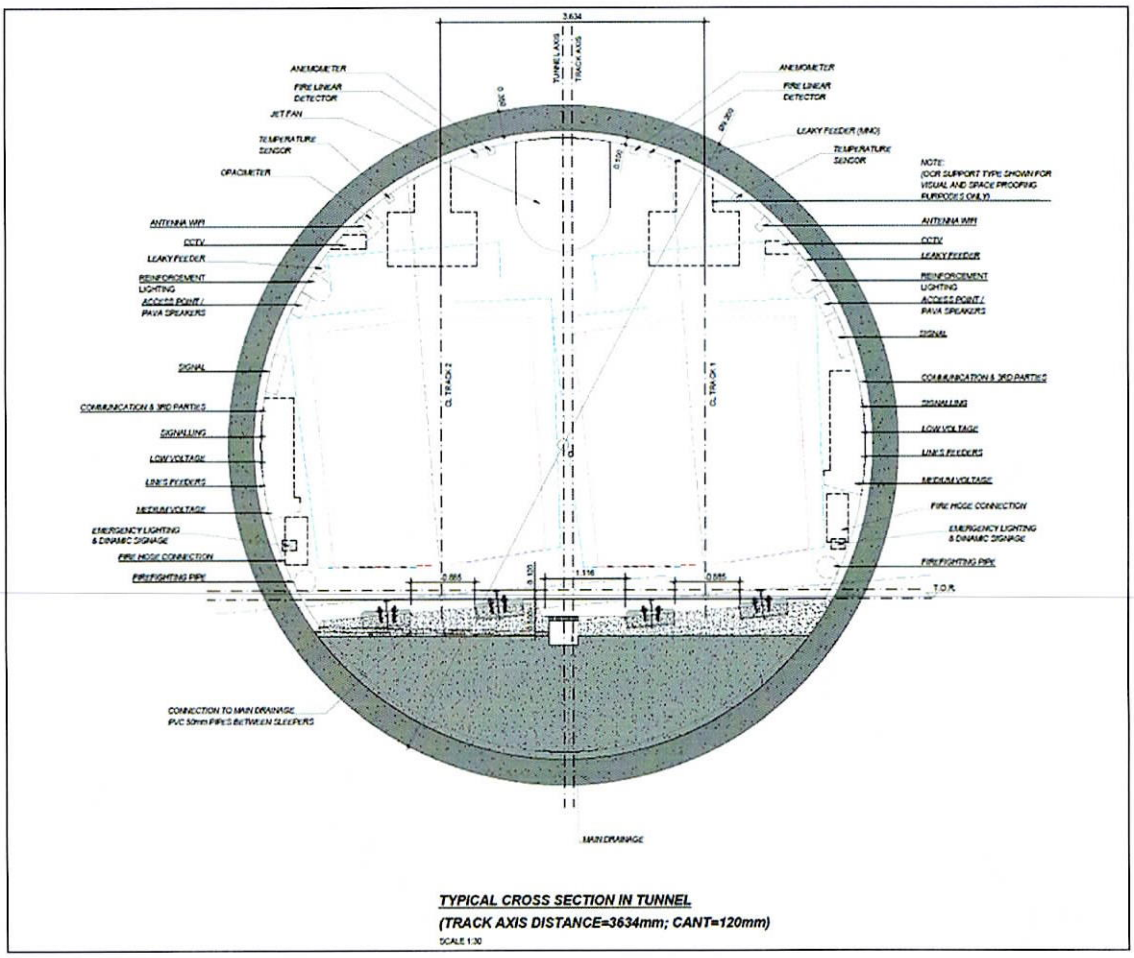


Figure 8 – Tunnel Cross Section at Maximum Applied CANT

TBM Steering Difficulties on a tighter radius

We have assessed the alternative alignments and do not agree that a tighter radius would result in any more or less control of the TBM alignment. In the zone beneath TCD, a full face of homogeneous competent Argillaceous Limestone rock is expected which should provide excellent conditions for steering the tunnelling machine. South of Tara St. Station (circa chainage 17+675) the amount of rock cover decreases but it is not expected that mixed face conditions will be encountered. The rock is overlain with the Dublin Boulder Clays which are known to be generally stiff cohesive clays.

A significant length of tunnel will have already been built by the time the TBM drives beneath TCD; issues relating to learning curve will therefore have long since passed. We would advise that a design radius of 225m or above would not pose any difficulties for ring building, alignment control or logistical backup for a machine of this size, in the ground conditions expected to be encountered.

Operational Speed restrictions leading to increased journey times

We accept that in the interest of passenger comfort, a tighter radius curve leaving Tara St towards St Stephen's Green will require a modest reduction in speed which will result in a negligible increase in journey time. This however needs to be offset against an overall reduction in the length between the two stations which will reduce journey time.

Non-compliance with Metrolink's Design parameters

Jacobs IDOM have described their design principles and limiting values for the track and the tunnel cross section in their report Volume 4 - Chapter 3: Alignment & Cross Sections - ML1-JAI-PLD-ROUT_XX-RP-Y-00403 | P02 - 18/12/2020. This report is not included within the Draft Order but has been previously provided to TCD by Metrolink. The standards which Metrolink's Designer (Jacobs/IDOM) have used for the design are referenced at clause 2.1.3 of this report (Figure 9).

2.1.3 Standards and Reference Documents

This guide has been elaborated in accordance with the following European Standards:

EN 13803-1:2018	Railway Applications - Track - Track alignment design parameters - Track gauges 1435mm and wider - Part 1: Plain line
EN 13803-2:2018	Railway Applications - Track - Track alignment design parameters - Track gauges 1435mm and wider - Part 2: Switches and crossings and comparable alignment design situations with abrupt changes of curvature
EN 13232:2012	Railway applications – Track – Switches and crossings –
EN 15273:2017	Railway applications – Gauges – Parts 1 and 3.

Additionally, the following design handbook from the American NAS has been taken into account:

TCRP Report 155	Track Design Handbook for Light Rail Transit, Second Edition 2012

Figure 9 - Extract from the Designer's Alignment Report showing standards and references they have used

The Designer explains in their report that the design principles of EN 13803 have been adopted along with the associated to Normal (Desired) Limit Values and Exceptional Limit Values. They also state that in instances where limiting values are not available in EN 13803, they have taken guidance from the American Handbook for Light Rail (TCRP Report 155).

At Clause 2.1.4 of the Designer's report however, they state that the values they have used for design are more onerous than those that the European Standard recommends. An extract of clause 2.1.4 is shown in Figure 10.

2.1.4 Limiting Values

Within this document reference is made to Normal (Desired) Limit Values and Exceptional Limit Values, mostly defined by the European Standards. Whenever the EN do not fix a limiting value for a given parameter, the recommended values by the handbook are used.

Normal limit values correspond to limit not normally exceeded. Design values for new lines should normally have a margin to the normal limits. These values ensure a specific level of service to the maximum degree as possible while maintenance costs of the track are kept at a reasonable level.

However, in case physical constraints advise so, exceptional limit values will be exceptionally adopted to keep some important train performance criteria. These exceptional limit values are extreme and cannot be exceeded.

Desired limit values are based on an evaluation of maximum passenger comfort, initial construction cost and maintenance considerations. They are to be used where no significant physical restrictions or significant cost differences are encountered.

Figure 10 - Extract from the Designer's Track Alignment Report regarding Limiting Values for Design

The Limiting Values are fundamental inputs to the design and have a significant impact on the alignment considerations between Tara St and St Stephen's Green stations. A comparison of the limiting values used by the Designer and the values recommended in the Standards is provided in Table 1.

Table 1 - Limiting Values for Design Purposes

Design Parameter	Designer's Normal Limit Value	Designer's Exceptional Limit Value	EN 13803 Normal Limit Value	EN 13803 Exceptional Limit Value	TCRP Report 155
Cant (mm)	120*	150	160	180	N/A
Cant Deficiency (mm)	100	130	153	180	N/A
Unbalanced lateral acceleration (m/s^2)	0.65	0.85	None given	None given	1 to 1.5
Minimum Radius in a Tunnel (m)	350	None given	150	150	N/A

*The Designers Alignment report states a Normal Limit Value of 150mm (the same as the Exceptional Value) but have used a limit of 120mm in practice

Inspection of the values in Table 1 reveals an exceptionally conservative approach to the design when compared with recognised European and international best practice. We therefore do not accept that compliance with Metrolink's *"gold plated"* design parameters should be viewed as a fixed constraint. We would also challenge if the use of such parameters will deliver best value to TII and the people of Ireland.

Wheel-Rail Interference

Wheel-rail interference is a highly complex issue which is dependent upon many factors, only one of which is the tightness of the rail curvature. We do not accept however that the risk of wheel-rail interference is significant at any of the radii currently being contemplated. Wheel-rail interference would not normally be expected to be encountered on a properly maintained system above the minimum radius of 150m as recommended in the European Standard.

Minimum Acceptable Radius for Tunnel Construction

Risk associated with TBM driving tolerances and reduced tunnelling outputs are raised for Options 3 & 4. We have assessed that a tunnel radius as small as 225m would have no impact on the ability to steer the tunnelling machine or to maintain efficient logistical backup. The tunnel ring, TBM and logistics would simply be designed for this minimum radius. This is very different to the Designer's minimum radius of 350m.

Settlement

Chapter 20 of the EIAR contains information on the geology and on Metrolink's predicted ground settlements along the route. At the point of reduced rock cover (circa chainage 17+675), a significant localised increase in settlement is predicted by Metrolink as shown in Figure 11. The maximum predicted settlement at this location is 60mm. Unfortunately this analysis has been undertaken on an out of date alignment and hence the high predicted settlements are simply wrong.

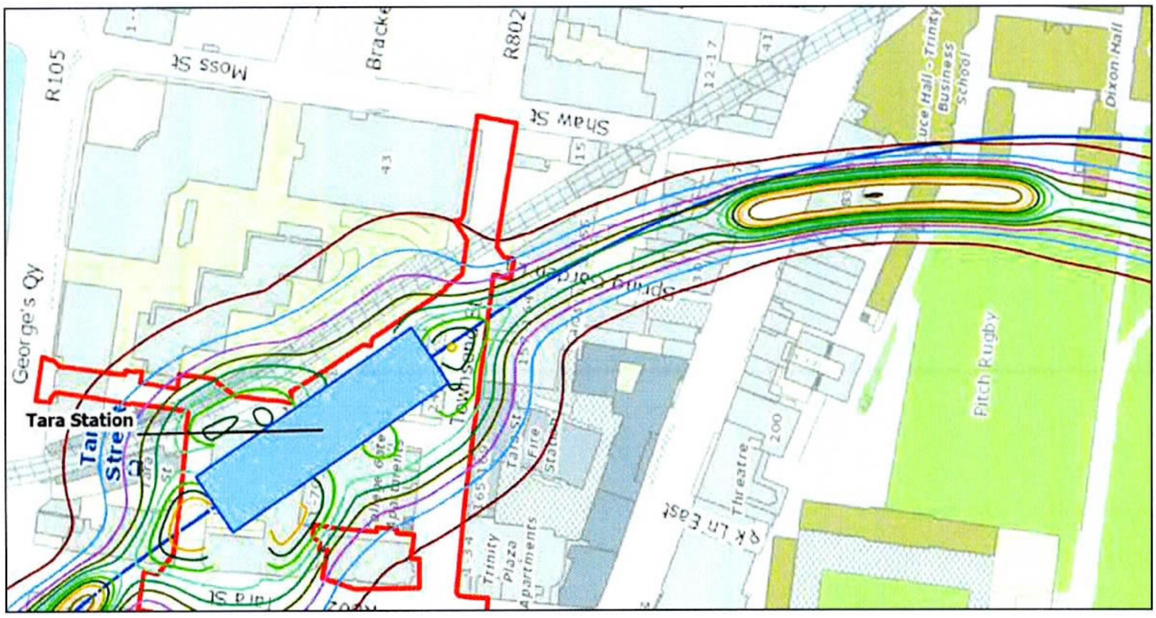


Figure 11 - Predicted ground surface settlement contours (EIAR Chapter 20)

We have therefore produced a corrected longitudinal section showing the correct vertical elevation of the tunnel. An extract from this drawing is shown in Figure 12.

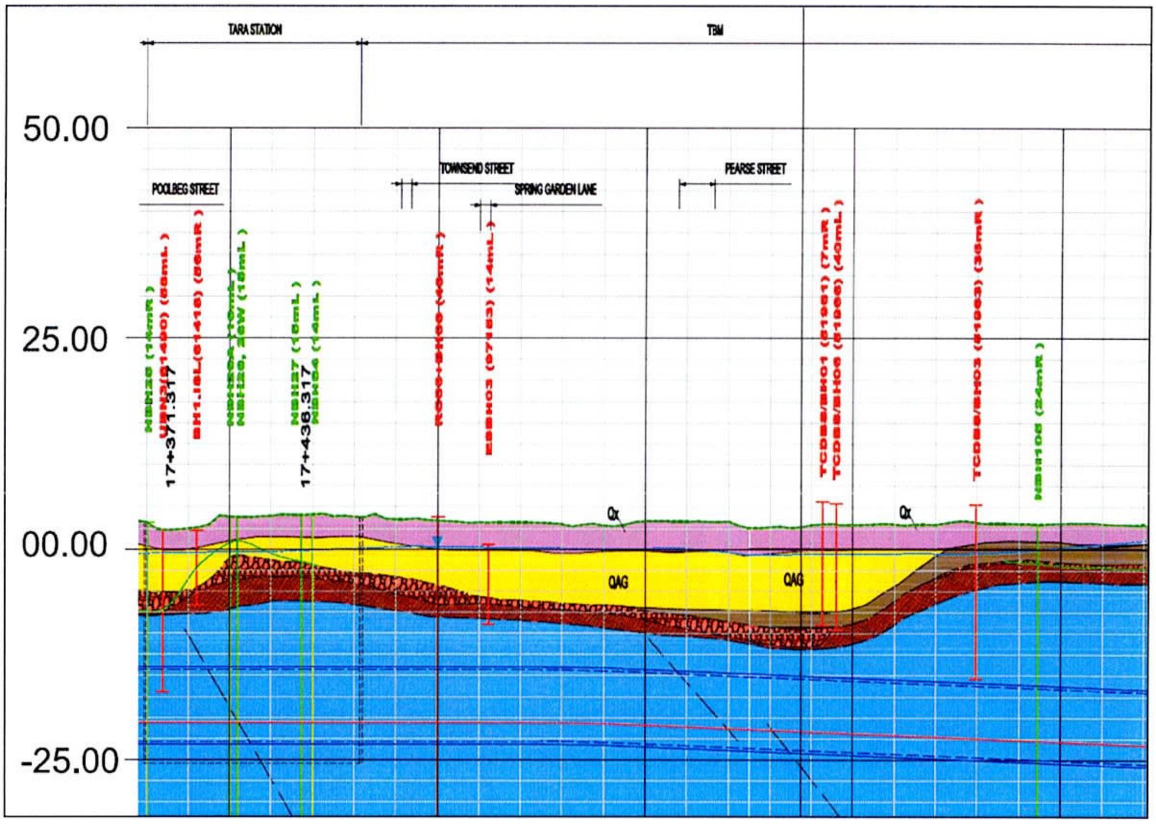
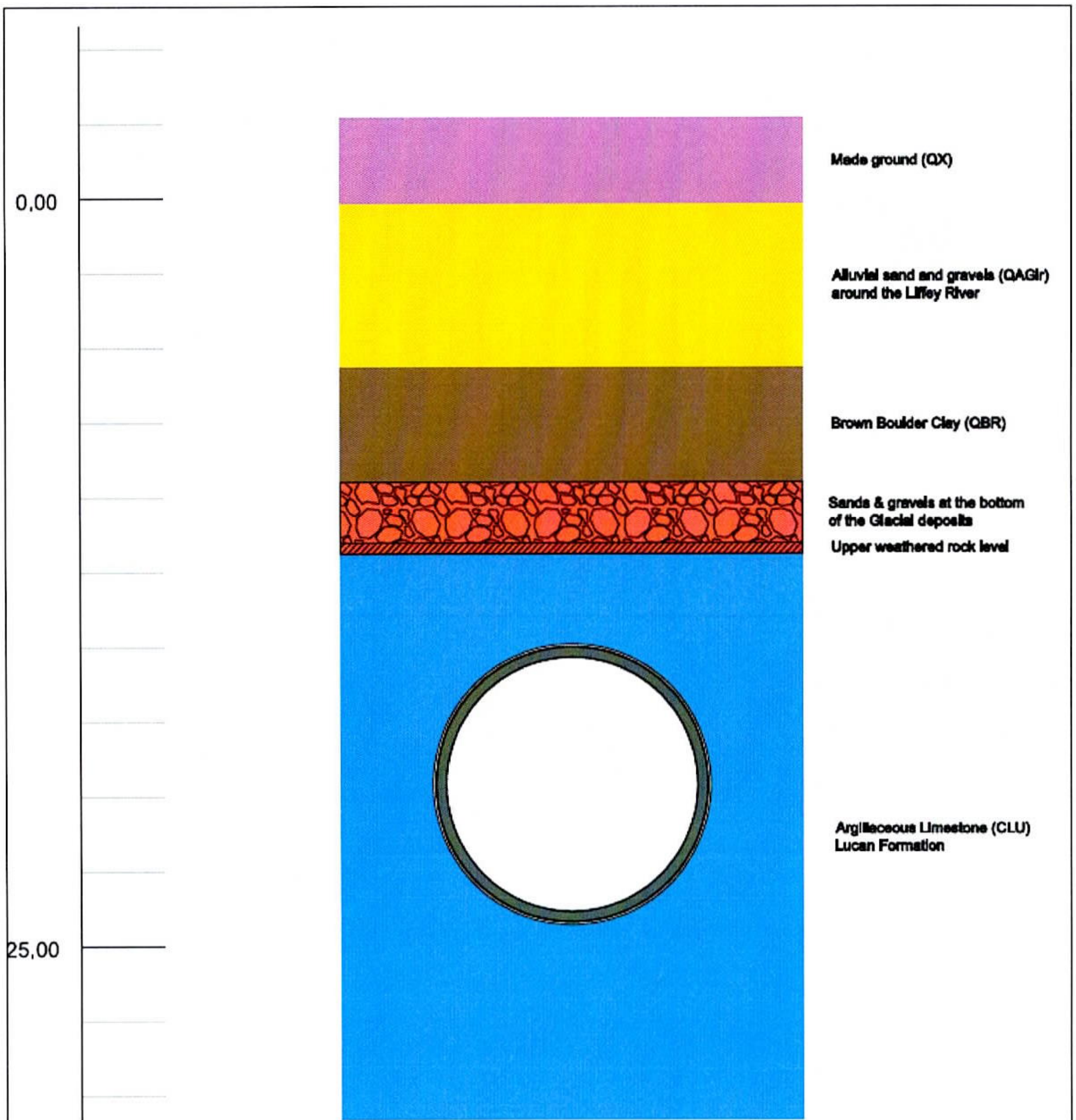


Figure 12 - Longitudinal geological section (South of Tara St Station) with the correct vertical alignment of the tunnel

The minimum rock cover still occurs at chainage 17+675 but with the correct vertical alignment, the cross-section at this location (Figure 13) now shows a healthy amount of competent rock cover above the tunnel. In such ground conditions, we predict that negligible settlement will be experienced and that the risk to the built environment will also be negligible.

All of the above discussion however only relates to the issue of ground response to excavation by a full face TBM. Irrespective of the type of TBM chosen by the Contractor, continuous face and annulus support should always be provided and the associated volume loss in the rock will then be very small. The issue under discussion here therefore is the relative merit of tunnels constructed on curves of different radii. In soft ground it is generally accepted that greater settlement can occur when driving on a tighter radius as the volume of excavation slightly increases. Even in soft ground however this is not always the case and control of unstable ground around the periphery of the TBM can be achieved in several ways. This however is irrelevant to this discussion as the tunnel will be driven in a full face of rock and therefore instability is highly unlikely to occur and the annulus would stand even if unsupported.

In conclusion, we do not accept that construction of the tunnel on a tighter radius will increase settlements. Furthermore, it should also be recognised that a more Westerly route moves some of the tunnel from beneath the buildings into the playing fields thereby further reducing the risk to the existing built environment.



Cross Section at Point of Minimum Cover (17+675)

Figure 13 - Geological cross section at point of minimum rock cover (17+675)

3 TCD Westerly Alternative

In order to avoid significant detrimental impacts on the research activities of TCD, we are strongly of the opinion that a more Westerly alignment must be considered. This can be achieved by combining the following solutions:

- Rotation of Tara St Station
- Reducing the minimum design radius leaving Tara St towards St Stephen's Green
- Reducing the operational speed adjacent to Tara St. Station

There are of course numerous permutations that can be applied to the problem. One of these is as follows:

- One-degree clockwise rotation of Tara St Station
- Reducing the minimum design radius to 260m
- Reducing the operational speed to 60 km/h

The proposed rotation of Tara St Station will be undertaken from a point of rotation on the Southern end of the station box. This therefore maintains exactly the same separation between the station box and the 2440mm foul sewer that runs beneath Townsend Street. The rotated station is shown in Figure 14.

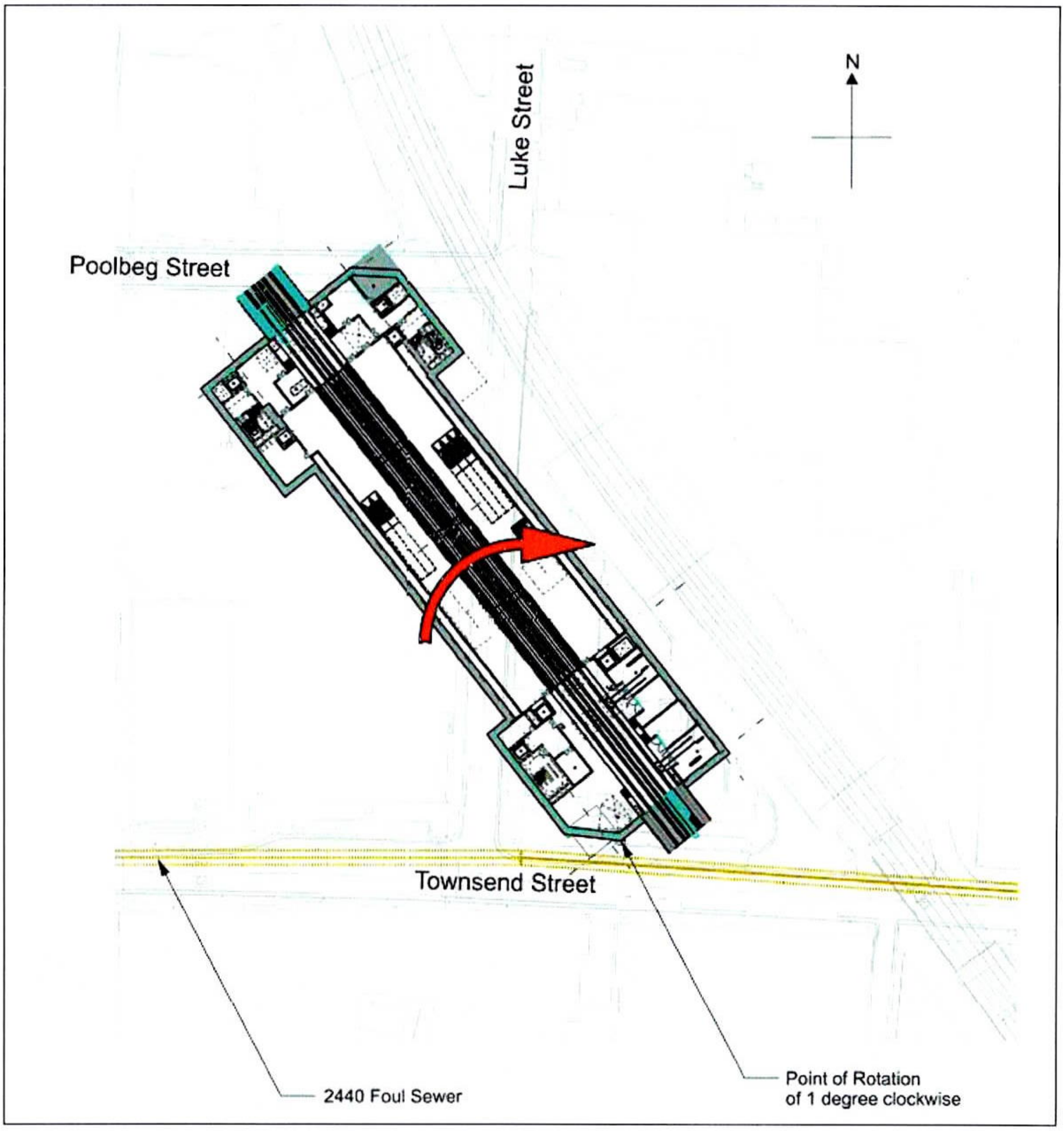


Figure 14 - Tara St. Station rotated by one degree

This alignment option is shown in Figure 15 and shows a significant increase in separation from the TCD sensitive receptors.

This proposed alignment was first presented to Metrolink in a letter from TCD 18th May 2021. A copy of this letter can be found in Appendix A. Two options were included in this letter. The most Westerly of the two options was described as Option B and is the option shown in Figure 15.

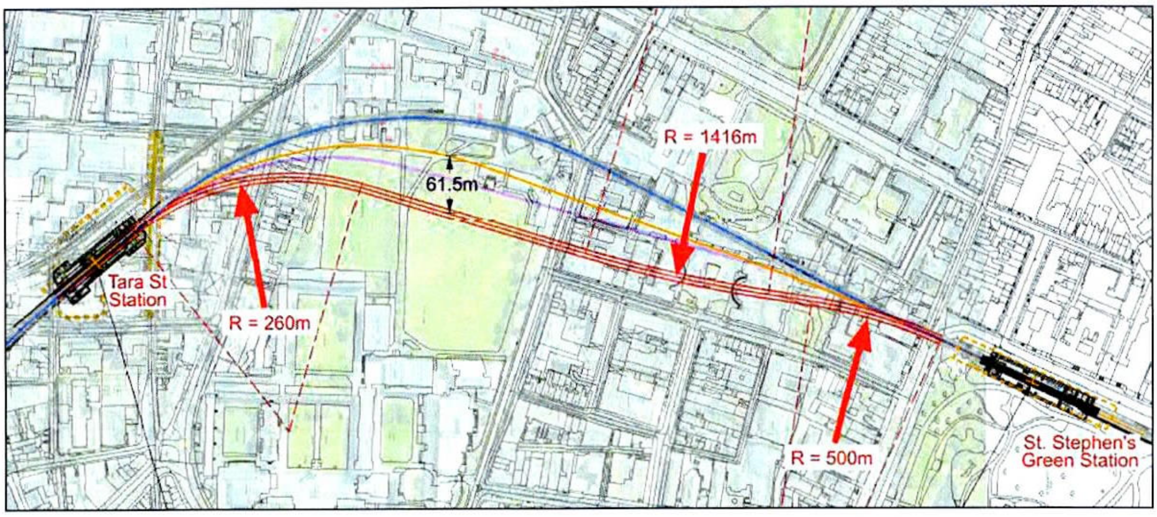


Figure 15 – TCD Westerly Alternative

For this option, the overall length of tunnel between Tara St and St Stephen's Green is slightly reduced and therefore the overall impact of the operational speed restriction is reduced to less than **one second**. A speed Vs Chainage plot comparing Metrolink's preferred Option 2 and the TCD Westerly Alternative is shown in Figure 16.

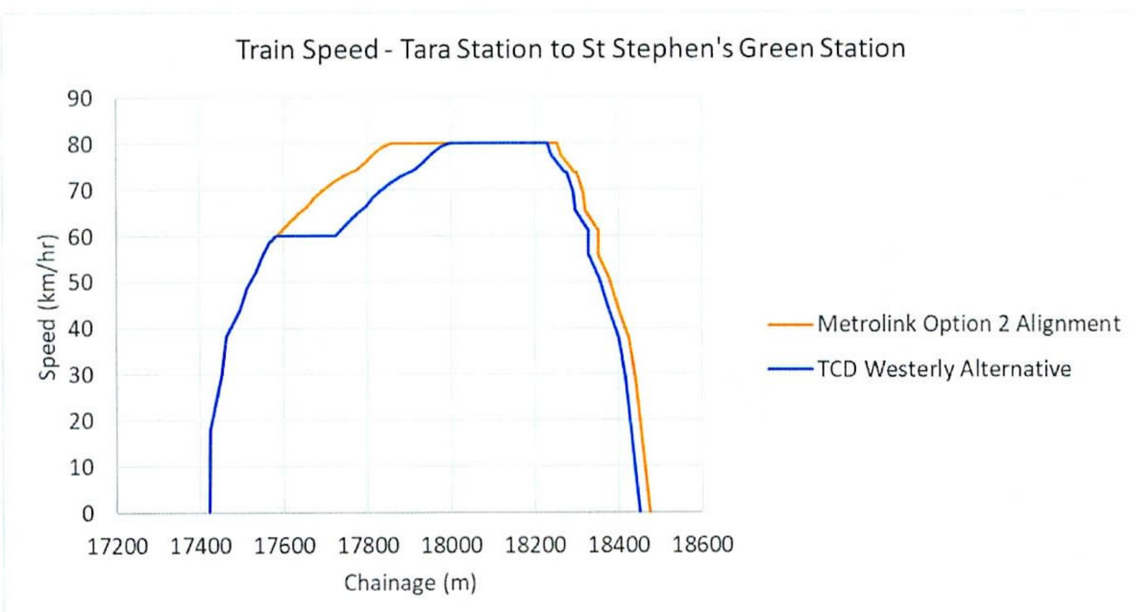


Figure 16 - Comparison of Alignment Options Between Tara St and St Stephen's Green

4 Conclusions

The preferred route presented in the Draft Railway Order will have a significant detrimental effect on the research activities of TCD due to its proximity to TCD's assets. A more Westerly alignment which increases the separation between the Metrolink and the highly sensitive equipment research equipment is required. We have proposed an alternative route which would avoid TCD's assets and minimise disruption. This route requires the following changes to the solution proposed in the Draft Railway Order:

- One-degree clockwise rotation of Tara St Station
- Reducing the minimum design radius to 260m
- Reducing the operational speed to 60 km/h

This is by no means a unique solution, and other permutations of these types of changes may be used to achieve the same goal. Metrolink has rejected similar solutions in their options assessment based on a number of assumptions. We have addressed these concerns in our report and reiterate the main points here:

Concern Raised by Metrolink	Assessment
Inadequate spaceproofing of the tunnel to accommodate the dynamic kinematic envelope of the train operating on a tighter radius	The dynamic kinematic envelope design for the tunnel considers the worst coexistent combination of horizontal and vertical curvature. The proposed horizontal alignment immediately South of Tara St. Station is relatively flat and therefore would not generate the same envelope. We therefore contend that sufficient space exists to accommodate the TCD Westerly alignment.
TBM steering difficulties operating on a tighter radius	We have assessed that a tunnel radius as small as 225m (i.e. significantly smaller than we propose) would have no impact on the ability to steer the tunnelling machine or to maintain efficient logistical backup. The tunnel ring, TBM and logistics would simply be designed for this minimum radius. In the zone beneath TCD, a full face of homogeneous competent Argillaceous Limestone rock is expected which should provide excellent conditions for steering the tunnelling machine. A significant length of tunnel will have already been built by the time the TBM drives beneath TCD and issues relating to learning curve will therefore have long since passed.
Operational Speed restrictions leading to increased journey times	The new proposed alignment would require a modest reduction in operational speed which will result in a negligible increase in journey time. This however needs to be offset against an overall reduction in the length between the two stations which will reduce journey time. We calculate the net increase in journey time to be less than 1 second.
Non-compliance with Metrolink's Design Parameters	Inspection of the values used by the Designer reveals an exceptionally conservative approach to the design when compared with recognised European and international best practice. We therefore do not accept that compliance with Metrolink's *"gold plated"* design parameters should be viewed as a fixed constraint.

Wheel-Rail Interference	Wheel-rail interference would not normally be expected to be encountered on a properly maintained system above the minimum radius of 150m as recommended in the European Standard. We therefore also reject this argument against the Westerly alignment.

APPENDICES

Appendix A Letter from TCD to Metrolink (18th May 2021)

Coláiste na Tríonóide, Baile Átha Cliath
Trinity College Dublin
Ollscoil Átha Cliath | The University of Dublin

18th May 2021

Aidan Foley Esq
Project Director - Metrolink
Transport Infrastructure Ireland
Parkgate Business Centre
Parkgate Street
Dublin 8

Dear Aidan

RE: TRINITY COLLEGE DUBLIN AND THE METROLINK PROJECT

I refer to our meeting in February where we discussed the concerns of the University in relation to the current proposed route alignment and where TII agreed to explore moving the alignment.

The University has engaged its own advisors in this regard and they have carried out analysis and revisions to the current proposed route under the 'East End' of the campus which are set out further below. As you are aware the current route is a significant issue for the University in terms of the impacts on our research facilities.

1 Context

From the very start of our discussions in late 2018, we have represented that if the tunnel could avoid being under the East End of the campus, it would avoid some of the most detrimental impacts on the University research activities in this area. If the alignment can be moved from this location, it would substantially remove the main source of disruption to the University and as a result, avoid extensive and unproven mitigation measures being implemented.

2 Options for Consideration

Our expert team have considered a number of factors and have come up with two realignment proposals which we believe will deliver a better outcome for the University without detriment to the Metrolink project:

2.1 Option A

This option rotates the station axis by 3.5 degrees from the TII alignment at Tara Street but maintains the minimum curve radius of 350m used in the TII design.

Other points to note as follows:

- Design in accordance with Metrolink and international alignment standards;
- All curves and transitions designed for 80Km/Hr operation;
- Allows for through running at full speed (80kph), which may not be possible with the intrusion of the platform edge and screen doors into the kinematic envelope;
- No change made at this point to the vertical alignment; and
- Shortening of the tunnel results in a slight improvement to the journey time in normal operation.

Appendix A refers and the alternative route is marked in red.

2.2 Option B

This option rotates the station axis by 1 degree from the TII alignment at Tara Street and reduces the minimum radius to 260m, which we believe should still be acceptable.

Other points to note as follows:

- Design in accordance with Metrolink and international alignment standards;
- Curves and transitions generally designed for 80Km/Hr operation;
- Transition clothoid into the south end of Tara St Station has been reduced to 40Km/Hr for through running, which is compatible with a normal stopping-service train;
- There is a minimum of a 46m straight between curves;
- No change made at this point to the vertical alignment; and
- No change to the journey time in normal operation.

Appendix B refers and the alternative route is marked in red.

I trust that TII will consider these proposals which we are advised are viable alternatives to avoid significant on the University.

As you will appreciate, the University has incurred considerable expense in the engagement of experts to advise on these alternative routes and I await hearing from you in relation to the next steps to progress our dialogue in this matter.

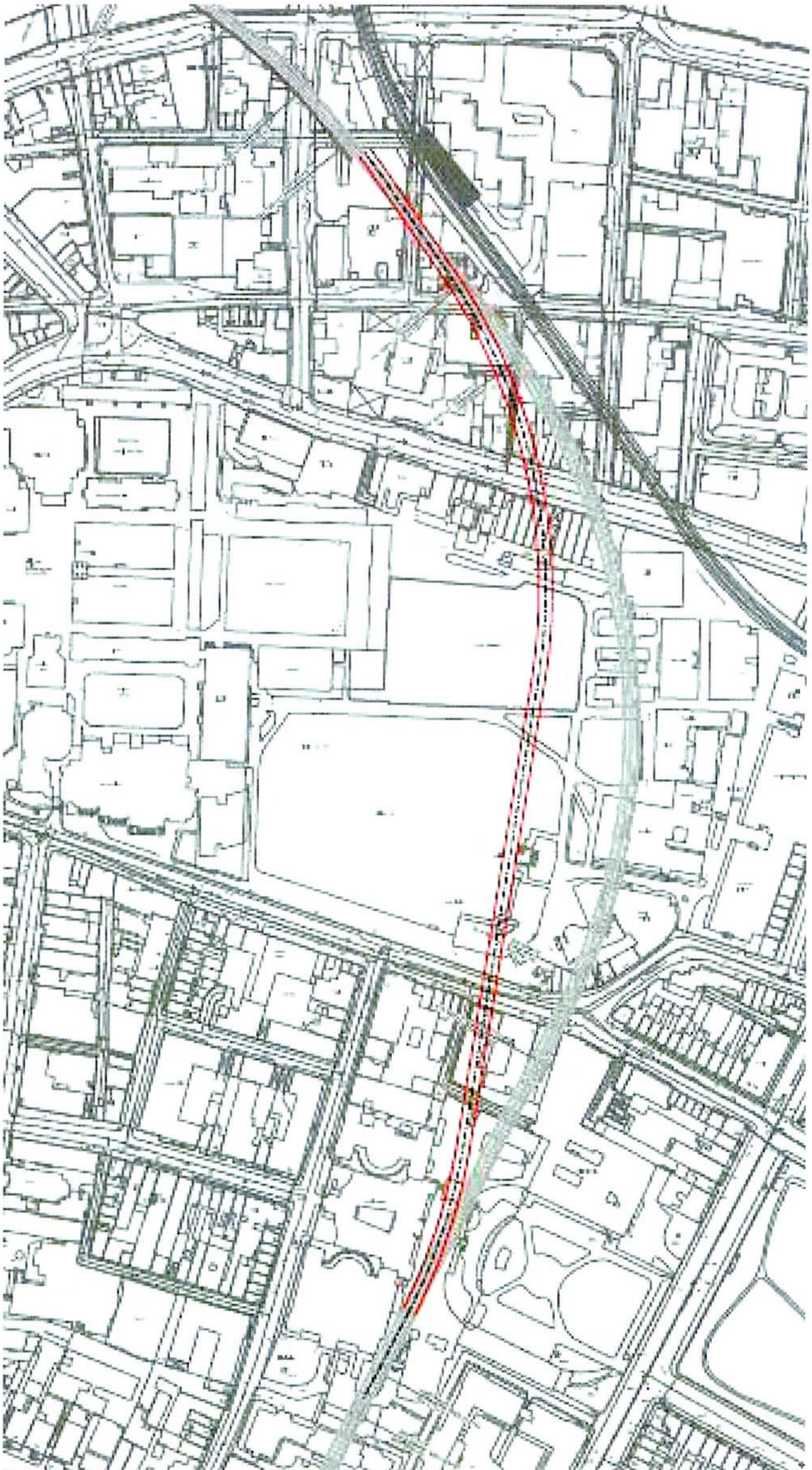
Yours sincerely

For and on behalf of Trinity College Dublin

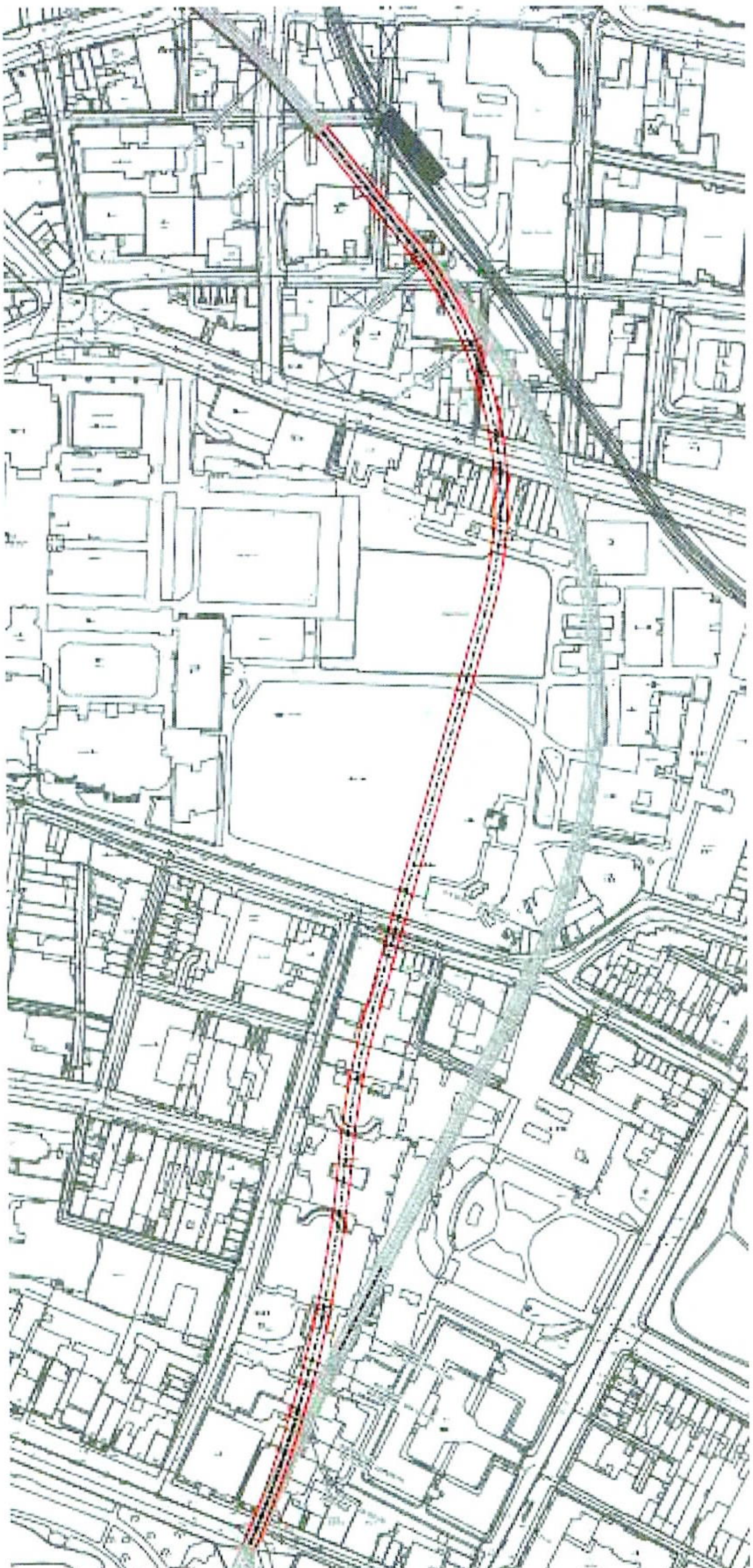
Mike Clark
Director of Campus Infrastructure

e-Mail: mike.clark@tcd.ie
Mobile: 087 345 5786

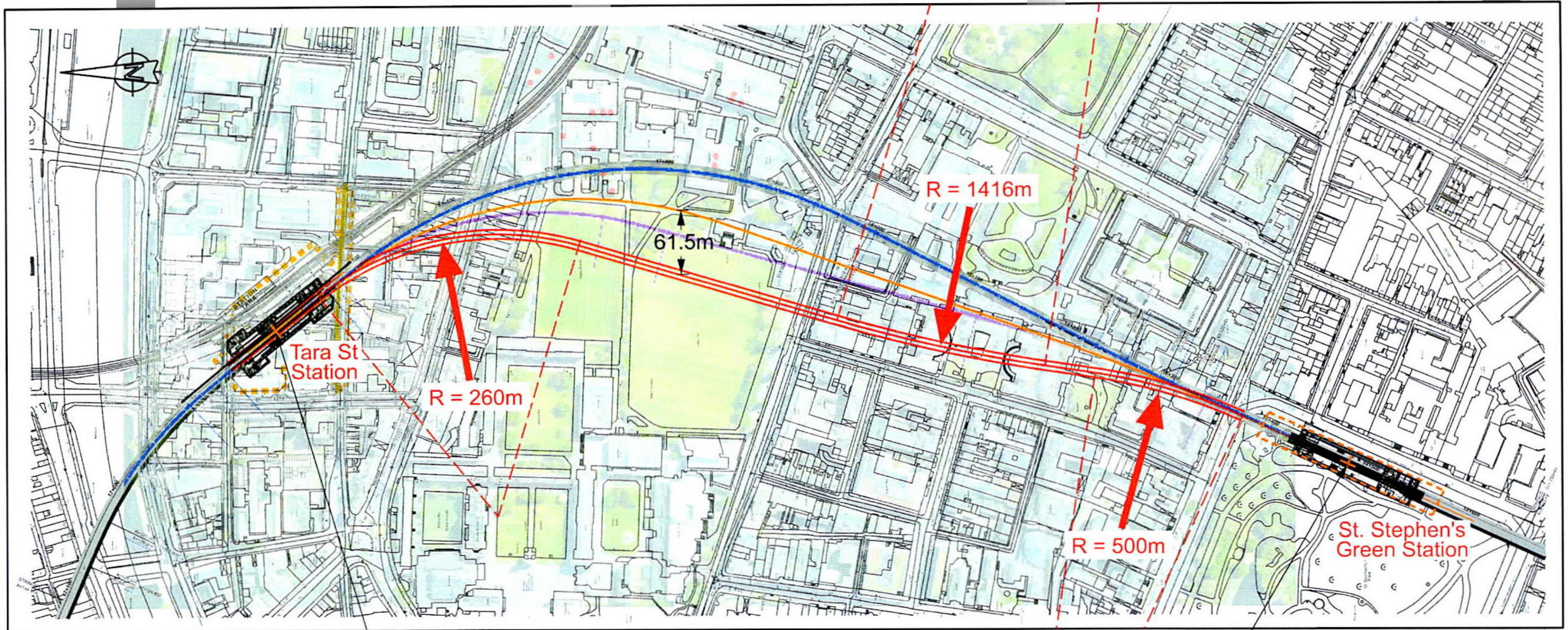
Appendix A
Option A – Tunnel rotated by 3.5 degrees from TII alignment at Tara Street



Appendix B
Option B – Tunnel rotated by 1 degree from TII alignment at Tara Street



Appendix B CECL Drawings



Length from Tara St to St Stephen's Green:

Metrolink's Option 2 = 1052m
TCD's Westerly Alternative = 1028m

Metrolink Alignment Options provided 20/07/21

Center of Station Platform

Center of Station Platform

Key

- Metrolink's Option 2 Line
- TCD's Westerly Alternative Line

Notes:

REV.	DATE	DESCRIPTION	DWN	CHKD	APPD
B	17.10.2022	Station Name Added	RMH	EH	CME
A	22.07.2021	DRAFT FOR DISCUSSION	RMH	AM	CME

Trinity College Dublin
The University of Dublin

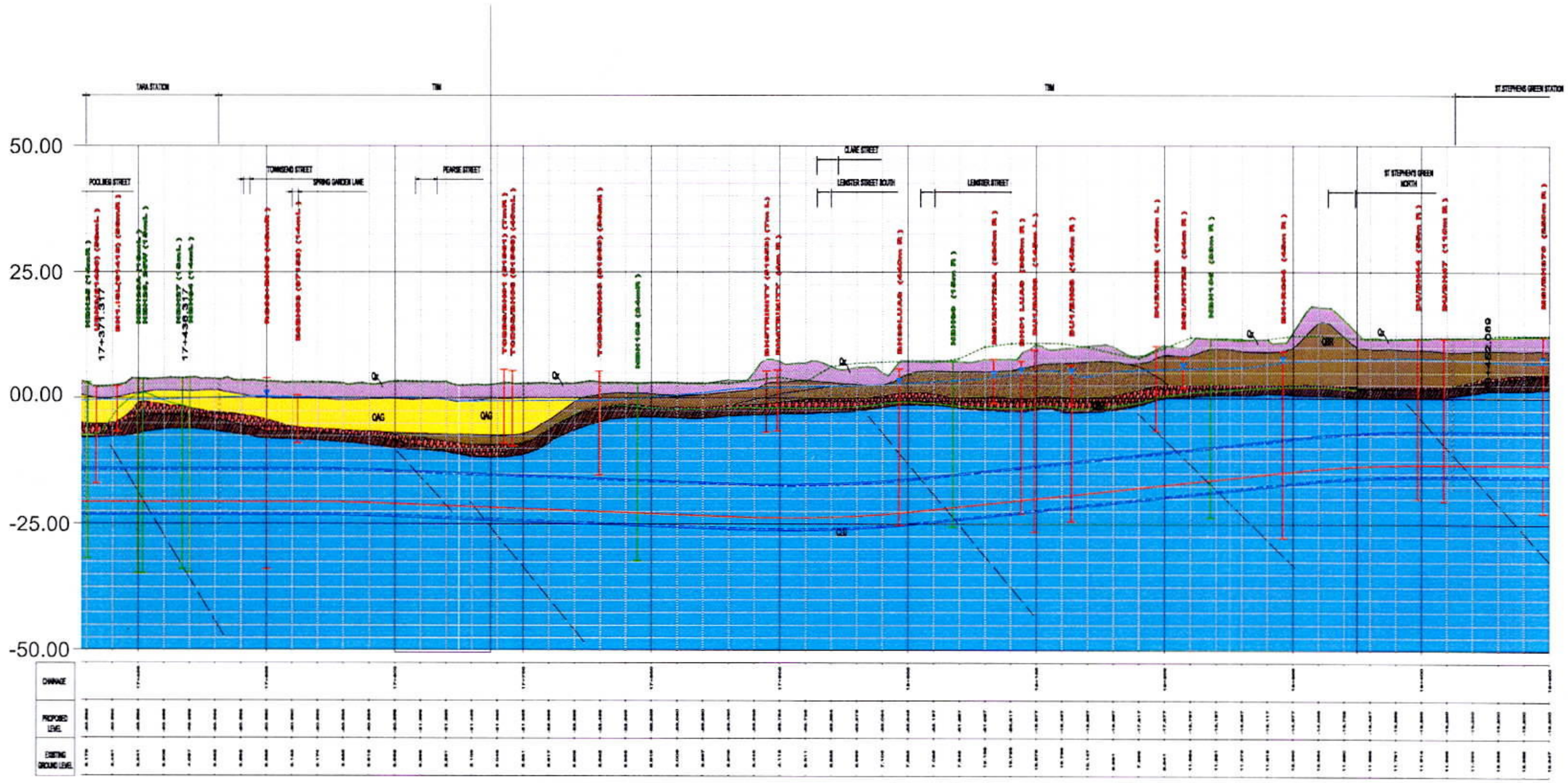
The Priory
Priory Road
Wolston
Warwickshire
Great Britain
CV8 3FX

CECL GLOBAL

Trinity College Dublin

Alignment Comparison

CECL / 0037 / DR / 0006 / B



Vertical Scale: 1:1000
Horizontal Scale: 1:4000

Geological Legend:

- Made ground (QX)
- Alluvial sand and gravels (QAGwd) around the Ward River
- Alluvial sand and gravels (QAGlr) around the Liffey River
- Fluvio-Glacial sands within Glacial deposits
- Brown Boulder Clay (QBR)
- Black Boulder Clay (QBL)
- Sands & gravels at the bottom of the Glacial deposits
- Upper weathered rock level
- Phreatic level
- Interpreted Bedding
- Interpreted Faults
- Argillaceous Bioclastic Limestone (CMUP) Upper member of Malahide Formation
- Biomicritic Limestone with thin shale interbedded (CMLO) Lower member of Malahide Formation
- Micritic Limestone (CWA) Waulsortian Formation
- Calcareous Shale (CTO) Tober Colleen Formation
- Argillaceous Limestone (CLU) Lucan Formation

Note:

Vertical alignment taken from drawings:
ML1-JAI-ARD-ROUT_XX-DR-Y-01016 P03 12/05/22
ML1-JAI-ARD-ROUT_XX-DR-Y-01017 P03 12/05/22

Geology taken from drawing:
ML1-JAI-GEO-ROUT-XX-M2-Y-00013-24 11/12/20
ML1-JAI-GEO-ROUT-XX-M2-Y-00013-25 11/12/20
ML1-JAI-GEO-ROUT-XX-M2-Y-00013-26 11/12/20

Notes:

REV.	DATE	DESCRIPTION	DWN	CHKD	APPD
A	21.10.2022	DRAFT FOR DISCUSSION	RMH	EH	CME

Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

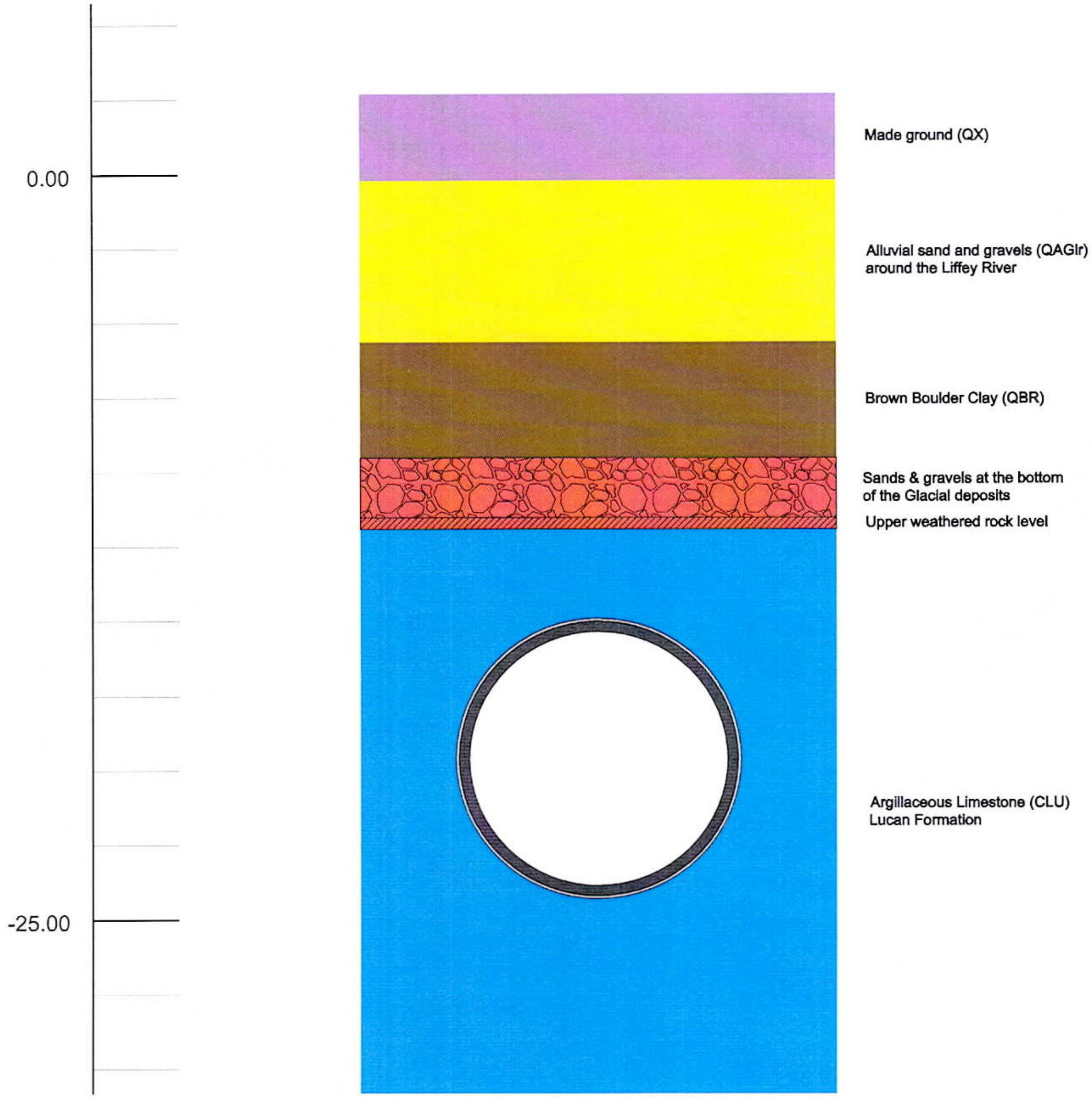
The Priory
Priory Road
Wolston
Warwickshire
Great Britain
CV8 3FX

CECL GLOBAL

Trinity College Dublin

Geological Long Section between Tara St and St Stephen's Green Stations

CECL / 0037 / DR / C[redacted]A



Cross Section at Point of Minimum Cover (17+675)

Notes:

REV.	DATE	DESCRIPTION	DWN	CHKD	APPD
A	21.10.2022	DRAFT FOR DISCUSSION	RMH	EH	CME

Trinity College Dublin
Coláiste na Trionóide, Baile Átha Cliath
The University of Dublin

The Priory
Priory Road
Wolston
Warwickshire
Great Britain
CV8 3FX

CECL GLOBAL

Trinity College Dublin

Cross Section showing minimum rock cover between Tara St and St Stephen's Green Stations

CECL / 0037 / DR / 0010 /A

APPENDIX E

METROLINK IMPACTS – ELECTROMAGNETIC INTERFERENCE (EMI)
PREPARED BY ARUP

ARUP

Trinity College Dublin

Metrolink impacts

Electromagnetic Interference (EMI)

Reference: 277168-00/EMI/R04

Final | November 2022

Job number 277168-00

Ove Arup & Partners Ltd
8 Fitzroy Street, London, W1T 4BJ
arup.com

ARUP

Document verification

Project title	Metrolink impacts
Report title	Electromagnetic Interference (EMI)
Job number	277168-00
Document ref	277168-00/EMI/R04
File reference	R04

Revision	Date	Filename			
Final	24 Nov 22	Description	Final report		
			Prepared by	Checked by	Approved by
		Name	Anna Coppel	Steve Walker	Steve Walker
		Signature			
		Filename			
		Description			
			Prepared by	Checked by	Approved by
		Name			
		Signature			
		Filename			
		Description			
			Prepared by	Checked by	Approved by
		Name			
		Signature			

Issue Document verification with document ✓

Contents

Executive Summary

The proposals by Transport Infrastructure Ireland (TII) presented in the EIAR to construct and operate a new metro system introduces significant risk of Electromagnetic Interference (EMI) to Trinity College Dublin's (TCD) electromagnetic (EM) sensitive facilities located at the eastern end of College Green, Dublin 2.

The equipment at TCD of primary concern each requires an extremely stable environment to perform as demanded by the advanced research activities they are used in; this applies both to electromagnetic interference (EMI) and to vibration.

The nuclear magnetic resonance devices (NMR), scanning electron microscopes (SEM) and magnetic resonance imaging (MRI) devices that form the principal subjects of this report, are very susceptible to a particular type of EMI: relatively slow changes in background magnetic fields. This is just the type of interference that MetroLink will generate and fundamentally degrades the performance of the equipment affected, undermining the ability of the instrument to deliver the outputs required by researchers. The physical mechanism and sensitivity vary with the equipment type concerned, for example, for SEMs such EMI would result in image distortions and blurring.

Means to mitigate EMI interference effects exist but their effectiveness and practicality needs to be assessed on a case-by-case basis, by far the best solution is to increase the distance between the source of interference and the equipment sensitive to it.

The following main points are noted:

- The authors of the EIAR appear to accept that there will be significant negative impact due to EMI on sensitive equipment at TCD. TCD is the only listed receptor along the entire MetroLink route which has "significant" "negative" effects as a consequence of EM emissions from MetroLink.
- The following equipment in TCD has been identified as being at risk of negative impact from the MetroLink:
    1. 3No. Scanning Electron Microscopes (SEM) in the Panoz Institute
    2. 3No. Nuclear Magnetic Resonance (NMR) machines in Chemistry
    3. 2No. Magnetic Resonance Imaging (MRI) machines in the Lloyd Institute
    4. 1No. SQUID machine in Sami Nasr Institute of Advanced Materials (SNIAMS)
- During the construction phase, the impact from EMI on this sensitive equipment will be minimal, however, it has been proposed in the EIAR that equipment that is also vibration sensitive will be turned off as the Tunnel Boring Machine (TBM) passes near to TCD.
- During the operational phase, it appears to be accepted by the authors of the EIAR that the predicted EM fields at the location of the sensitive equipment will not meet the performance requirements for some of the equipment under the proposed preferred route alignment (Option 2) and mitigation will be required.
- The EIAR contains a surveyed baseline carried out by TII; Arup have separately carried out a baseline survey for TCD. At all sensitive equipment locations, without exception, Arup's baseline measurements were higher than those reported in the EIAR. However, it is acknowledged that surveys represent a snapshot in time and some differences are to be expected.
- The predictions of emissions from the MetroLink in the operation phase are broadly in agreement between Arup and in the EIAR. However, the EIAR does not attempt to assess the cumulative effect of the emissions associated with the existing baseline environment and the new emissions from MetroLink.

- The following mitigation options are available to reduce EM fields at the location of the sensitive equipment:

  1. Alternative route alignments which move the MetroLink further west – by moving the route further west the distance between the MetroLink and the sensitive equipment would increase and thus the EM fields will be lower at the location of the sensitive equipment.

     - Alternative route alignments have been partially explored in the EIAR, as the proposed routes do not fully mitigate EMI impacts on all of the sensitive equipment.

     - Arup have assessed the required westward offset to mitigate the negative impacts at all sensitive equipment locations, this would result in a material benefit as it removes the need for unproven mitigation at the location of the NMRs (see point 3 below "Active Cancellation Systems (ACS)"). The alignment would need to move an additional 175m (using Arup baseline measurements and predicted MetroLink emissions) or additional 65m (using the EIAR baseline measurements and predicted MetroLink emissions) west of alignment Option 2 to meet the performance requirements for the NMRs.

  2. Relocation of the sensitive equipment – by increasing the distance between the Metrolink and the sensitive equipment the EM fields at the sensitive equipment would be lower.

     - Relocation of sensitive equipment has been suggested as a mitigation option in the EIAR, but not explored in any detail. It would be extremely disruptive to TCD and would limit future research opportunities.

  3. Active Cancellation Systems (ACS) – these systems consist of a number of orthogonal coils typically located around the room where the sensitive equipment is located, with a magnetic field sensor placed beside the sensitive equipment. The coils are used to create varying magnetic fields which oppose any magnetic field fluctuations at the sensor location. This is the mitigation option proposed in the EIAR at the location of the sensitive equipment.

     ACS is presented in the EIAR as a viable mitigation option at the location of the SEMs and the NMRs. However, there is no consideration provided as to how the ACS systems would work with 3 no. SEMs located in close proximity, nor is there consideration of the practicality of using an ACS with NMRs. Arup have been unable to find precedents or, indeed, a proven manufacturer ACS products for mitigation of EMI for NMRs.

     The EIAR and Arup have explored the suitability of this mitigation method for all alignment options and sensitive equipment at TCD:

     - Options 0 and 1 (R=400m) - equipment performance requirements are exceeded at all sensitive equipment locations. In the EIAR ACS is presented as a viable mitigation option at all the sensitive equipment locations. However, in practice, the EM field gradients will likely be too high for the NMRs and would restrict the use of such systems. The EIAR does not consider field gradients.

     - Option 2 (R=350m) – equipment performance requirements are exceeded at the location of the NMRs and SEMs when the emissions from the MetroLink are considered on their own. If the baseline environment is considered along with the MetroLink emissions, the MRIs would also be impacted.

     - Option 3 (R=302 m) - equipment performance requirements are exceeded at the location of the NMRs and SEMs when the emissions from the MetroLink are considered on their own. If the baseline environment is considered along with the MetroLink emissions, the MRIs would also be impacted. In the EIAR, no mitigation is recommended. Arup do not agree with this approach, as EM field levels exceed the equipment performance requirements at the location of the NMRs and SEMs and likely also the MRIs.

- Option 4 (R=302m) – this option has not been assessed with respect to EM fields and equipment mitigation in the EIAR. We believe this route alignment would also result in EM fields in excess of the equipment performance requirements at the location of the SEMs and NMRs and likely also the MRIs.
- Option 5 (Proposed Alternative) - a localised realignment of the line beneath the Campus which moves the alignment 61.5m westward of the current proposed alignment (Option 2). With this option the negative impacts from the MetroLink on sensitive equipment would be largely mitigated. Further longer-term monitoring of baseline EM environment is recommended to provide further confidence in the baseline values as these will dictate the extent of any additional mitigation (e.g. ACS at the location of the SEMs) required for Option 5.

4. Passive shielding – this mitigation option involves installing a high permeability material such as mumetal on all six sides (floor, ceiling and walls) of the room or laboratory. Compared with ACS passive shielding is highly disruptive and very costly. This option is partially explored as a solution for the NMRs, however, the budget proposed in the EIAR is unrealistic.
5. Compensation conductor – this mitigation option would be installed at the location of the source of the emissions, the MetroLink. The practicalities of this kind of system and its effectiveness have not been fully explored in A12.6 "19E8382-1 TCD DC and Near DC Field Simulation Testing" or elsewhere in the EIAR.

Recommended further information requests

It is recommended that the following further information is requested from the Applicant:

- More details of the mitigation proposals, as well as evidence of their successful use, are required to demonstrate that EMI risks to all TCD's facilities can be minimised to an acceptable level. This additional information should include evidence of ACS being successfully used for NMRs, SEMs (multiple SEMs in close proximity) and MRIs.
- It is recommended that a trial of an ACS system is conducted for the SEMs in Panoz and the results of this trial shared with TCD. Careful consideration should be given to the system design during this trial, given the close proximity of 3 no. SEMs in Panoz.
- Due to the significant difference between the EIAR and Arup surveys, it is recommended that additional longer-term monitoring (c. 2-4weeks) of the baseline EM environment is required to be carried out, at a minimum at the location of the NMRs and the monitoring data shared with TCD.

1. Introduction

The proposals by Transport Infrastructure Ireland (TII) presented in the EIAR to construct and operate a new metro system introduces significant risk of Electromagnetic Interference (EMI) to Trinity College Dublin's (TCD) electromagnetic (EM) sensitive facilities located at the eastern end of College Green, Dublin 2

As originally proposed, the alignment would pass directly, or very close to, beneath the most sensitive facilities.

Arup has been working with TCD to understand and quantify the risks from EMI. In this contest, a realignment of the Metrolink tunnel is proposed for consideration, which would require the alignment to move a short distance west and so further away from the sensitive facilities. Mitigation in the form of active cancellation systems (ACS) has also been proposed in the EIAR.

This report presents Arup's assessment of electromagnetic fields and their impact on the sensitive equipment at TCD. The route and the information regarding the emissions from the Metrolink are from the information contained in the EIAR or provided directly to Arup by TII. The primary focus is on operational phase of the proposed scheme (i.e. EMI caused by train movements) but consideration is also given to the risks presented during construction (tunnel boring and use of a temporary construction railway).

2. Summary of relevant Railway Order documents

This section reviews the information published on https://www.metrolinkro.ie/ the website was accessed on 30th September 2022 and the documents below were downloaded on that date.

The key EMC documents reviewed are listed below:

1. EIA Report Volume 3 – Book 1: Population and Human Health, Traffic, Noise and Vibration and EMI/EMC Chapter 12: Electromagnetic Compatibility and Stray Current [1]
2. EIA Report Volume 5 – Appendices Chapter 12 EMC
    a. A12.1 MetroLink Electromagnetic Radiation Baseline Survey Report [2]
    b. A12.2 Trinity College Dublin Direct Current and Near Direct Current Electromagnetic Radiation Survey Report [3]
    c. A12.6 19E8382-1 TCD DC and Near DC Field Simulation Testing [4]
3. EIA Report Volume 2 – Chapter 07 Consideration of Alternatives [5]
4. EIA Report Volume 5 – Appendices Chapter 7 Consideration of Alternatives
    a. A7.10 Trinity College - Alignment Options Assessment [6]
5. EIA Report Volume 3 – Chapter 31 Summaries of the route wide mitigation and monitoring proposed [7]

2.1 Baseline

In the EIAR, TCD is categorised as having a baseline rating with respect to electromagnetic fields as "*very high*" as it has "*highly sensitive equipment in universities, colleges and schools*". (Table 12.4 in Section 12.4.4.4 of EIA Report Volume 3 Chapter 12 and Table 12.11 in Section 12.7.4 of EIA Report Volume 3 Book 1 Chapter 12)

Due to this *"very high"* rating, baseline surveys were carried out *at TCD on 29 November 2018 at two locations. Follow up DC surveys were then also carried out on 25 February 2019 and 19 March 2019 as part of consultations with the college.* (Section 12.7.4 of EIA Report Volume 3 Book 1 Chapter 12)

Appendices A12.2 to the EIAR "Trinity College Dublin Direct Current and Near Direct Current Electromagnetic Radiation Survey Report" and A12.6 "TCD DC and Near DC Field Simulation Testing" describe the baseline surveys. The baseline surveys which were carried out in the context of preparing the EIAR are described in Section 4.1 of this report and in general, the methods reported are appropriate and consistent with those used on schemes elsewhere.

In Section 3.0 of A12.2 to the EIAR, Table 3 reports the measured baseline at the location of the sensitive equipment or *Current DC Field fluctuations*. These measured baseline values reported in the EIAR are compared to the measured baseline values as recorded by Arup in Section 4.3 of this report. In general, the baseline EM field measurements at the sensitive equipment locations reported in the EIAR are lower than those recorded by Arup. Both sets of measurements represent a snapshot in time, but provide a useful range of baseline readings. We would recommend that further longer term (c.2-4weeks) monitoring of the baseline environment is carried out to provide more confidence in the baseline values.

Also in Section 3.0 of Appendix A12.2, Table 3 reports *equipment sensitive to DC and near DC fields*. There are two pieces of equipment where Arup's assumptions differ to those stated in the EIAR.

In the EIAR it is assumed that all SEMs have same performance requirement of 0.1μT p-p, however, the Zeiss Sigma Installation Requirements [8] supplied by Panoz technical lead on 5 August 2020, state a requirement of 0.05μT p-p. Arup have therefore assumed that the Zeiss Sigma300 has a sensitivity of 0.05μT.

Secondly, in the EIAR the SQUID in SNIAMS has an assumed a sensitivity of 0.01μT p-p. Arup have revised this to 0.1μT/m after discussion with technical lead for the SQUID on 17 August 2022.

2.2 Construction

Construction phase impacts are described in Sections 12.6.1 and 12.10.1 of EIA Report Volume 3 Book 1 Chapter 12:

> *"No impacts from an EMI, EMF or stray current perspective are likely during the Construction Phase of the proposed Project and therefore no detailed investigation was deemed necessary for this aspect of the Project.*
>
> *Electromagnetic emissions from the Construction Phase of the project will differ only slightly from a typical large-scale construction project. The significance of effects on all identified receptors will vary between imperceptible to slight. ...The TBM itself is so large (100m or slightly longer) that it will affect the earth's DC magnetic field creating a localised distortion to the lines of flux. The rate of movement of the machine is so slow however that any impact on potentially sensitive equipment would be difficult to detect."*

Construction phase impacts are discussed in Section 5 of this report and, in general, Arup agrees with the EIAR on these impacts. It is however expected that good practice will be followed in minimising emissions from power distribution equipment during the construction phase.

2.3 Operation

The methodology for predicting the EM fields generated by the MetroLink is described in Section 12.4.5 of EIA Report Volume 3 Book 1 Chapter 12 and the modelling which was carried out is described in Section 12.10.2.1.1 of EIA Report Volume 3 Book 1 Chapter 12, in the following terms:

> *"Once the baseline was defined and sensitive receptors identified and categorised following review of the data sources listed in Table 12.3, it was then necessary to predict anticipated levels of EMI for these locations. The purpose of this exercise was to inform the predicted impacts."*

In general, the assumptions and methods reported are appropriate and consistent with those used on schemes elsewhere. A comparison of the predicted values presented in the EIAR and Arup predicted EM fields for Option 2 are given in Table 6 in Section 6.2 of this report and, in general, reasonable agreement is apparent.

However, despite the below statement from Section 12.4.5 of EIA Report Volume 3 Book 1 Chapter 12, there is no explicit consideration of the cumulative effect of the baseline and predicted environment:

> *"A combination of field acquired data from surveys conducted on similar electrified rail systems and modelling was used to determine the worst-case DC magnetic field perturbations that are likely to occur from the proposed Project once operational at various distances from the alignment."*

In Section 12.10.2.2 of EIA Report Volume 3 Book 1 Chapter 12 and, specifically in Table 12.16, TCD is the only listed receptor along the entire MetroLink route which has "*significant*" "*negative*" effects predicted from DC magnetic fields during the operation phase.

Section 12.10.2.1.3 of EIA Report Volume 3 Book 1 Chapter 12 describes the impacts on Trinity College Dublin during operation. The MRIs, SEMs and NMRs are all identified in the EIAR as being impacted. Firstly, considering the SEMs in Panoz:

> *"The SEMs experienced the most interference at the highest magnification levels of the equipment. While these magnification levels are not used continually the problem would manifest itself occasionally when the required maximum sensitivities of the instrument are needed.*
>
> *Since the 0.3μT modelled is worst-case it is reasonable to assume that actual operational levels will be lower than this. Therefore, it is unlikely that the SEMs will experience any continual interference from the proposed Project."*

There are two issues in particular with this statement. Firstly, the EIAR does not take into account the cumulative impact of the MetroLink and the baseline environment, which will mean that conditions are worse than assumed (so it is not a worst-case). Second, the EIAR assumes that the research that is being carried out currently (or in the snapshot in time that they discussed research in Panoz) will be what always happens. The research involving the SEMs will evolve and therefore research may be compromised if no mitigation is carried out.

Next consideration of the impact on the MRIs and NMRs:

> *"The proximity of the MRIs and NMRs to the proposed alignment suggests that these are of the biggest concern to interference. In the case of the NMRs, it is likely that routine scans and measurements will be affected rendering some quantities unmeasurable due to a much-reduced resolution. While the duration of the effect may be only momentary, these momentary disruptions could occur several times an hour throughout the day during the operation of the proposed Project.*
>
> *The effects of DC magnetic fields on the TCD campus have been determined as Significant with a quality of effects classed as Negative. Mitigation measures will likely need to be employed within one building at least (the Chemistry Building)."*

Arup agree that the impact on the MRIs and NMRs, as well as the SEMs, will be "significant" and "negative" and that mitigation measures will need to be employed. In the EIAR, however, the emphasis is on introducing mitigation at the location of the sensitive equipment.

The EIA Report Volume 5 – Appendices Chapter 7 Consideration of Alternatives describes the alternative alignment options considered:

> *"Following consultation with TCD on the potential impacts, TII proceeded to assess potential alternatives to the tunnel alignment under TCD to reduce potential effects and reduce the requirement for mitigation measures at the location of sensitive equipment."*

Finally, there is also some discussion of residual impacts on equipment in TCD in Section 12.12 of EIA Report Volume 3 Book 1 Chapter 12:

> *"Locations within the TCD, Rotunda and Mater Campuses where DC and quasi-DC magnetic field perturbations are at elevated levels from the operation of the proposed Project may not be suitable for the installation or relocation of equipment with sensitivities to these types of fields."*

Arup agree that the Metrolink project will restrict the future research activities which can take place in TCD. These residual impacts are also discussed in Section 6.3 of this report.

2.4 Mitigation

2.4.1 Construction

Construction phase mitigation is described in Section 12.10.1 of EIA Report Volume 3 Chapter 12:

> *"Some receptors are documented in Chapter 14 (Ground-borne Noise & Vibration) that are common to this chapter. As part of mitigation measures for noise and vibration some of these (particularly in TCD) will not be in operation as the TBM passes, reducing the likelihood of DC magnetic field interference to nil for those equipment types."*

We understand the above statement to mean that the mitigation during the construction phase is dictated by the vibration requirements and will necessitate the TCD equipment being switched off whilst the TBM passes.

2.4.2 Operation

Section 12.10.2.1.3 of EIA Report Volume 3 Book 1 Chapter 12 states that:

> *"Mitigation measures will likely need to be employed within one building at least (the Chemistry Building)."*

In Section 12.11 of EIA Report Volume 3 Book 1 Chapter 12, some further information is provided on mitigation measures:

> *"With regards to DC magnetic field impacts on sensitive medical and scanning equipment such as those located in TCD, the Rotunda and the Mater the following mitigation measures are available:*
>
> - *Relocation of effected equipment;*
> - *Installation of an active-cancellation system; and*
> - *Shielding of the labs/rooms using specialised material designed to attenuate magnetic fields.*
>
> *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 TCD, in previous meetings, so if such a system were 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 measures focus only on what can be done to at the location of the sensitive equipment. There is no consideration here of what can be done to reduce the emissions from the MetroLink. Moreover, this is the only mention of field testing or trialling ACS systems. There is also no discussion of the effectiveness of ACS for NMRs or MRIs and what extra considerations are required when more than one piece of sensitive equipment is in the same room. Arup believe that trialling the ACS system at the location of the SEMs will be beneficial and that having 3 no. SEMs in close proximity will introduce complexity into the ACS mitigation solution proposed.

Active cancellation systems and passive shielding

In Section 12.11 of EIA Report Volume 3 Book 1 Chapter 12, some further information is provided on passive shielding mitigation:

> *"A final solution would be the installation of fixed shielding, a solution with which some of the departments and institutes at TCD are already familiar. The Scanning Transmission Microscope at the Advanced Microscopy Lab (AML), for example (not currently located on the main TCD campus) has a sensitivity of 6nT or 0.006μT and has already been installed in a double shielded room constructed from Mu-metal."*

In Section 4.0 of Appendix A7.10 Trinity College - Alignment Options Assessment limited information is provided on the installation of ACS and passive shielding systems:

> *"The physical installation of Active Cancellation is relatively straightforward in comparison to passive shielding (typical system downtime of 3 days or at least at a reduced operational resolution to facilitate the installation, routing of cables and tuning of the system). Passive shielding would require a much longer downtime as the affected room would need to be stripped back and existing services re-routed. Passive shielding utilised for the main lab housing the NMRs would cost approximately €90,000 (utilising silicon steel as Mu-metal should not be required for the NMRs). There is no guarantee that it would be needed if the Active Cancellation system successfully achieves the desired results.*
>
> *Sensitive research equipment is critical to the world class research being undertaken at a number of TCD departments now and in the future. As a result, it is important that MetroLink is designed such that impacts on sensitive equipment are minimised where possible.*
>
> *Active Cancellation is an industry recognised and accepted and cost-effective method of providing appropriate EMI protection to sensitive equipment when protection at source is either not feasible or desirable. Support for the provision of this mitigation has been confirmed by TII to TCD."*

The extent of the disruption and cost of the passive shielding systems proposed is optimistic, mu-metal would be required as silicon steel is not effective for quasi-DC fields. No consideration is given as to whether ACS systems are established technology for NMRs and MRIs, nor the complexity of installing ACS systems where multiple SEMs are in close proximity and in existing buildings. Information on ACS systems and their installation is provided in Section 6.3.2 of this report.

Moreover, it should be emphasised that separation of emission source and sensitive receptor is the most effective mitigation method and, accordingly, an alternative route alignment which moves the MetroLink westwards and further away from the sensitive receptors should be prioritised as the most effective mitigation method.

In Appendix A7.10 Trinity College - Alignment Options Assessment a list of projects is provided where ACS have been used.

> *"JI specialist consultants and industry recognised experts Compliance Engineering International (CEI) have confirmed that Active Cancellation is a viable option to address residual EMI effects on TCD equipment. This is based on their practical experience gathered from projects including:*
>
> *1. Neils Bohr Building, Copenhagen, Denmark (SEMs)*
>
> *2. Qatar Science and Technology Park, Doha*
>
> *3. Francis Crick Institute, London (NMRs, SEMs)*
>
> *4. Irvine Materials Research Institute, California (TEMs) – used in combination with shielded room*
>
> *5. Royal Hospital Melbourne, Australia (Linac) – Ongoing"*

Active cancellation systems are a recognised mitigation option with SEMs. However, there are limitations for ACS systems where multiple SEMs are in close proximity, as is the case with the SEMs in Panoz, this is discussed in more detail in Section 6.3.2 of this report, but not considered at all in the EIAR.

Arup are unaware of any instances of ACS being used with NMRs, although reference is made in the EIAR of its use at the Francis Crick Institute, London. However, to Arup's knowledge the final design documents concluded that ACS were not required for the Francis Crick Institute.

Moving the route westwards - alternative alignment options

In terms of effective mitigation by design, other alignment options which move the MetroLink further west of the sensitive equipment than the preferred route alignment option "Option 2: New R350m Horizontal Alignment" are considered. Although alternative alignment options are reported in A7.10 to the EIAR: Trinity College - Alignment Options Assessment, they are not referenced in the main EIAR in the context of EMC (EIAR Volume 3 Book 1 Chapter 12).

Appendix A7.10 to the EIAR (Trinity College - Alignment Options Assessment) and Section 7.7.9.4.1 of EIAR Report Volume 5 – Appendices Chapter 7 Consideration of Alternatives considers the mitigation options for each of the alternative alignment options 0, 1, 2 and 3. A limited discussion on Option 4 is included.

> *"Option 0, R=400m. This alignment requires Active Cancellation measures at all identified TCD sensitive equipment locations* (assumed to mean NMRs, MRIs and SEMs*) to mitigate EMI effects.*
>
> *An Active Cancellation (costed at €40,000 - €50,000 per system) should achieve the required level of mitigation on its own without the need for supplementary passive shielding for the majority of the systems, if they require it. In the case of the NMRs (where initial modelling suggested magnetic fields of 10-14 μT) the installation would not be without challenge and the possibility of passive shielding may need to be explored if investigations determine that the desired Active Cancellation system efficacy cannot be achieved.*
>
> *Option 1, R=400m. This option does not provide any significant benefit in terms of EMI or vibration effects on TCD equipment, which would continue to require provision of Active Cancellation measures for all assessed equipment* (assumed to mean NMRs, MRIs and SEMs*) noting that this is a proven method for mitigation of EMI effects and has been successfully used elsewhere.*
>
> *In the case of the NMR equipment in the Chemistry Department, previous modelling projected worst case magnetic fields of 10-14 μT. With the added depth at the relevant chainage this is reduced to 5-6 μT. This reduction is significant and would mean the implementation of an active cancellation system should be more straightforward and reduces the likelihood of any passive shielding being needed even further. As an example, taking a system specified by a manufacturer to cancel a 15 μT field. This would need to be installed to close to 100 % efficacy when tuning the system. It is more straightforward for a system than would need to be tuned for lower field perturbations of the order of 5-6 μT. The requirement for mitigation for the MRIs and SEMs is reduced, but as with Option 0, "may still need to be installed.*

In summary, for Option 0 and Option 1, the EIAR states that ACS is considered a necessary and viable mitigation option for all sensitive equipment (assumed to mean NMRs, MRIs and SEMs*)*. However, there is no consideration of the vertical gradients which may render such systems ineffective for the NMRs. Moreover, the very fact that the EIAR considers passive shielding is indicative that ACS may not be viable at the location of the NMRs. Indeed, Arup were unable to find example or precedents of ACS systems being used for NMR equipment. Finally, it is not clear if the cumulative effect of baseline and predicted emissions from the MetroLink is considered. It is clear that these cumulative effects are important.

> *"Option 2 (preferred route alignment), R=350m - would provide EMI/EMC mitigation to a larger area of the campus than option 0 or option 1. The NMRs would still be recommended to utilise Active Cancellation as a mitigation measure with worst-case field levels of 1.9 μT modelled for this*

alignment option. While the SEMs may not require mitigation in practice the fact that the modelled worst-case levels of 0.3 µT exceeds the equipment's stated sensitivity may mean that the operators may still favour having these systems installed, even if they are never required to be used once the MetroLink is operational. No mitigation measures would be expected to the required at the other equipment locations [assumed to mean the MRIs in Lloyd]. "

In the EIAR, ACS is considered a necessary and viable mitigation for Option 2 in respect of the NMRs. However, it is reiterated that Arup we were unable to find example or precedents of ACS systems being used for NMR equipment. Despite modelled field levels exceeding the equipment performance requirements for the SEMs in Panoz, mitigation is not deemed necessary by the authors of the EIAR, but is considered viable. Our analysis would indicate that ACS is necessary at the location of the SEMs and its installation, although viable, would be complex due to the close proximity of 3No. SEMs. Again, it is not clear if the cumulative effects of baseline and predicted emissions from the MetroLink are considered. It is clear that these cumulative effects are important.

> *"Option 3, R=302 - This option would provide a further westward movement of the alignment and our assessment indicates that no Active Cancellation measures would be required at known TCD equipment locations under this Option. As with Option 2 (R=350m), however, the theoretical worst-case levels still exceed the sensitivities for both the NMRs and the SEMs, but the implementation of mitigation measures would likely be of no benefit to the equipment whereby the systems should not be required to be used in practice."*

Despite modelled field levels exceeding the equipment performance requirements for the SEMs in Panoz, mitigation is not deemed necessary here, but is considered viable. Arup's analysis indicates that ACS is necessary at the location of the SEMs and its installation, although viable, would be complex due to the close proximity of 3No. SEMs.

Arup's expectation is that mitigation would also be required for the NMRs and possibly the MRIs for Option 3. Again, Arup were unable to find example or precedents of ACS systems being used for NMR equipment. Moreover, as stated above, it is not clear if the cumulative effects of baseline and predicted emissions from the MetroLink are considered in the EIAR, which is an important consideration.

> *"Option 4, R=302 – was not considered to provide any additional benefit to the EMI mitigation whilst increasing the construction and operational impacts associated with the two tighter 302m curves required compared to the minimum 350m curve adopted elsewhere."*

No predictions of emissions are reported in the EIAR for Option 4, however, through Arup's modelling (described in Section 6.2) it is believed that Option 4 does perform similarly to Option 3 and mitigation would still be required for the NMRs and SEMs and possibly the MRIs.

In relation to Active Cancellation measures, the EIAR Section 5.6.4 of Appendix A7.10 Trinity College - Alignment Options Assessment states as follows:

> *"Whereas Option 3 allows all current identified research equipment to operate in the absence of localised mitigation measures, all route options considered would allow the equipment to successfully operate with the implementation of Active Cancellation measures at sensitive equipment locations."*

Arup do not agree with this statement, firstly "localised" mitigation would still be required with Option 3 as EM field levels exceed the equipment performance criteria. Secondly, we do not believe all the equipment would successfully operate with ACS as a mitigation method for all the route options. ACS is unproven for NMRs and there are challenges and complexities around installation and operation for the SEMs in Panoz.

Compensation conductors

Compensation conductors are discussed as a possible mitigation option in Section 4.1 of Appendix A12.6 - 19E8382-1 TCD DC and Near DC Field Simulation Testing, particularly in respect of mitigating the fields in Chemistry. However, this mitigation option is not referenced in the main EIAR Volume in relation to EMC

(EIA Report Volume 3 Book 1 Chapter 12) or elsewhere in the Railway Order documentation. Compensation conductors have not been considered by Arup as insufficient information was provided in the EIAR documents to evaluate it.

Power reduction

In Section 5.6.8 of Appendix A7.10 Trinity College - Alignment Options Assessment, power reduction as a form of mitigation is described:

> *"Rather than providing alternative alignments as a means of mitigating EMI effects on the TCD equipment, the potential for controlling the maximum current in the section in order bring EMI emissions within the limits that are compatible with the sensitive equipment was considered.*
>
> *However, appraisal of the potential requirements to achieve the necessary reduction in EMI effects indicated particular problems in achieving the necessary power reduction. Even applying a significant reduction of 50% in the power in this section is considered unlikely to achieve the desired outcomes, with for example, the Chemistry department* (NMRs) *sensitivity levels will likely still be exceeded.*
>
> *Achieving a power reduction through this section would require a reduction in the traction power and, therefore, the maximum current at the OLE conductors. In the TCD section it would require either increasing the headway of trains or reducing the operational speed. Both solutions would need to be applied along the entire section between the traction substations at Tara and Charlemont.*
>
> *Neither of these outcomes is viable from an operational requirement, indicating that current reduction as a mitigation option is not a viable option."*

It is not clear whether a power reduction has been considered in combination with a shift westward in the route alignment. Arup are unable to offer further recommendations since it is not in a position to undertake the design of the traction power and other systems needed to implement such a strategy.

2.5 Overall assessment

In Section 7.7.9.4.2 of EIA Report Volume 5 – Appendices Chapter 7 Consideration of Alternatives the following conclusions are made after consideration of the baseline surveys, modelling and mitigation options:

> *"The overall assessment has considered the balance of advantages and disadvantages of all the options equally. It is considered that Option 2 offers advantages over Option 0 (the PDR alignment), and when considered against the other alternatives is the preferred Option to be taken forward.*
>
> *It is therefore recommended than an amendment is made to the proposed alignment. The horizontal alignment was adjusted by moving it west of the preferred route proposed alignment using a 350m horizontal curve and further adjusted in the vertical section to deepen the alignment by approximately 3m under the TCD Campus area.*
>
> *TII will continue to work with TCD with respect to provision of appropriate mitigation to protect sensitive equipment at locations that would still require some protection based on this revised alignment."*

While it is accepted that Option 2 does offer some advantages over Option 0, mitigation in the form of further westward movement of the route, such as the proposed Option 5, should be considered as a viable alternative to ACS at all sensitive equipment locations. The use of ACS with NMRs is unproven and presents a significant risk to the research at Trinity.

3. EM Sensitive equipment

The equipment in Table 1 has been identified through consultation with TCD users and departmental equipment lists as being EM sensitive.

Table 1: List of EM sensitive equipment and their location

Ref	Equipment Name	Department	Room / Floor
EM-1	Bruker Advance II 600 NMR	Chemistry	0.4 / Ground
EM-2	Bruker Advance HD-400 NMR	Chemistry	0.4 / Ground
EM-3	Bruker Advance III 400 NMR	Chemistry	0.5 / Ground
EM-4	Zeiss Sigma300 SEM	Panoz Institute	B23 / Basement Block B
EM-5	Tescan Mira3 Tiger SEM	Panoz Institute	B24 / Basement Block B
EM-6	Tescan S8000 SEM	Panoz Institute	B28 / Basement Block B
EM-7	Bruker BioSpec 70/30 Advance III 7T MRI	Lloyd Institute	UB14 / Upper Basement
EM-8	Siemens Magnetom Prisma 3T MRI	Lloyd Institute	UB16 / Upper Basement
EM-9	Quantum Design MPMS-XL SQUID	SNIAMS	0.16 / Ground

The performance requirements for each piece of equipment are listed in Table 2, these requirements were obtained through discussions with the TCD Technical Leads in August 2020 and August 2022 and through equipment technical documentation supplied by the TCD Technical Leads ([8]-[10]). As is discussed in Section 2.1 the EIAR and Arup agree as to the performance requirements of each piece of sensitive equipment except in the case of the Zeiss Sigma300 SEM and Quantum Design MPMS-XL SQUID, the "SQUID" (see footnotes [1,2]).

Table 2: Performance requirements for EM sensitive equipment

Ref	Equipment Name	Location	Quasi-DC performance requirements
EM-1	Bruker Advance II 600 NMR	Chemistry 0.4	0.5μT p-p
EM-2	Bruker Advance HD-400 NMR	Chemistry 0.4	0.5μT p-p
EM-3	Bruker Advance III 400 NMR	Chemistry 0.5	0.5μT p-p
EM-4	Zeiss Sigma300 SEM	Panoz Institute B23	0.05μT p-p[1]
EM-5	Tescan Mira3 Tiger SEM	Panoz Institute B24	0.1μT p-p
EM-6	Tescan S8000 SEM	Panoz Institute B28	0.1μT p-p

[1] The EIAR assumes all SEMs have same performance requirement of 0.1μT p-p, however the Zeiss Sigma Installation Requirements (2019) supplied by Panoz technical lead on 5th August 2020 [8], state a requirement of 0.05μT p-p.

Ref	Equipment Name	Location	Quasi-DC performance requirements
EM-7	Bruker BioSpec 70/30 Advance III 7T MRI	Lloyd Institute UB14	1.0μT p-p
EM-8	Siemens Magnetom Prisma 3T MRI	Lloyd Institute UB16	1.0μT p-p
EM-9	Quantum Design MPMS-XL SQUID	SNIAMS 0.16	0.1μT/m (vertical gradient)[2]

4. Baseline

Two baseline assessments have been undertaken, the first in the EIAR and the second by Arup, as outlined below. A comparison is then made between the results of the two studies. It should be noted that surveys represent a snapshot in time and differences are to be expected.

4.1 EIAR baseline EM field measurements

4.1.1 Survey overview

The information in this section is extracted from EIA Report Volume 5 – Appendices Chapter 12 EMC, A12.1 MetroLink Electromagnetic Radiation Baseline Survey Report (19E7901-1) [2] and A12.2 - Trinity College Dublin Direct Current and Near Direct Current Electromagnetic Radiation Survey Report (19E7900-1) [3].

CEI visited the TCD campus (on behalf of TII) in November 2018 to perform a baseline survey of the electromagnetic spectrum from DC up to 18 GHz. The results of this survey are detailed in report A12.1 MetroLink Electromagnetic Radiation Baseline Survey Report (19E7901-1) [2]. Notably, these were conducted outside the Zoology Department and in the basement corridor of the SNIAM building.

On 25 February 2019 CEI visited Trinity College again (on behalf of TII) to view some of the equipment listed in Table 1 and identify their locations more accurately with respect to the proposed development. On this day CEI visited the CRANN, Fitzgerald and SNIAM buildings. Some additional baseline measurements of DC and near DC magnetic fields were also conducted.

Another visit was conducted on 19 March 2019 and where the Chemistry, Lloyd and Panoz buildings were toured, equipment identified, and their locations noted. Again, some baseline measurements were conducted. Figure 1 and Table 3 identify the survey locations.

[2] TII assumed a sensitivity of 0.01μT p-p. Revised to 0.1μT/m after discussion with technical lead for the SQUID on 17 August 2022.

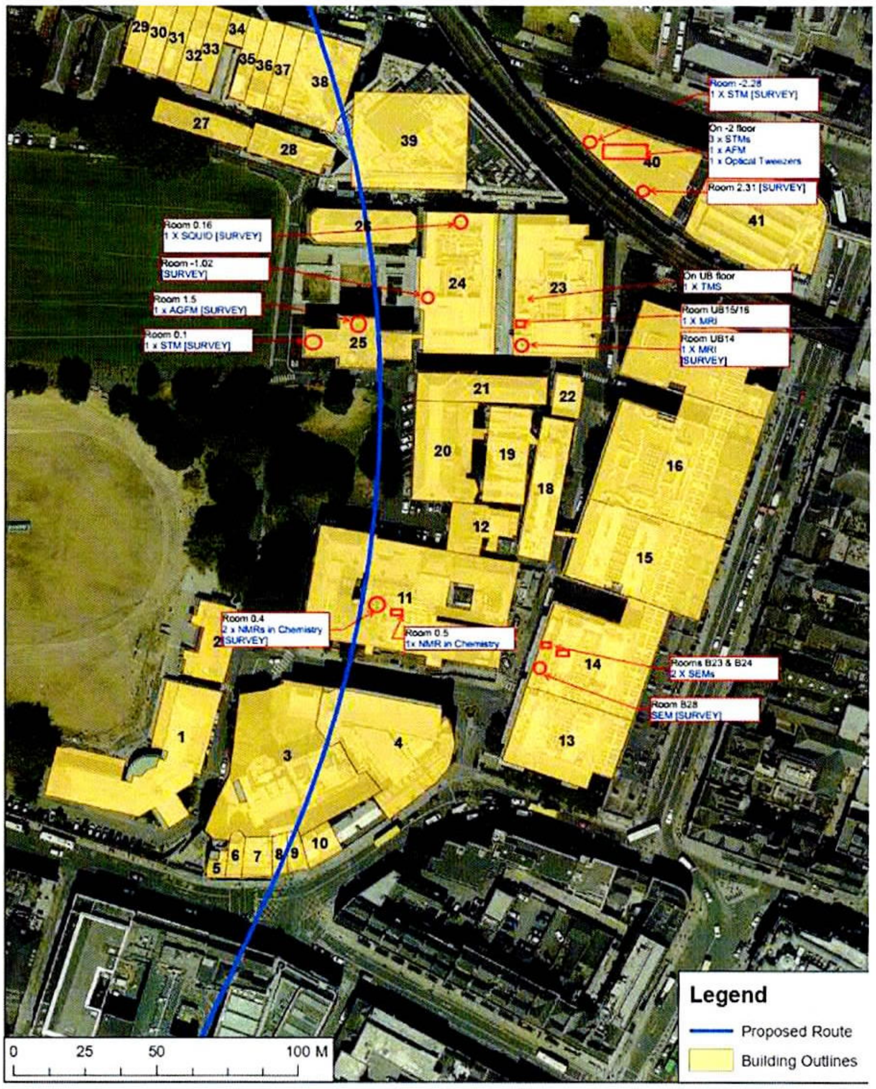


Figure 1: EIAR baseline measurement locations Proposed route shown is Option 0.

Table 3: EIAR survey locations (to be used in conjunction with Figure 1)

Index	Building Name	Measurement location
11	Chemistry	Room 0.4 (middle of room between 600 and 400 NMRs)
14	Panoz (EE4)	iCRAG Room B28 beside the Tescan S8000
23	Lloyd Institute	Room UB14 (approx. 8 metres below ground level) in the room adjacent to the 7 Tesla MRI
24	SNIAM	Room 0.16, beside SQUID machine Room -1.02
25	Fitzgerald	Room 0.1, beside an STM Room 1.5, beside the AGFM
40	CRANN	Room -2.28 beside an STM Room 2.31 close to window overlooking the DART. Room contained an XPS machine.

4.1.2 Equipment and methods

A Bartington Magnetometer (MAG 03MC) sensor was used. This sensor was monitored using Labview data acquisition and analysis software.

Measurements were taken at a standard elevation of 1m above grade, using a non-metallic support. The equipment was configured to record data in the three orthogonal planes (x, y and z) from which the resultant field was calculated.

4.2 Arup baseline EM field measurements

4.2.1 Survey overview

An electromagnetic (EM) field survey was conducted on 17th and 18th August 2022 at TCD to establish the baseline EM environment in which each piece of sensitive equipment currently operates. At the time of survey construction activity was ongoing at TCD.

Measurements were taken in each of the 9 locations listed in Table 1.

The location of the 9 pieces of equipment is shown in Figure 2. Note EM-1 and EM2 are located in the same room.

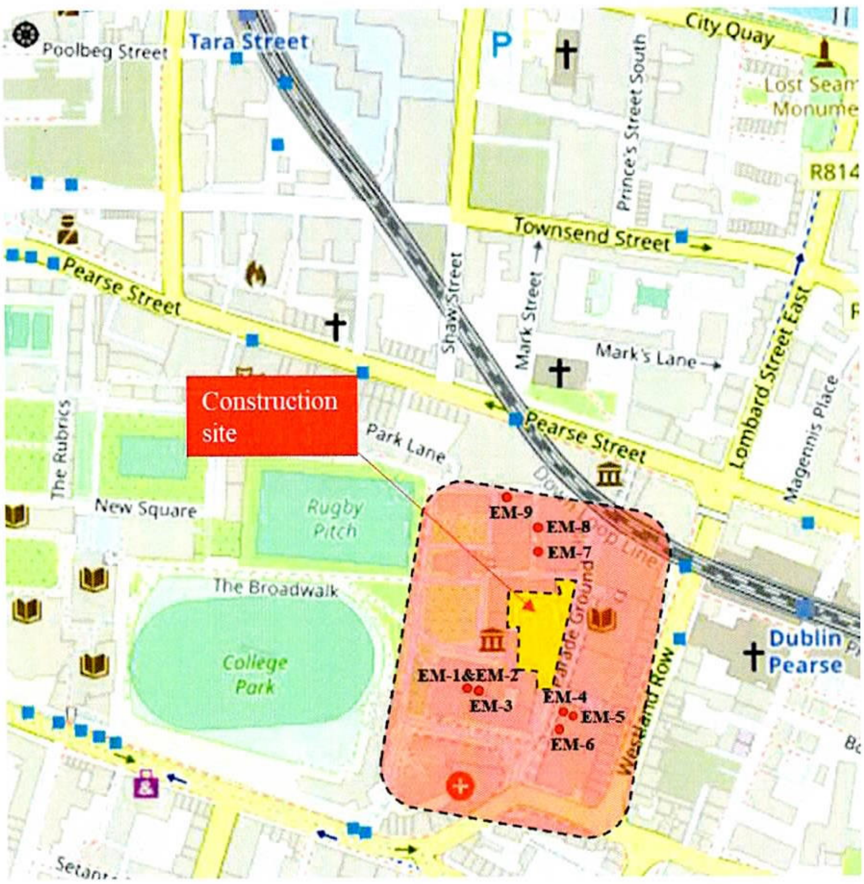


Figure 2: Arup baseline survey locations

The Dart railway runs to the N-NW of the site with trains between Tara Street and Dublin Pearse running approximately every 10mins during weekdays[3].

[3] https://www.irishrail.ie/Admin/IrishRail/media/Timetable-PDF-s/Connolly-DART-timetables/4-_18-_dart_commuter.pdf

4.2.2 Equipment and methods

Electromagnetic field levels were measured in the each of the sensitive equipment locations EM1-EM9 using Bartington magnetic field sensors (magnetometers). At each measurement location, x2 10mins readings were taken.

The following pieces of equipment were used. All equipment is battery powered.

- Magnetometer equipment:
    - Two MAG-03 3-axis magnetic field sensors (magnetometers), with two tripods;
    - A SPECTRAMAG-6 data acquisition unit (DAU); and
    - A laptop computer.

Each magnetometer was mounted on a tripod approximately 1.2m above ground level (or equipment height).

The magnetometers and data acquisition unit have been calibrated and certified for use by the manufacturer (Bartington).

The MAG-03 gives results in the 0-3kHz range, has a range up to 1mT, and a noise floor of 10pTrms/√Hz at 1Hz.

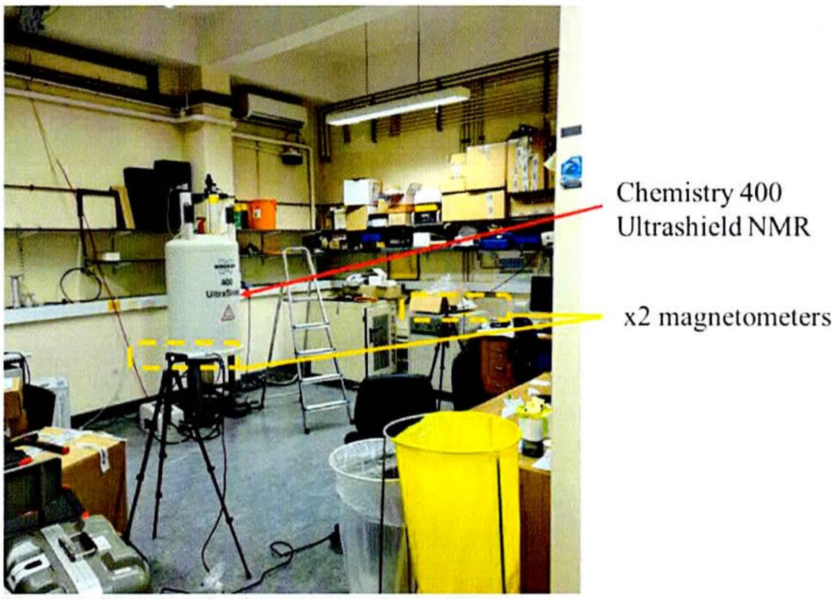


Figure 3: Photograph of magnetometer equipment

4.3 Comparison of EIAR and Arup measured baseline

Table 4 provides a summary comparing the EIAR and Arup baseline measurements at each of the 9 equipment locations. At each of the equipment locations the Arup measured baseline values (August 2022) are higher than the EIAR measured baseline values (February/March 2019). Due to the nature of site surveys being a snapshot in time, it is not possible to pinpoint why there are differences, but the presence of an active construction site in the Arup measured baseline (August 2022) survey may have contributed to the higher field levels seen in August 2022 compared with February/March 2019.

Table 4:Comparison of EIAR and Arup measured baseline EM data

Ref	Equipment Name	Location	Quasi-DC performance requirements	Arup measured baseline (Aug-22) Quasi-DC fluctuation	EIAR measured baseline (Feb/Mar-19) Quasi-DC fluctuation	Comments on baseline environment
EM-1	Bruker Advance II 600 NMR	Chemistry 0.4	0.5μT p-p	0.43μT p-p	0.20μT p-p	Meets performance requirements Meets user's current requirements Little margin for additional EM fields
EM-2	Bruker Advance HD-400 NMR	Chemistry 0.4	0.5μT p-p	0.43μT p-p	0.20μT p-p	
EM-3	Bruker Advance III 400 NMR	Chemistry 0,5	0.5μT p-p	0.43μT p-p	0.20μT p-p	
EM-4	Zeiss Sigma300 SEM	Panoz Institute B23	0.05μT p-p	0.81μT p-p	0.30μT p-p	Does not meet performance requirements Meets user's current requirements Further increases in EM fields may limit equipment use, and future capability.
EM-5	Tescan Mira3 Tiger SEM	Panoz Institute B24	0.1μT p-p	0.46μT p-p	0.30μT p-p	
EM-6	Tescan S8000 SEM	Panoz Institute B28	0.1μT p-p	0.46μT p-p	0.30μT p-p	
EM-7	Bruker BioSpec 70/30 Advance III 7T MRI	Lloyd Institute UB14	1.0μT p-p	0.95μT p-p	0.40μT p-p	Meets performance requirements Meets user's current requirements Little margin for additional EM fields
EM-8	Siemens Magnetom Prisma 3T MRI	Lloyd Institute UB16	1.0μT p-p	0.75μT p-p	0.40μT p-p	
EM-9	Quantum Design MPMS-XL SQUID	SNIAMS 0.16	0.1μT/m (vertical gradient)	0.03μT/m	n/a	Does not meet performance requirements assumed in EIAR. Meets user's current requirements; however measurements did not capture fluctuations due to vehicles or machinery in adjacent workshop. The user has incorporated mitigation measures to manage EMI.

5. Construction phase EM emissions

Limited impact from EMI is predicted by either Arup or in the EIAR during the construction phase. However, the movement of TBMs and a temporary construction railway are noteworthy.

The TBMs are large moving bodies of ferromagnetic material that will affect the earth's DC magnetic field creating a localised distortion to the lines of flux. The rate of movement of the machine is however slow, and this will reduce the risk of EMI from the TBM during construction

Operation of a temporary construction railway required to transport materials (for example, tunnel lining segments) from construction access points to the TBM may also pose a risk of EMI. The period of operation of a temporary railway is much longer than the passing of a TBM.

All of the EM sensitive equipment listed in Table 1 is also noise and vibration sensitive and these requirements will dictate the mitigation during construction.

6. Operation phase EM emissions

Although MetroLink have presented a single preferred route alignment option in the EIA Report Volume 3 Book 1 Chapter 12 [1], there has been consideration of 4No. alternatives with variations on the vertical and horizontal alignments. Option 2 which has a radius of 350m is the EIAR preferred route. All route alignment options are discussed in this Section. The 5No. route alignment options considered in the EIAR (the preferred route + 4No. alternatives) as well as the alternative Option 5 presented by Trinity, are shown in Figure 6.

The evaluation is based on:

- Field predictions of the DC electromagnetic fields generated by the Metrolink ([11]-[14])
- Survey measurements of the baseline EM environment at TCD carried out by Arup (17-08-2022 and 18-08-2022) and CEI [2, 3]
- Equipment sensitives provided by TCD technical leads during meetings held during Aug-20 and during the site visit in Aug-22 and/or equipment technical documentation ([8]-[10]).

6.1 Input assumptions

6.1.1 Route alignment options

Alternative route alignment Options 0, 1, 2, 3 and 4 have been evaluated in respect of electromagnetic interference (EMI) from the proposed Metrolink on electromagnetically sensitive equipment located within Trinity College Dublin. The options are described below and shown in Figure 4 [6].

- **Option 0 -** ***PDR (Preliminary Design Report) Alignment*** - This is the original route which was presented, retained as the current Preliminary Design alignment, with a 400m curve radius (R400).
- **Option 1 -** ***R400m Modified PDR*** – this retains the same horizontal alignment as Option 0 but changes the vertical profile to increase the tunnel depth between Tara and St. Stephen's Green stations. It is up to approx. 5m deeper south of Tara St Station.
- **Option 2 -** ***New R350m Horizontal Alignment*** – an alternative horizontal alignment running to the west of Option 1 and with the same adjusted vertical profile (increased depth) as per Option 1.
- **Option 3 -** ***New R302m Alignment*** - an alternative horizontal alignment running to the west of Option 2 and with the same adjusted vertical profile (increased depth) as per Option 1.

- **Option 4 - New *R302m Alignment*** including a 1-degree rotation of Tara station in order to further increase the westwards movement of the metro alignment past the TCD campus.
- **Option 5 – *Proposed Alternative*** a localised realignment of the line beneath the Campus which moves the alignment 61.5m westward of the current proposed alignment (Option 2).

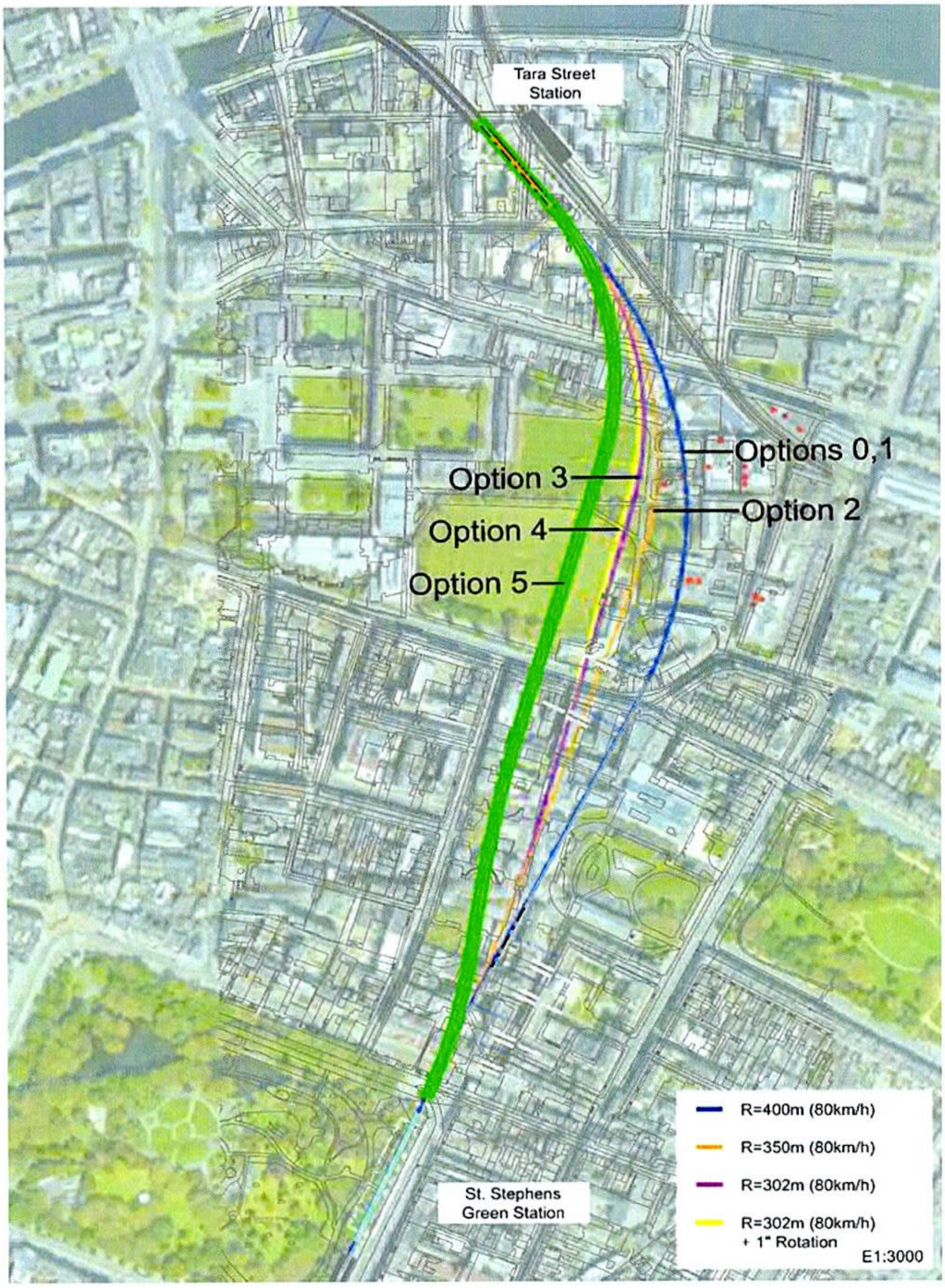


Figure 4: Route alignment options [6]

The route alignment options were provided as DWG files to Arup [14] along with *20220705 Tara_SSG Alignment.dwg* [12] which contains the DWG of the city centre.

Each of the route alignment options has an assumed depth as the tunnel passes beneath TCD, Table 5.

Table 5: Tunnel depth from ground level to the top of the rail at 17+800 (TCD) [6]

Route Alignment Option	Depth from ground level to top of the rail at 17+800
0	20.8
1	26.2
2	26.4
3	26.1
4	25.9

6.1.2 Traction power and conductor arrangement

Information on the tractor power and conductor arrangement was provided by TII [11] and [13]. This is information is reproduced below.

Maximum load currents in operation, accounting for multiple trains on the line, acceleration, and deceleration [11].

- 2,500A maximum available current per line
- 1,250A the return current is split equally between the two rails (1250A in each)

The conductor arrangement is shown in Figure 5 [13]

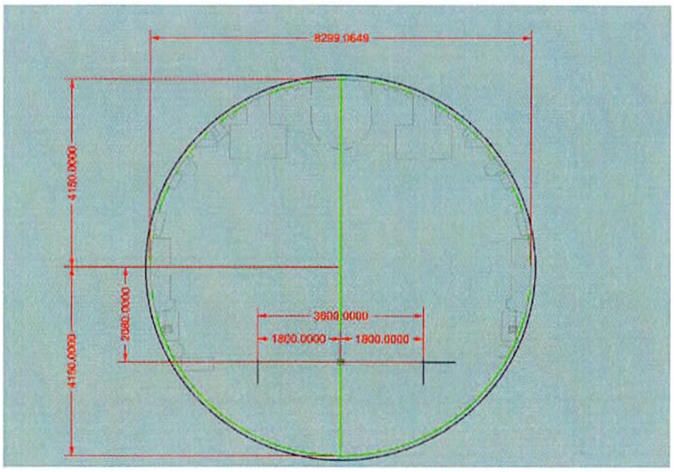
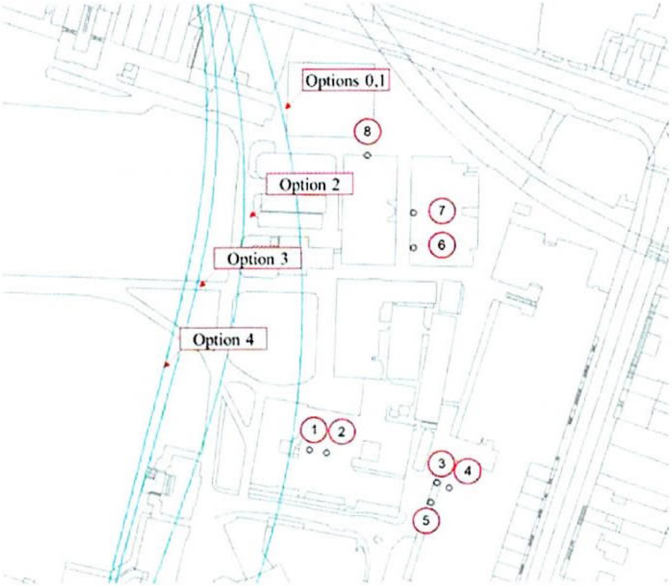


Figure 5: Tunnel cross section at location beneath TCD campus [13]

6.1.3 EM sensitive equipment

The EM sensitive equipment locations and their performance requirements are key in determining the impact of the Metrolink. The equipment and their sensitivities are described in Section 3. There are differences between the EIAR and Arup assumed performance requirements for the Zeiss Sigma300 SEM and the SQUID which are described in Section 2.1.

Figure 6 presents the 5 route alignment options overlaid onto a site plan of TCD with equipment locations labelled.



Key	Location	Equipment
1	Chemistry Room 0.4	NMRs - Bruker400MHz and Bruker600MHz
2	Chemistry Room 0.5	NMR - Bruker400MHz
3	Panoz Room B23	SEM - ZeissSigma300
4	Panoz Room B24	SEM - Mira3Tiger
5	Panoz Room B28	SEM – TecanS8000
6	Lloyd Room UB14	MRI - Bruker7T
7	Lloyd Room UB16	MRI - Seimens3T
8	SNIAMS Room 0.16	SQUID

Figure 6 Route alignment options with EM sensitive equipment locations overlaid.

6.2 Comparison of EIAR and Arup predictions

A comparison of the EIAR and Arup predictions of the EM field emissions from Metrolink are shown in Table 6. Predictions are generally very similar either exactly matching or within 0.1μT p-p.

The following are noted:

- Field gradients were modelled by Arup but not in the EIAR, these are of relevance to the SQUID particularly and to mitigation options for the NMRs.
- Option 4 has been modelled by Arup but not in the EIAR. This option provides some improvement compared with Option 3, but not significant.
- Option 5 has been modelled by Arup but not in the EIAR as it is a Proposed Alternative alignment option.

Comparison of the performance requirements of the EM sensitive equipment and the emissions from Metrolink in Table 6 the following can be concluded:

- The emissions from route alignment Options 0 and 1 exceed the performance requirements for all sensitive equipment, except the SQUID.
- The emissions from route alignment Options 2, 3 and 4 are lower than with alignment Options 0 and 1. The predicted emissions exceed the performance requirements for the NMRs and the SEMs, but not the MRIs or the SQUID.
- However, it is important to note that these predictions of MetroLink emissions do not take account of the baseline environment.

In addition, the cumulative effect of the of Metrolink emissions on the existing baseline condition was considered by Arup but not in the EIAR as shown in Table 7 and Table 8. The Arup measured baseline values and MetroLink emissions are shown in Table 7 and the EIAR measured baseline and MetroLink emissions are shown in Table 8. The proposed train frequency (at its most intense, a train every 100 seconds) is such that peaks in emissions will coincide with the peaks observed in the baseline environment and therefore both should be taken into account.

Considering the cumulative effect of the Metrolink emissions on the existing baseline conditions the following conclusions are made:

- There is a significant difference in the baseline survey measurements performed by TII and those recorded by Arup and the conclusions about the mitigation required at the location of the sensitive equipment are dependent on these baseline survey measurements. Further longer-term monitoring of the baseline EM environment is therefore recommended.
- For each of the 5 proposed Metrolink route alignment options, the EM field levels at the location of the EM sensitive equipment are predicted to be in excess of the equipment performance requirements, except for the SQUID.
- With Option 5, the Proposed Alternative route alignment option, the negative impacts from the MetroLink on sensitive equipment would be largely mitigated. Further longer-term monitoring of baseline EM environment is recommended to provide further confidence in the baseline values as these will dictate the extent of any additional mitigation (e.g. ACS at the location of the SEMs) required for Option 5.

Table 6: Predicted EM fields at sensitive equipment locations for each route alignment option

Equipment	Location	Sensitivity		Predicted EM fields (µT p-p) at sensitive equipment locations for each route alignment option												
				Op0		Op1		Op2		Op3		Op4		Op5
		Arup	EIAR	Arup	EIAR	Arup	EIAR	Arup	EIAR	Arup	EIAR	Arup	EIAR	Arup
Bruker Advance II 600 NMR	Chemistry 0.4	0.50	0.50	10.40	10.0-14.0	6.70	5.0-6.5	1.50	1.4-1.9	0.80	0.68-0.8	0.70		0.32
Bruker Advance HD-400 NMR	Chemistry 0.4	0.50	0.50	10.40	10.0-14.0	6.70	5.0-6.5	1.50	1.4-1.9	0.80	0.68-0.8	0.70		0.32
Bruker Advance III 400 NMR	Chemistry 0.5	0.50	0.50	6.90	10.0-14.0	5.00	5.0-6.5	1.10	1.4-1.9	0.60	0.68-0.8	0.60		0.28
Tescan S8000 SEM	Panoz B28	0.10	0.10	0.80	0.80	0.80	0.80	0.30	0.30	0.20	0.20	0.20		0.13
Tescan Mira3 Tiger SEM	Panoz B24	0.10	0.10	0.70	0.80	0.70	0.80	0.30	0.30	0.20	0.20	0.20	n/a - not reported	0.12
Zeiss Sigma300 SEM	Panoz B23	0.05	0.10	0.80	0.80	0.80	0.80	0.30	0.30	0.20	0.20	0.20		0.13
Bruker BioSpec 70/30 Advance III 7T MRI	Lloyd UB14	1.00	1.00	1.40	1.50	1.30	1.20	0.60	0.70	0.40	0.50	0.40		0.17
Siemens Magnetom Prisma 3T MRI	Lloyd UB13	1.00	1.00	1.30	1.50	1.20	1.20	0.60	0.70	0.40	0.50	0.40		0.17
Quantum Design MPMS-XL SQUID	SNIAMS 0.16	0.1µT/m (vertical gradient)	n/a	0.01	n/a	0.03	n/a	0.01	n/a	0.01	n/a	0.01		0.004

Table 7: Cumulative EM fields (Arup baseline + MetroLink emissions) at sensitive equipment locations for each route alignment option

Equipment	Location	Sensitivity		Cumulative EM fields (µT p-p) at sensitive equipment locations for each route alignment option					
		Arup	EIAR	Op0	Op1	Op2	Op3	Op4	Op5
Bruker Advance II 600 NMR	Chemistry 0.4	0.50	0.50	10.83	7.13	1.93	1.23	1.13	0.75
Bruker Advance HD-400 NMR	Chemistry 0.4	0.50	0.50	10.83	7.13	1.93	1.23	1.13	0.75
Bruker Advance III 400 NMR	Chemistry 0.5	0.50	0.50	7.33	5.43	1.53	1.03	1.03	0.71
Tescan S8000 SEM	Panoz B28	0.10	0.10	1.26	1.26	0.76	0.66	0.66	0.59
Tescan Mira3 Tiger SEM	Panoz B24	0.10	0.10	1.16	1.16	0.76	0.66	0.66	0.58
Zeiss Sigma300 SEM	Panoz B23	0.05	0.10	1.61	1.61	1.11	1.01	1.01	0.94
Bruker BioSpec 70/30 Advance III 7T MRI	Lloyd UB14	1.00	1.00	2.35	2.25	1.55	1.35	1.35	1.12
Siemens Magnetom Prisma 3T MRI	Lloyd UB13	1.00	1.00	2.05	1.95	1.35	1.15	1.15	0.92
Quantum Design MPMS-XL SQUID	SNIAMS 0.16	0.1µT/m (vertical gradient)	n/a	0.04	0.06	0.04	0.04	0.04	0.034

Table 8: Cumulative EM fields (EIAR baseline + MetroLink emissions) at sensitive equipment locations for each route alignment option.

Equipment	Location	Sensitivity		Cumulative EM fields (µT p-p) at sensitive equipment locations for each route alignment option					
		Arup	EIAR	Op0	Op1	Op2	Op3	Op4	Op5
Bruker Advance II 600 NMR	Chemistry 0.4	0.50	0.50	10.60	6.90	1.70	1.00	0.90	0.52
Bruker Advance HD-400 NMR	Chemistry 0.4	0.50	0.50	10.60	6.90	1.70	1.00	0.90	0.52
Bruker Advance III 400 NMR	Chemistry 0.5	0.50	0.50	7.10	5.20	1.30	0.80	0.80	0.48
Tescan S8000 SEM	Panoz B28	0.10	0.10	1.10	1.10	0.60	0.50	0.50	0.43
Tescan Mira3 Tiger SEM	Panoz B24	0.10	0.10	1.00	1.00	0.60	0.50	0.50	0.42
Zeiss Sigma300 SEM	Panoz B23	0.05	0.10	1.10	1.10	0.60	0.50	0.50	0.43
Bruker BioSpec 70/30 Advance III 7T MRI	Lloyd UB14	1.00	1.00	1.80	1.70	1.00	0.80	0.80	0.57
Siemens Magnetom Prisma 3T MRI	Lloyd UB13	1.00	1.00	1.70	1.60	1.00	0.80	0.80	0.57
Quantum Design MPMS-XL SQUID	SNIAMS 0.16	0.1µT/m (vertical gradient)	n/a	vertical gradient not reported in EIAR baseline survey					

6.2.1 Detailed analysis of cumulative magnetic fields at the NMRs for Option 2 and Option 5

The existing EMI environment differs quite significantly between the results reported in the EIAR and those found by Arup (the latter were higher), these were evaluated in greater detail (using vector feild quantities) for Option 5 and compared with Option 2. These results are summarised in Table 9 below.

Table 9 detailed analysis of cumulative fields for Option 2 and Option 5

Case	Sensitivity (μT p-p)	Cumulative EM fields (μT p-p)
Option 2 EIAR survey data + MetroLink emissions	0.50	1.60 to 1.63
Option 2 Arup survey data + MetroLink emissions	0.50	1.77 to 1.83
Option 5 EIAR survey data + MetroLink emissions	**0.50**	**0.42 to 0.46**
Option 5 Arup survey data + MetroLink emissions	0.50	0.60 to 0.66

In all cases, the more detailed evaluation carried indicates lower values than those in table 7 and 8 for Options 2 and 5.

For the most favourable result (highlighted in Table 9, for Option 5 using the survey data reported in the EIAR) the impact of the MetroLink EMI emissions is sufficiently low that no further mitigation would be needed for the Chemistry NMRs. This is not a fully conclusive outcome: assumptions were used and some interpolation was necessary because the EIAR documents did not provide the magnetic field vector values used in this evaluation; moreover, there is a significant difference between the field measurements in the Arup survey and that carried reported in the EIAR. This lends further weight to the recommendation that longer term monitoring of the EM environment at TCD is carried out.

6.3 Mitigation

As described in Section 6.2, the equipment limits for all sensitive equipment, except the SQUID, will be exceeded in all 5 of the route alignment options considered in the EIAR when baseline environment and the MetroLink emissions are both included in the assessment[4]. Accordingly, in order to ensure that the equipment can operate as it should in the environment in which it is located, further mitigation should be considered, including mitigation by design.

The suitability of three established methods for mitigation of EMI for laboratory equipment are discussed in the sections below.

6.3.1 Separation of emission source and sensitive equipment

Separation of the emission source from the sensitive equipment would be achieved by moving the alignment further westward in order to meet the performance requirements for all items of equipment. In circumstances where this mitigation by design measure is implemented, no additional mitigation would be required. This option also has the benefit of not impacting upon future research activities or relocation of current equipment within the campus.

Relocation of laboratory equipment to increase the separation distance is also an option to consider, however, given the site constraints, this would cause considerable disruption to the research activities at TCD, given the limited options where the equipment could be relocated on the College Green campus.

The NMRs in Chemistry dictate the separation distance as they are predicted to be exposed to high emissions from MetroLink and also are relatively sensitive to EMI (compared to the MRIs and the SQUID).

[4] If the Arup baseline measurements are considered with MetroLink emissions then the SEMs, NMRs and MRIs exceed the performance requirements, if the TII baseline measurements are considered with the MetroLink emissions then NMRs and SEMs exceed performance requirements.

Arup have calculated that the alignment would need to move an additional 175m west of alignment option 2 to meet the performance requirements for the NMRs. This assumes a cumulative effect of the measured baseline (Arup August 2022) and the MetroLink emissions.

If the cumulative effect of the lower measured baseline (TII, February/March 2019) and the MetroLink emissions are considered then the alignment would need to move an additional 65m west of alignment option 2 to meet the performance requirements for the NMRs.

With Option 5 (Proposed Alternative) the negative impacts from the MetroLink on sensitive equipment would be largely mitigated. Further longer-term monitoring of baseline EM environment is recommended to provide further confidence in the baseline values as these will dictate the extent of any additional mitigation (e.g. ACS at the location of the SEMs) required for Option 5.

6.3.2 Active cancellation systems (ACS)

These systems consist of a number of orthogonal coils typically located around the room where the sensitive equipment is located, with a magnetic field sensor placed beside the sensitive equipment. The coils are used to create varying magnetic fields which oppose magnetic field fluctuations at the sensor location. A schematic of this setup is shown in Figure 7.

As the sensors oppose magnetic field fluctuations at a single location they have limited effectiveness where there are large field gradients in the room, as is the case with NMRs in Option 0.

With this setup the cancellation is specific to the location in the room where the sensor is located. Where multiple pieces of sensitive equipment are in the same room, as is the case with the SEMs in Panoz, a more bespoke approach may be required. Figure 8 shows one such solution [15] which mounts the coils in a free-standing cage. This set up would be disruptive for the equipment users and may limit research activities.

Finally, the coils of the active cancellation system cannot be placed close to reinforcement bars or other large ferrous masses as this will reduce its effectiveness, this may be challenging in an existing building.

ACS systems are widely used with SEMs (noting the restrictions above where there are multiple SEMs in the same room and installation in existing buildings) and they have also been used with MRIs. To the best of Arup's knowledge, ACS systems are not established technology for NMRs and precedents for their use were not found.

It is recommended an ACS system is trialled at the location of the SEMs in Panoz at the earliest opportunity.

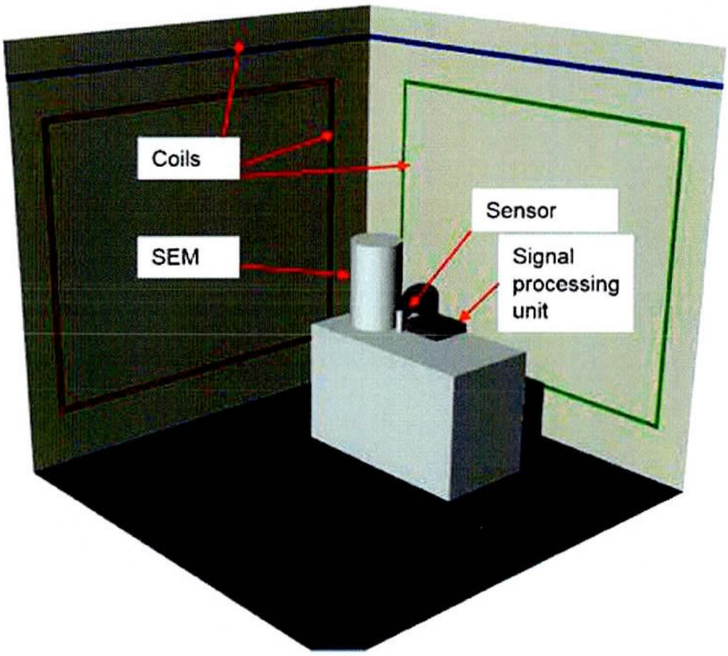


Figure 7: Schematic of an active cancellation system

Figure 8: Mag-NetX Active Magnetic Field Cancellation system [15]

6.3.3 Passive shielding systems

Passive shielding involves installing a high permeability material such as mumetal, so that the room can be effectively shielded using the flux shunting mechanism.

The shielding should surround the room on all 6 sides, with as few openings as possible. It may be preferable to use multiple layers of material, as this can provide higher attenuation than just one layer of the equivalent total thickness. The shielding can either be supported by the walls and ceiling of the room, or by a custom-built portal frame within the room as shown in Figure 9.

Installation of passive shielding is extremely costly and would be very disruptive to install in an existing building. Coordination with mechanical and electrical services is vital to the success of these types of installation and the laboratories would need to be completely stripped back to re-route services and install the shielding material.

Passive shielding is feasible for the NMRs and for the SEMs, but it is costly and extremely disruptive in existing buildings.

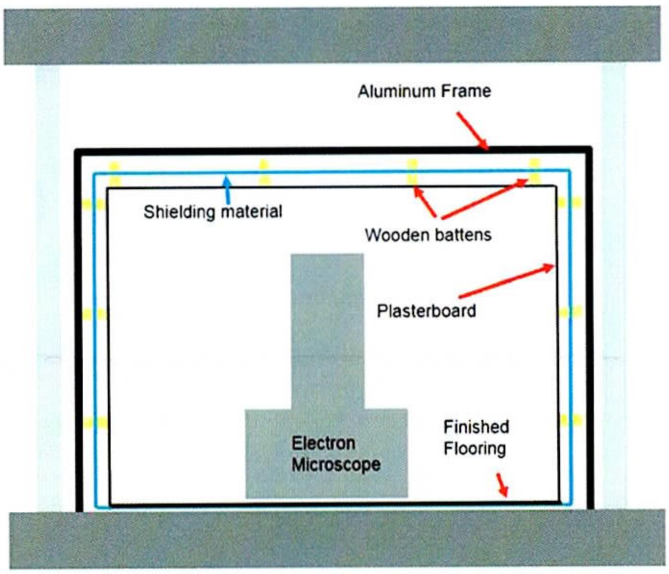


Figure 9: Schematic of box type construction for passive shielding system

6.3.4 Summary

Table 9 provides a summary of which mitigation options are suitable for each of the sensitive equipment, assuming EMI is the only consideration. It is also possible that combinations of mitigation options can be used together e.g., separation and an ACS for the SEMs in Panoz.

It is Arup's conclusion that it is only by further increasing the separation between the MetroLink and sensitive equipment that the performance of the research activities at TCD can be assured.

Accordingly, Arup do not agree with the assertion made in the EIAR that ACS provide acceptable protection to the NMRs at TCD. Furthermore, ACS would need careful consideration for the SEMs in Panoz.

Table 10: Summary of suitability of mitigation options for each sensitive equipment type

Sensitive Equipment	Separation	ACS	Passive shielding
NMRs	Yes	unproven	Yes
SEMs	Yes	Yes	Yes
MRIs	Yes	Yes	n/a

7. Conclusions

EM sensitive equipment

- The following equipment in TCD has been identified as being at risk of negative impact from the MetroLink:
  1. 3No. Scanning Electron Microscopes (SEM) in the Panoz Institute
  2. 3No. Nuclear Magnetic Resonance (NMR) machines in Chemistry
  3. 2No. Magnetic Resonance Imaging (MRI) machines in the Lloyd Institute
  4. 1No. SQUID machine in Sami Nasr Institute of Advanced Materials (SNIAMS)

Baseline

- At each of the equipment locations the Arup measured baseline values (August 2022) are higher than the EIAR measured baseline values (February/March 2019).
- Due to the nature of site surveys being a snapshot in time, it is not possible to pinpoint why there are differences, but the presence of an active construction site in the Arup measured baseline (August 2022) survey may have contributed to the higher field levels seen in August 2022 compared with February/March 2019.
- Due to the significant difference between the EIAR and Arup surveys, it is recommended that additional longer-term monitoring (c. 2-4weeks) of the baseline EM environment is carried out, as a minimum at the location of the NMRs.

Construction phase EM emissions

- Limited impact from EMI is predicted by either Arup or in the EIAR during the construction phase. However, the movement of TBMs and a temporary construction railway are noteworthy.
- All of the EM sensitive equipment considered is also noise and vibration sensitive and these requirements will dictate the mitigation during construction.

Operation phase EM emissions

- Field gradients were modelled by Arup but not in the EIAR. These field gradients are of relevance to the SQUID particularly and to mitigation options for the NMRs.
- Option 4 has been modelled by Arup but not in the EIAR. This option provides some improvement compared with Option 3 but is not significant.
- The emissions from route alignment Options 0 and 1 exceed the performance requirements for all sensitive equipment, except the SQUID.
- The emissions from route alignment Options 2, 3 and 4 are lower than with alignment options 0 and 1. The predicted emissions exceed the performance requirements for the NMRs and the SEMs, but not the MRIs or the SQUID.
- The predictions contained in the EIAR of MetroLink emissions do not take account of the baseline environment in their effects on TCD.

Considering the cumulative effect of the Metrolink emissions on the existing baseline conditions the following conclusions are made:

- There is a significant difference in the baseline survey measurements performed by TII and those recorded by Arup and the conclusions about the mitigation required at the location of the sensitive equipment are dependent on these baseline survey measurements. Further longer-term monitoring of the baseline EM environment is therefore recommended.

- For each of the 5 proposed Metrolink route alignment options, the EM field levels at the location of the EM sensitive equipment are predicted to be in excess of the equipment performance requirements, except for the SQUID.
- Arup and the EIAR agree that there will be significant negative impacts due to EMI on sensitive equipment at TCD. TCD is the only listed receptor along the entire MetroLink route which has "significant" "negative" effects because of EM emissions from the MetroLink.

Mitigation

- Arup have assessed the required westward offset of the alignment required to mitigate the negative impacts at all sensitive equipment locations. The implementation would result in a material benefit as it removes the need for unproven mitigation at the location of the NMRs. The alignment would need to move an additional 175m (using Arup survey and predicted emissions) or additional 65m (using the EIAR survey and predicted emissions) west of alignment Option 2 to meet the performance requirements for the NMRs. The differences between the baseline surveys would be best resolved through long term monitoring (2 to 4 weeks) at TCD to establish a more reliable baseline as noted above.
- More details are required from the Applicant in respect of the mitigation proposals and evidence of their successful use is required to demonstrate that EMI risks to all TCD's facilities can be minimised to an acceptable level. This should include evidence of ACS being successfully used for NMRs, SEMs (multiple in SEMs in close proximity) and MRIs.
- ACS systems are widely used with SEMs (noting the restrictions above where there are multiple SEMs in the same room and installation in existing buildings) and they have also been used with MRIs. However, it is our understanding that ACS systems are not established technology for NMRs.
- Where multiple pieces of sensitive equipment are in the same room, as is the case with the SEMs in Panoz, a more bespoke approach is required to ensure effective mitigation and preserve research usage needs.
- It is recommended that a trial of an ACS system is conducted for the SEMs in Panoz. Particular consideration should be given to the close proximity of 3No. SEMs in this building.
- Finally, the coils of the active cancellation system cannot be placed close to reinforcement bars or other large ferrous masses as this will reduce its effectiveness, this may be challenging in an existing building.
- With Option 5, the Proposed Alternative route alignment option, the negative impacts from the MetroLink on sensitive equipment would be largely mitigated. Further longer-term monitoring of baseline EM environment is recommended to provide further confidence in the baseline values as these will dictate the extent of any additional mitigation (e.g. ACS at the location of the SEMs) required for Option 5.

References

[1] EIA Report Volume 3 – Book 1: Population and Human Health, Traffic, Noise and Vibration and EMI/EMC Chapter 12: Electromagnetic Compatibility and Stray Current – accessed 30th September 2022

[2] EIA Report Volume 5 – Appendices Chapter 12 EMC A12.1 MetroLink Electromagnetic Radiation Baseline Survey Report – accessed 30th September 2022

[3] EIA Report Volume 5 – Appendices Chapter 12 EMC A12.2 Trinity College Dublin Direct Current and Near Direct Current Electromagnetic Radiation Survey Report – accessed 30th September 2022

[4] EIA Report Volume 5 – Appendices Chapter 12 EMC A12.6 19E8382-1 TCD DC and Near DC Field Simulation Testing" – accessed 30th September 2022

[5] EIA Report Volume 2 – Chapter 07 Consideration of Alternatives– accessed 30th September 2022

[6] EIA Report Volume 5 – Appendices Chapter 7 Consideration of Alternatives A7.10 Trinity College - Alignment Options Assessment– accessed 30th September 2022

[7] EIA Report Volume 3 – Chapter 31 Summaries of the route wide mitigation and monitoring proposed– accessed 30th September 2022

[8] Zeiss Sigma Installation Requirements (2019) supplied by Panoz technical lead on 5th August 2020

[9] InstallationSiteInstructions-MIRA-MAIA3-EN.dot supplied by Panoz technical lead on 28th March 2019

[10] Site Planning for AVANCE Systems 300-700 MHz User Guide Version 005 (2008)

[11] EMC Information.pdf – received 9th June 2022

[12] 20220705 Tara_SSG Alignment.dwg – received 8th July 2022

[13] 20220705 Tunnel Cross-section.dwg – received 8th July 2022

[14] 20220330 TCD.dwg – received 15th July 2022

[15] https://www.techmfg.com/products/electric-and-magnetic-field-cancellation/mag-netx - accessed 11-10-2022

APPENDIX F

METROLINK IMPACTS – VIBRATION ASSESSMENT PREPARED BY ARUP

ARUP

Trinity College Dublin

Metrolink impacts

Vibration assessment

Reference: 277168-00\R04

Final | November 2022

Job number 277168-00

Arup International Partners Limited
6th Floor, 3 Piccadilly Place
Manchester Mi 3BN, UK
arup.com

ARUP

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Issue Document verification with document ✓

Contents

1. Introduction

Transport Infrastructure Ireland (TII) proposes to construct and operate a new metro system that, for a section of the proposed route, would pass beneath the eastern end of Trinity College's (TCD's) campus.

As originally proposed, the MetroLink alignment would pass directly, or very close, beneath TCD's most sensitive research, teaching and commercial facilities and would introduce significant risks of disturbance by vibration. Arup has been working with TCD to understand and quantify the risks from vibration.

Subsequently, TII considered four other options that moved the alignment a short distance west and so slightly further away from the sensitive facilities and in two cases these options included a train speed reduction. Of these options, the EIAR focuses on 'Option 2'. Improved vibration isolation to the track has also been proposed. TCD has also suggested Option 5, that would move the alignment further west without impacting on TII's proposed Tara station. These six route options are illustrated in Figure 1.

This report presents Arup's appraisal, based on the information currently available, of the likely significant vibration effects from the design proposals presented in the EIAR and assesses the risks of these proposals to the sensitive facilities on TCD's campus. Consideration is given to the risks presented during both the construction and operation phases (i.e. vibration caused by train movements) of the proposed scheme. Impacts from TCD's proposed Option 5 are also assessed and compared.

Baseline vibration surveys have been undertaken by TII (November 2019) and by Arup on behalf of TCD (August 2022). These are considered in relation to the vibration requirements for sensitive equipment, to ensure that the vibration environment within TCD's facilities is not compromised by TII's proposals and to ensure that the proposed vibration limits are not more onerous than the conditions currently on site.

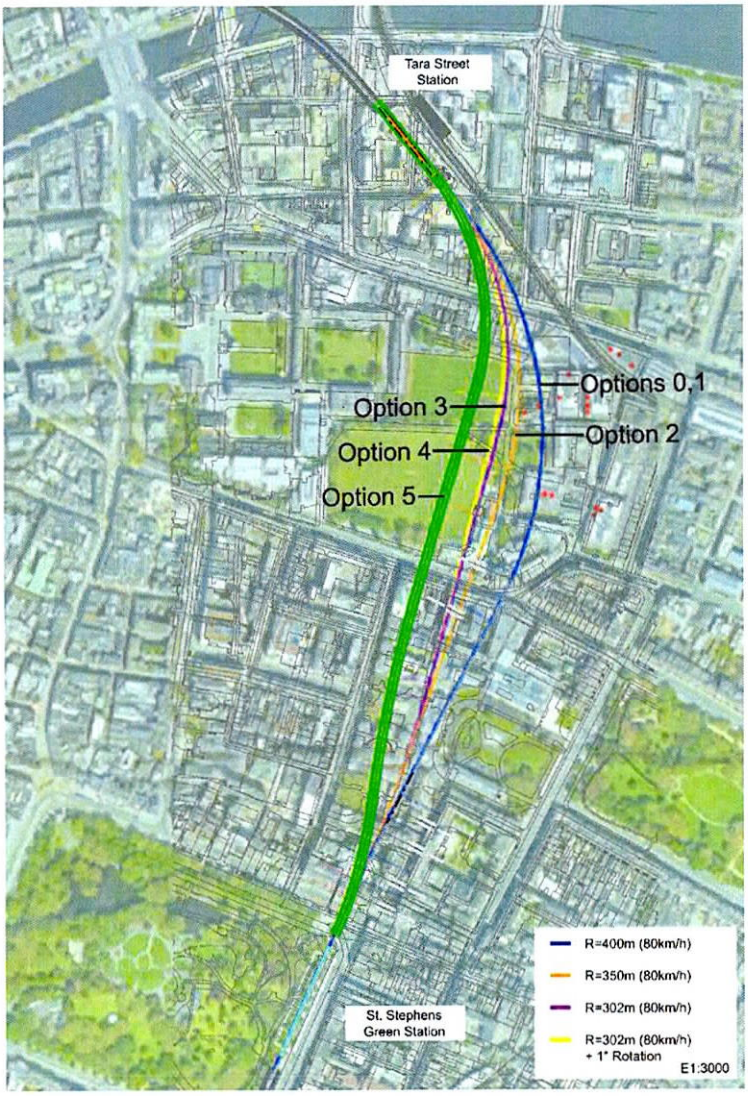

Figure 1: TII's proposed route alignment options with TCD's proposed Option 5

2. Summary of relevant Railway Order documents

This section reviews the information published on the MetroLink Railway Order[1] website that is relevant to groundborne vibration impacts at TCD's vibration sensitive facilities:

- EIAR Volume 2 Chapter 5 MetroLink Construction Phase
- EIAR Volume 2 Chapter 6 MetroLink Operations and Maintenance
- EIAR Volume 3 Book 1 Chapter 14 Ground-borne Noise and Vibration
- EIAR Volume 5 Appendix A13.5
- EIAR Volume 5 Appendices A14.2, A14.3, A14.4, A14.5.

[1] Home - MetroLinkWeb (metrolinkro.ie)

In general, the methods reported and the assessment criteria described in the EIAR are appropriate and consistent with those used on schemes elsewhere. However, there are a number of specific issues in terms of likely significant vibration effects which remain of concern to TCD.

2.1 Baseline

Table 14.18 of Volume 3 Book 1 Chapter 14 Section 14.3.1.4 *Sensitive Receptors AZ4 Northwood to Charlemont* page 23-24 provides assessment thresholds for groundborne noise (GBN) and vibration. For Trinity College, only three sensitive locations are identified: "*Chemistry Extension Building; Sami Nasr Institute; Moyne Institute*", all of which are assigned the same assessment thresholds of 45dB$L_{Amax,S}$ for GBN from TBM passage; 40dB$L_{Amax,S}$ for mechanical excavation and operation; and VC-E for vibration from all activities. This does not reflect the range and extent of vibration sensitive locations and facilities that would potentially be affected, both by construction and operation of MetroLink.

Volume 3 Book 1 Chapter 14 Section 14.3.2.2 *Vibration Surveys at TCD Buildings* page 26 and Table 14.21 list the locations at which TII has conducted vibration surveys. This better reflects the range of facilities than those listed in Table 14.18 but is not comprehensive.

Sections 14.3.2.2.1 to 14.3.2.2.10 of the EIAR summarise the baseline vibration measured in the listed locations. It is not stated why the results are presented in the format used i.e. 'overall maximum acceleration' and 'overall maximum velocity', both considering the frequency ranges of 0.4Hz to 31.5Hz and 1Hz to 100Hz. The approach to presenting the results does not relate to any specific equipment criteria or to one third octave frequency VC curves commonly used in relation to vibration sensitive equipment.

Reference is made (at Volume 3 Book 1 Chapter 14 Section 14.3.1.4 Page 26) to Appendix A13.5 of the EIAR, which it is stated provides "*Full details of survey location, methodologies, parameter definitions and results of the baseline surveys at TCD*". Full results are not provided in the appendix, only a summary of the results is included. The full survey dataset appears not to have been published but has separately been supplied by TII to TCD. This is discussed further in Section 3.1 below.

2.2 Construction

2.2.1 Tunnel boring

Vibration from tunnel boring has been predicted using the FINDWAVE® numerical modelling method (Section 14.2.5.2.1 *General*, Page 16), with details of the methodology said to be presented in Appendix A14.4 *Groundborne Noise Numerical Modelling Method FINDWAVE*. The appendix only describes the software application to operation of Metrolink and not the construction.

Table 14.14 (Section 14.2.5.4.1 *Construction Phase*, Page 19) states that tunnel boring is a:

> *"Potential source of vibration and groundborne noise impacts which may extend up to a plan distance of 100m either side of the tunnel if not mitigated."*

The following section 14.2.5.4.2 *Operational Phase* (Page 19) says:

> *"...operation of the rail line could affect highly sensitive equipment up to a distance of 100m."*

It would be expected that vibration during construction would affect a much wider corridor than operation. This is confirmed in Section 14.4 *Predicted Impacts* subsection 14.4.1.7 *Section AZ4 Northwood to Charlemont*, which notes on page 34:

> *"With regard to vibration effects on sensitive equipment, Criterion VC-E will occur within a distance of 250m either side of the tunnel centreline, and during the passage of the TBM there is a potential significant effect on the operation of sensitive equipment."*

The predicted vibration impacts during passage of the TBM are given in Section 14.4.1.9 *AZ4 – Groundborne Vibration during Construction*, Table 14.32, pages 37-39. For TCD, predictions are only tabulated for the three buildings: Chemistry Building and Sami Nasr Institute are predicted would have vibration above VC-A; and Moyne Institute is predicted would experience a level of VC-A. Appendix A14.5 *Groundborne Noise and Vibration and Blasting Modelling Results* Section 14.4 provides a table of all vibration modelling results and shows the whole of the TCD campus to be exposed to vibration above VC-A.

No predictions are provided for the many other facilities within the 250m wide corridor (either side of the tunnel) where it is stated VC-E will occur.

Table 14.29 *Predicted Groundborne Noise during TBM Passage at Non-Residential Receptors in AZ4*, page 35 identifies that groundborne noise would also be a "*significant*" impact and "*Noticeable to all and disturbing to some over a number of days*" in Chemistry Building, Sami Nasr Institute and Moyne Institute. As elsewhere, other TCD buildings are not mentioned but there is a general statement (section 14.4.1.8 *AZ4 – Groundborne Noise during Construction* page 36) that

> *"During the passage of the TBM there are exceedances of groundborne noise at all buildings within 65m-75m of the tunnel centre."*

Disturbance during construction will therefore potentially impact TCD in many other locations than those with vibration sensitive equipment. It would appear that neither direct nor indirect vibration impacts on these other locations in Trinity have been considered in the EIAR.

2.2.2 Blasting

The EIAR Section 14.2.5.2.2 *Drilling and Blasting*, page 16, describes assumptions and predictions of vibration from blasting works required for station openings. Figure 14.4 *Blasting Contours of PPV* shows the extent to which the vibration, quantified in terms of PPV, could occur around the stations, the closest to TCD being Tara Station (shown on Page 6 of Figure 14.4), extending as far as Townsend Street. This indicates blasting to be required at approximately 250m from SNIAMs building. Using the prediction approach reported in the EIAR indicates that there is a potential risk to the operation of sensitive equipment from blasting vibration. Despite this, risks from blasting vibration impacts to TCD's sensitive equipment have not been identified, examined or assessed in the EIAR.

2.2.3 Rate of tunnelling

Volume 2 Chapter 5 *Metrolink Construction Phase* describes the construction process. Section 5.5.3 *Tunnelling*, page 39 says

> ***"City Tunnel**: The longer bored tunnel, at approximately 9.4km, runs from Northwood Station to south of Charlemont Station (AZ4). A TBM launch site will be constructed at Northwood Station and from here a TBM will drive south from Northwood to Charlemont. It is estimated that the tunnel drive will take approximately 45 months to progress."*

Tunnelling rate is therefore c.209m/month or 7m/day. Section 5.10.1 *City Tunnel*, page 96 says the tunnel drive would take 'at least 45 months' so the rate could be slower and the period of risk of disturbance to TCD therefore longer.

2.2.4 Tunnel boring machine support equipment

Volume 2 Chapter 5 *Metrolink Construction Phase* Section 5.5.3.1.3 *Tunnelling Support Plant and Equipment*, page 41 describes equipment needed to support the TBM but does not describe how personnel and materials such as tunnel lining segments would be transported through the tunnel to the TBM. Volume 3 Chapter 14 assessment methodology Section 14.2.5.1 *Assumptions* Table 14.13, page 15, states that

> *"The TBM will not be serviced by a temporary construction railway, but instead conveyors will be used for the transfer of materials from the TBM and out of the tunnel Rubber tyred vehicles will also be used for the transportation of material and people."*

It will be important to ensure that these measures, or other suitable mitigation, are included to prevent a long period of potential disruption to TCD's equipment should a temporary railway be used.

2.3 Operation

The service pattern is outlined in EIAR Volume 2 Book 1 Chapter 6 *MetroLink Operations and Maintenance* section 6.4.3 *Service Pattern*. It is stated that services are anticipated to operate between 05:30 and 00:30 every day. Table 6.2 on Page 10 provides a summary showing that for the majority of the operating period, trains would have a headway of around two minutes.

Volume 3 Book 1 Chapter 14, section 14.2.5.3 *Operation*, page 18 describes the methodology, using *FINDWAVE®* primarily to predict groundborne noise levels arising in the buildings above the operational railway, with explanation detailed in Appendix A14.4. It is not stated in section 14.2.5.3 *Operation* but it is understood that the same software has been used to predict vibration in TCD's sensitive facilities. On page 20, section 14.2.5.4.3 *Model Uncertainty* notes that "*At Trinity College Dublin examples of the most sensitive cases were fully modelled in three dimensions*". Details of the modelling for each building have not been included in the EIAR and TCD has not separately been provided with any additional information in this respect.

Volume 5 Appendix 14.2 *Train Characteristics* provides details of the assumed rolling stock and train speed profiles that have been used for modelling vibration. Appendix 14.3 *Track Support Properties* provides details of the track and track support system. Appendix A14.4 *Groundborne Noise Numerical Modelling Method FINDWAVE* describes the assumptions and process used to model groundborne noise and vibration from operation of the MetroLink.

Groundborne noise and vibration impacts from operation of MetroLink are described in Volume 3 Book 1 Chapter 14, section 14.4.2 *Operational Phase Impacts*. Table 14.44 provides the predicted groundborne noise levels, those at TCD being on page 48. Again, only three buildings (Chemistry Building, Sami Nasr Institute and Moyne Institute) are assessed and these are reported to be well below the assessment threshold – ranging from 30 to 35dB$L_{Amax,S}$.

Table 14.46 on page 51 provides the predictions of vibration at the three TCD buildings. A potential significant impact is identified at all three buildings, for which VC-A is predicted, against a threshold level of VC-E.

2.4 Mitigation

Volume 3 Book 1 Chapter 14 Section 14.5 (page 51) describes mitigation for groundborne noise and vibration.

2.4.1 Construction

Section 14.5.1.1 *Tunnel boring* (page 52) states "*there are no effective methods are [sic] available to reduce groundborne noise or vibration from TBMs at source*". Mitigation measures for groundborne noise and vibration are proposed as public consultation and stakeholder engagement, "*additional measures on a case-by-case basis*" in accordance with the Noise and Vibration Mitigation Policy (EIAR Appendix A14.6); and:

> "*With regard to vibration effects on the use of sensitive equipment, there is potential to plan the passage of the TBM during weeks when critical use of the equipment can be avoided. The programme for the TBM will be planned by the contractor. Consultation will be undertaken with TCD as soon as this programme is available to ensure that sensitive research operations on the campus do not coincide with the passage of the TBM.*"

At the expected rate of tunnelling (see Section 2.2.3 above), this mitigation would result in disruption to TCD's activities over an extended period of time, as discussed below (Section 4).

Section 14.6 Page 54 sets out the expected residual significant effects of groundborne noise and vibration. Table 14.49 summarises the residual impacts (ie those remaining after mitigation has been incorporated) of tunnel boring. Residual impacts are reported to remain significant at TCD.

2.4.2 Operation

Section 14.5.2 *Operational Phase* (page 53) describes mitigation of vibration at source (in the track system design) and at receptors. In respect of the track design:

> *"With regard to all but a limited number of sensitive receptors, no significant effects are predicted during the Operational Phase. There are some locations where an enhanced track support system will be required.*
>
> *In the case of buildings that are sensitive to groundborne noise, including buildings containing particularly sensitive equipment as well as large auditoria and studios, mitigation in the form of floating slab track will be incorporated into the design to remove any significant effects during the Operational Phase."*

Table 14.2 in Appendix 14.3 *Track Support Properties* provides the assumed properties of floating slab track that would be used under 'highly sensitive receptors'. With a dynamic stiffness of each bearing of 1.034MN/m (4.136 MN/m per slab unit) and the slab mass of 2,396kg, the movement of the rail as the train travels is likely to be considerably greater than what is normal or proven for floating slab track. No evidence has been provided to confirm the practicability of the proposed system.

Section 14.5.2 also acknowledges that there are facilities within TCD that will require detailed consideration in the design to comply with the equipment requirements. Furthermore, it acknowledges that there may be changes in equipment between the present and the opening of MetroLink that need to be considered and mitigated:

> *"With regard to sensitive laboratory equipment, detailed building-specific numerical modelling will be required to establish the likely exceedance of equipment specifications, and to find the optimum specification for the track support system to minimise exceedances. Mitigation at the receptor for specific rooms within sensitive buildings in the form of the installation of base-isolated foundation slabs to support the equipment may also be required. As the specific sensitive equipment in use at TCD is expected to change between the time of this assessment and the opening of the proposed Project close consultation should be undertaken between TII and TCD in relation to the specifically sensitive rooms."*

The proposal to mitigate residual significant effects through the use of base-isolated foundation slabs would not be practicable for all equipment and buildings, especially for locations where equipment is not on a groundfloor or basement level slab. Even where this solution could be possible, it would require significant disruption to TCD's activities to construct.

Table 14.47 summarises locations where mitigation in the form of track design measures would be required and includes the above for TCD.

Section 14.6.2 Page 59 describes the residual impacts following implementation of proposed mitigation. It is stated in Section 14.6.2.2 *Vibration* that

> *"Only in the case of highly sensitive laboratory equipment is it likely to prove difficult to avoid exceeding manufacturers' specification for ambient vibration, which will necessitate receptor-specific mitigation."*

The summary in Table 14.54 states that residual impacts would not be significant, with the mitigation described as:

> *"Design of track support system (floating slab track). Detailed design measures for specific rooms containing sensitive electronic equipment."*

2.4.3 Summary

The proposed mitigation appears to be deficient as follows.

- There is no practicable way to reduce TBM vibration and the duration of the tunnelling works means that it would be hugely disruptive to TCD to stop using their facilities for the period they would be potentially affected.

- With the track isolation system as proposed, the movement of the rail under the weight of the trains is likely to be considerably greater than what is normal or proven for floating slab track.
- No evidence has been provided to confirm the practicability and effect of the proposed track isolation system.
- Mitigating residual significant effects at the equipment, through the use of base-isolated foundation slabs, would not be practicable for all the sensitive equipment. Even where this solution could be possible, it would be very disruptive to TCD's activities during its installation. Isolating individual items of equipment still leaves the rest of the buildings and facilities unisolated, such that any new equipment acquired throughout the lifetime of MetroLink may require additional cost to restore the vibration environment to be equivalent to the current baseline.

3. Baseline

Two baseline assessments have been undertake as outlined below, the first on behalf of TII and the second by TCD. A comparison is then made between the results of the two studies.

3.1 TII baseline vibration report

A baseline survey was undertaken by Accon UK on behalf of TII in November 2019. Measurements were made over periods of typically around 30 minutes and summary overall vibration acceleration and velocity levels are tabulated. This report is comprised in Appendix A13.5 of the EIAR as discussed in Section 2.1 above. However, the report does not provide the full data required to determine appropriate baselines for all the sensitive equipment. Separately, TCD has been provided with the full data in Excel spreadsheet format from which Accon UK had derived the summary levels. The data were provided as tabulated one-third octave frequency band acceleration in 0.05s intervals.

3.2 TCD baseline vibration survey

3.2.1 Equipment and method

The equipment used in the latest survey is listed in Appendix C. All Arup instrumentation is calibrated annually by UKAS/Traceable accredited calibration laboratories. Calibration certificates are set out at Appendix C to this report.

The PCB Piezotronics 393B31 type accelerometers have a high sensitivity and very low noise floor, which is particularly important for sensitive equipment applications. The operating frequency range is specified as 0.1Hz to 200Hz (±5%).

It was not possible to check the calibrations of the transducers on site so a side by side comparison (Figure 2) of the outputs from the two sets of equipment was recorded. The results are summarised in (Figure 2) below which confirms the systems were measuring consistently.

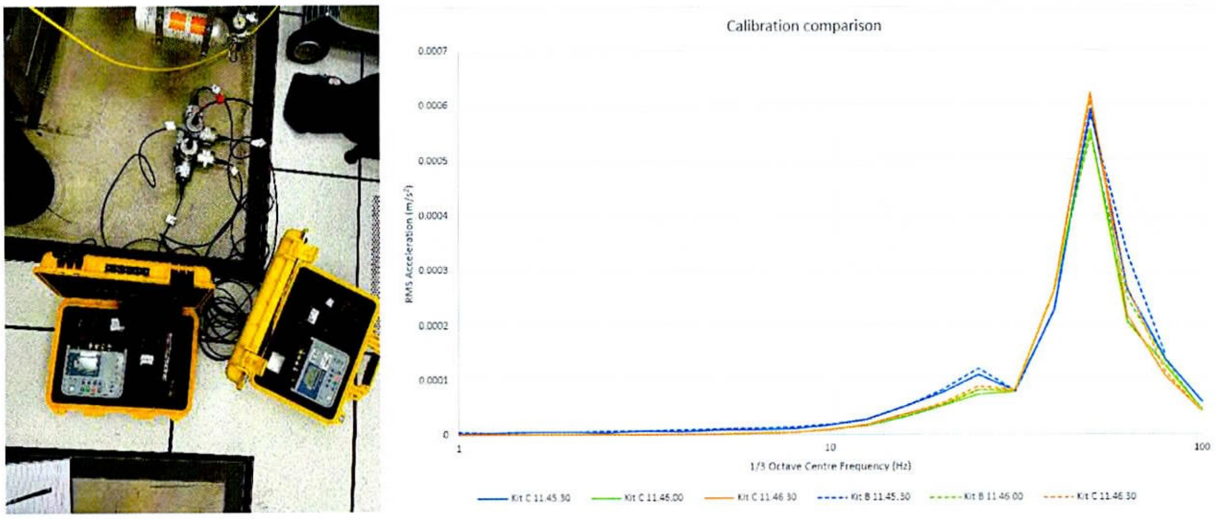

Figure 2: Instrumentation arrangement (left) and vertical accelerometer output data comparison (right)

The accelerometers were mounted onto a magnetic block. Each block was magnetically connected to a steel plate, which in turn was affixed to the floor covering using beeswax. In all spaces except the Panoz Building, the floor covering was vinyl and locations were selected where this appeared to be securely adhered to the floor beneath. An example of the set up is shown in Figure 3.

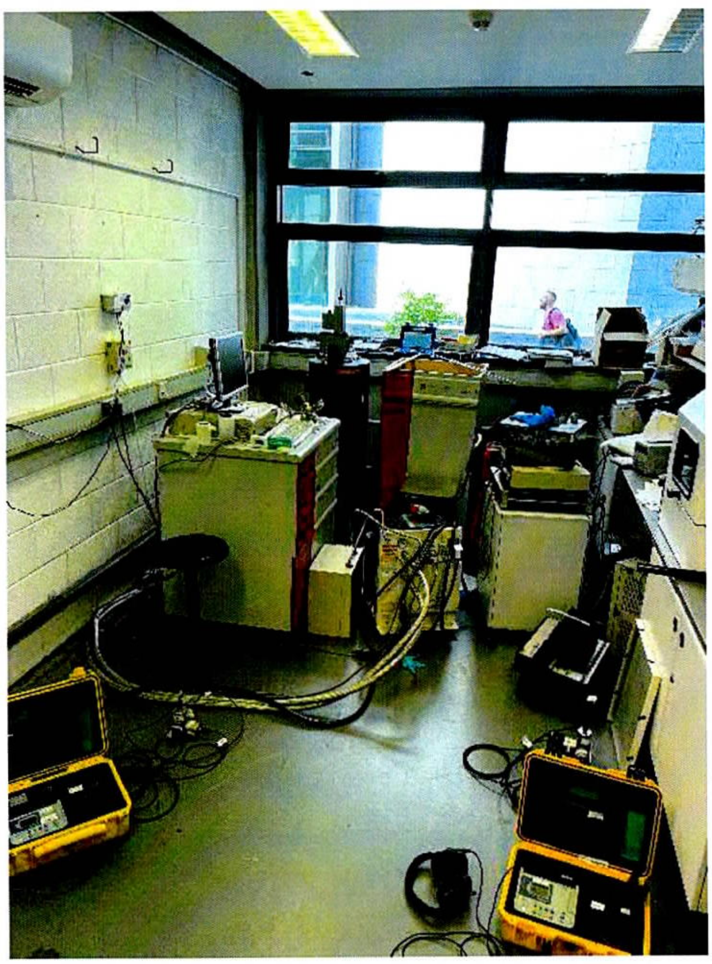

Figure 3: Vibration measurement set up at the SQUID facility in SNIAMS

In Panoz, the spaces in which the sensitive equipment (SEMs) was located was carpeted so measurements were made in the closest adjacent spaces that had vinyl floor covering.

Accelerometer outputs were recorded as continuous .WAV files for typically around 30 minutes. Two locations were measured in most spaces.

The .WAV files were post processed to derive a series of non-overlapping one second rms third octave band spectra over the full recording period at each location. These have then been analysed statistically to determine the arithmetic mean and mean+2 standard deviations in each one-third octave frequency band.

The full results of the baseline measurements are presented in Appendix B and are summarised in the following section. The baseline graphs show data for each measurement position in each facility.

3.3 Comparison of TII and Arup measured baseline

All the baseline measurement results comparing TII's survey (undertaken by Accon) and TCD's survey (undertaken by Arup) are shown graphically in Appendix A and Figure 4 presents an example.

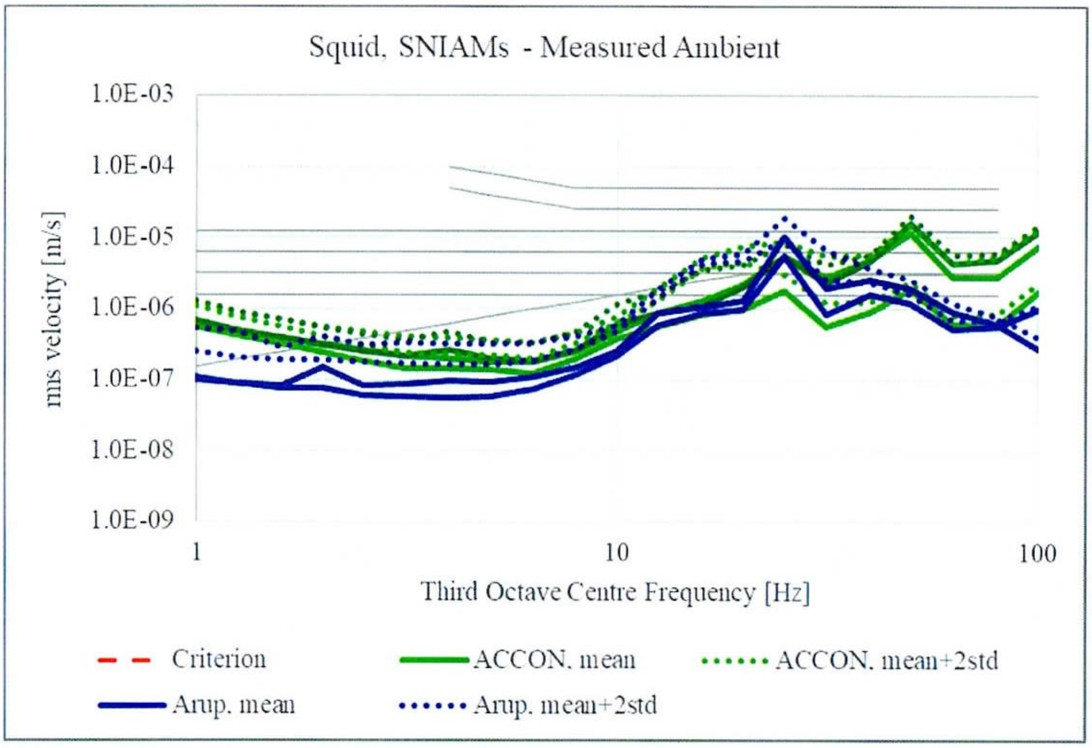

Figure 4: Example of baseline vibration measured by Accon and by Arup

Baseline vibration surveys undertaken by TCD are broadly consistent with those reported by TII. At the lowest frequencies, the TII typically data report higher levels of vibration than TCD but rather than being an actual difference in the vibration, this appears likely to be a result of the TCD measurement system having a lower noise floor i.e. the TII equipment cannot measure as low levels of vibration at low frequencies.

Although there are some differences in the results, these may reflect natural variation in vibration levels due to the relatively short time period over which the baselines were measured in each survey. It is therefore considered that they provide a reasonable basis for the current assessment.

Baseline vibration levels in the various sensitive spaces are generally consistent with the required operating conditions for the equipment but in some cases are higher than the assumed equipment criteria.

4. Potential vibration impacts

Without effective mitigation, the following impacts would significantly affect TCD's vibration sensitive facilities.

4.1 Construction

- Vibration from the TBM would be too high, over an extended period of time, for much of TCD's equipment to be operated reliably.
- A temporary construction railway would create impacts of even longer duration.
- Blasting at Tara Street may be intermittently problematic for vibration sensitive equipment.
- Groundborne noise from the TBM is likely to be disturbing when the tunnelling is close to TCD, although the affected area would be smaller than that potentially directly affected by vibration.

4.2 Operation

- The 'standard' trackform (proposed elsewhere for most of the tunnel length) would lead to many of TCD's facilities being unserviceable on the site.
- Headway between trains would be insufficient to allow the very large majority of equipment to be used at any time, other than in some instances potentially during night time hours when MetroLink is not operating and on occasions when no maintenance trains are running.

5. Mitigation Measures

5.1 Construction

- The only way to mitigate vibration during tunnelling would be to move the alignment sufficiently far away from the vibration sensitive facilities to minimise risk; this would not be possible with the Tara Station location and geometry.
- A compromise solution could be to drive the tunnel intermittently, so that some days TCD could make full use of its facilities and during the alternate periods the tunnel could be driven.
- Use of rubber tyred vehicles, rather than a temporary railway, to service the TBM would be able to mitigate this vibration impact risk.

5.2 Operation

- The most effective mitigation approach would be to move the MetroLink alignment as far west as possible.
- Instead, or in addition, it may be possible to design a trackform that could be demonstrably able to mitigate vibration to the very low levels required for vibration sensitive facilities, including for low frequency vibration. TII has not robustly demonstrated that this is viable and would be effective.
- Maximising the separation of the railway from TCD's facilities would minimise the uncertainty and risks associated with track mitigation.
- If, following mitigation, residual vibration remains too high, it may be possible to provide local mitigation for some of the equipment in some locations although it is unlikely to be suitable everywhere. Provision would also be required to mitigate vibration in other spaces to be no higher

than current levels to ensure the future viability and flexibility of use of the buildings.

6. Predicted residual vibration effects (construction phase)

As identified in the EIAR (see Section 2.2 above), construction of the MetroLink would present a significant risk of vibration sensitive equipment being exposed to vibration greater than the assessment criteria and baseline levels from the tunnel boring machine (TBM) used to excavate the tunnel. There would also be a risk from blasting for Tara Station and, depending on the method used, from operation of the systems required to transport materials (for example, tunnel lining segments) from construction access points to the TBM.

For the TBM, assuming a tunnelling rate of 7m per day (refer to Section 2.2.3 above), if the effects on sensitive equipment would be apparent up to 100m from the tunnel face as reported in the EIAR (refer to Section 2.2.1 above) disruption could be 29 days continuously (including both before and after the TBM passes). The EIAR also suggests that the affected corridor could extend to 250m around the TBM (see Section 2.2.1 above) which would increase the period during which VC-E is exceeded to 71 days. Slower rates of tunnelling would further extend the duration of the disruption.

For comparison with the EIAR, representative data in terms of peak particle velocity (PPV) have been published by Orr[2] from driving the Dublin Port Tunnel, which was constructed through similar geological conditions to those at TCD. At a slant distance of 20m, around 2mm/s PPV was measured (see Figure 5, magenta diamonds), which is between two and three orders of magnitude higher than the criteria for the most sensitive equipment. This information supports the conclusion that disturbance from the TBM would occur over a wide corridor and for an extended period.

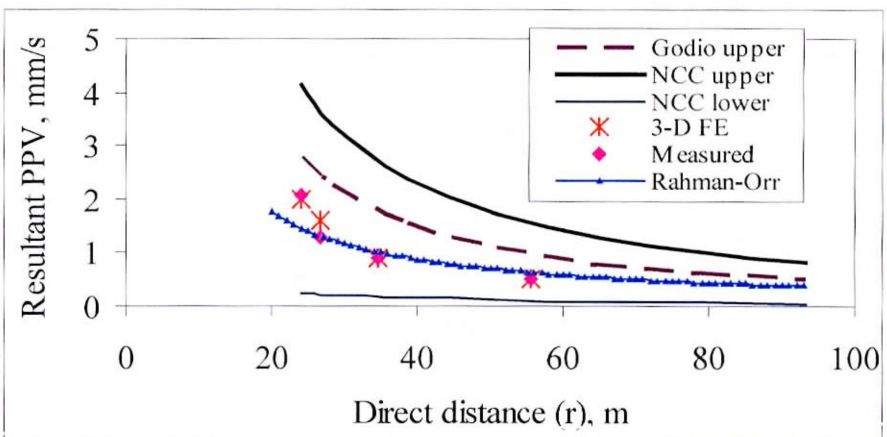

Figure 5: Vibration data from Dublin Port Tunnel (Orr, 2007)

The proposal is to drive the tunnel from the north, terminating the drive at Charlemont. Whatever system is used to transport materials to the TBM would need to be in use and potentially impacting on TCD's facilities from when construction is beneath TCD until completion of construction. No programme is available but disturbance to TCD could be expected for several months unless a system designed to mitigate vibration is provided. It would be expected that a rubber tyred vehicle system assumed for the vibration assessment (see

[2] Orr TLL, 2007. Ground Vibrations and the Dublin Port Tunnel, Swedish Geotechnical Society, Stockholm.

Section 2.2.4) would provide suitable mitigation against vibration provided that the roadway is maintained in a good condition, free from significant surface irregularities.

7. Predicted vibration from MetroLink operation (construction phase)

7.1 Method and assumptions

The vibration assessment has been undertaken using Arup's empirical prediction method which is consistent with BS ISO 14837-1:2005 *Mechanical vibration - Ground-borne noise and vibration arising from rail systems - Part 1: General guidance* and has been applied to many rail schemes globally (Singapore MRT; MetroLink, UK; Sydney's Tangara Australia; Crossrail UK, High Speed 2, UK).

The method is underpinned by large datasets but limited information is available at low frequencies (below 8Hz). Low frequency vibration is an important consideration for vibration sensitive equipment. Furthermore, TII's proposals include a complex trackform intended to mitigate vibration that consists of a floating track slab and resilient track pads. The resonance frequency of a floating track slab system would be in this low frequency range, which presents an additional risk to TCD. Consequently, in addition to the empirical approach, numerical modelling has been undertaken to investigate further these low frequency risks. This is described in Section 7.2 below.

Assumptions and other information used in vibration calculations is tabulated in Appendix A. Figure 6, taken from Jacobs IDOM report *Tara Station to SSG Station Alternative Alignment Options Assessment* reference ML1-JAI-CPS-ROUT_XX-PL-Z-00001 | P02 dated 22 April 2022, shows five possible route alignments for which Arup has undertaken prediction calculations. TII's preferred route taken forward in the EIAR is Option 2, which is the only option for which the EIAR reports the vibration impacts.

An additional route alignment proposed by CECL and Arup on behalf of TCD, that moves the alignment as far west as practicable without affecting the route to the north of Tara Station (as shown, in general terms, as Option 5 in Figure 7) has also been assessed. The detail of the Option 5 alignment is illustrated in Figure 7 below.

The impacts at vibration sensitive equipment locations for each of these routes are described below in Section 7.4.1.

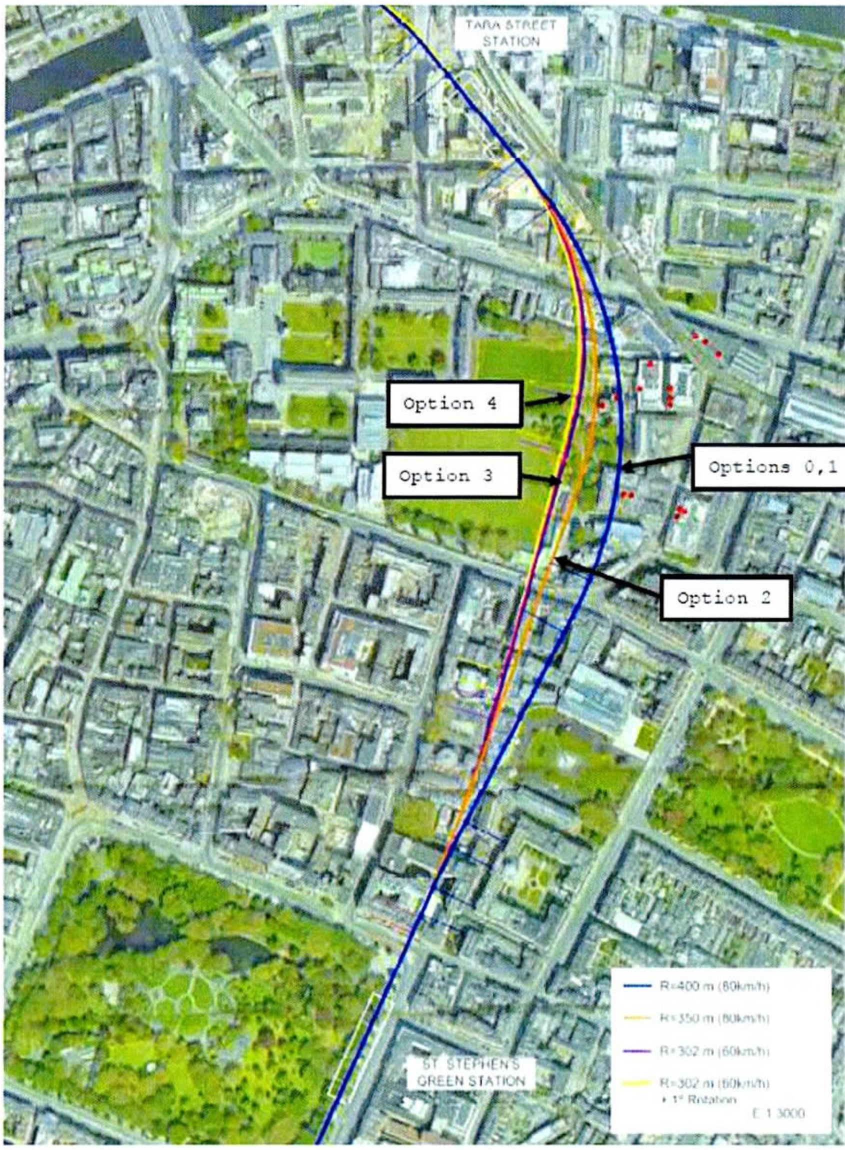

Figure 6: TII's proposed route alignment options

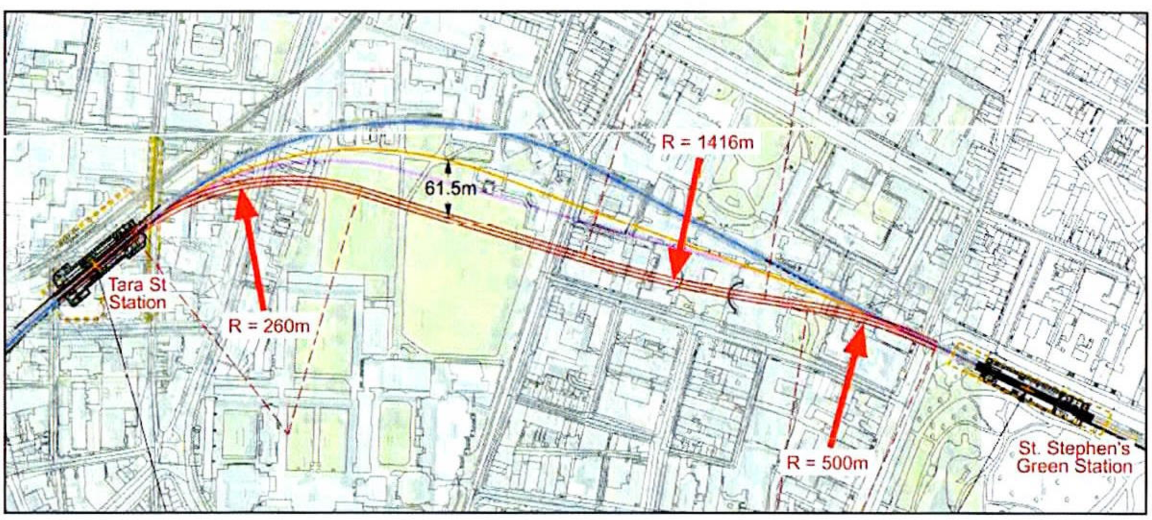

Figure 7: Option 5 proposed alternative westerly alignment

7.2 Numerical modelling

Details of the numerical modelling method are set out in Appendix A. The modelling takes account of the static load of the train and was modelled travelling at 80km/h. The train model includes the carriage, bogie and the un-sprung (eg. axles and wheels sets) masses. Modelling includes wheel-rail interaction and an assumed roughness spectrum. The vibrations were calculated at the ground surface and then incorporated within the empirical model to predict further propagation through the intervening ground and within the buildings. Numerical models of each building were not created.

The model incorporates dynamic properties of the track and support system and has used parameter values consistent with those in TII's modelling. Each floating track slab unit is modelled as supported on steel springs with a stiffness of 1kN/mm and a loss factor of 0.2. This stiffness value is very low: a stiffness of around 6kN/mm would be expected for a railway floating slab track. Similarly, steel string would typically have a loss factor of around 0.0025 rather than the 0.2 for the steel springs assumed in TII's model. A model with higher stiffness spring input has been calculated.

TII has also provided information of ground characteristics (Poisson's ratio, shear modulus and compression modulus). The parameters were found to be inconsistent with expected value for dynamic soil response. Models have also been run with different ground parameters based on those used by TII.

7.3 Assessment criteria

The vibration sensitivities of the various items of equipment have been determined from several sources. Where available, datasheets or site requirements information from equipment suppliers have been used to derive the assessment criteria. Alternatively, internet searches have been carried out for information related to specific items of equipment where the make and model were known. In cases where neither of these was suitable, generic criteria taken from Table 45 of the ASHRAE Handbook[3] (which is similar to Figure 8) or information from other sources related to similar equipment have been used.

Where the existing baseline already exceeds the criteria derived as above, the baseline has been used to assess the risk of adverse impacts on TCD.

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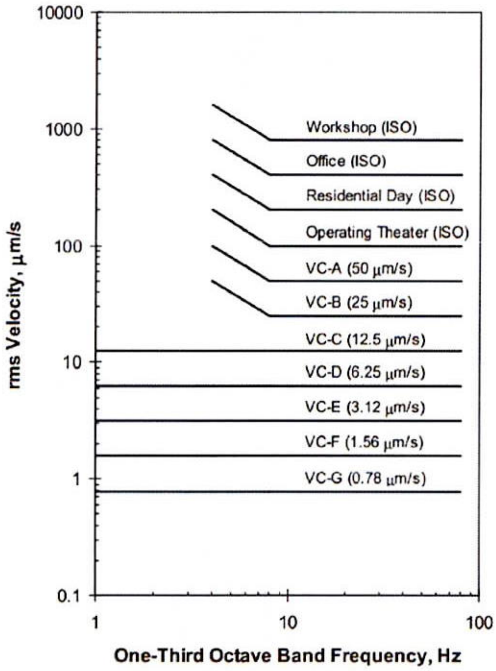
[3] 2019 ASHRAE Handbook – HVAC Applications (SI), Chapter 49



Criterion Curve	Amplitude[1] μm/s (μin/s)	Detail size[2] μm	Description of use
Workshop (ISO)	800 (32 000)	N/A	Distinctly perceptible vibration. Appropriate to workshops and nonsensitive areas.
Office (ISO)	400 (16 000)	N/A	Perceptible vibration. Appropriate to offices and nonsensitive areas.
Residential day (ISO)	200 (8 000)	75	Barely perceptible vibration. Appropriate to sleep areas in most instances. Usually adequate for computer equipment, hospital recovery rooms, semiconductor probe test equipment, and microscopes less than 40x.
Operating theatre (ISO)	100 (4 000)	25	Vibration not perceptible. Suitable in most instances for surgical suites, microscopes to 100x and for other equipment of low sensitivity.
VC-A	50 (2 000)	8	Adequate in most instances for optical microscopes to 400x, microbalances, optical balances, proximity and projection aligners, etc.
VC-B	25 (1 000)	3	Appropriate for inspection and lithography equipment (including steppers) to 3 μm line widths.
VC-C	12.5 (500)	1 – 3	Appropriate standard for optical microscopes to 1000x, lithography and inspection equipment (including moderately sensitive electron microscopes) to 1 μm detail size, TFT-LCD stepper/scanner processes.
VC-D	6.25 (250)	0.1 – 0.3	Suitable in most instances for demanding equipment, including many electron microscopes (SEMs and TEMs) and E-Beam systems.
VC-E	3.12 (125)	< 0.1	A challenging criterion to achieve. Assumed to be adequate for the most demanding of sensitive systems including long path, laser-based, small target systems, E-Beam lithography systems working at nanometer scales, and other systems requiring extraordinary dynamic stability.
VC-F	1.56 (62.5)	N/A	Appropriate for extremely quiet research spaces; generally difficult to achieve in most instances, especially cleanrooms. Not recommended for use as a design criterion, only for evaluation.
VC-G	0.78 (31.3)	N/A	Appropriate for extremely quiet research spaces; generally difficult to achieve in most instances, especially cleanrooms. Not recommended for use as a design criterion, only for evaluation.

[1]As measured in one-third octave bands of frequency over the frequency range 8 to 80 Hz (VC-A and VC-B) or 1 to 80 Hz (VC-C through VC-G).

[2]The detail size refers to line width in the case of microelectronics fabrication, the particle (cell) size in the case of medical and pharmaceutical research, etc. It is not relevant to imaging associated with probe technologies, AFMs, and nanotechnology.

The information given in this table is for guidance only. In most instances, it is recommended that the advice of someone knowledgeable about applications and vibration requirements of the equipment and processes be sought.

Figure 8: Generic vibration assessment criteria (taken from EIAR Diagram 14.3, page 11 Volume 3, Book 1, Chapter 14)

7.4 Results

7.4.1 The EIAR route assessment

Full results of the predicted vibration levels for all the route options as one-third octave band spectra at each sensitive equipment location are provided in Appendix B. Table 1 summarises the predictions based on the empirical model for the EIAR route and compares them with the equipment sensitivities.

Table 1: Summary of predicted train vibration for the EIAR route (Option 2 in Figure 6)

Key (see Figure 9)	Location	Equipment	Assessment criteria	Arup Assessment
A	Chemistry	1x NMR (Bruker 400MHz)	VC-C	VC-D
A		1 x NMR (Brucker 600MHz)	VC-C	VC-D
B		1x NMR (Bruker 400MHz)	VC-C	VC-D
C	Panoz	1x SEM (Tecsan S8000)	Manufacturer's	VC-E
C		1x SEM (Tecsan Mira3 Tiger)	Manufacturer's	VC-E
C		1x SEM (Zeiss Sigma 300)	Manufacturer's	VC-E
D	Lloyd	1x MRI (Bruker BioSpec 70/30 AVANCE III 7T)	Manufacturer's	VC-E
E		1x MRI (Siemens Magnetom Prisma 3T)	Manufacturer's	VC-E
F		2x TMS machine (DuoMag)	Not more than existing baseline	VC-E
G		3x EEG machine (TruScan)	Not more than existing baseline	VC-E
H		1x Confocal Microscope (Zeiss LSM 501)	NIST-A	VC-E
I		1x Confocal Microscope (Zeiss LSM 880)	NIST-A	VC-E
J	SNIAMs	1x SQUID (Quantum Design MPMS-XL)	Not more than existing baseline	VC-C
K	CRANN	1x AFM (Bruker Multimode 8)	NIST-A	VC-E
K		2x UHV AFM (Omicron VT and RT)	NIST-A	VC-E
L		2x Nanoindenter (KLA XP and DCM), 1x 3D Contact Mechanics Tester (Fast Forward Devices)	NIST-A	VC-E
M		1x Stylus Profileometer (Bruker Dektak)	NIST-A	VC-E
N		2x Optical Tweezer Instruments	NIST-A	VC-E
O		1x XPS	NIST-A	VC-E
P		4x STM (Omicron Variable Temperature STM, 2x Omicron Cryogenic STM, Empa designed AFM/STM)	NIST-A	VC-E
Q		1x SEM (proposed in future)	VC-D	VC-E
R	Fitzgerald	2x STM	NIST-A	VC-C
		1x STM	NIST-A	VC-C
S		1x AGFM	NIST-A	VC-C
T		1x optical telescope	Not more than existing baseline	VC-C
T		1x radio telescope	Not more than existing baseline	VC-C

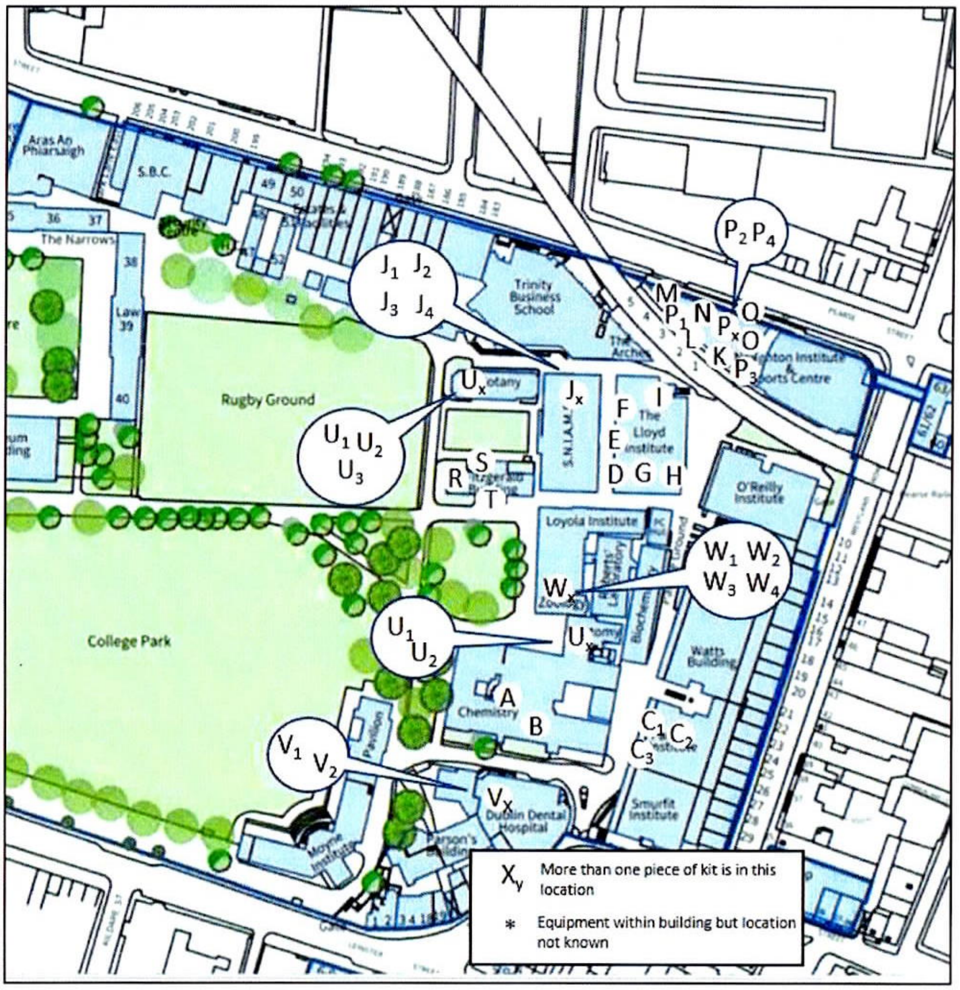


Figure 9 Vibration sensitive equipment locations

Appendix B includes the results from all route options. Table 2 summarises the outcomes of the assessment for each route compared to the equipment sensitivity criteria. Green indicates that there is a low risk of an assessment criterion being exceeded; red indicates an unacceptable risk of the criterion being exceeded.

Table 2: Comparison of the predicted train vibration for each route with the assessment criteria

Location	Equipment	Option 0	Option 1	Option 2	Option 3	Option 4	Option 5
Chemistry	1x NMR (Bruker 400MHz)	VC-C	VC-C	VC-D	VC-E	VC-E	VC-E
	1 x NMR (Brucker 600MHz)	VC-C	VC-C	VC-D	VC-E	VC-E	VC-E
	1x NMR (Bruker 400MHz)	VC-C	VC-D	VC-D	VC-E	VC-E	VC-E
Panoz	1x SEM (Tecsan S8000)	VC-D	VC-E	VC-E	VC-F	VC-F	VC-F
	1x SEM (Tecsan Mira3 Tiger)	VC-D	VC-E	VC-E	VC-F	VC-F	VC-F
	1x SEM (Zeiss Sigma 300)	VC-D	VC-E	VC-E	VC-F	VC-F	VC-F
Lloyd	1x MRI (Bruker BioSpec 70/30 AVANCE III 7T)	VC-D	VC-D	VC-E	VC-E	VC-E	VC-F
	1x MRI (Siemens Magnetom Prisma 3T)	VC-D	VC-D	VC-E	VC-E	VC-E	VC-F
	2x TMS machine (DuoMag)	VC-D	VC-D	VC-E	VC-E	VC-E	VC-F
	3x EEG machine (TruScan)	VC-D	VC-D	VC-E	VC-E	VC-E	VC-F
	1x Confocal Microscope (Zeiss LSM 501)	VC-D	VC-D	VC-E	VC-E	VC-E	VC-F
	1x Confocal Microscope (Zeiss LSM 880)	VC-D	VC-D	VC-E	VC-E	VC-E	VC-F
SNIAMs	1x SQUID (Quantum Design MPMS-XL)	VC-C	VC-C	VC-C	VC-D	VC-D	VC-D
CRANN	1x AFM (Bruker Multimode 8)	VC-E	VC-E	VC-E	VC-F	VC-F	VC-F
	2x UHV AFM (Omicron VT and RT)	VC-E	VC-E	VC-E	VC-F	VC-F	VC-F
	2x Nanoindenter (KLA XP and DCM), 1x 3D Contact Mechanics Tester (Fast Forward Devices)	VC-E	VC-E	VC-E	VC-F	VC-F	VC-F
	1x Stylus Profileometer (Bruker D ektak)	VC-D	VC-D	VC-E	VC-E	VC-E	VC-E
	2x Optical Tweezer Instruments	VC-E	VC-E	VC-E	VC-F	VC-F	VC-F
	1x XPS	VC-E	VC-E	VC-E	VC-E	VC-E	VC-F
	4x STM (Omicron Variable Temperature STM, 2x Omicron Cryogenic STM, Empa designed AFM/STM)	VC-E	VC-E	VC-E	VC-F	VC-F	VC-F
		VC-E	VC-E	VC-E	VC-F	VC-F	VC-F
		VC-E	VC-E	VC-E	VC-F	VC-F	VC-F
		VC-E	VC-E	VC-E	VC-F	VC-F	VC-F
	1x SEM (proposed in future)	VC-E	VC-E	VC-E	VC-E	VC-E	VC-F
Fitzgerald	2x STM	VC-C	VC-D	VC-C	VC-D	VC-D	VC-E
	1x STM	VC-C	VC-D	VC-C	VC-D	VC-D	VC-E
	1x AGFM	VC-B	VC-B	VC-C	VC-D	VC-D	VC-D
	1x optical telescope	VC-B	VC-B	VC-C	VC-D	VC-D	VC-D
	1x radio telescope	VC-B	VC-B	VC-C	VC-D	VC-D	VC-D

The predictions for the proposed route alignment and the mitigated trackform show a significant improvement in the vibration risk compared with TII's original alignment proposals but, as shown above, there remains an appreciable risk that vibration will exceed the assessment criteria in some locations. Generally, these are the equipment items requiring vibration not to exceed VC-E/NIST-A and are already in a location with a low vibration environment.

7.4.2 Numerical modelling

The numerical modelling aimed to provide a better understanding of the low frequency vibration, where the empirical model has a greater degree of uncertainty than at higher frequencies. The modelling showed the predictions to be heavily dependent on the assumed ground stiffness parameters and the track isolation assumptions.

Using the parameter values assumed in the EIAR, some of which appear to yield an unviable trackform solution, the modelling predicted vibration to be low at low frequencies. There is, however, always considerable uncertainty in the ground properties assumptions and small differences in the assumed values have a large effect on the predicted vibration.

Furthermore, the EIAR assumes a very low spring stiffness which, due to the resulting deflection that would occur under the static loading of the train, would not appear to be a practicable track design solution. Modelling with a more typical spring stiffness, that would adequately control the static deflection, leads to higher predicted vibration.

Using a more realistic value for the track spring stiffness produces results that closely align with the empirical model results at the higher frequencies and therefore provide further validation of the empirical model for the higher frequencies.

8. Summary and conclusions

8.1 General

In the EIAR submitted to the Board in respect of the MetroLink project, impacts are identified for only a small number of TCD's buildings and facilities. The EIAR does not reflect the range and extent of vibration sensitive locations and facilities that would potentially be affected, both by construction and operation of Metrolink.

8.2 Baseline

Baseline vibration surveys are reported in the EIAR, however, the way in which the results are reported does not relate to any specific equipment criteria or to the generic VC curves commonly used in relation to vibration sensitive equipment. (Section 2.1)

It is stated that full baseline results are provided in the appendix but only a summary of the results is included. The full survey dataset appears not to have been published but has separately been supplied by TII to TCD and is included in this report. (Section 2.1)

Although there are some differences in the results of the baseline vibration surveys carried out by TII and TCD, these may reflect natural variation in vibration levels due to the relatively short time period over which the baselines were measured in each survey. It is therefore considered that they are sufficiently consistent to provide a reasonable basis for the current assessment. (Section 3.3)

8.3 Construction

There is inconsistency in the reported extent of the corridor potentially adversely impacted by vibration during construction of the tunnel. In one section it is stated that the corridor would be 100m either side of the tunnel and elsewhere 250m is stated. Furthermore, the 100m corridor is the same as that stated for the operational impacts: a wider corridor would be expected for tunnelling than from operation of the railway. (Section 2.2.1)

The description of the construction works (EIAR Volume 2 Chapter 5 Metrolink Construction Phase) does not describe how personnel and materials such as tunnel lining segments would be transported through the tunnel to the TBM. The EIAR vibration assessment, however, is based on the assumption that there would not be a temporary construction railway but rubber tyre vehicles will be used instead. This would be essential to prevent an extended period of potential disruption to TCD's equipment. (Section 2.2.3)

The EIAR states that the most sensitive facilities were fully modelled in three dimensions. Details of the modelling for each building have not been reported. (Section 2.3)

It is accepted that, at the expected rate of tunnelling, disruption to TCD's activities would occur for an extended period of time. The only mitigation proposed would be for TCD to work around the tunnelling programme, which would significantly disrupt TCD's activities. (Section 2.4.1) At the expected tunnelling rate, the effects on sensitive equipment during construction would be apparent continuously for many weeks. Slower rates of tunnelling would extend the duration of the disruption. (Section 4)

There is a small risk that groundborne vibration from blasting works for Tara Station could exceed the vibration criteria for some sensitive equipment. This has not been reported in the EIAR and would need to be assessed before any such works are undertaken and blasting designed accordingly.

8.4 Operation

With the track system proposed elsewhere on the MetroLink, the EIAR identifies that there would be significant risk to TCD's equipment from vibration during operation. The conclusions to the vibration assessment chapter state that these impacts will be fully mitigated by track design and by local mitigation at the sensitive equipment, where needed.

To mitigate vibration impacts, a complex track support system is proposed by TII. Whilst Arup's analysis, undertaken on behalf of TCD, indicates that the proposed track support system would address the majority of significant effects, there are some items of equipment for which the criteria would be exceeded in considering the Option 2 route.

There remains uncertainty about the predictions at low frequencies due to uncertainties and sensitivity of numerical modelling to assumptions about the ground properties. Furthermore, the track support system properties stated would result in a system for which deflection of the rails under the static load imposed by the train is likely to be considerably greater than what is normal or proven for floating slab track. No confirmation of the practicability of the proposed system is provided. (Section 2.4.2)

The proposal in the EIAR to mitigate residual significant effects at the receptor (sensitive equipment) through the use of base-isolated foundation slabs would not be practicable for all equipment and buildings, especially for locations where equipment is not on a groundfloor or basement level slab. Even where this solution could be possible, construction would cause disruption to TCD's activities. Furthermore, any future requirements for vibration sensitive equipment to be installed in the same facilities could also be compromised (Section 2.4.2)

It cannot, therefore, be concluded with any degree of certainty that the proposed trackform and the route option presented in the EIAR would mitigate all vibration risks to TCD's equipment. Furthermore, provision of mitigation at any affected items of equipment would at least be disruptive but could also be impracticable.

The headway between trains is generally only around two minutes. If vibration from operation was to compromise the working environment, the time between trains would be insufficient for it to be practicable to carry out vibration sensitive activities during these short quiescent periods.

Appendix A

Information used for vibration calculations and numerical modelling approach

The following information provided by TII has been used as inputs to the vibration calculations.

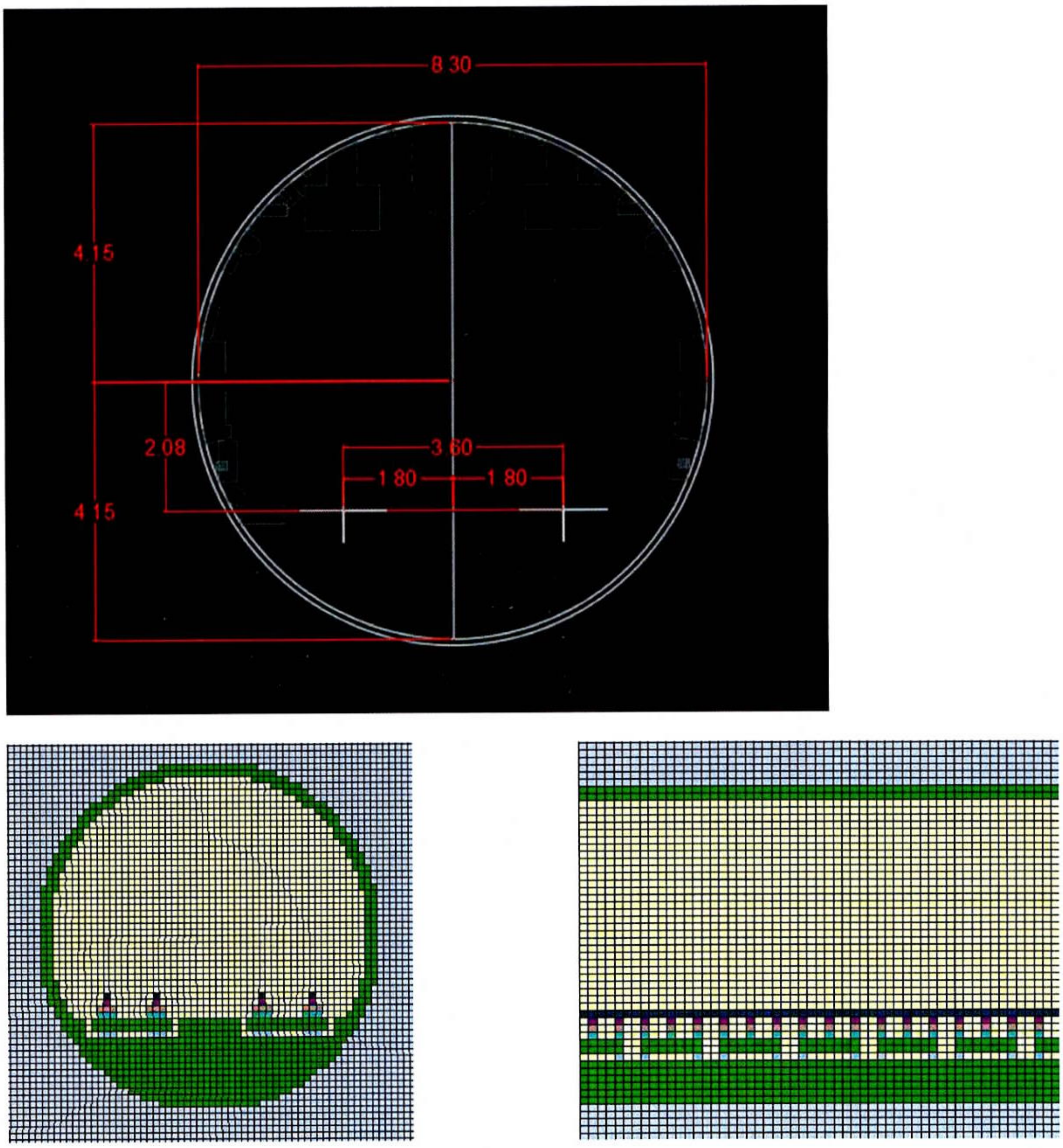


Figure 10: Tunnel Geometry

Cell size 176mm x 176mm x 217mm (along tunnel centreline)

Geology

Tunnel would be driven through Limestone with boulder clay (glacial till) overburden.

Glacial till: 8.8m deep; density 2350 kg/m^3; shear modulus 0.45 GPa; compression modulus 3.26 GPa; Poisson's ratio 0.42; loss factor 0.05.

Limestone: 2700 kg/m^3; shear modulus 2.26 GPa; compression modulus 13.69 GPa; Poisson's ratio 0.4; loss factor 0.05.

Track

Rail roughness (combined with wheel roughness): 30 dB re 1 micron at wavelength of 2m decreasing at 15 dB per decade.

Rail profile: Raiol CEN60 profile

Rail mass: 60kg/m

Sleeper spacing: 650mm

Rail bending stiffness: 6MNm^2

Rail pad dynamic stiffness: 0.15GN/m, loss factor 0.2 at 5Hz

No baseplate

Block mass: 125 kg

No sleeper

Floating slab mass
2936 kg (1950mm spacing)

Floating slab bending stiffness: 0.23 GNm^2

FTS mat/spring mass: 36kg

FTS mat/spring stiffness: 0.35 MN/m (two at 1300mm spacing), loss factor 0.2 at 5Hz

Boot stiffness: 17MN/m, loss factor 0.2 at 5Hz

Rolling stock

Operating speed: 80 km/h

Number of carriages:
One 64m long double-articulated four-bogie vehicle (model actually 60m long connected end-to-end with axles spaced as below)

Carriage length: N/A

Inter-bogie spacing: Modelled as 13.5m and 10.5m

Axle spacing (bogie wheelbase): 2.25m

Unsprung mass: 690.5kg per wheel

Primary suspension stiffness: 1.15MN/m

Primary suspension damping: 10kNs/m per wheel

Bogie mass: 1078.25 kg (of which 387.75 sprung) per wheel

Secondary suspension stiffness: 2.4MN/m per wheel

Secondary suspension damping: 11kNs/m per wheel

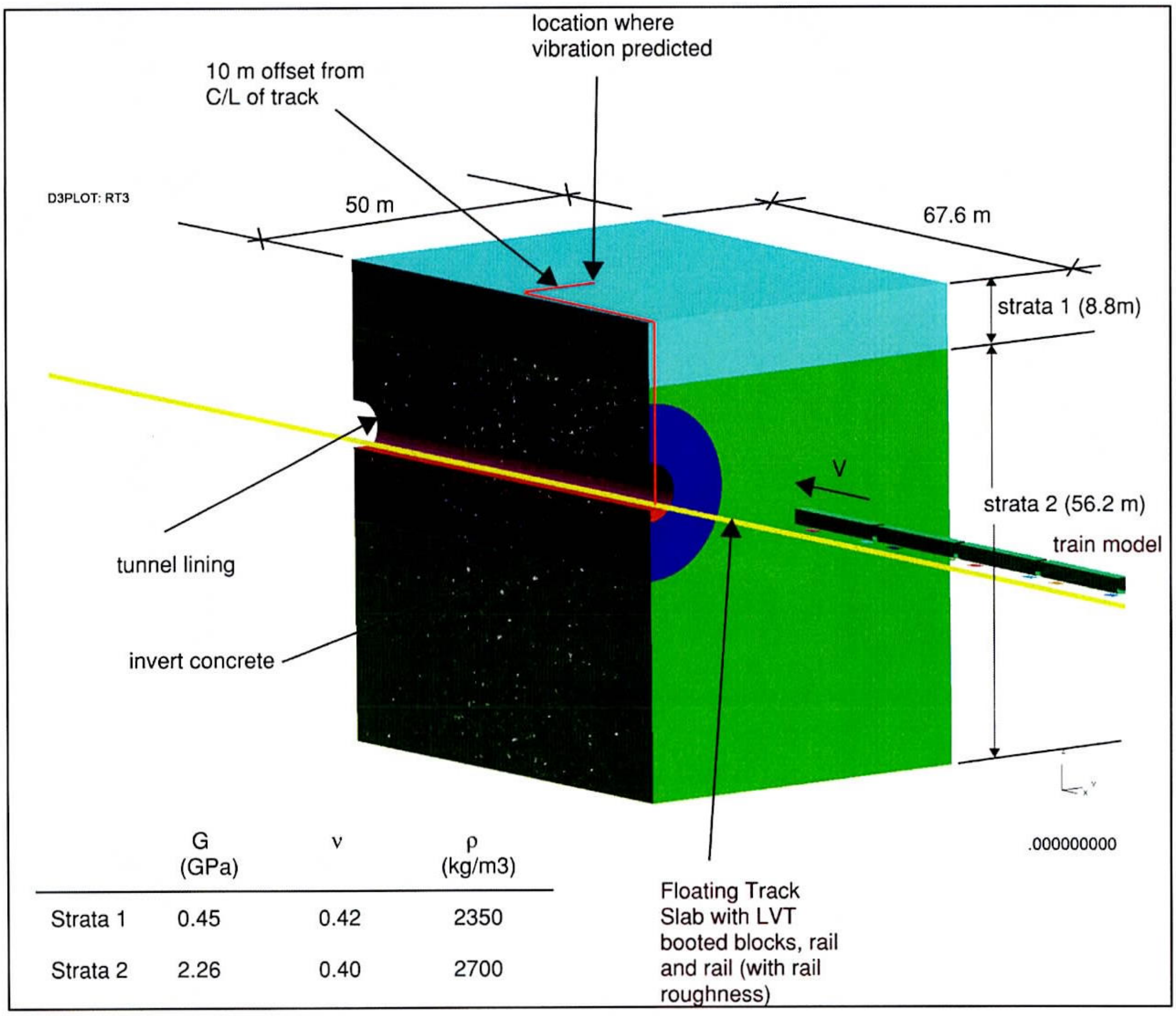
Carriage body mass: 5127.5kg per wheel

Wheel roughness: Included in combined wheel/rail roughness – see above

Wheel type: Assumed monobloc

Numerical modelling approach

The ground-train interaction model is shown in **Error! Reference source not found.**. The train was pre-loaded onto the track under gravity and then assigned a speed of 80km/h. A wheel-rail contact is included in the model which has a roughness profile based upon an assumed roughness spectrum. The vibrations at ground level were predicted as shown in **Error! Reference source not found.**. These ground surface predictions were then incorporated with the empirical model to predict vibration within the buildings: separate numerical models of each building were not created.



	G (GPa)	ν	ρ (kg/m3)
Strata 1	0.45	0.42	2350
Strata 2	2.26	0.40	2700

Figure 11: Ground and tunnel model

The details of the train are shown in **Error! Reference source not found.**. The model includes the mass of the carriage, bogey and the un-sprung mas (eg. axles and wheels sets). The values of the masses, suspension stiffness values and damping are also given in **Error! Reference source not found.**.

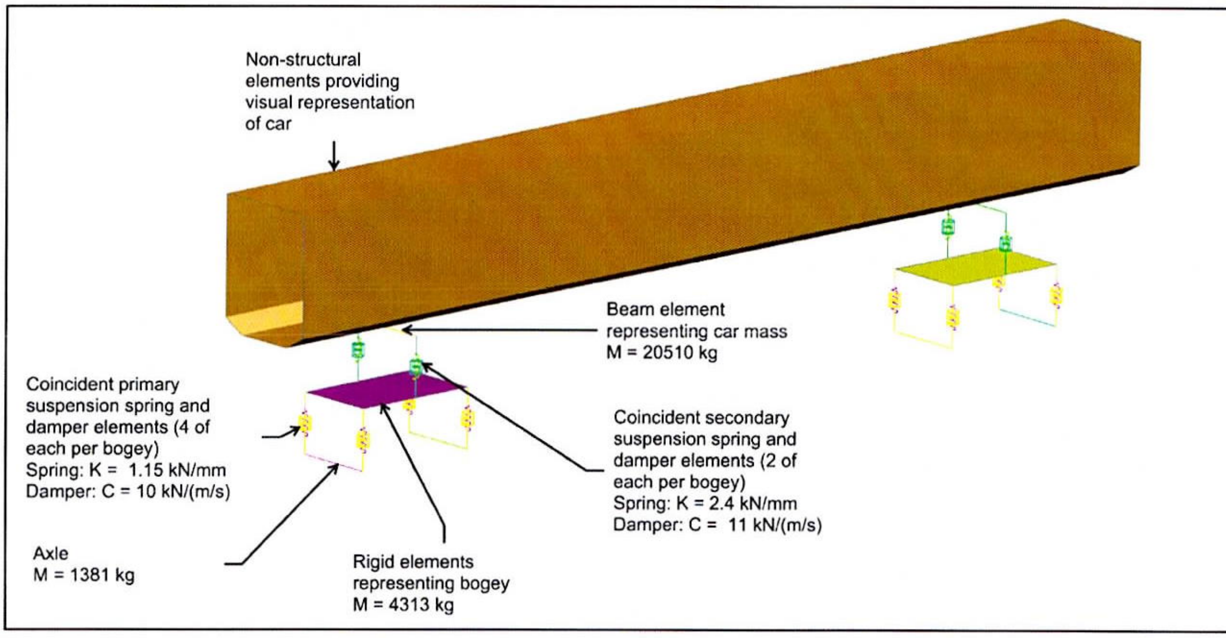


Figure 12: Train model

The track model is shown in **Error! Reference source not found.** which also includes the stiffness (K) and loss factor values (η). The rail is represented by beams supported on a mass-spring system to represent the floating slab track.

The sleeper boots are supported on springs which are in-turn supported on the short lengths of concrete floating slab. Each floating track slab unit is supported on steel springs with a very low stiffness of 1kN/mm and a loss factor of 0.2, using the parameters reported in TII's modelling. This is a very low stiffness: a stiffness of around 6kN/mm is common. Also steel springs would typically have a loss factor of only 0.0025 rather than the 0.2 for the steel springs assumed in TII's model.

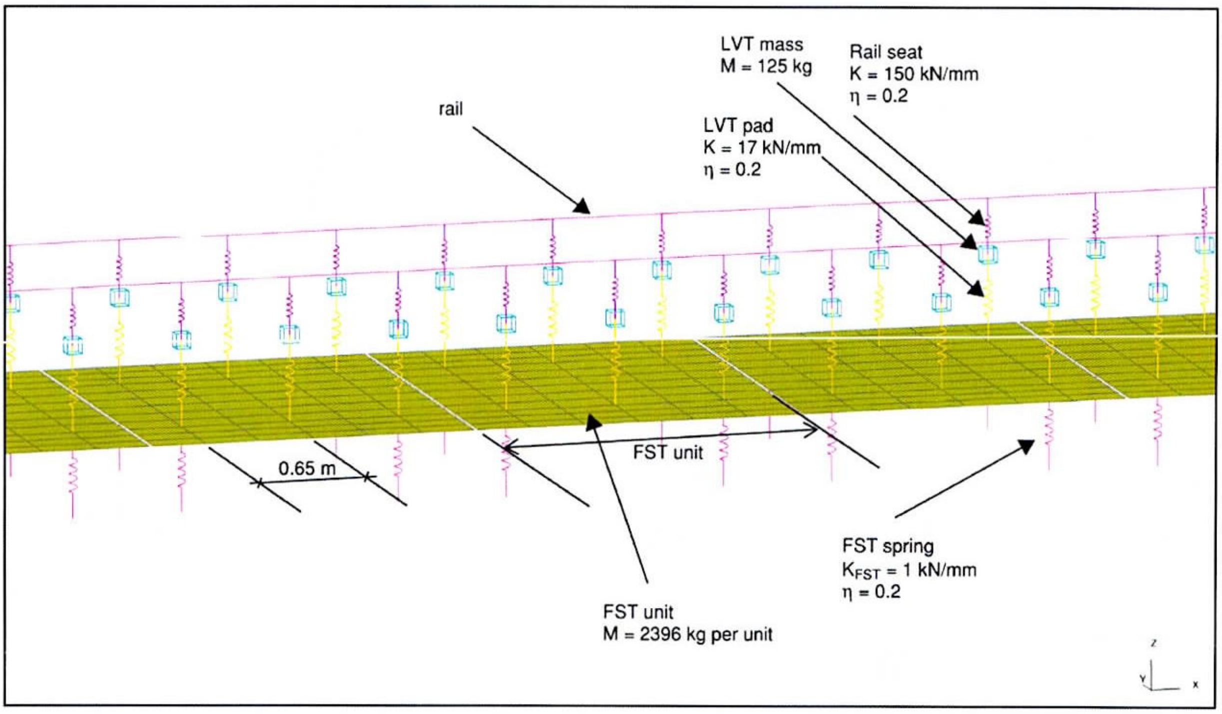
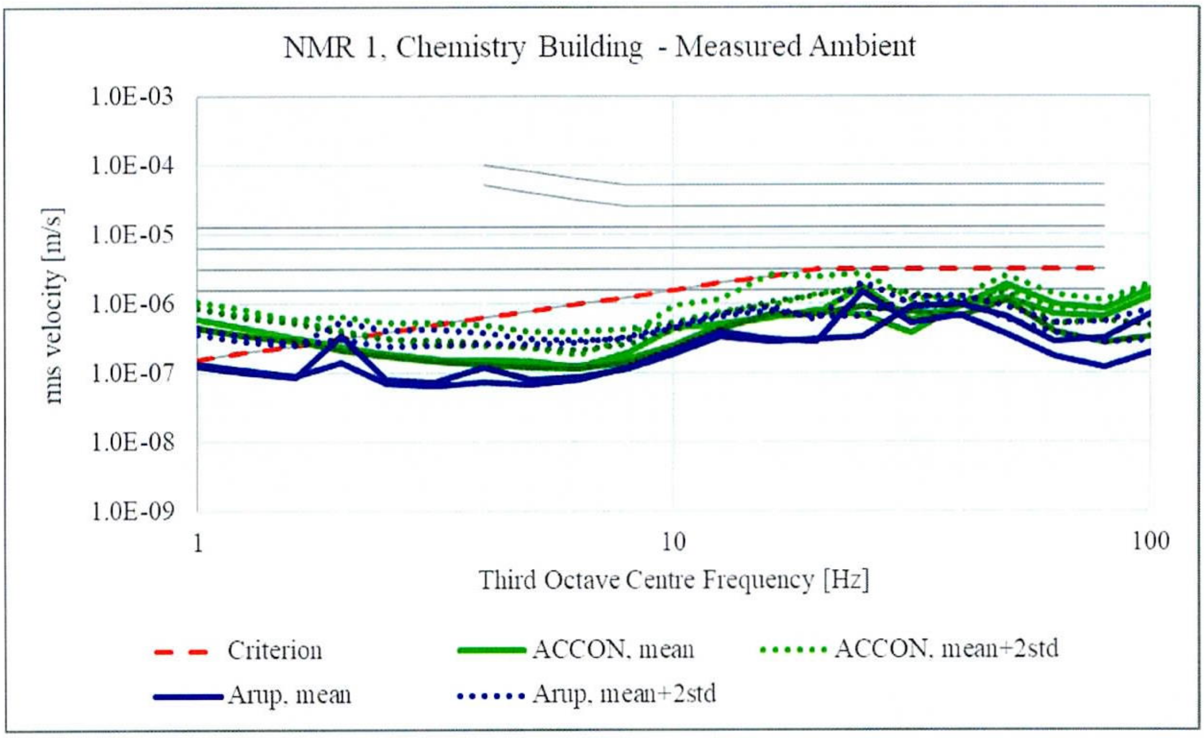


Figure 13: Track model

Appendix B

Baseline and predicted vibration data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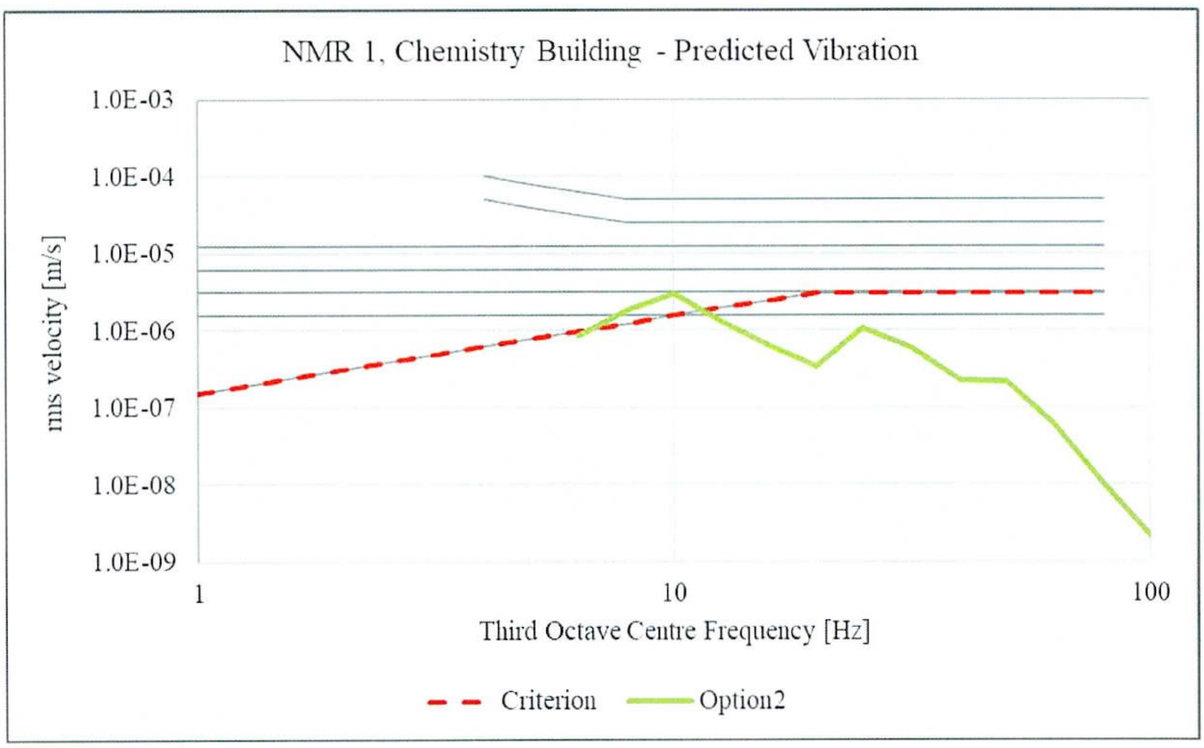
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
ACCON, mean
ACCON, mean+2std
Arup, mean
Arup, mean+2std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rms velocity [m/s]
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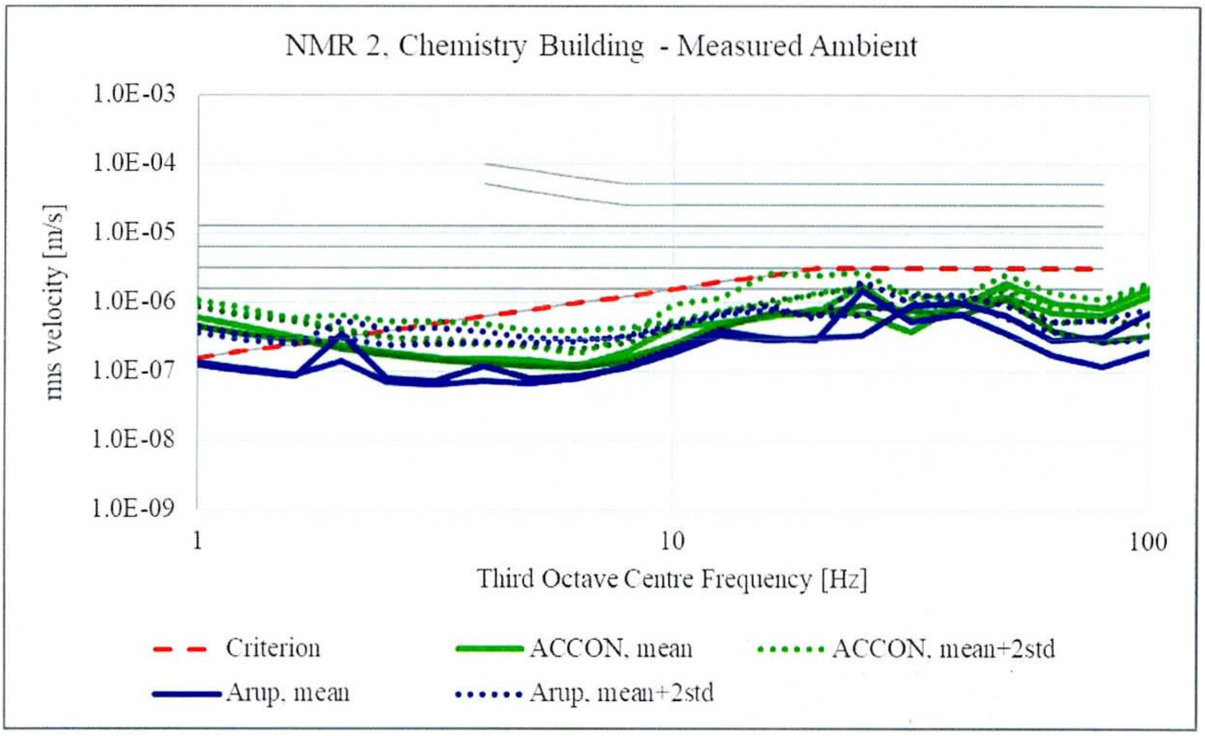
10
100
Third Octave Centre Frequency [Hz]
Criterion
Option2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rms velocity [m/s]
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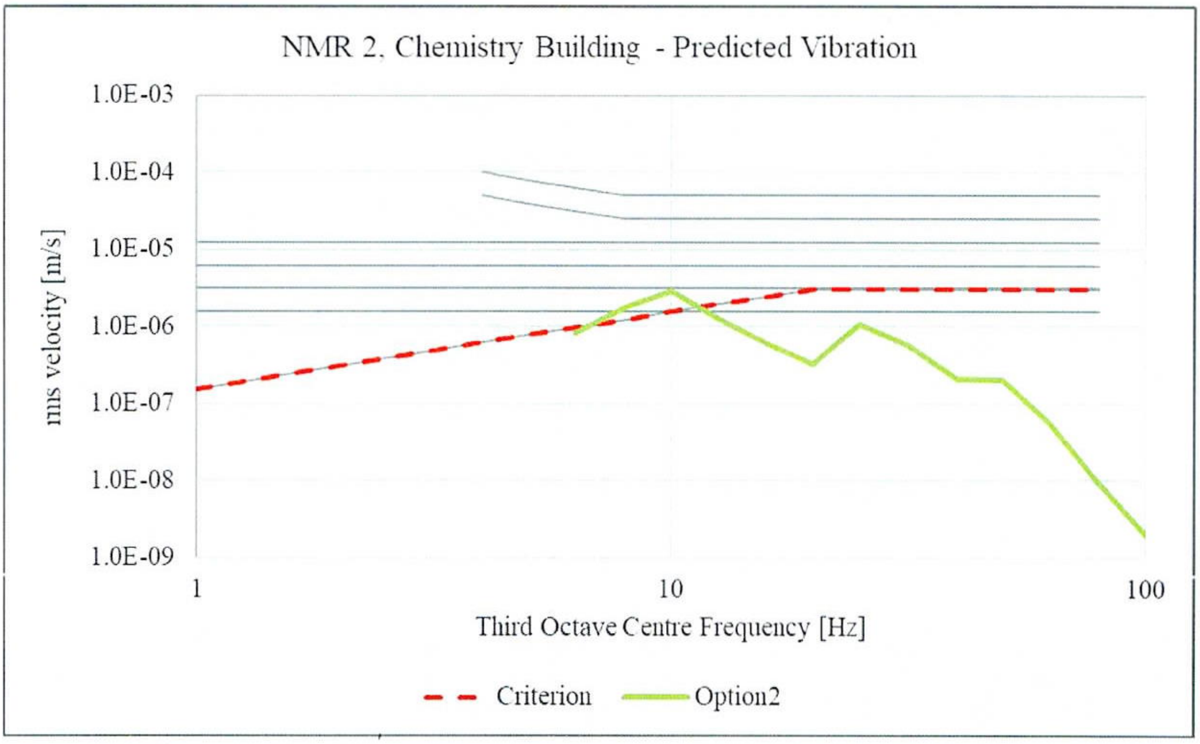
100
Third Octave Centre Frequency [Hz]
Criterion
ACCON, mean
ACCON, mean+2std
Arup, mean
Arup, mean+2std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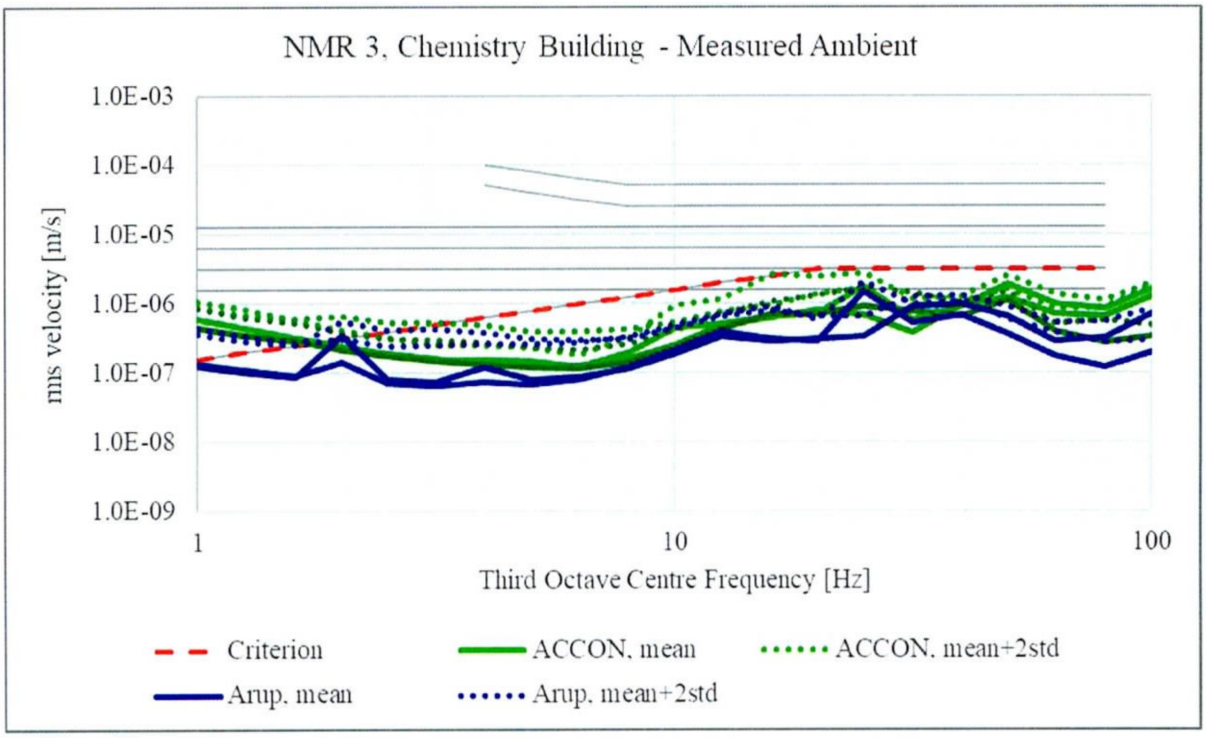
100
Third Octave Centre Frequency [Hz]
Criterion
Option2



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rms velocity [m/s]
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Third Octave Centre Frequency [Hz]
Criterion
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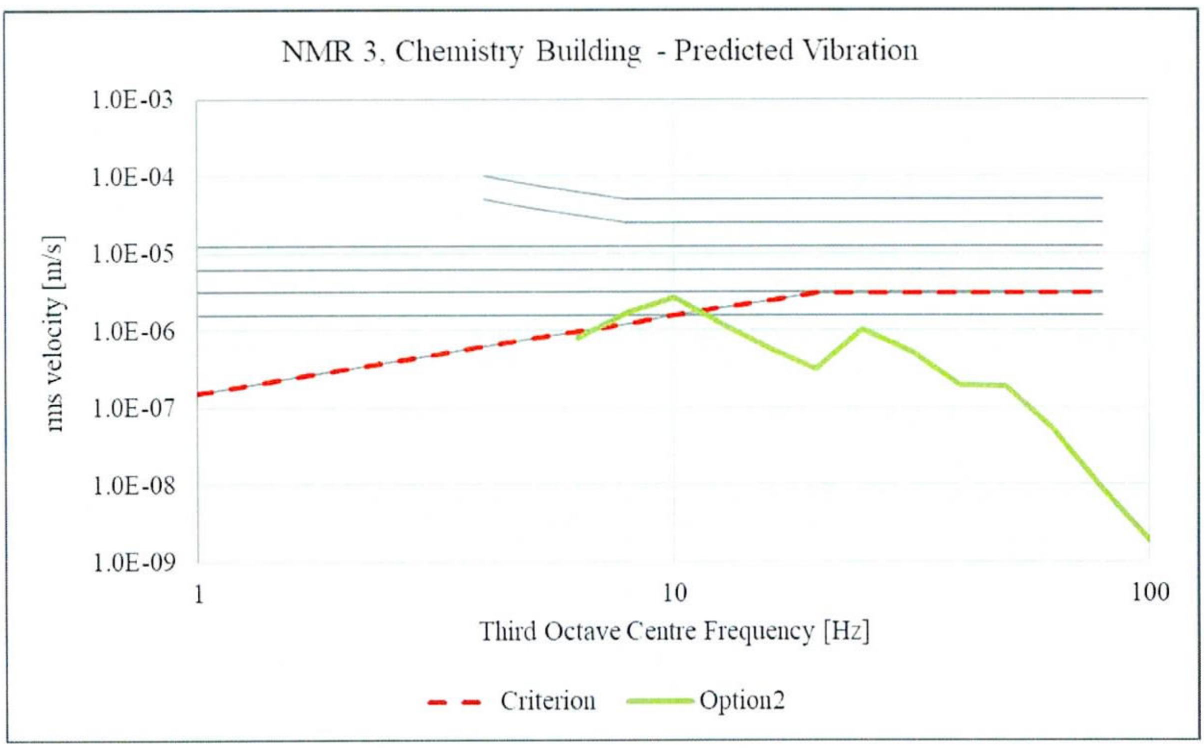
ACCON, mean+2std
Arup, mean
Arup, mean+2std



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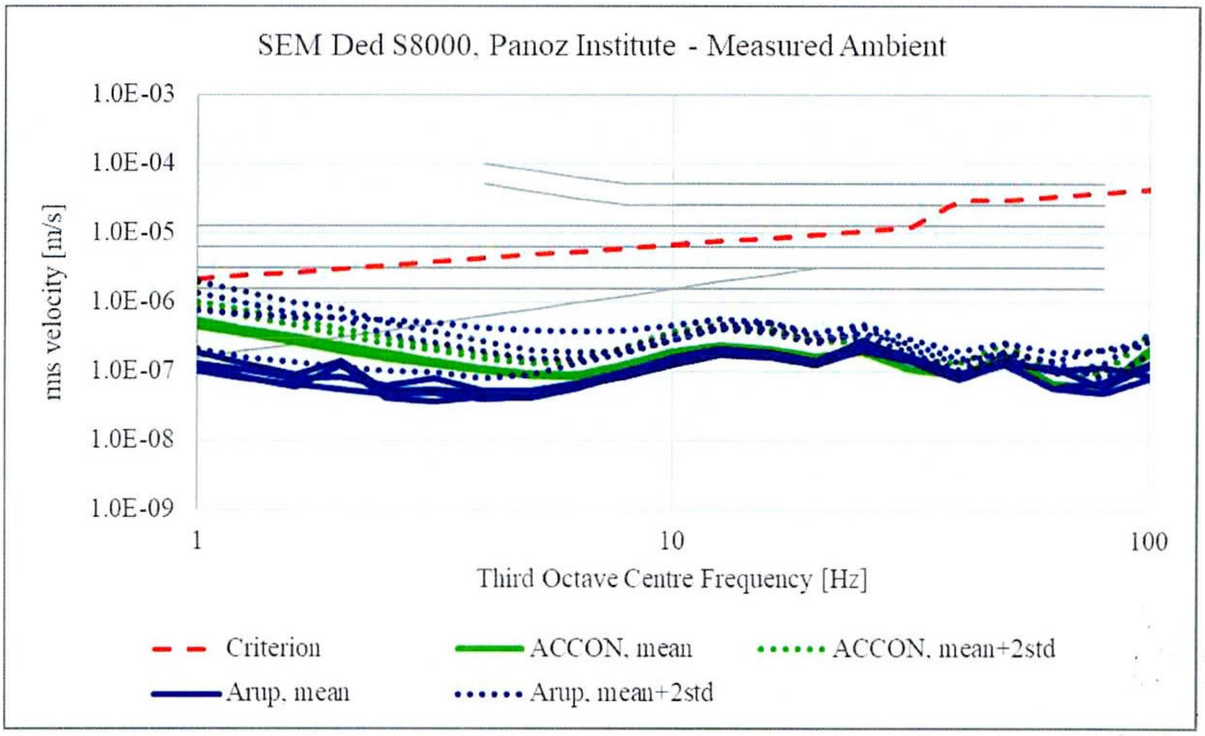
100
Third Octave Centre Frequency [Hz]
Criterion
Option2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rms velocity [m/s]
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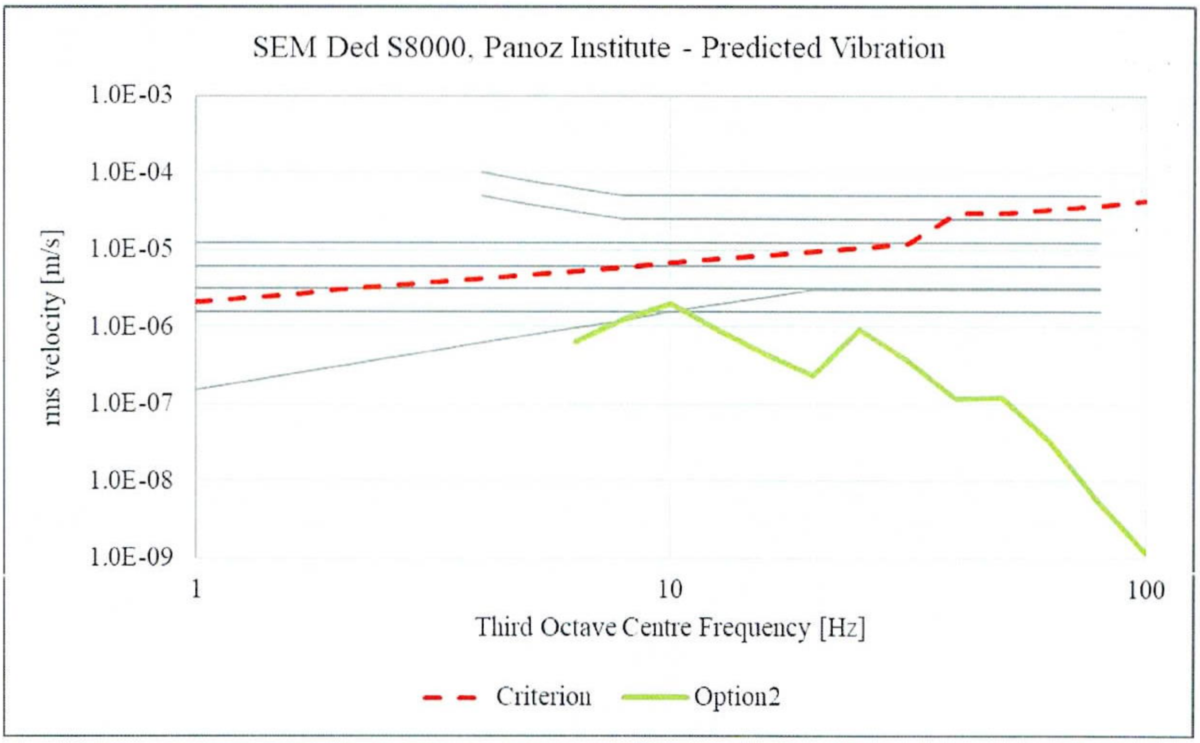
100
Third Octave Centre Frequency [Hz]
Criterion
ACCON, mean
ACCON, mean+2std
Arup, mean
Arup, mean+2std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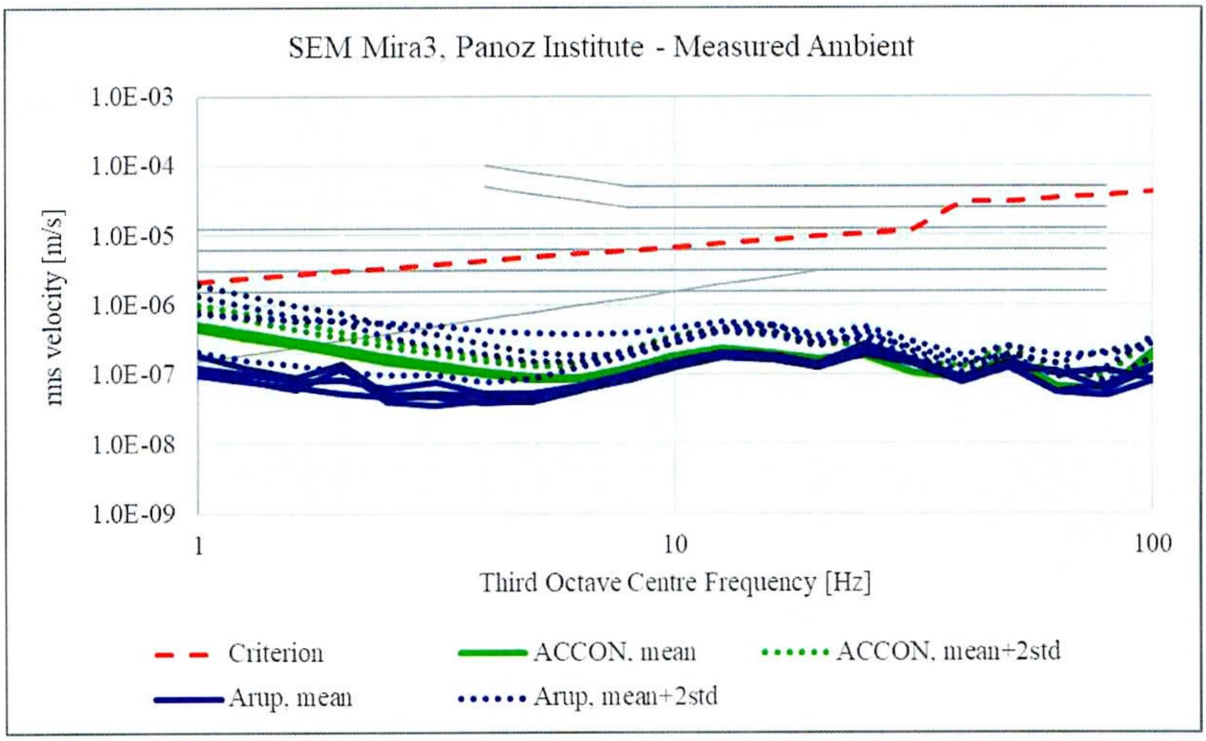
Criterion
Option2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rms velocity [m/s]
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Third Octave Centre Frequency [Hz]
Criterion
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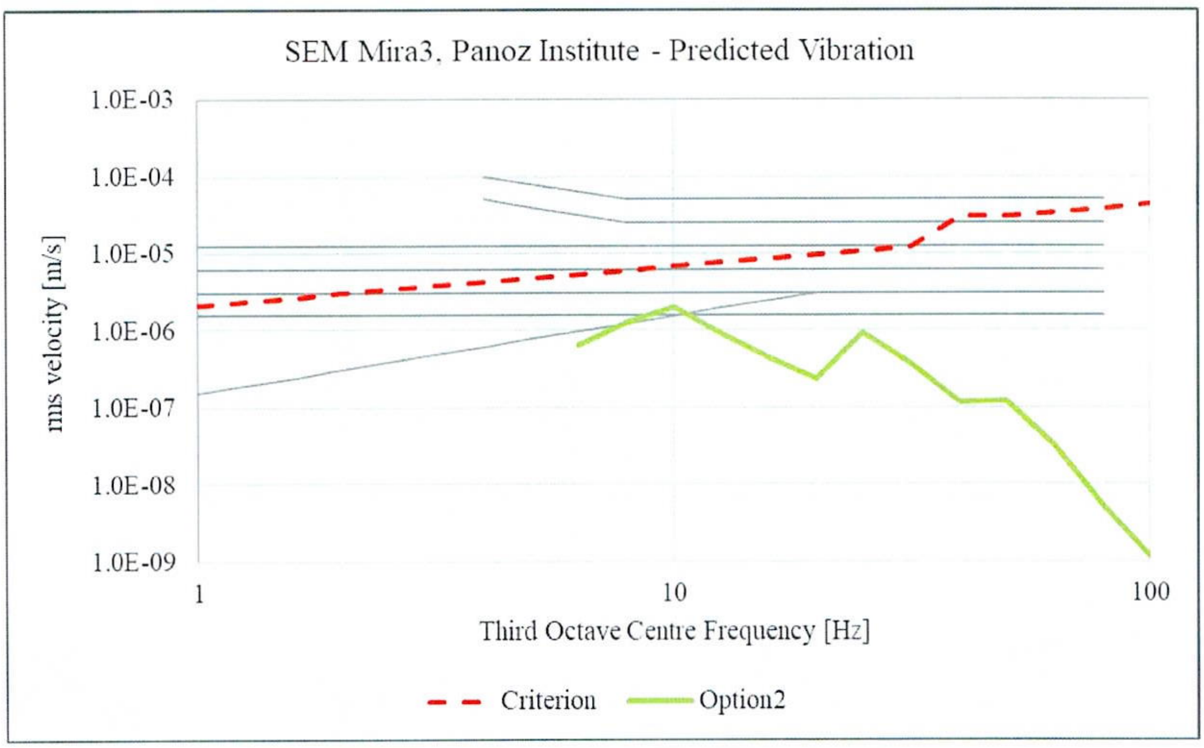
ACCON, mean+2std
Arup, mean
Arup, mean+2std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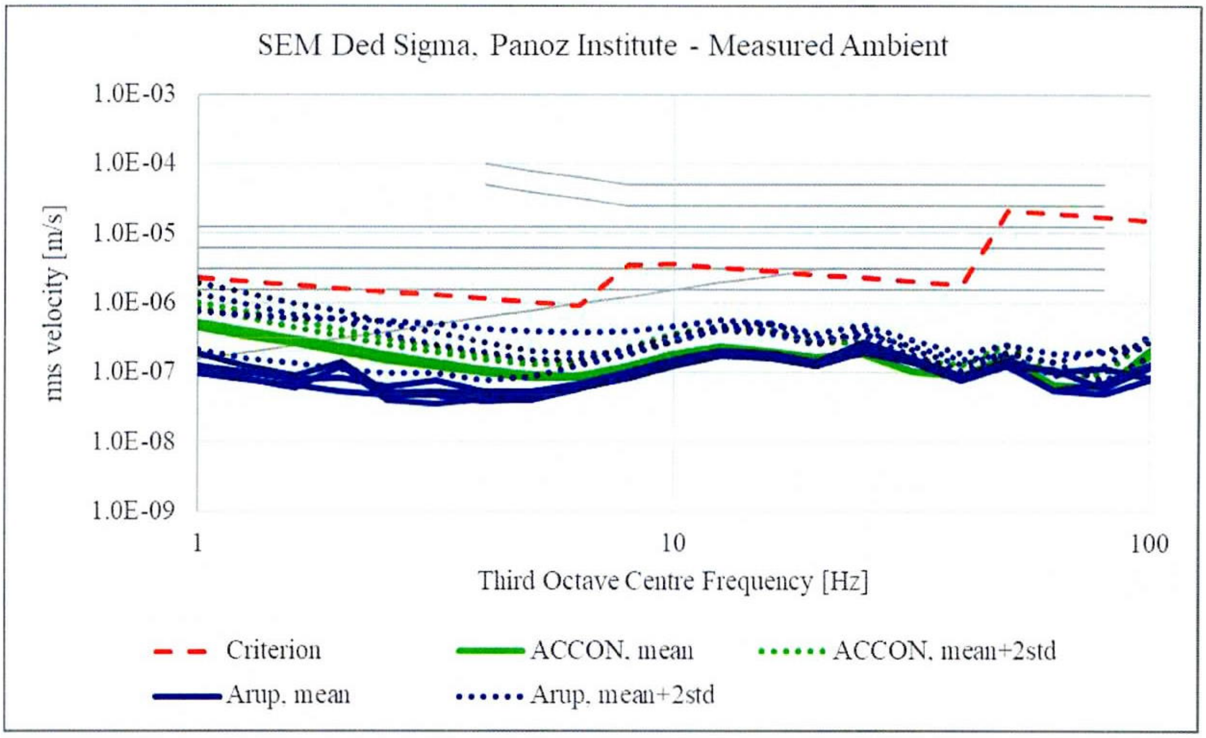
Third Octave Centre Frequency [Hz]
Criterion
Option2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rms velocity [m/s]
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Third Octave Centre Frequency [Hz]
Criterion
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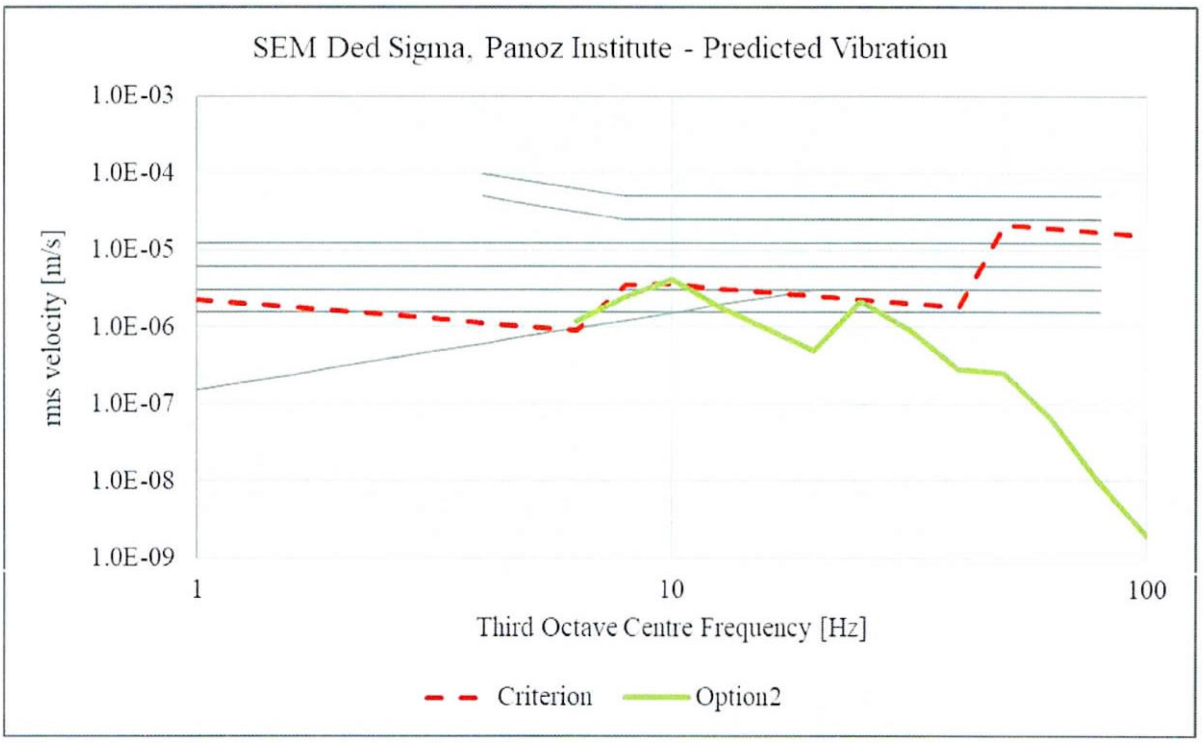
ACCON, mean+2std
Arup, mean
Arup, mean+2std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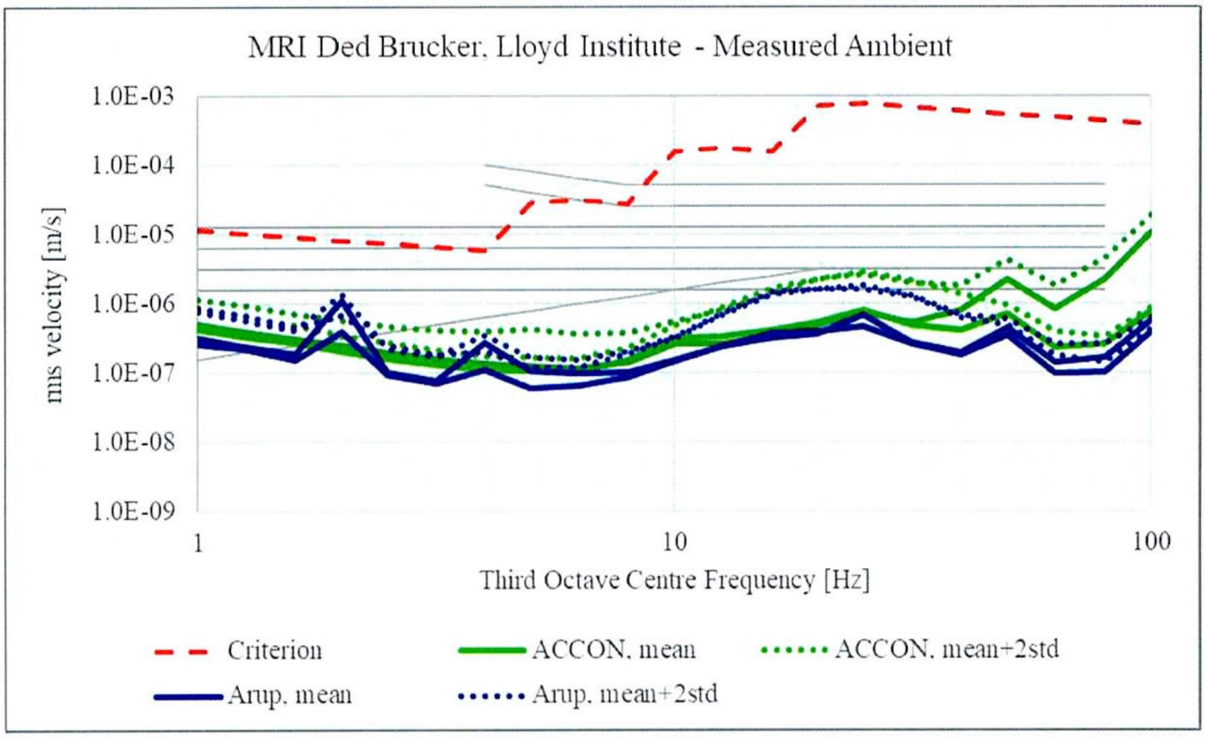
Criterion
Option2


MRI Ded Brucker, Lloyd Institute - Measured Ambient
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1.0E-07
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1.0E-09
rms velocity [m/s]
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Third Octave Centre Frequency [Hz]
Criterion
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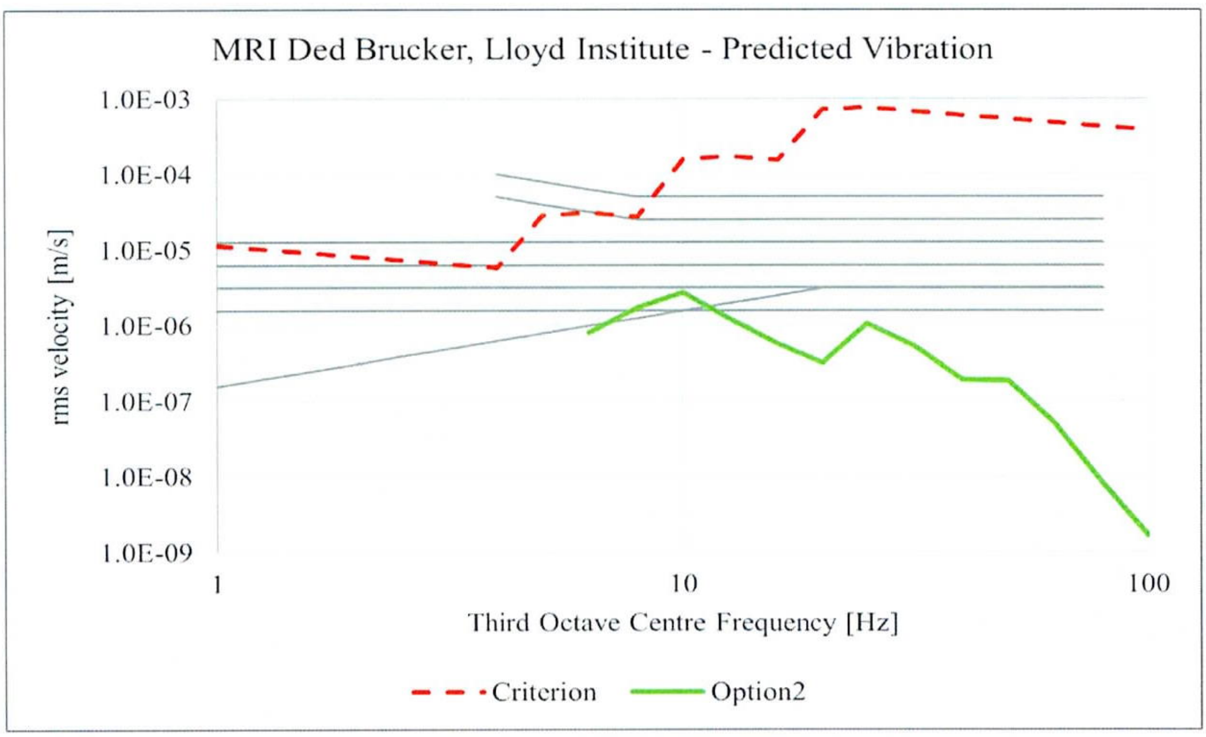
ACCON, mean+2std
Arup, mean
Arup, mean+2std


MRI Ded Brucker, Lloyd Institute - Predicted Vibration
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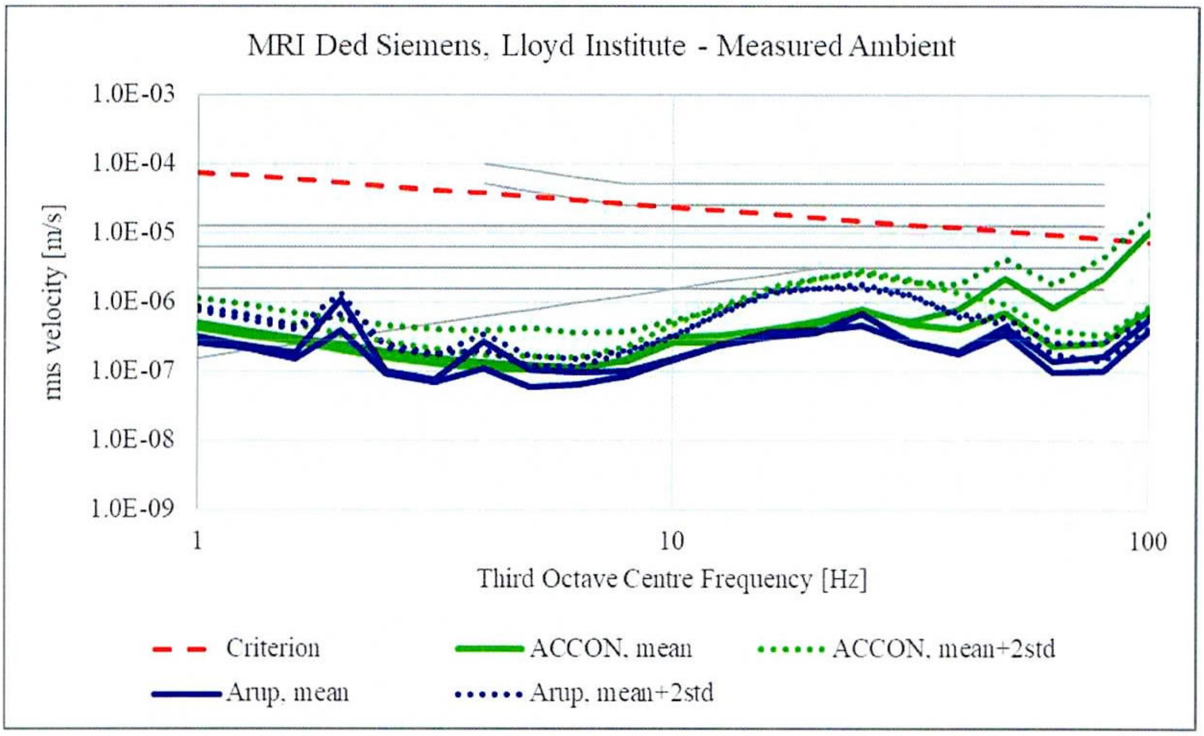
Criterion
Option2


MRI Ded Siemens, Lloyd Institute - Measured Ambient
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Third Octave Centre Frequency [Hz]
Criterion
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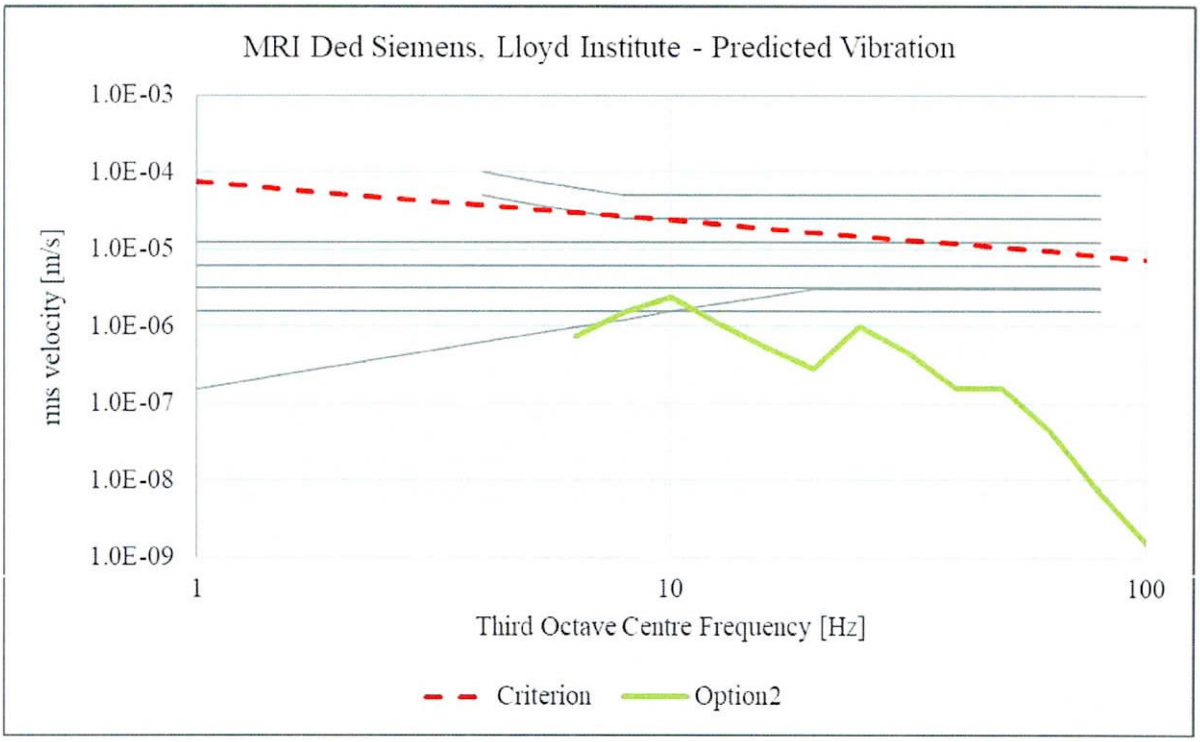
ACCON, mean+2std
Arup, mean
Arup, mean+2std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rms velocity [m/s]
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10
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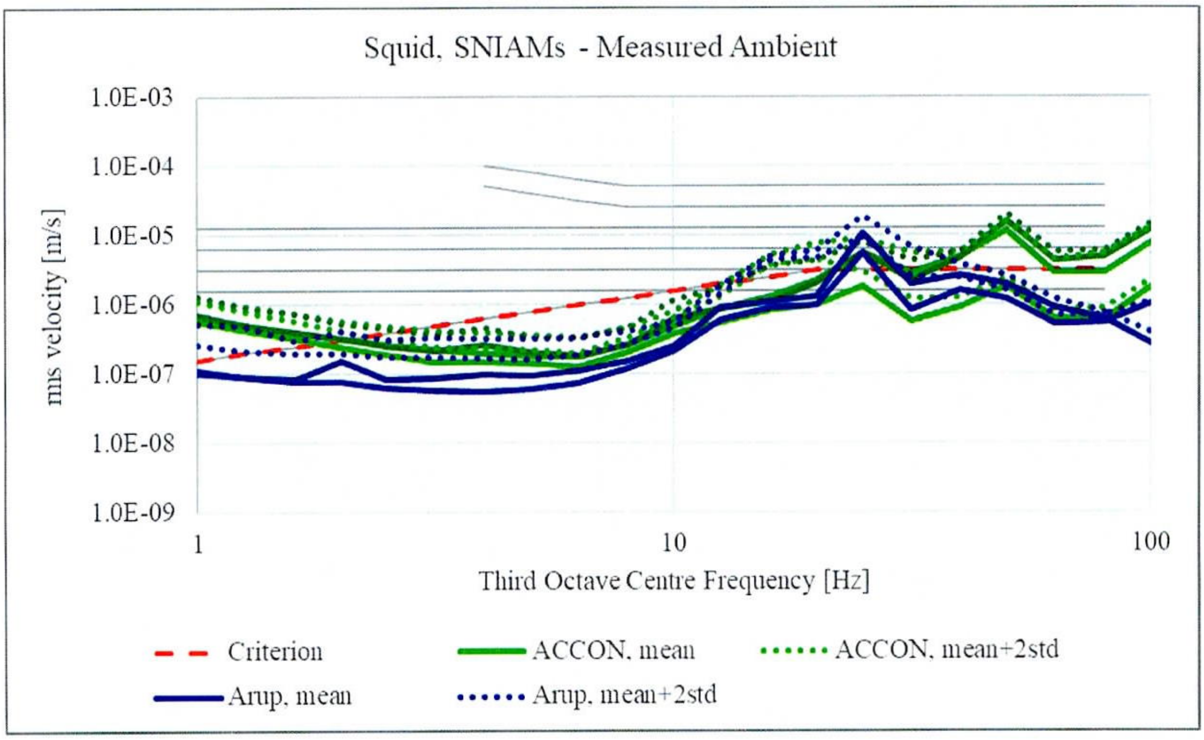
Third Octave Centre Frequency [Hz]
Criterion
Option2



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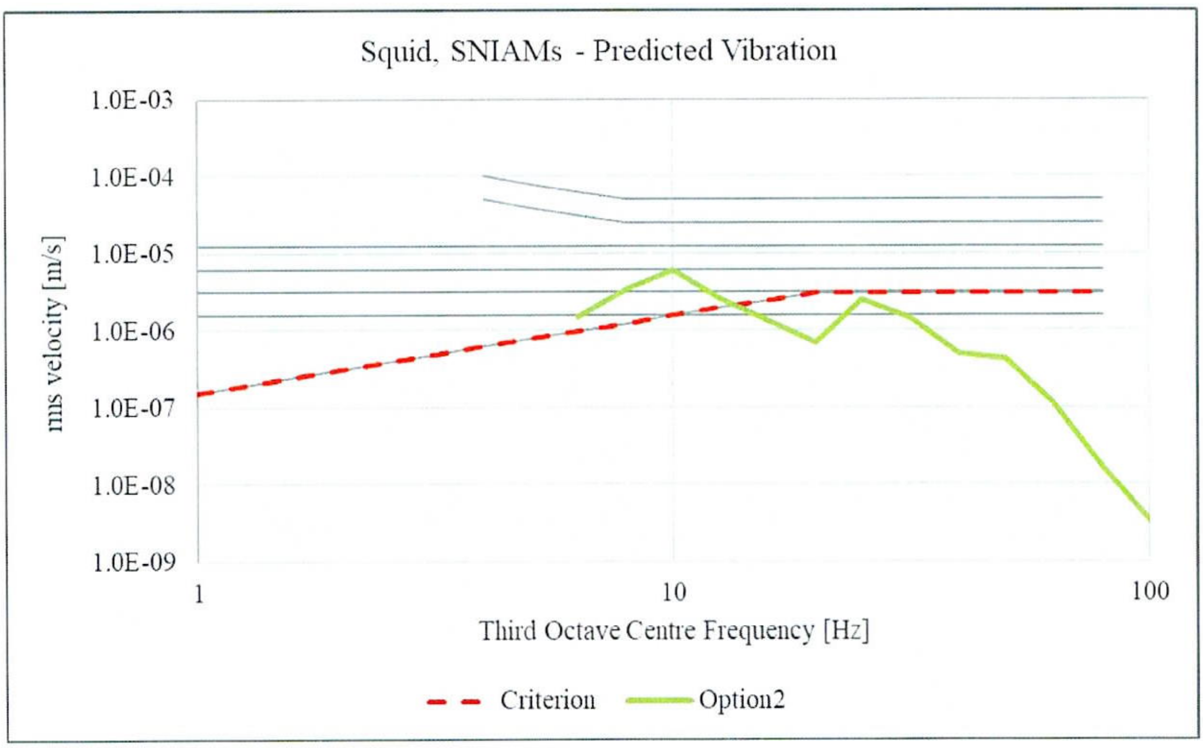
ACCON, mean+2std
Arup, mean
Arup, mean+2std



Squid, SNIAMs - Predicted Vibration
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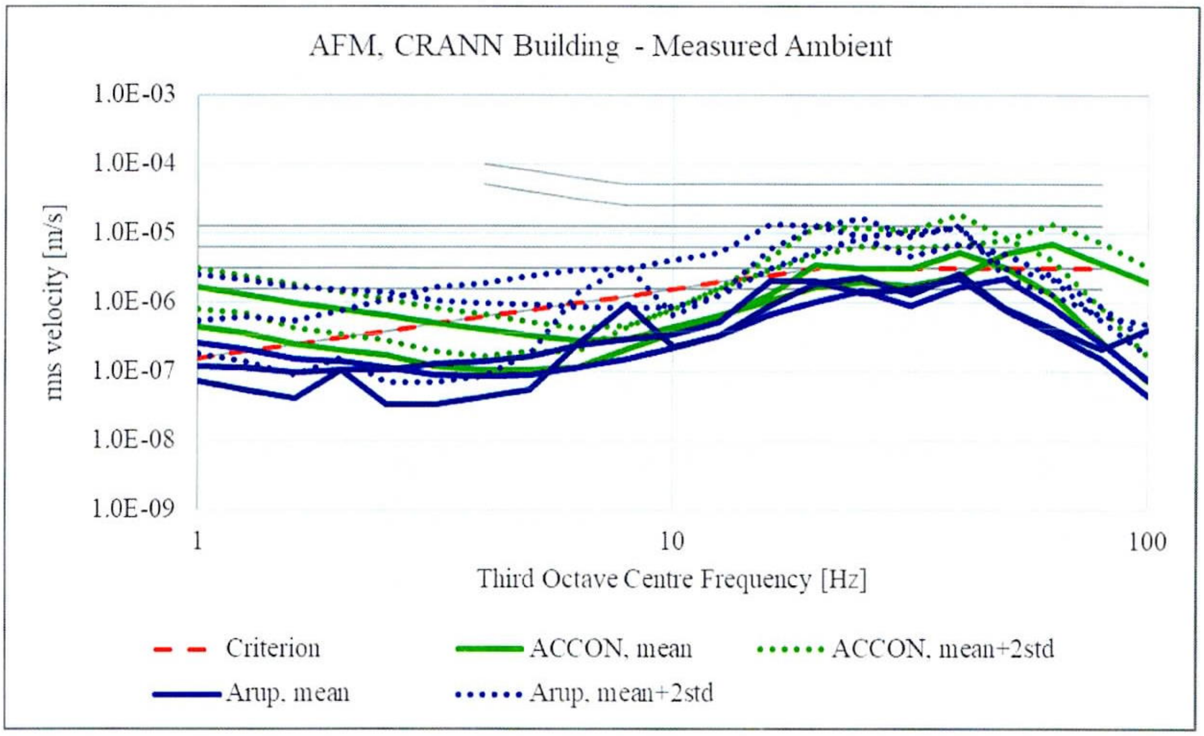
Criterion
Option2



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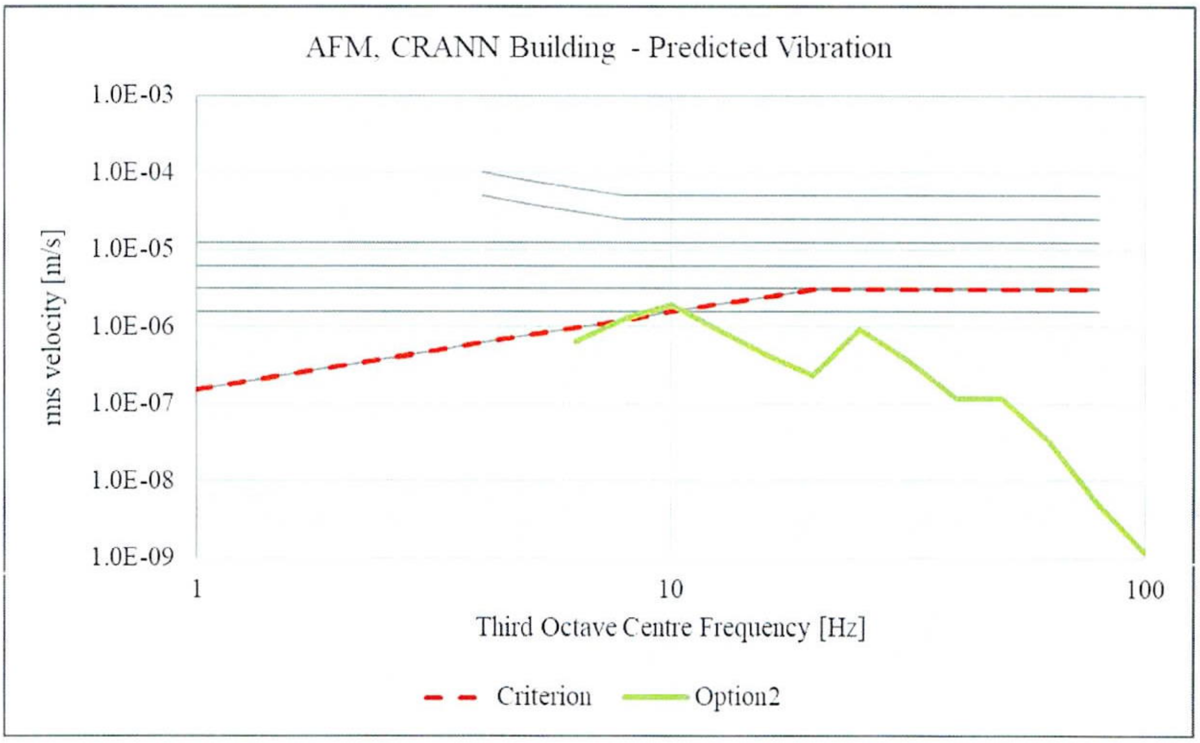
Arup, mean
Arup, mean+2std



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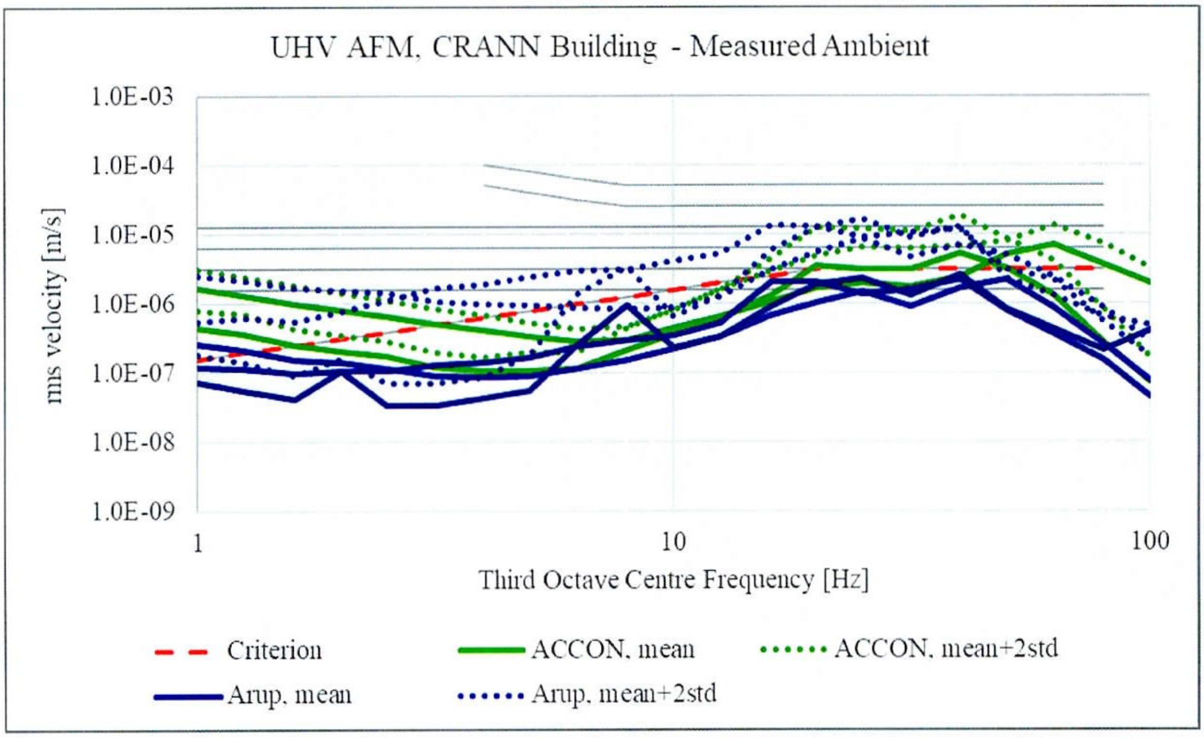
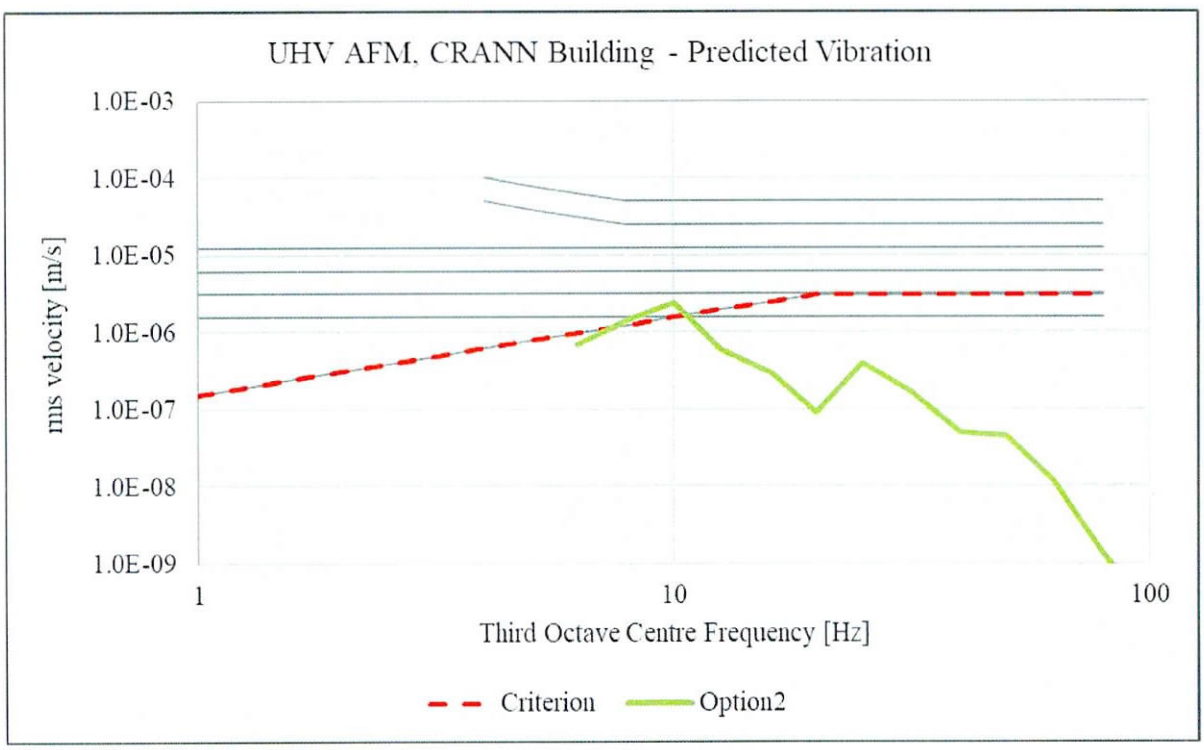
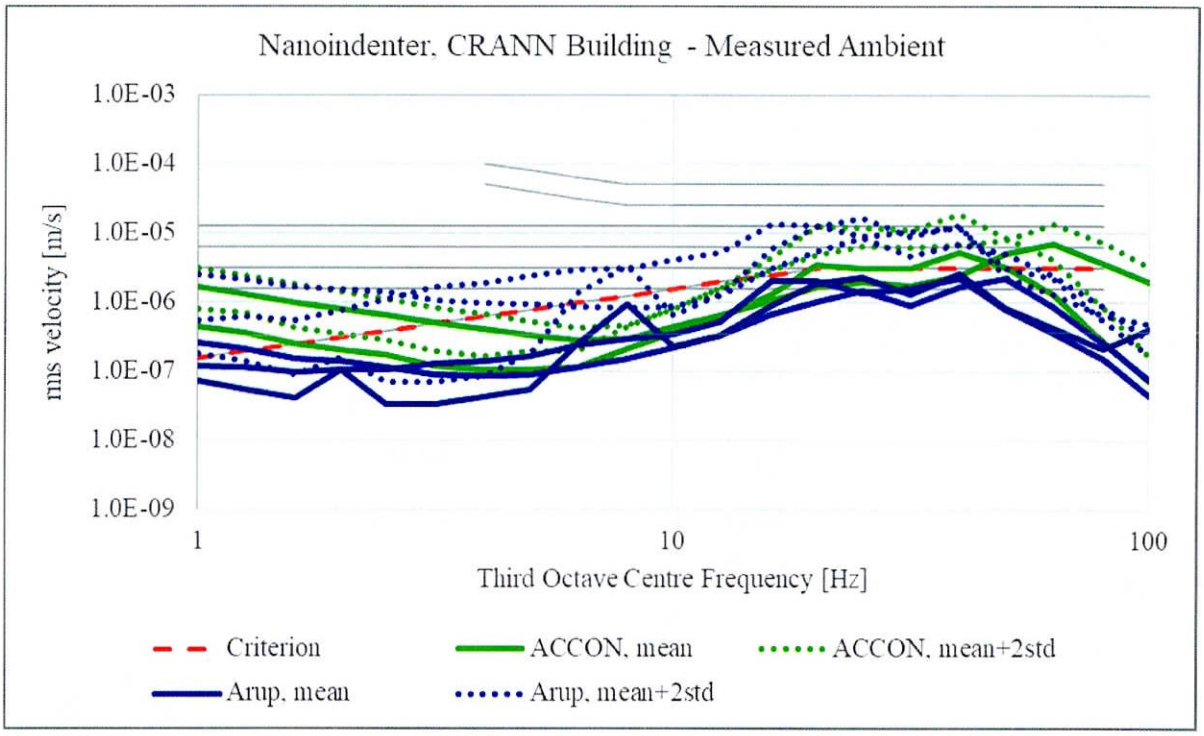
1
10
100
Third Octave Centre Frequency [Hz]
rms velocity [m/s]
Criterion
Option2

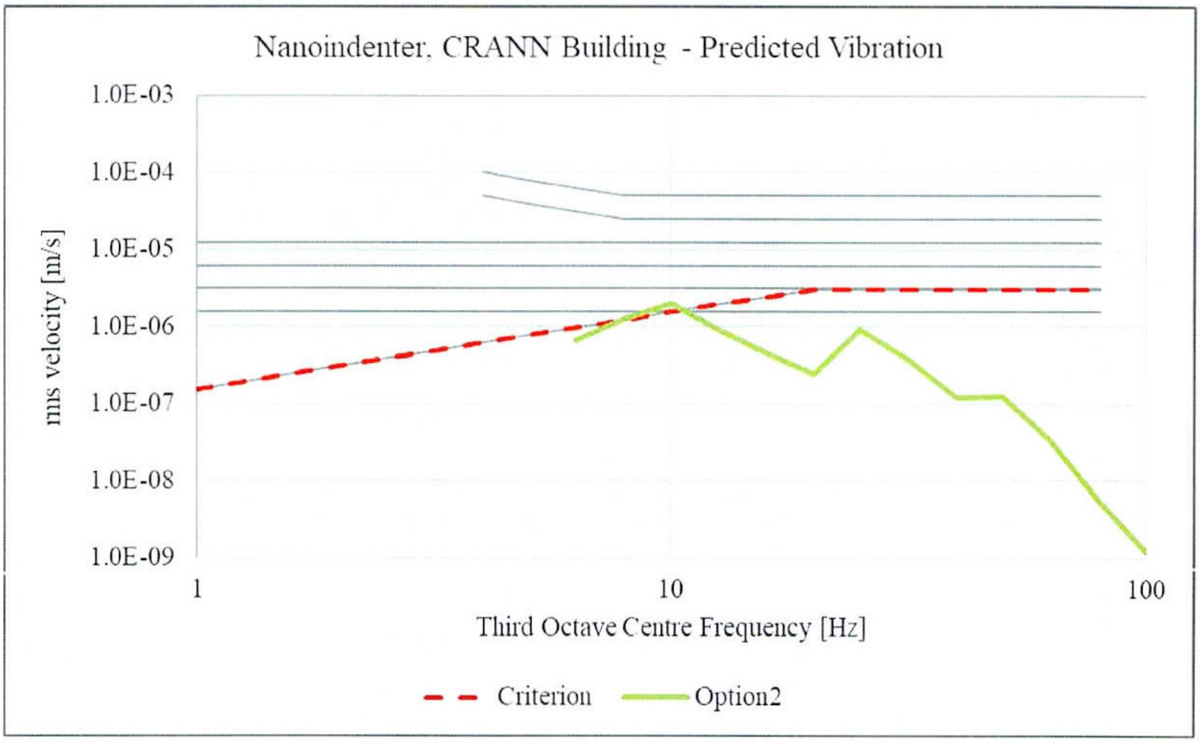


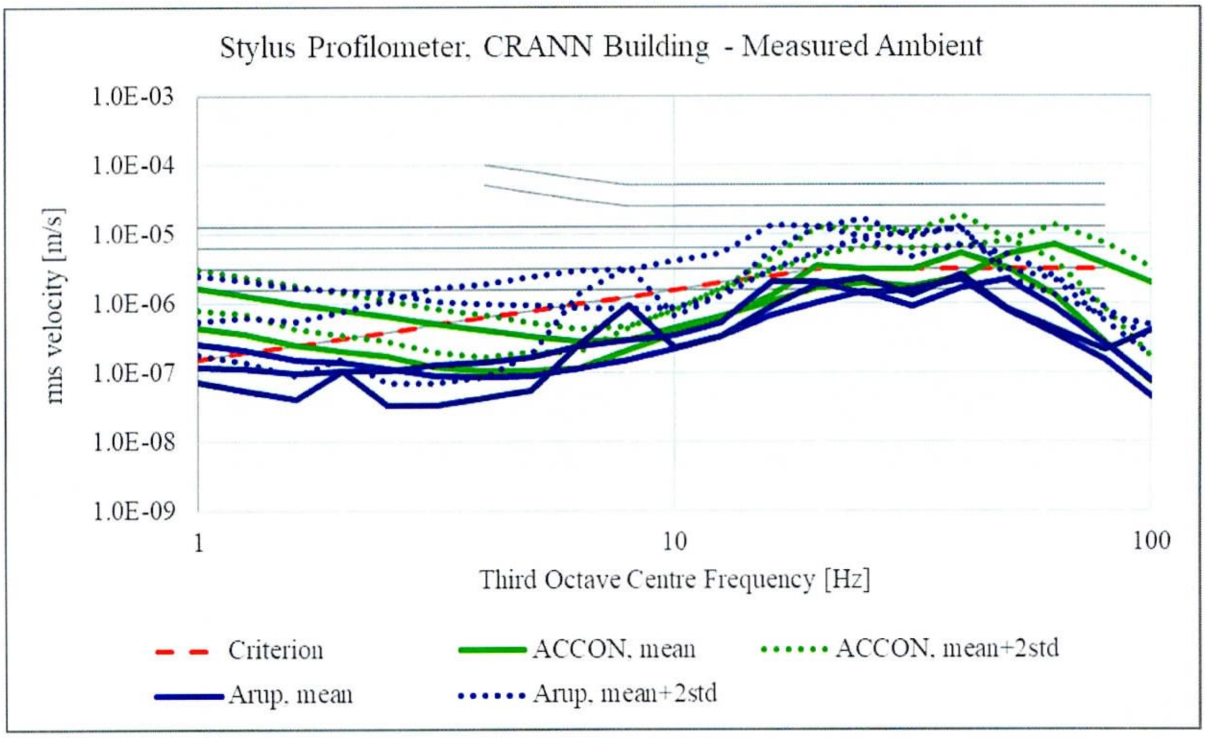
UHV AFM, CRANN Building - Measured Ambient
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
ACCON, mean
ACCON, mean+2std
Arup, mean
Arup, mean+2std

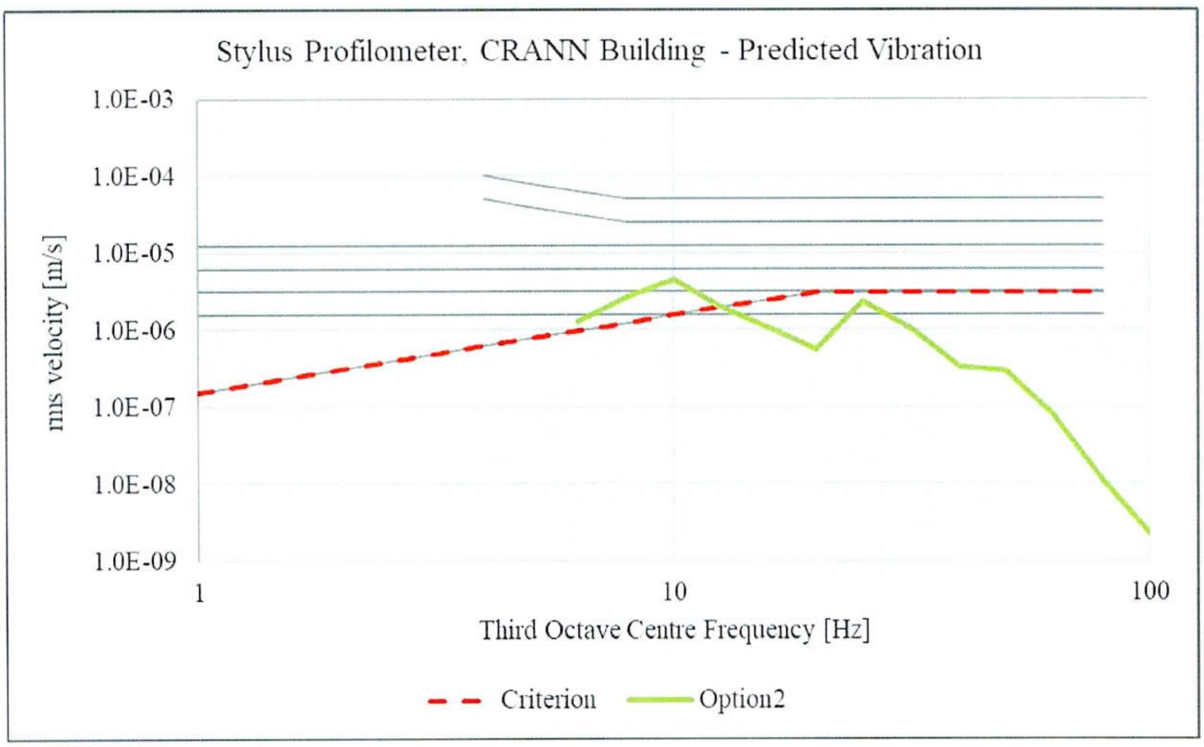


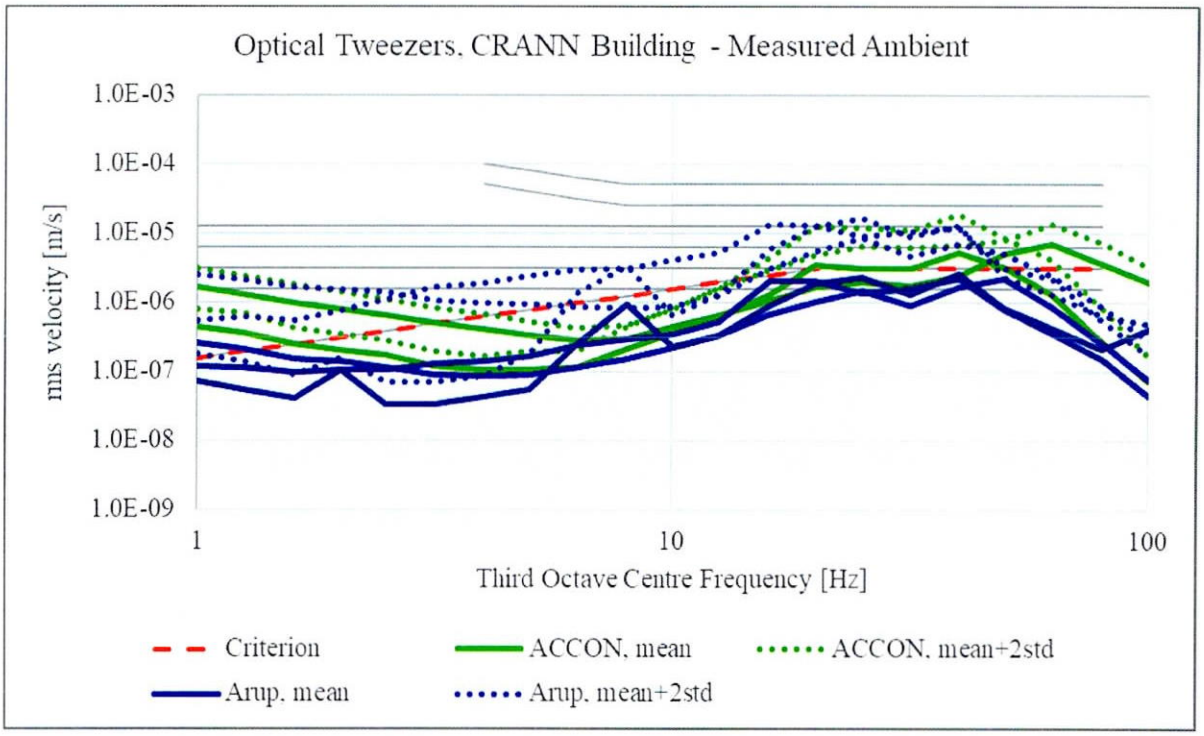
UHV AFM, CRANN Building - Predicted Vibration
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
Option2

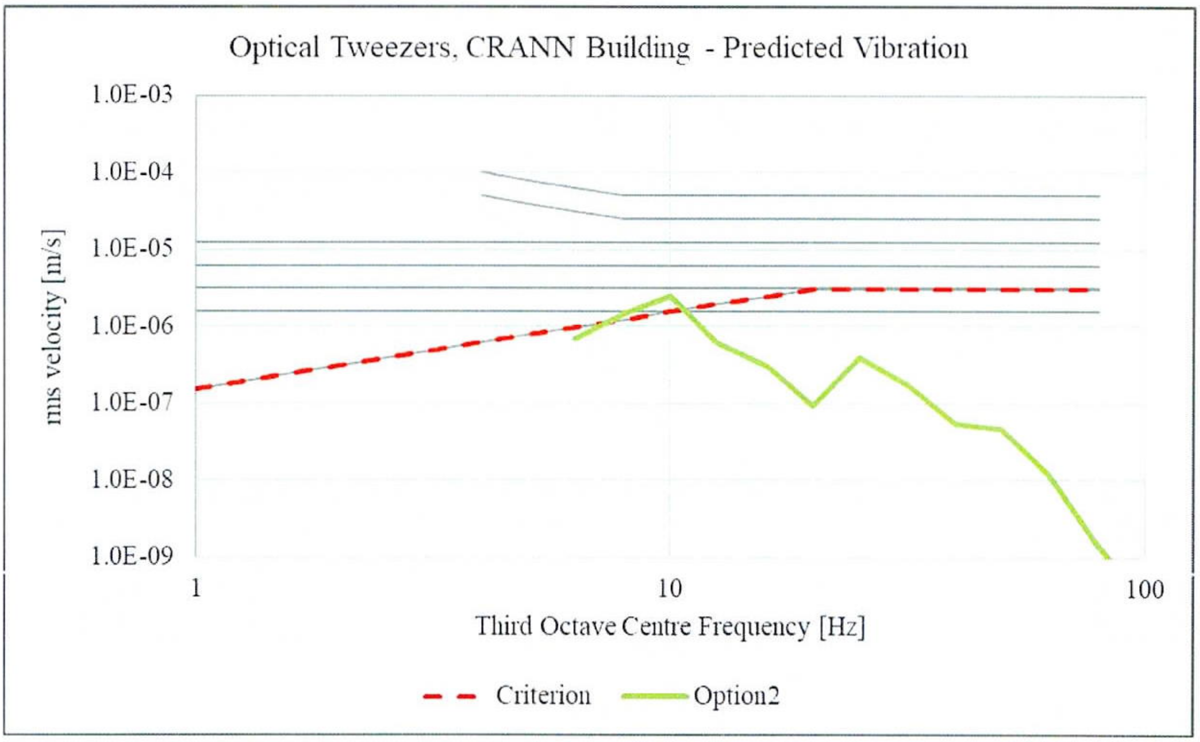

Nanoindenter, CRANN Building - Measured Ambient
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
ACCON, mean
ACCON, mean+2std
Arup, mean
Arup, mean+2std

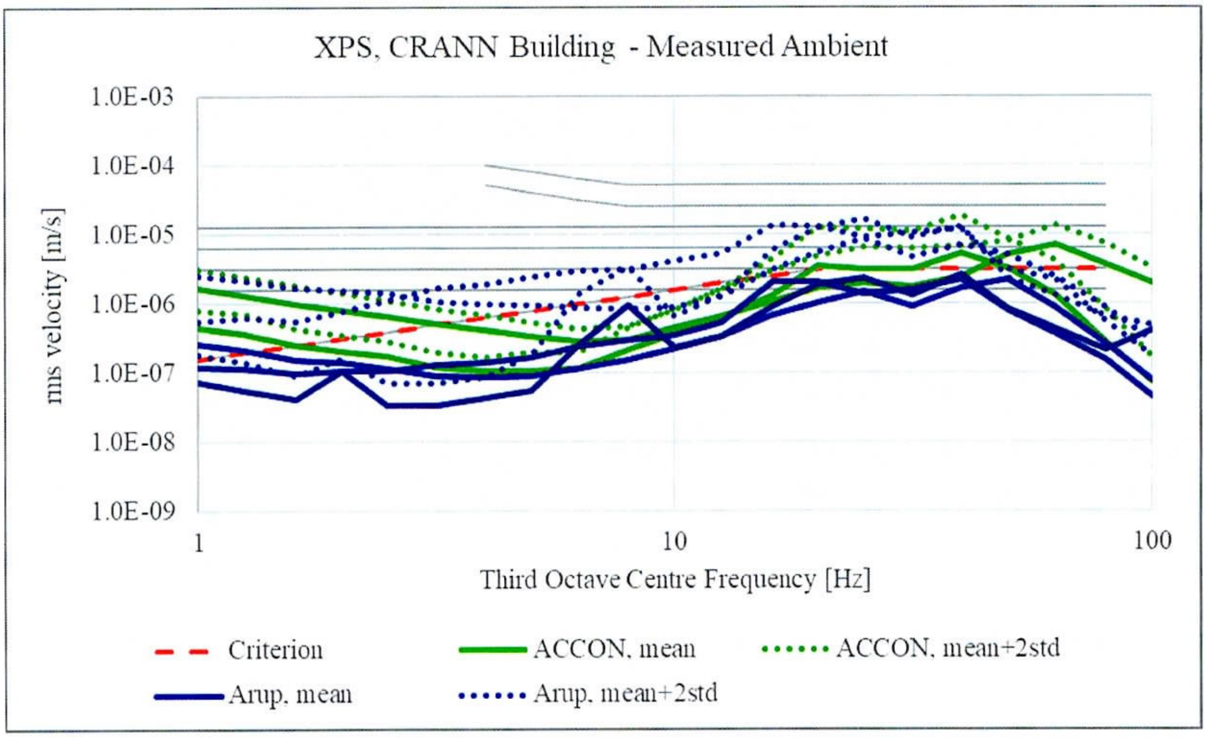

Nanoindenter, CRANN Building - Predicted Vibration
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
Option2

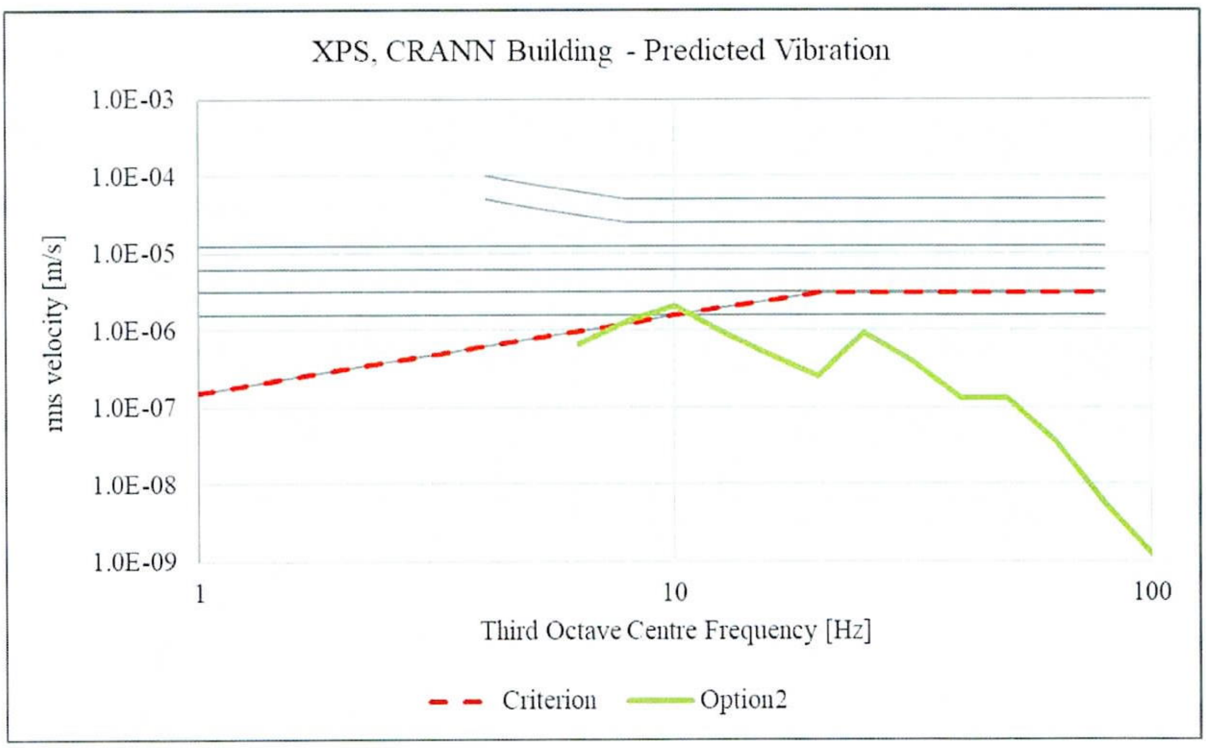

Stylus Profilometer, CRANN Building - Measured Ambient
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
ACCON, mean
ACCON, mean+2std
Arup, mean
Arup, mean+2std

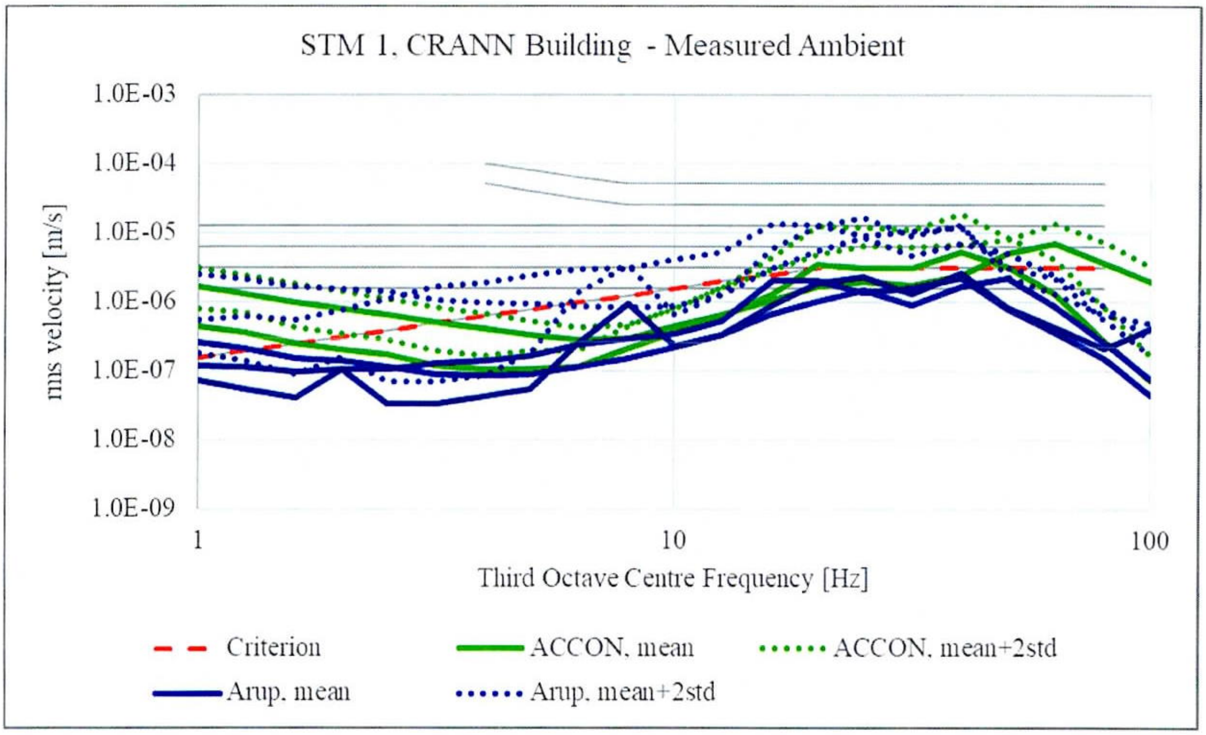

Stylus Profilometer, CRANN Building - Predicted Vibration
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
Option2

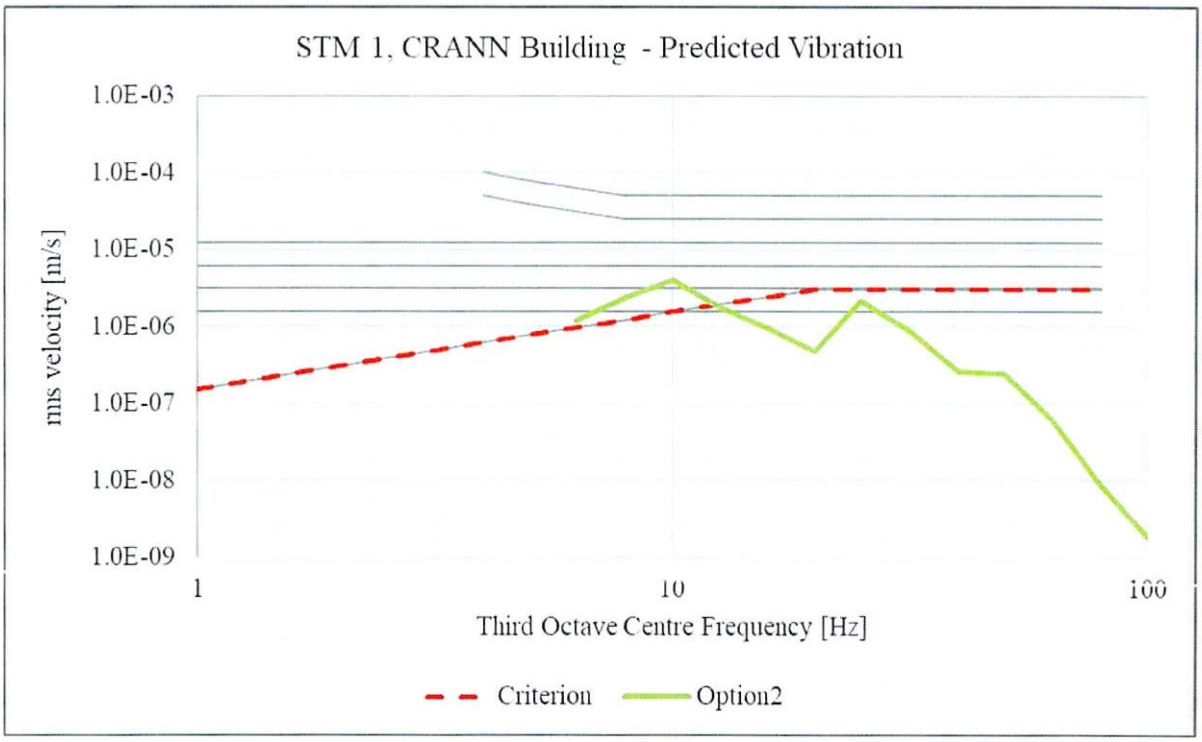

Optical Tweezers, CRANN Building - Measured Ambient
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
ACCON, mean
ACCON, mean+2std
Arup, mean
Arup, mean+2std

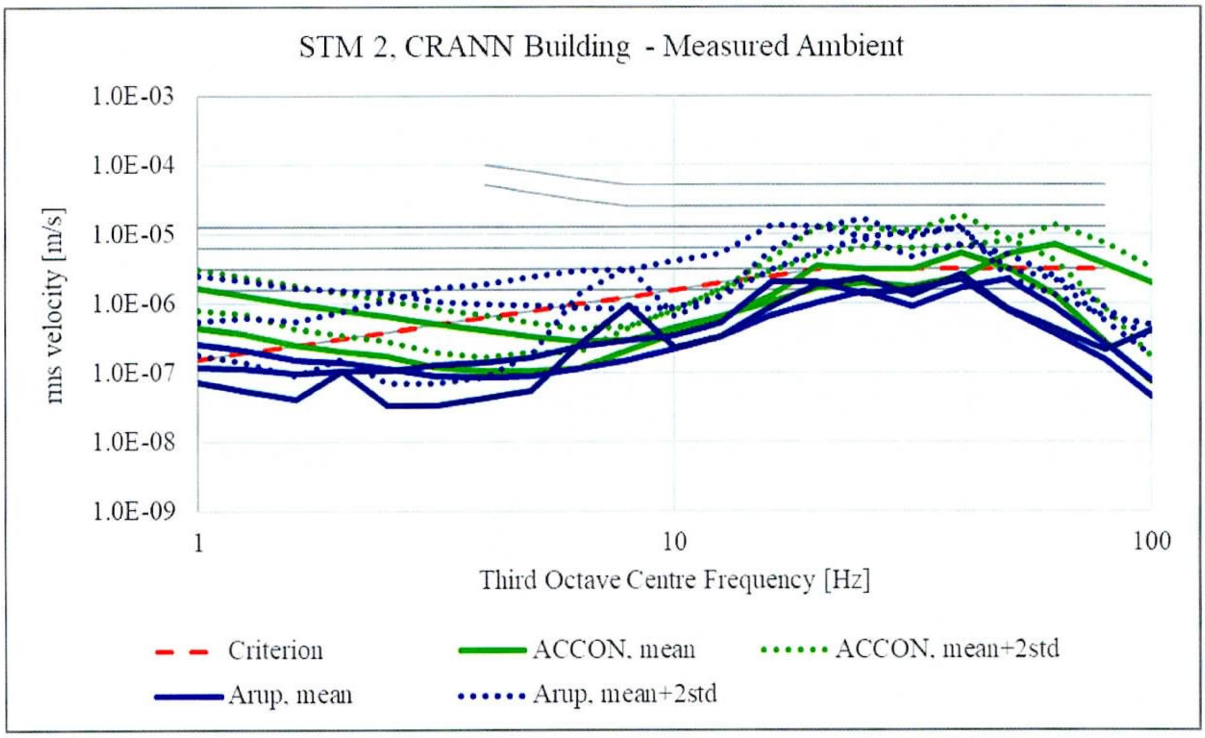

Optical Tweezers, CRANN Building - Predicted Vibration
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
Option2

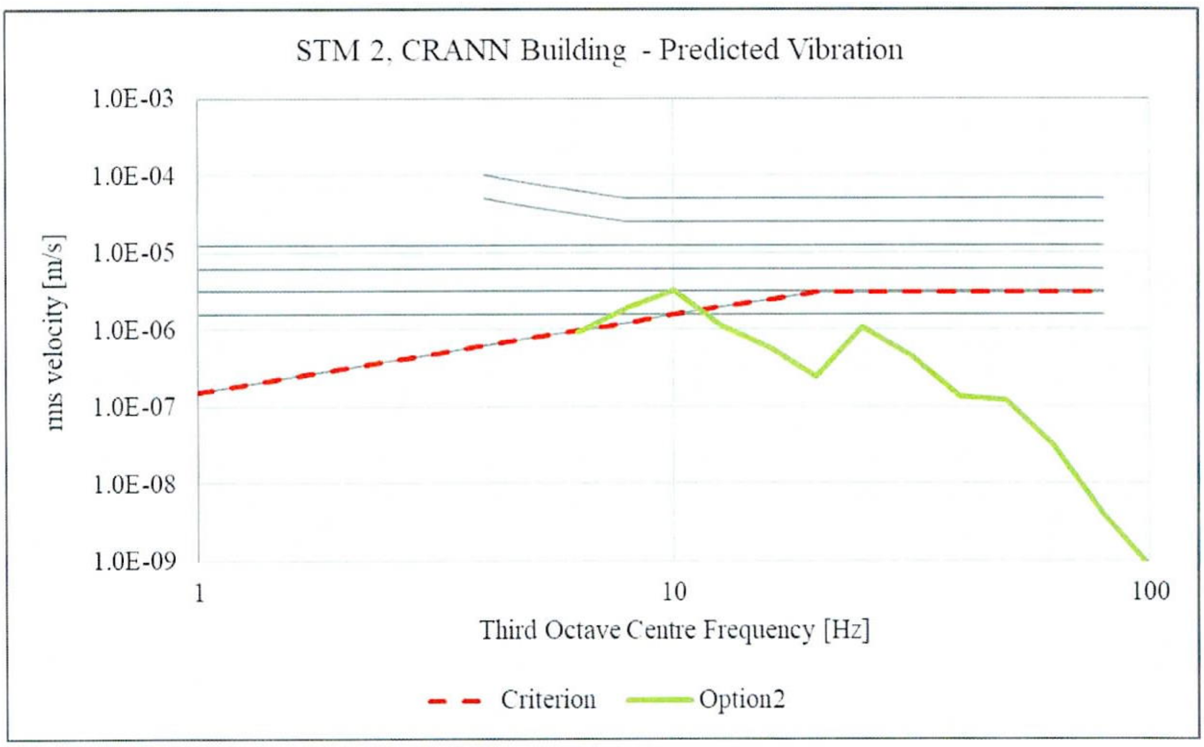

XPS, CRANN Building - Measured Ambient
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
ACCON, mean
ACCON, mean+2std
Arup, mean
Arup, mean+2std

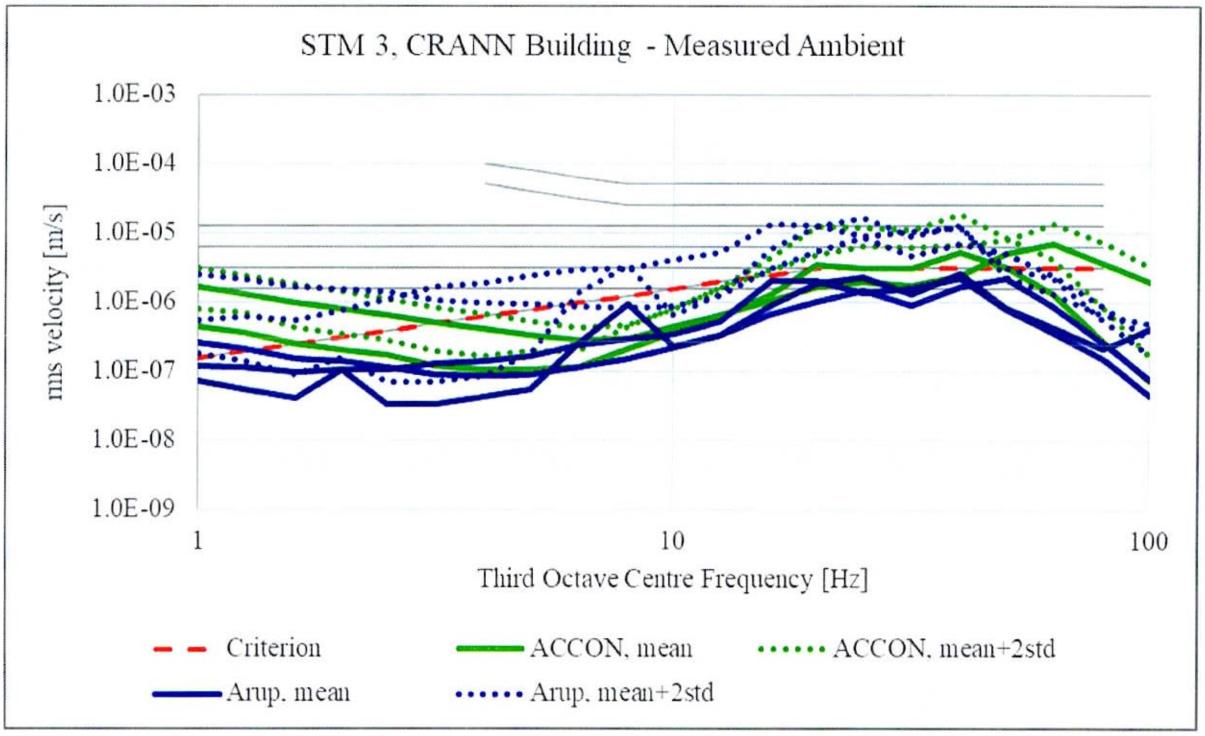

XPS, CRANN Building - Predicted Vibration
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
Option2


STM 1, CRANN Building - Measured Ambient
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
ACCON, mean
ACCON, mean+2std
Arup, mean
Arup, mean+2std

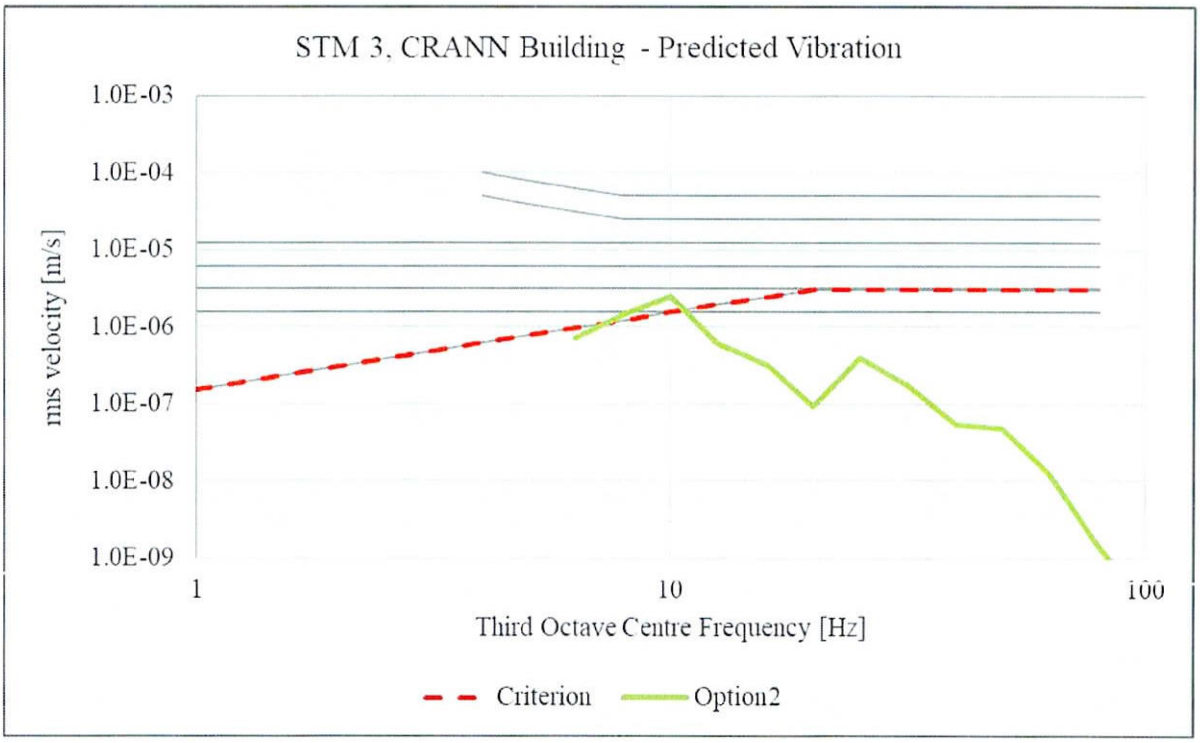

STM 1, CRANN Building - Predicted Vibration
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
Option2


STM 2, CRANN Building - Measured Ambient
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
ACCON, mean
ACCON, mean+2std
Arup, mean
Arup, mean+2std

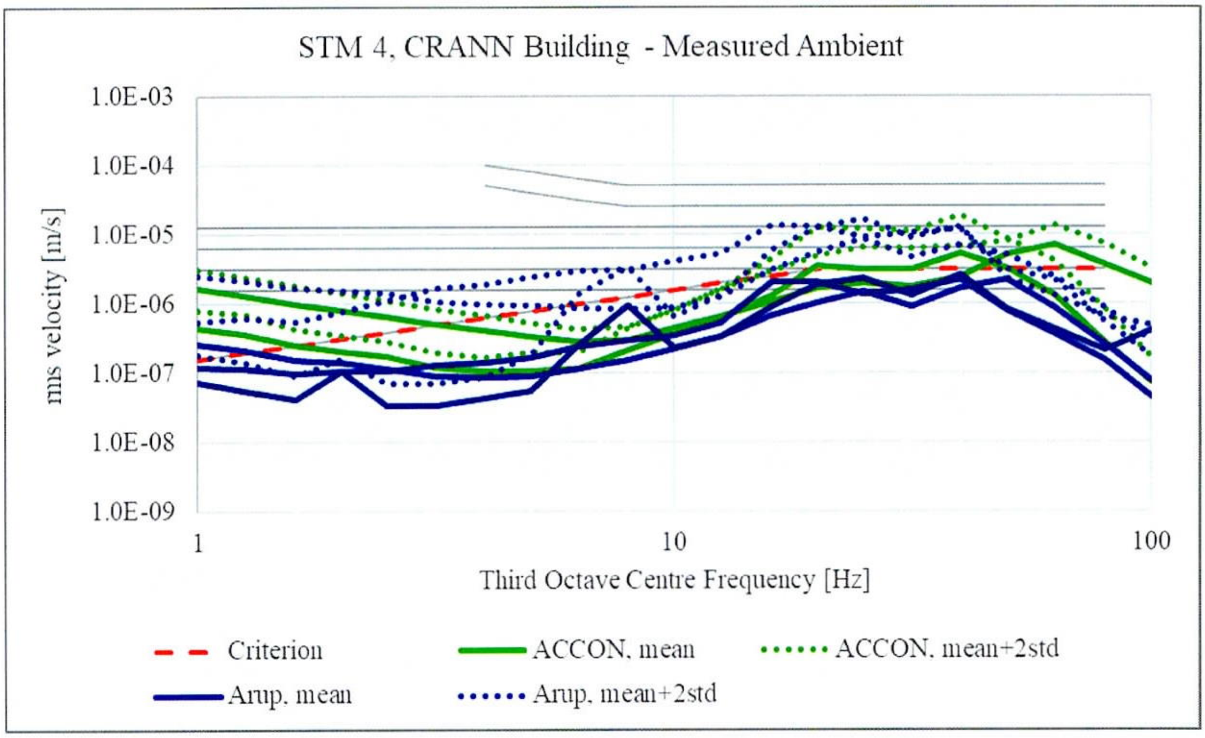

STM 2, CRANN Building - Predicted Vibration
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
Option2

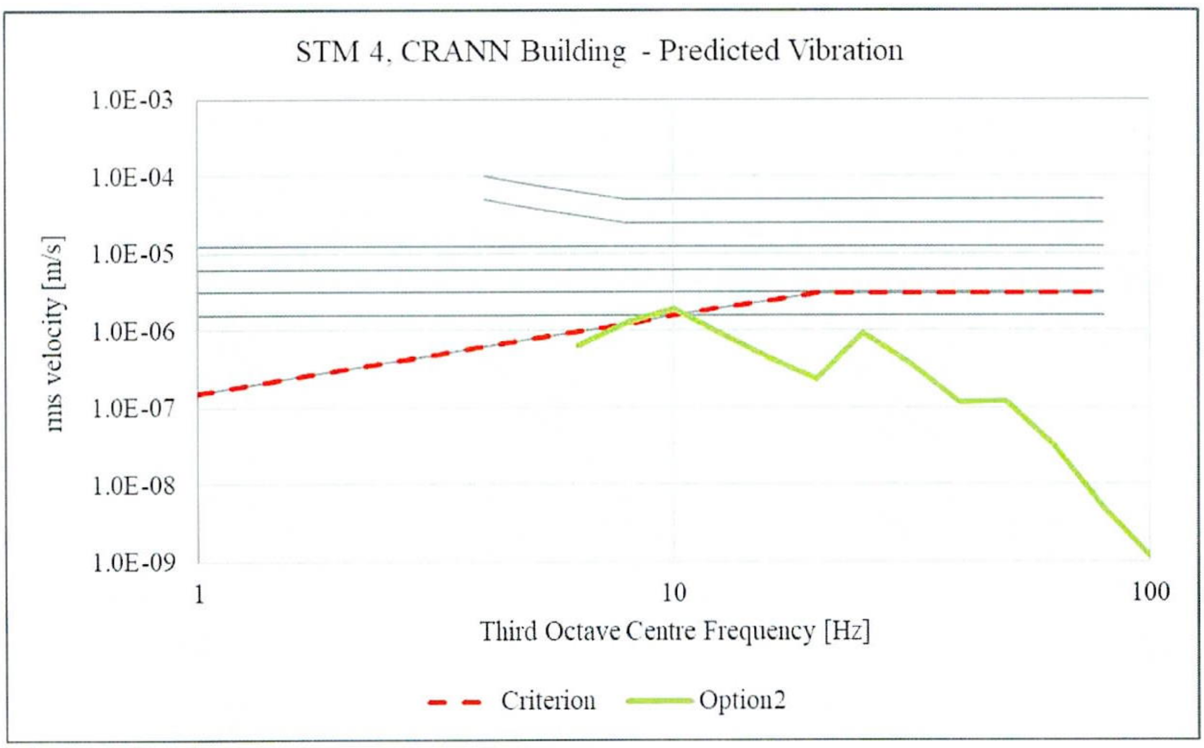


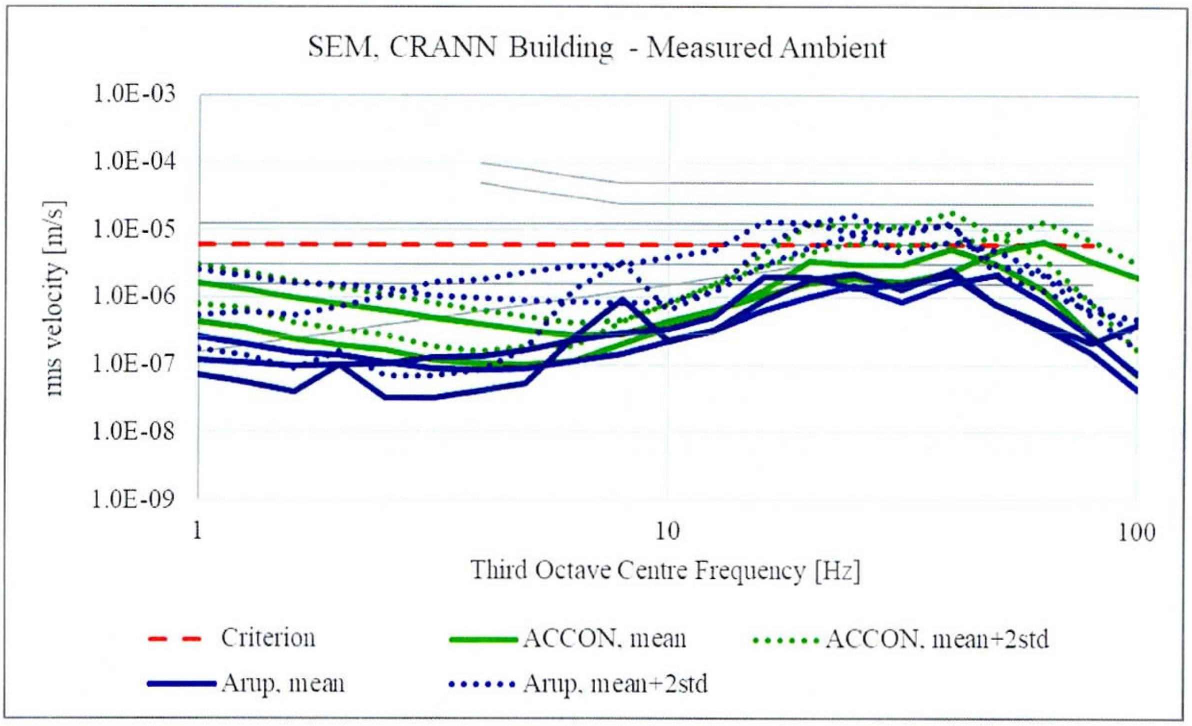
STM 3, CRANN Building - Measured Ambient
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
ACCON, mean
ACCON, mean+2std
Arup, mean
Arup, mean+2std

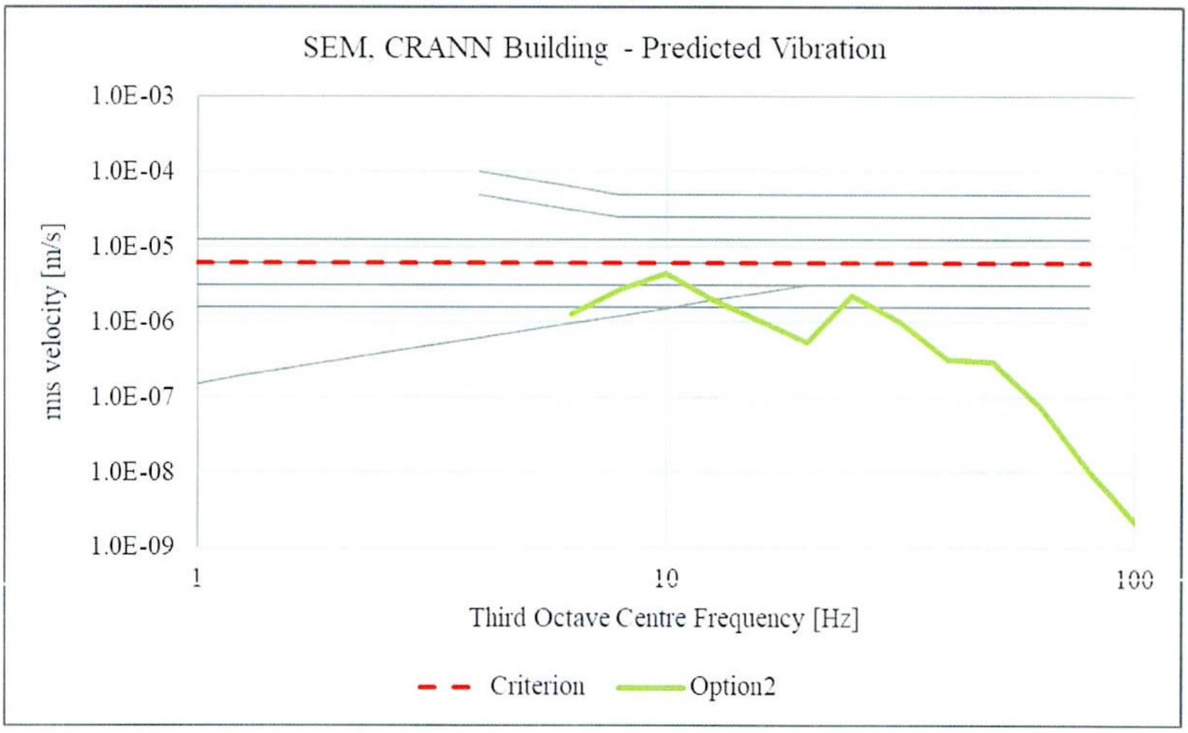


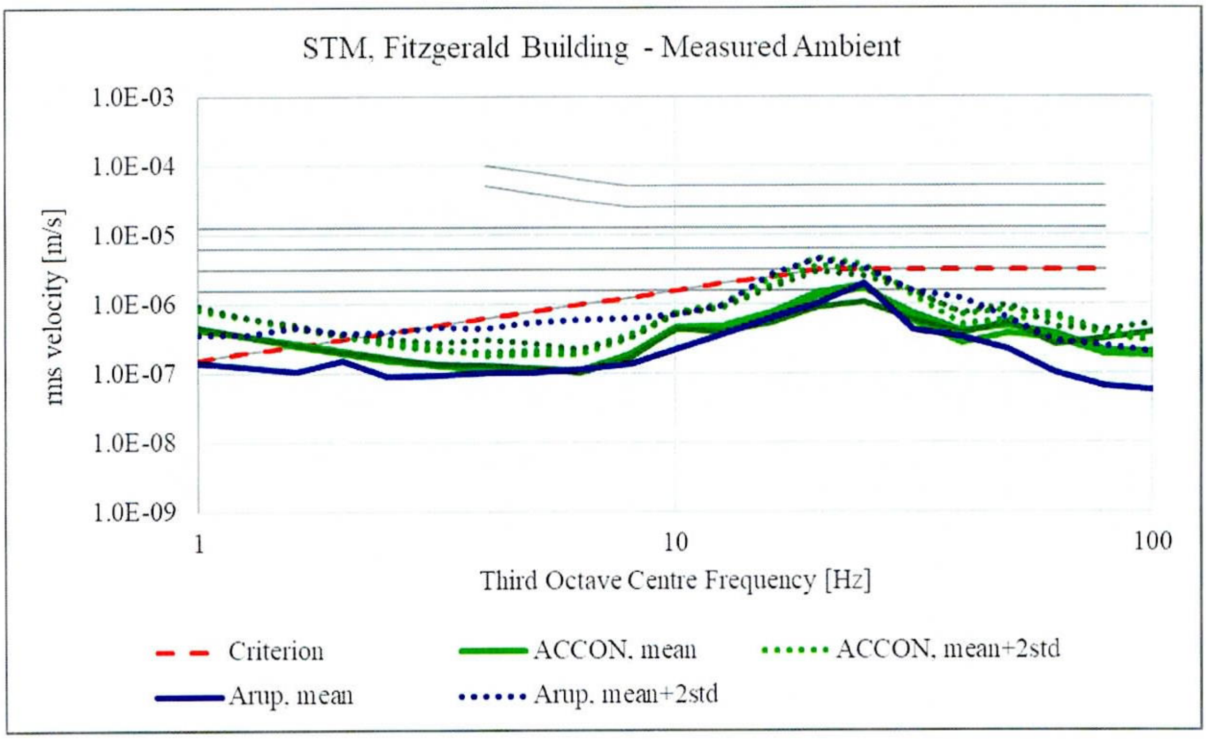
STM 3, CRANN Building - Predicted Vibration
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
Option2

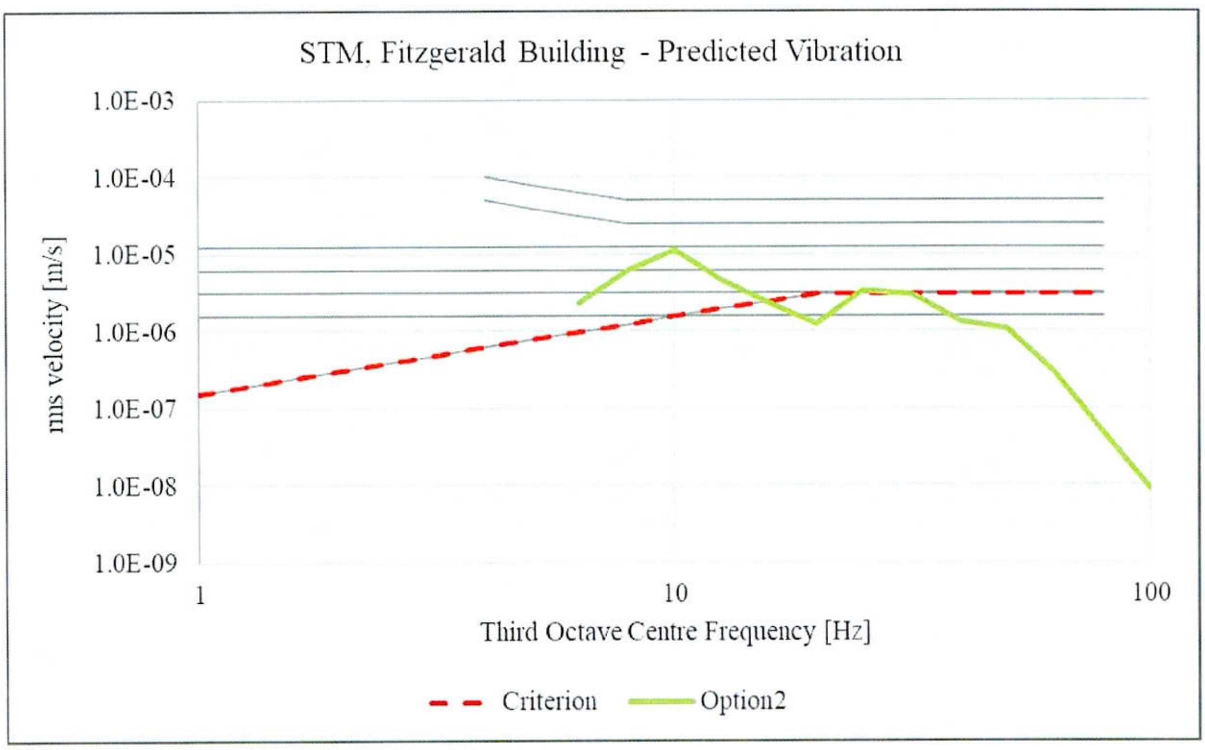

STM 4, CRANN Building - Measured Ambient
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
ACCON, mean
ACCON, mean+2std
Arup, mean
Arup, mean+2std

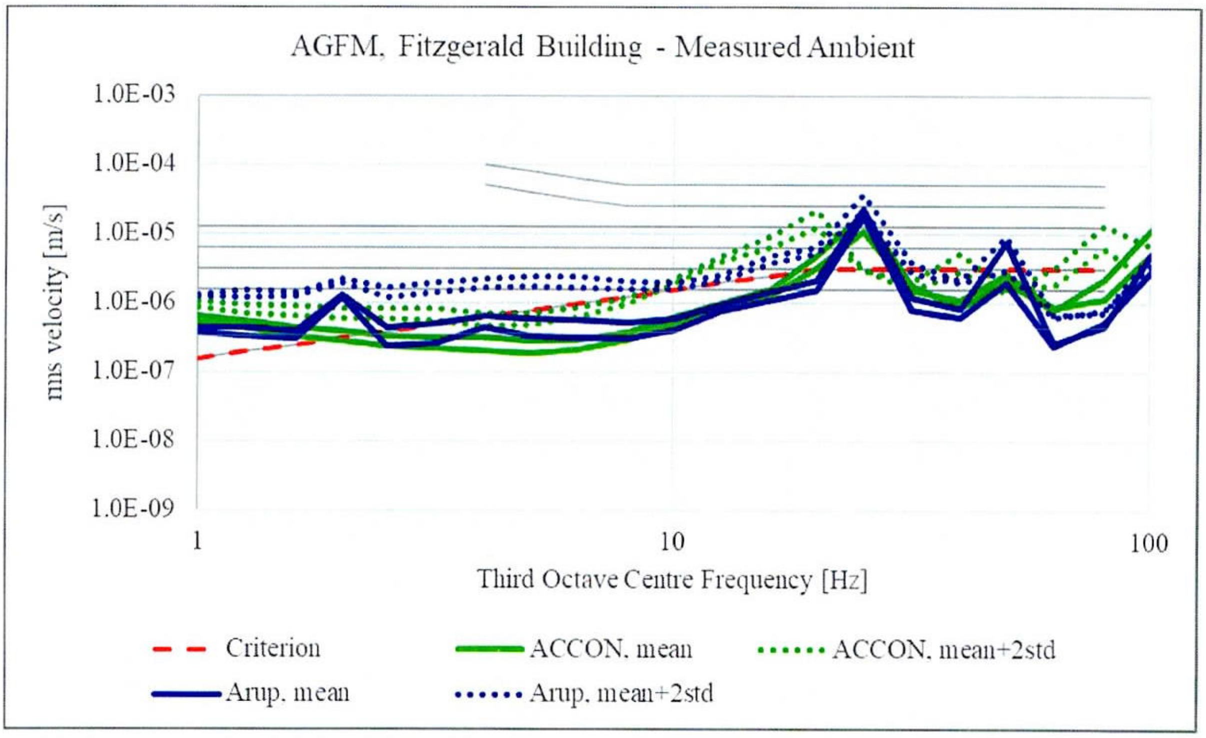

STM 4, CRANN Building - Predicted Vibration
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
Option2

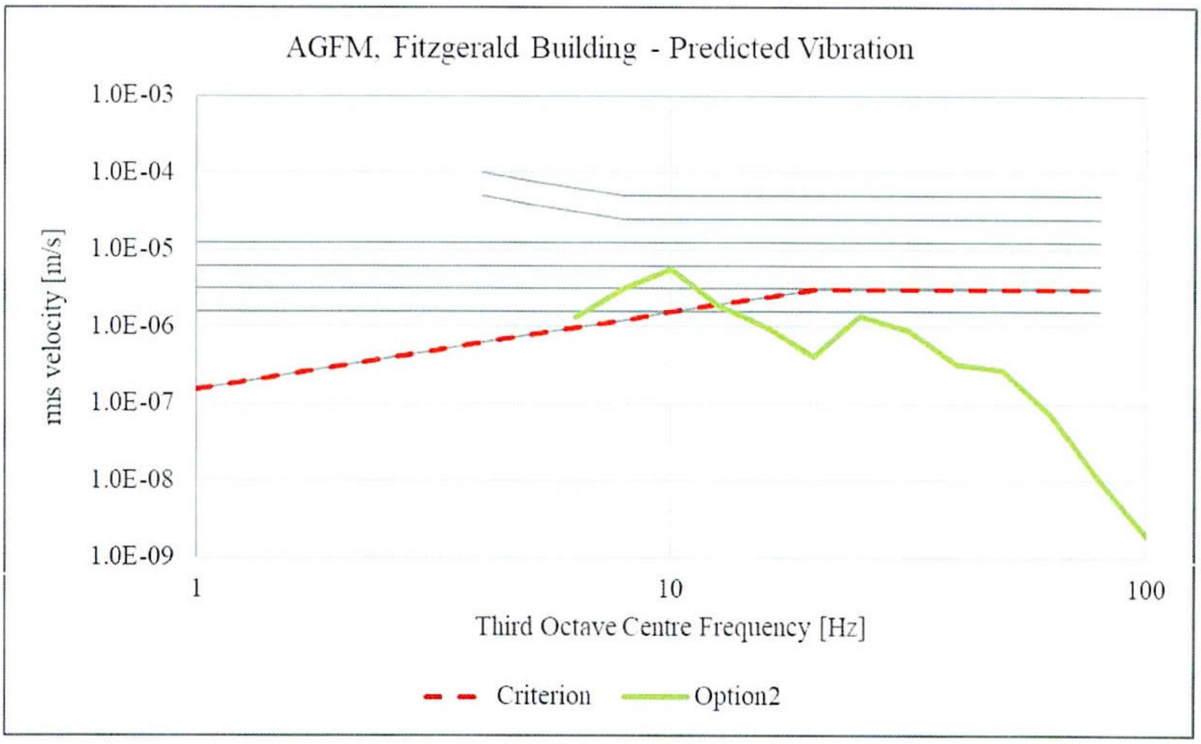

SEM, CRANN Building - Measured Ambient
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
ACCON, mean
ACCON, mean+2std
Arup, mean
Arup, mean+2std

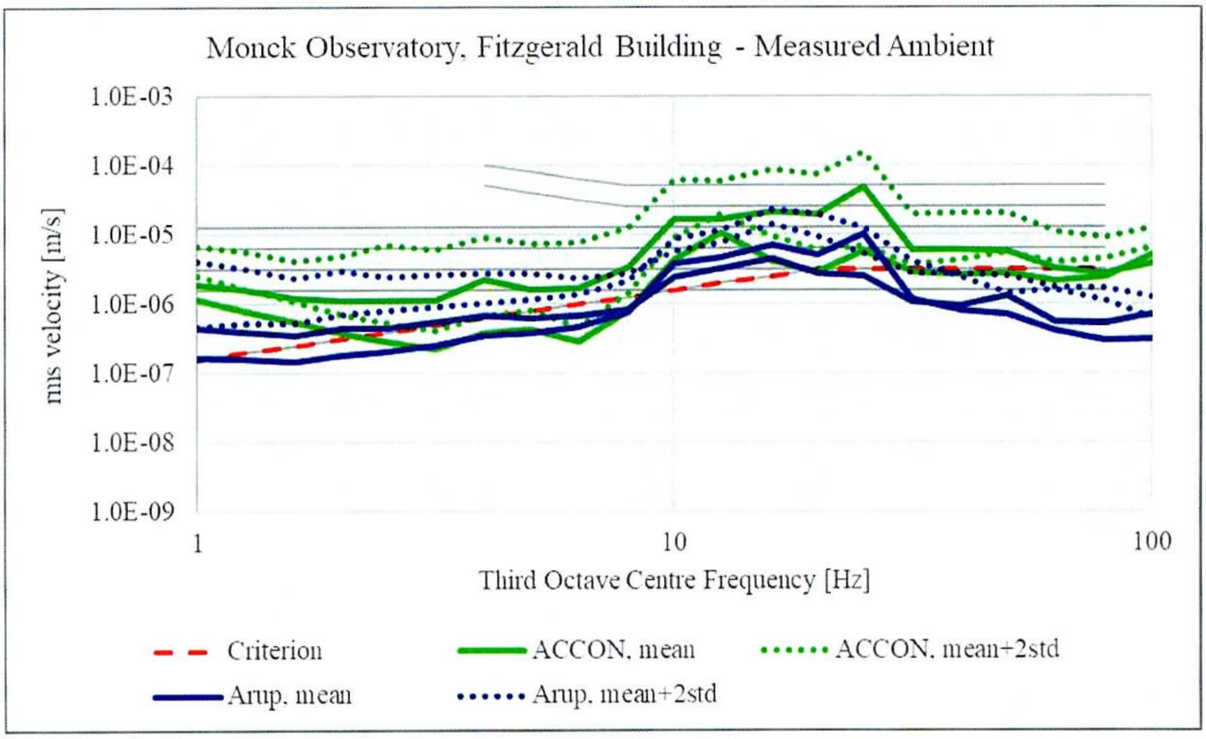

SEM, CRANN Building - Predicted Vibration
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
Option2

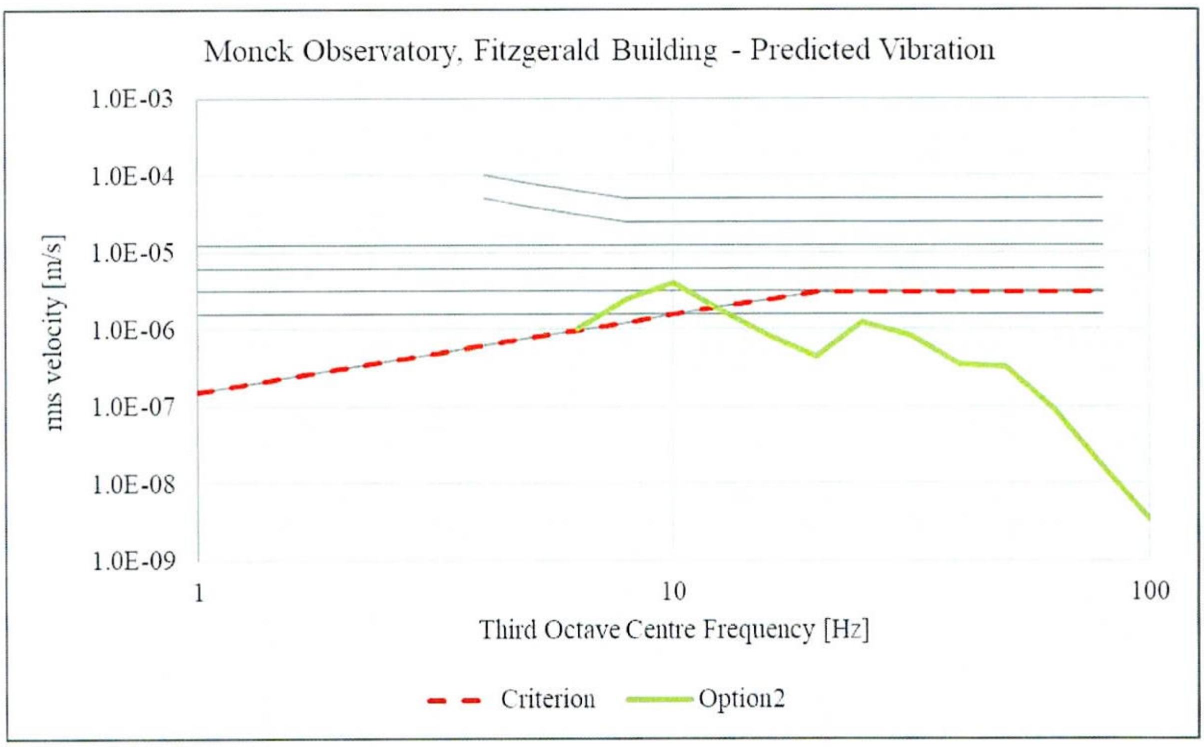

STM, Fitzgerald Building - Measured Ambient
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
ACCON, mean
ACCON, mean+2std
Arup, mean
Arup, mean+2std

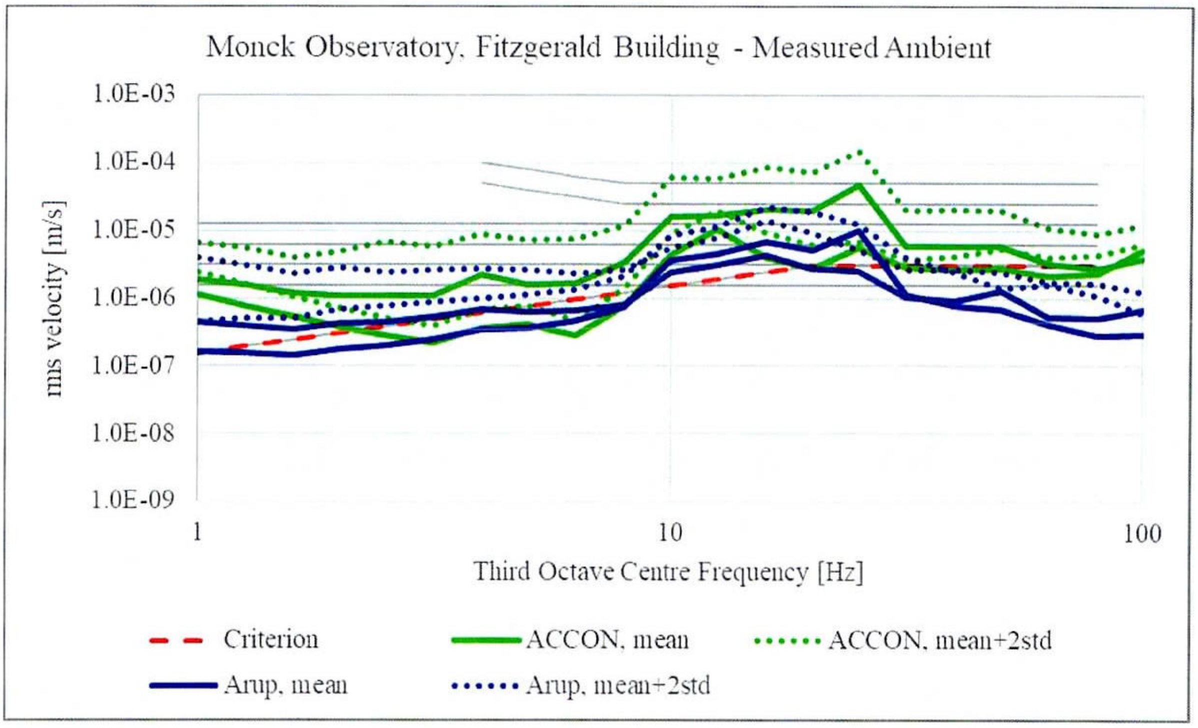

STM, Fitzgerald Building - Predicted Vibration
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
Option2

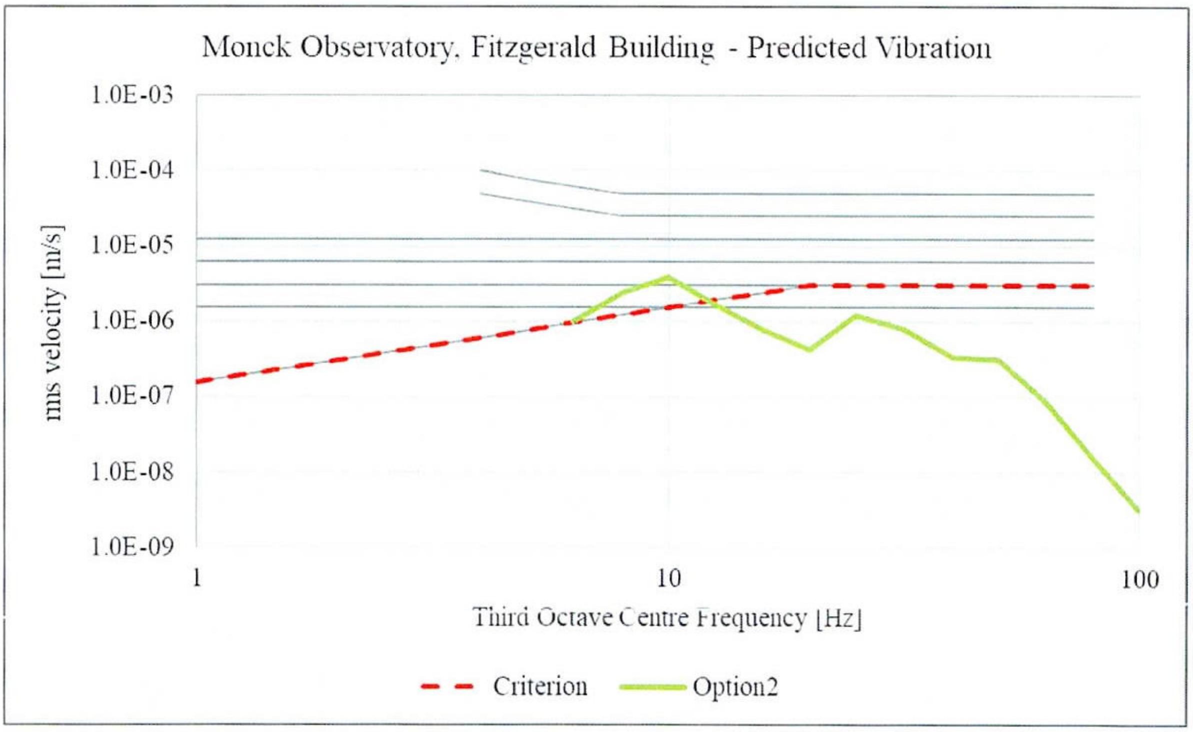

AGFM, Fitzgerald Building - Measured Ambient
rms velocity [m/s]
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
ACCON, mean
ACCON, mean+2std
Arup, mean
Arup, mean+2std


AGFM, Fitzgerald Building - Predicted Vibration
rms velocity [m/s]
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
Option2


Monck Observatory, Fitzgerald Building - Measured Ambient
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
ACCON, mean
ACCON, mean+2std
Arup, mean
Arup, mean+2std


Monck Observatory, Fitzgerald Building - Predicted Vibration
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
Option2


Monck Observatory, Fitzgerald Building - Measured Ambient
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
ACCON, mean
ACCON, mean+2std
Arup, mean
Arup, mean+2std


Monck Observatory, Fitzgerald Building - Predicted Vibration
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
rms velocity [m/s]
1
10
100
Third Octave Centre Frequency [Hz]
Criterion
Option2

Appendix C

Measurement equipment calibration certificates

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

DATE OF ISSUE: 21 March 2022 CERTIFICATE NUMBER: **1125391**

11 Frensham Road
Norwich
Norfolk
NR3 2BT

Tel: +44 1603 279557

Approved Signatory
Electronically Authorised Document

☐ P K CLARK ☐ J FRYER
☐ R J WADE ☐ M FOY
☐ M A FROST
☒ M S PARDOE

CUSTOMER	**MANUFACTURER**	**PCB PIEZOTRONICS**
PCB PIEZOTRONICS LTD	**DESCRIPTION**	**ACCELEROMETER**
O/B OF OVE ARUP & PARTNERS	**MODEL**	**393B31**
INTERNATIONAL LTD	**SERIAL No.**	**25115**
THE BUSINESS AND TECHNOLOGY	**IDENT No.**	**AACW 393B31 KIT A**
CENTRE	**DATE RECEIVED**	**21 MARCH 2022**
BESSEMER DRIVE	**DATE OF CALIBRATION**	**21 MARCH 2022**
STEVENAGE	**ORDER No**	**UKPO001156**
HERTFORDSHIRE		
SG1 2DX		
UNITED KINGDOM		

ENVIRONMENT
The instrument was placed in the Vibration Laboratory environment and allowed to stabilise prior to calibration. The laboratory is maintained at ambient conditions of 22°C ±3°C, relative humidity 45% ±15%.

STABILITY
The results contained in this Certificate refer to the measurements made at the time of test and not to the accelerometers ability to maintain calibration.

PROCEDURE
Measurements were performed in accordance with the in house Laboratory procedure No.0169 which conforms to ISO16063-21 back to back comparison method for frequency sweep, and ISO16063-22 for Shock.

The uncertainty evaluation has been carried out in accordance with UKAS requirements.

ACCELEROMETER DATA

Nominal Sensitivity @ 40Hz	8.7598V/g
Temperature	Ambient

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

UKAS ACCREDITED CALIBRATION LABORATORY No. 0654

Calibration Equipment Used:

Cert Number	Ident Number	Model	Serial Number	Test Equipment Calibration Due
1121170IH	185	9155C	19883933	4 Jan 2023

Uncertainties:

Accelerometer Sweep - Ambient Temperature

	Sensitivity Range	Frequency Range	Uncertainty
Charge	0.3 - 1000pC/g	1Hz - 2Hz	3.0%
Voltage	0.3 - 10000mV/g	2Hz - 5Hz	1.2%
Resistive/Capacitive	0.1 - 1000mV/g	5Hz - 5kHz	0.8%
		5kHz - 10kHz	0.9%
Charge	0.04 - 0.3pC/g	20Hz - 10kHz	3.0%
Voltage	0.04 - 0.3mV/g	20Hz - 10kHz	3.0%

Accelerometer Sweep - Temperature -60°C to +180°C

	Sensitivity Range	Frequency Range	Uncertainty
Charge	0.3 - 1000pC/g	20Hz - 630Hz	3.0%
Voltage	0.3 - 10000mV/g	20Hz - 630Hz	3.0%
Resistive/Capacitive	0.1 - 1000mV/g	20Hz - 630Hz	3.0%

Accelerometer Shock - Ambient Temperature

	Sensitivity Range	Shock Range	Uncertainty
Charge	0.01 - 1000pC/g	40g - 10000g	3.0%
Voltage	0.01 - 1mV/g	40g - 10000g	3.0%
Resistive/Capacitive	0.01 - 1mV/g	40g - 10000g	3.0%
Voltage	1.00 - 10mV/g	40g - 1000g	3.0%
Resistive/Capacitive	1.00 - 10mV/g	40g - 1000g	3.0%
Voltage	10.0 - 100mV/g	40g - 100g	3.0%
Resistive/Capacitive	10.0 - 100mV/g	40g - 100g	3.0%

Based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%

Notes:

Results given in g are calculated using Standard Gravity $1g_n = 9.80665ms^{-2}$
Estimated Local Gravity for the Calibration Laboratory is $9.81297ms^{-2}$ $\pm0.00001ms^{-2}$

Reference grade accelerometers are mounted via a suitable thread or thread adapter on to the reference shaker. The transfer standard weighing 10.5 grams is mounted on top of the accelerometer being calibrated to minimise the possibility of differential motion and reduce the affects of mass loading

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

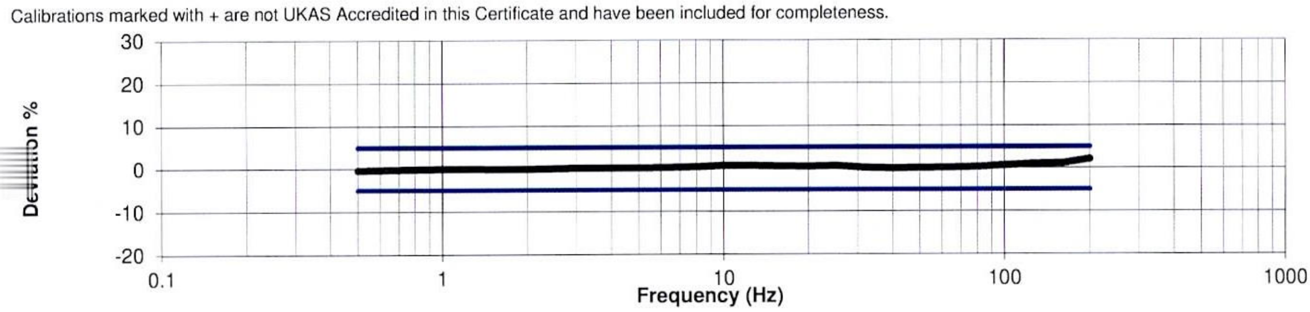
UKAS ACCREDITED CALIBRATION LABORATORY No.: 0654

CERTIFICATE NUMBER
1125391
Page 4 of 4

Freq Hz	Sensitivity V/g	Sensitivity V/m/s²
0.5 +	8.7282	0.8900
1	8.7635	0.8936
2	8.7529	0.8925
3	8.7707	0.8944
4	8.7739	0.8947
5	8.7743	0.8947
6.25	8.7792	0.8952
8	8.7933	0.8967
10	8.8168	0.8991
12.5	8.8191	0.8993
16	8.8055	0.8979
20	8.7970	0.8970
25	8.8082	0.8982
31.5	8.7721	0.8945
40	8.7598	0.8933
63	8.7740	0.8947
80	8.7882	0.8961
125	8.8423	0.9017
160	8.8636	0.9038
200	8.9446	0.9121

Freq Hz	Sensitivity V/g	Sensitivity V/m/s²

Calibrations marked with + are not UKAS Accredited in this Certificate and have been included for completeness.



This curve is for guidance only and does not represent the sensitivity at the frequencies other than those measured, and does not include the uncertainty of measurement.

Test Data	
Nominal Test Level	0.10g
Reference Freq	40 Hz
Axis	Uni-Axial

Notes

Results relate only to the items calibrated.
This certificate may not be reproduced except in full, without written permision.

Method: Calibration is performed in compliance with ISO 9001 and ISO 17025

1g = 9.80665ms-2

TEST ENGINEER: Richard Wade

DATE: 21 March 2022

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

DATE OF ISSUE: 21 March 2022 CERTIFICATE NUMBER: **1125392**

ilac-MRA

UKAS CALIBRATION

11 Frensham Road
Norwich
Norfolk
NR3 2BT

Tel: +44 1603 279557

Approved Signatory
Electronically Authorised Document

☐ P K CLARK ☐ J FRYER
☐ R J WADE ☐ M FOY
☐ M A FROST
☒ M S PARDOE

CUSTOMER	**MANUFACTURER**	**PCB PIEZOTRONICS**
PCB PIEZOTRONICS LTD	**DESCRIPTION**	**ACCELEROMETER**
O/B OF OVE ARUP & PARTNERS	**MODEL**	**393B31**
INTERNATIONAL LTD	**SERIAL No.**	**25116**
THE BUSINESS AND TECHNOLOGY	**IDENT No.**	**AACW 393B31 KIT A**
CENTRE	**DATE RECEIVED**	**21 MARCH 2022**
BESSEMER DRIVE	**DATE OF CALIBRATION**	**21 MARCH 2022**
STEVENAGE	**ORDER No**	**UKPO001156**
HERTFORDSHIRE		
SG1 2DX		
UNITED KINGDOM		

ENVIRONMENT

The instrument was placed in the Vibration Laboratory environment and allowed to stabilise prior to calibration. The laboratory is maintained at ambient conditions of 22°C ±3°C, relative humidity 45% ±15%.

STABILITY

The results contained in this Certificate refer to the measurements made at the time of test and not to the accelerometers ability to maintain calibration.

PROCEDURE

Measurements were performed in accordance with the in house Laboratory procedure No.0169 which conforms to ISO16063-21 back to back comparison method for frequency sweep, and ISO16063-22 for Shock.

The uncertainty evaluation has been carried out in accordance with UKAS requirements.

ACCELEROMETER DATA

Nominal Sensitivity @ 40Hz	8.2942V/g
Temperature	Ambient

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

UKAS ACCREDITED CALIBRATION LABORATORY No. 0654

CERTIFICATE NUMBER
1125392
Page 2 of 4

Calibration Equipment Used:

Cert Number	Ident Number	Model	Serial Number	Test Equipment Calibration Due
1121170IH	185	9155C	19883933	4 Jan 2023

Uncertainties:

Accelerometer Sweep - Ambient Temperature

	Sensitivity Range	Frequency Range	Uncertainty
Charge	0.3 - 1000pC/g	1Hz - 2Hz	3.0%
Voltage	0.3 - 10000mV/g	2Hz - 5Hz	1.2%
Resistive/Capacitive	0.1 - 1000mV/g	5Hz - 5kHz	0.8%
		5kHz - 10kHz	0.9%
Charge	0.04 - 0.3pC/g	20Hz - 10kHz	3.0%
Voltage	0.04 - 0.3mV/g	20Hz - 10kHz	3.0%

Accelerometer Sweep - Temperature -60°C to +180°C

	Sensitivity Range	Frequency Range	Uncertainty
Charge	0.3 - 1000pC/g	20Hz - 630Hz	3.0%
Voltage	0.3 - 10000mV/g	20Hz - 630Hz	3.0%
Resistive/Capacitive	0.1 - 1000mV/g	20Hz - 630Hz	3.0%

Accelerometer Shock - Ambient Temperature

	Sensitivity Range	Shock Range	Uncertainty
Charge	0.01 - 1000pC/g	40g - 10000g	3.0%
Voltage	0.01 - 1mV/g	40g - 10000g	3.0%
Resistive/Capacitive	0.01 - 1mV/g	40g - 10000g	3.0%
Voltage	1.00 - 10mV/g	40g - 1000g	3.0%
Resistive/Capacitive	1.00 - 10mV/g	40g - 1000g	3.0%
Voltage	10.0 - 100mV/g	40g - 100g	3.0%
Resistive/Capacitive	10.0 - 100mV/g	40g - 100g	3.0%

Based on a standard uncertainty multiplied by a coverage factor *k*=2, providing a level of confidence of approximately 95%

Notes:

Results given in g are calculated using Standard Gravity $1g_n = 9.80665ms^{-2}$
Estimated Local Gravity for the Calibration Laboratory is $9.81297ms^{-2}$ $\pm 0.00001ms^{-2}$

Reference grade accelerometers are mounted via a suitable thread or thread adapter on to the reference shaker. The transfer standard weighing 10.5 grams is mounted on top of the accelerometer being calibrated to minimise the possibility of differential motion and reduce the affects of mass loading

CERTIFICATE OF CALIBRATION

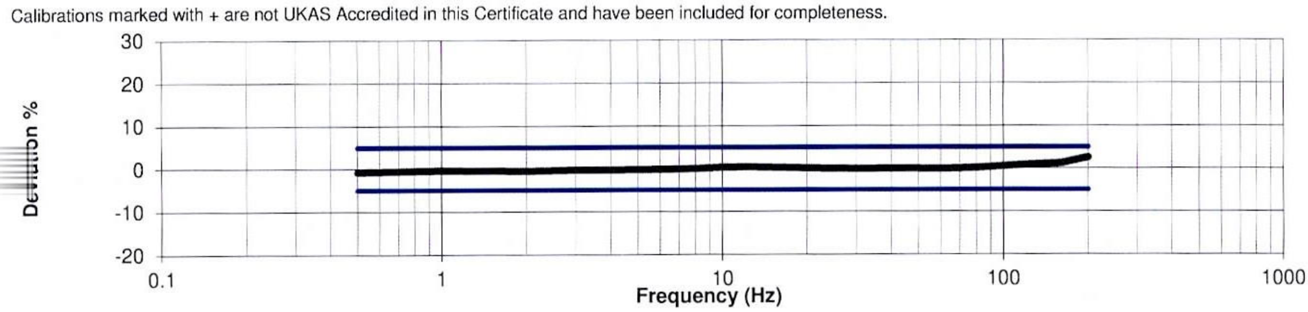
ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

UKAS ACCREDITED CALIBRATION LABORATORY No.: 0654

Freq Hz	Sensitivity V/g	Sensitivity V/m/s²
0.5 +	8.2333	0.8396
1	8.2643	0.8427
2	8.2534	0.8416
3	8.2691	0.8432
4	8.2729	0.8436
5	8.2742	0.8437
6.25	8.2803	0.8444
8	8.2973	0.8461
10	8.3186	0.8483
12.5	8.3229	0.8487
16	8.3125	0.8476
20	8.3034	0.8467
25	8.2975	0.8461
31.5	8.2911	0.8455
40	8.2942	0.8458
63	8.2907	0.8454
80	8.3071	0.8471
125	8.3659	0.8531
160	8.3987	0.8564
200	8.5053	0.8673

Freq Hz	Sensitivity V/g	Sensitivity V/m/s²

Calibrations marked with + are not UKAS Accredited in this Certificate and have been included for completeness.



This curve is for guidance only and does not represent the sensitivity at the frequencies other than those measured, and does not include the uncertainty of measurement.

Test Data

Nominal Test Level	0.10g
Reference Freq	40 Hz
Axis	Uni-Axial

Notes

Results relate only to the items calibrated.

This certificate may not be reproduced except in full, without written permision.

Method: Calibration is performed in compliance with ISO 9001 and ISO 17025

1g = 9.80665ms-2

TEST ENGINEER: Richard Wade

DATE: 21 March 2022

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

DATE OF ISSUE: 21 March 2022 CERTIFICATE NUMBER: **1125393**

Approved Signatory
Electronically Authorised Document

☐ P K CLARK ☐ J FRYER
☐ R J WADE ☐ M FOY
☐ M A FROST
☒ M S PARDOE

11 Frensham Road
Norwich
Norfolk
NR3 2BT

Tel: +44 1603 279557

CUSTOMER
PCB PIEZOTRONICS LTD
O/B OF OVE ARUP & PARTNERS
INTERNATIONAL LTD
THE BUSINESS AND TECHNOLOGY CENTRE
BESSEMER DRIVE
STEVENAGE
HERTFORDSHIRE
SG1 2DX
UNITED KINGDOM

MANUFACTURER	**PCB PIEZOTRONICS**
DESCRIPTION	**ACCELEROMETER**
MODEL	**393B31**
SERIAL No.	**25117**
IDENT No.	**AACW 393B31 KIT A**
DATE RECEIVED	**21 MARCH 2022**
DATE OF CALIBRATION	**21 MARCH 2022**
ORDER No	**UKPO001156**

ENVIRONMENT

The instrument was placed in the Vibration Laboratory environment and allowed to stabilise prior to calibration. The laboratory is maintained at ambient conditions of 22°C ±3°C, relative humidity 45% ±15%.

STABILITY

The results contained in this Certificate refer to the measurements made at the time of test and not to the accelerometers ability to maintain calibration.

PROCEDURE

Measurements were performed in accordance with the in house Laboratory procedure No.0169 which conforms to ISO16063-21 back to back comparison method for frequency sweep, and ISO16063-22 for Shock.

The uncertainty evaluation has been carried out in accordance with UKAS requirements.

ACCELEROMETER DATA

Nominal Sensitivity @ 40Hz	9.8268V/g
Temperature	Ambient

CERTIFICATE OF CALIBRATION	CERTIFICATE NUMBER 1125393
ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**	
UKAS ACCREDITED CALIBRATION LABORATORY No. 0654	

Calibration Equipment Used:

Cert Number	Ident Number	Model	Serial Number	Test Equipment Calibration Due
1121170IH	185	9155C	19883933	4 Jan 2023

Uncertainties:

Accelerometer Sweep - Ambient Temperature

	Sensitivity Range	Frequency Range	Uncertainty
Charge	0.3 - 1000pC/g	1Hz - 2Hz	3.0%
Voltage	0.3 - 10000mV/g	2Hz - 5Hz	1.2%
Resistive/Capacitive	0.1 - 1000mV/g	5Hz - 5kHz	0.8%
		5kHz - 10kHz	0.9%
Charge	0.04 - 0.3pC/g	20Hz - 10kHz	3.0%
Voltage	0.04 - 0.3mV/g	20Hz - 10kHz	3.0%

Accelerometer Sweep - Temperature -60°C to +180°C

	Sensitivity Range	Frequency Range	Uncertainty
Charge	0.3 - 1000pC/g	20Hz - 630Hz	3.0%
Voltage	0.3 - 10000mV/g	20Hz - 630Hz	3.0%
Resistive/Capacitive	0.1 - 1000mV/g	20Hz - 630Hz	3.0%

Accelerometer Shock - Ambient Temperature

	Sensitivity Range	Shock Range	Uncertainty
Charge	0.01 - 1000pC/g	40g - 10000g	3.0%
Voltage	0.01 - 1mV/g	40g - 10000g	3.0%
Resistive/Capacitive	0.01 - 1mV/g	40g - 10000g	3.0%
Voltage	1.00 - 10mV/g	40g - 1000g	3.0%
Resistive/Capacitive	1.00 - 10mV/g	40g - 1000g	3.0%
Voltage	10.0 - 100mV/g	40g - 100g	3.0%
Resistive/Capacitive	10.0 - 100mV/g	40g - 100g	3.0%

Based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%

Notes:

Results given in g_n are calculated using Standard Gravity $1g_n = 9.80665ms^{-2}$
Estimated Local Gravity for the Calibration Laboratory is $9.81297ms^{-2}$ $\pm0.00001ms^{-2}$

Reference grade accelerometers are mounted via a suitable thread or thread adapter on to the reference shaker. The transfer standard weighing 10.5 grams is mounted on top of the accelerometer being calibrated to minimise the possibility of differential motion and reduce the affects of mass loading

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

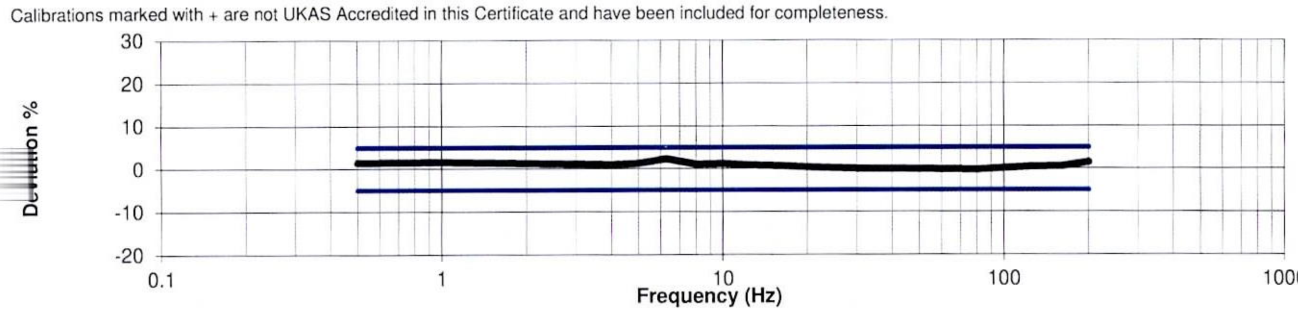
UKAS ACCREDITED CALIBRATION LABORATORY No.: 0654

CERTIFICATE NUMBER
1125393

Freq Hz	Sensitivity V/g	Sensitivity V/m/s²
0.5 +	9.9703	1.0167
1	9.9815	1.0178
2	9.9567	1.0153
3	9.9441	1.0140
4	9.9224	1.0118
5	9.9520	1.0148
6.25	10.0559	1.0254
8	9.9327	1.0129
10	9.9498	1.0146
12.5	9.9049	1.0100
16	9.8918	1.0087
20	9.8633	1.0058
25	9.8446	1.0039
31.5	9.8302	1.0024
40	9.8268	1.0021
63	9.8109	1.0004
80	9.8064	1.0000
125	9.8674	1.0062
160	9.8752	1.0070
200	9.9751	1.0172

Freq Hz	Sensitivity V/g	Sensitivity V/m/s²

Calibrations marked with + are not UKAS Accredited in this Certificate and have been included for completeness.



This curve is for guidance only and does not represent the sensitivity at the frequencies other than those measured, and does not include the uncertainty of measurement.

Test Data

Nominal Test Level	0.10g
Reference Freq	40 Hz
Axis	Uni-Axial

Notes

Results relate only to the items calibrated.
This certificate may not be reproduced except in full, without written permision.

Method: Calibration is performed in compliance with ISO 9001 and ISO 17025

1g = 9.80665ms-2

TEST ENGINEER: Richard Wade

DATE: 21 March 2022

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

DATE OF ISSUE: 21 March 2022 CERTIFICATE NUMBER: **1125397**

11 Frensham Road
Norwich
Norfolk
NR3 2BT

Tel: +44 1603 279557

Approved Signatory
Electronically Authorised Document

- ☐ P K CLARK
- ☐ J FRYER
- ☐ R J WADE
- ☐ M FOY
- ☐ M A FROST
- ☒ M S PARDOE

CUSTOMER
PCB PIEZOTRONICS LTD
O/B OF OVE ARUP & PARTNERS
INTERNATIONAL LTD
THE BUSINESS AND TECHNOLOGY
CENTRE
BESSEMER DRIVE
STEVENAGE
HERTFORDSHIRE
SG1 2DX
UNITED KINGDOM

MANUFACTURER	**PCB PIEZOTRONICS**
DESCRIPTION	**ACCELEROMETER**
MODEL	**393B31**
SERIAL No.	**44037**
IDENT No.	**AACW 393B31 KIT C**
DATE RECEIVED	**21 MARCH 2022**
DATE OF CALIBRATION	**21 MARCH 2022**
ORDER No	**UKPO001156**

ENVIRONMENT

The instrument was placed in the Vibration Laboratory environment and allowed to stabilise prior to calibration. The laboratory is maintained at ambient conditions of 22°C ±3°C, relative humidity 45% ±15%.

STABILITY

The results contained in this Certificate refer to the measurements made at the time of test and not to the accelerometers ability to maintain calibration.

PROCEDURE

Measurements were performed in accordance with the in house Laboratory procedure No.0169 which conforms to ISO16063-21 back to back comparison method for frequency sweep, and ISO16063-22 for Shock.

The uncertainty evaluation has been carried out in accordance with UKAS requirements.

ACCELEROMETER DATA

Nominal Sensitivity @ 40Hz	9.7993V/g
Temperature	Ambient

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

UKAS ACCREDITED CALIBRATION LABORATORY No. 0654

cmr

Calibration Equipment Used:

Cert Number	Ident Number	Model	Serial Number	Test Equipment Calibration Due
1121170IH	185	9155C	19883933	4 Jan 2023

Uncertainties:

Accelerometer Sweep - Ambient Temperature

	Sensitivity Range	Frequency Range	Uncertainty
Charge	0.3 - 1000pC/g	1Hz - 2Hz	3.0%
Voltage	0.3 - 10000mV/g	2Hz - 5Hz	1.2%
Resistive/Capacitive	0.1 - 1000mV/g	5Hz - 5kHz	0.8%
		5kHz - 10kHz	0.9%
Charge	0.04 - 0.3pC/g	20Hz - 10kHz	3.0%
Voltage	0.04 - 0.3mV/g	20Hz - 10kHz	3.0%

Accelerometer Sweep - Temperature -60°C to +180°C

	Sensitivity Range	Frequency Range	Uncertainty
Charge	0.3 - 1000pC/g	20Hz - 630Hz	3.0%
Voltage	0.3 - 10000mV/g	20Hz - 630Hz	3.0%
Resistive/Capacitive	0.1 - 1000mV/g	20Hz - 630Hz	3.0%

Accelerometer Shock - Ambient Temperature

	Sensitivity Range	Shock Range	Uncertainty
Charge	0.01 - 1000pC/g	40g - 10000g	3.0%
Voltage	0.01 - 1mV/g	40g - 10000g	3.0%
Resistive/Capacitive	0.01 - 1mV/g	40g - 10000g	3.0%
Voltage	1.00 - 10mV/g	40g - 1000g	3.0%
Resistive/Capacitive	1.00 - 10mV/g	40g - 1000g	3.0%
Voltage	10.0 - 100mV/g	40g - 100g	3.0%
Resistive/Capacitive	10.0 - 100mV/g	40g - 100g	3.0%

Based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%

Notes:
Results given in g are calculated using Standard Gravity $1g_n = 9.80665ms^{-2}$
Estimated Local Gravity for the Calibration Laboratory is $9.81297ms^{-2}$ $\pm0.00001ms^{-2}$

Reference grade accelerometers are mounted via a suitable thread or thread adapter on to the reference shaker. The transfer standard weighing 10.5 grams is mounted on top of the accelerometer being calibrated to minimise the possibility of differential motion and reduce the affects of mass loading

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

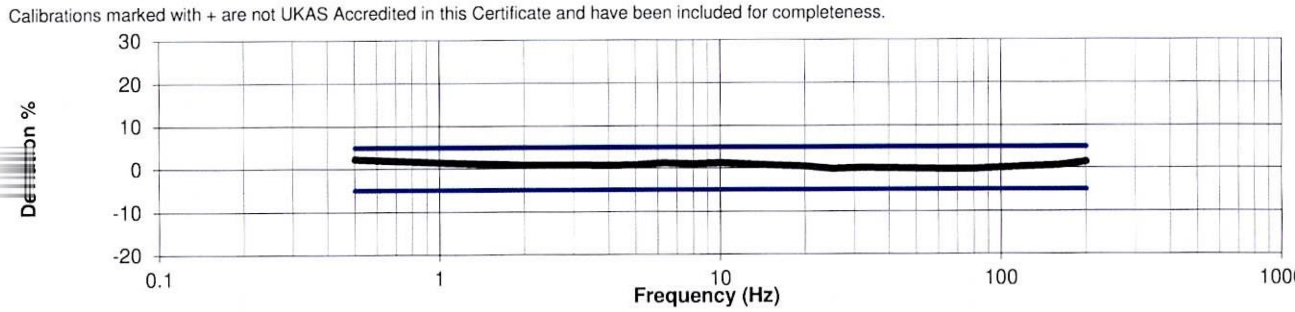
UKAS ACCREDITED CALIBRATION LABORATORY No.: 0654

CERTIFICATE NUMBER
1125397

Freq Hz	Sensitivity V/g	Sensitivity V/m/s²
0.5 +	10.0224	1.0220
1	9.9430	1.0139
2	9.8753	1.0070
3	9.8772	1.0072
4	9.8726	1.0067
5	9.8761	1.0071
6.25	9.9284	1.0124
8	9.9079	1.0103
10	9.9242	1.0120
12.5	9.8955	1.0091
16	9.8648	1.0059
20	9.8451	1.0039
25	9.7842	0.9977
31.5	9.8073	1.0001
40	9.7993	0.9993
63	9.7764	0.9969
80	9.7779	0.9971
125	9.8362	1.0030
160	9.8588	1.0053
200	9.9389	1.0135

Freq Hz	Sensitivity V/g	Sensitivity V/m/s²

Calibrations marked with + are not UKAS Accredited in this Certificate and have been included for completeness.



This curve is for guidance only and does not represent the sensitivity at the frequencies other than those measured, and does not include the uncertainty of measurement.

Test Data	
Nominal Test Level	0.10g
Reference Freq	40 Hz
Axis	Uni-Axial

Notes

Results relate only to the items calibrated.
This certificate may not be reproduced except in full, without written permision.

Method: Calibration is performed in compliance with ISO 9001 and ISO 17025

1g = 9.80665ms-2

TEST ENGINEER: Richard Wade

DATE: 21 March 2022

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

DATE OF ISSUE: 21 March 2022 CERTIFICATE NUMBER: **1125398**

11 Frensham Road
Norwich
Norfolk
NR3 2BT

Tel: +44 1603 279557

Approved Signatory
Electronically Authorised Document

☐ P K CLARK ☐ J FRYER
☐ R J WADE ☐ M FOY
☐ M A FROST
☒ M S PARDOE

CUSTOMER	**MANUFACTURER**	**PCB PIEZOTRONICS**
PCB PIEZOTRONICS LTD	**DESCRIPTION**	**ACCELEROMETER**
O/B OF OVE ARUP & PARTNERS	**MODEL**	**393B31**
INTERNATIONAL LTD	**SERIAL No.**	**44038**
THE BUSINESS AND TECHNOLOGY	**IDENT No.**	**AACW 393B31 KIT C**
CENTRE	**DATE RECEIVED**	**21 MARCH 2022**
BESSEMER DRIVE	**DATE OF CALIBRATION**	**21 MARCH 2022**
STEVENAGE	**ORDER No**	**UKPO001156**
HERTFORDSHIRE		
SG1 2DX		
UNITED KINGDOM		

ENVIRONMENT
The instrument was placed in the Vibration Laboratory environment and allowed to stabilise prior to calibration. The laboratory is maintained at ambient conditions of 22°C ±3°C, relative humidity 45% ±15%.

STABILITY
The results contained in this Certificate refer to the measurements made at the time of test and not to the accelerometers ability to maintain calibration.

PROCEDURE
Measurements were performed in accordance with the in house Laboratory procedure No.0169 which conforms to ISO16063-21 back to back comparison method for frequency sweep, and ISO16063-22 for Shock.

The uncertainty evaluation has been carried out in accordance with UKAS requirements.

ACCELEROMETER DATA

Nominal Sensitivity @ 40Hz	9.6767V/g
Temperature	Ambient

Calibration Equipment Used:

Cert Number	Ident Number	Model	Serial Number	Test Equipment Calibration Due
1121170IH	185	9155C	19883933	4 Jan 2023

Uncertainties:

Accelerometer Sweep - Ambient Temperature

	Sensitivity Range	Frequency Range	Uncertainty
Charge	0.3 - 1000pC/g	1Hz - 2Hz	3.0%
Voltage	0.3 - 10000mV/g	2Hz - 5Hz	1.2%
Resistive/Capacitive	0.1 - 1000mV/g	5Hz - 5kHz	0.8%
		5kHz - 10kHz	0.9%
Charge	0.04 - 0.3pC/g	20Hz - 10kHz	3.0%
Voltage	0.04 - 0.3mV/g	20Hz - 10kHz	3.0%

Accelerometer Sweep - Temperature -60°C to +180°C

	Sensitivity Range	Frequency Range	Uncertainty
Charge	0.3 - 1000pC/g	20Hz - 630Hz	3.0%
Voltage	0.3 - 10000mV/g	20Hz - 630Hz	3.0%
Resistive/Capacitive	0.1 - 1000mV/g	20Hz - 630Hz	3.0%

Accelerometer Shock - Ambient Temperature

	Sensitivity Range	Shock Range	Uncertainty
Charge	0.01 - 1000pC/g	40g - 10000g	3.0%
Voltage	0.01 - 1mV/g	40g - 10000g	3.0%
Resistive/Capacitive	0.01 - 1mV/g	40g - 10000g	3.0%
Voltage	1.00 - 10mV/g	40g - 1000g	3.0%
Resistive/Capacitive	1.00 - 10mV/g	40g - 1000g	3.0%
Voltage	10.0 - 100mV/g	40g - 100g	3.0%
Resistive/Capacitive	10.0 - 100mV/g	40g - 100g	3.0%

Based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%

Notes:
Results given in g are calculated using Standard Gravity $1g_n = 9.80665ms^{-2}$
Estimated Local Gravity for the Calibration Laboratory is $9.81297ms^{-2}$ $\pm 0.00001ms^{-2}$

Reference grade accelerometers are mounted via a suitable thread or thread adapter on to the reference shaker. The transfer standard weighing 10.5 grams is mounted on top of the accelerometer being calibrated to minimise the possibility of differential motion and reduce the affects of mass loading

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

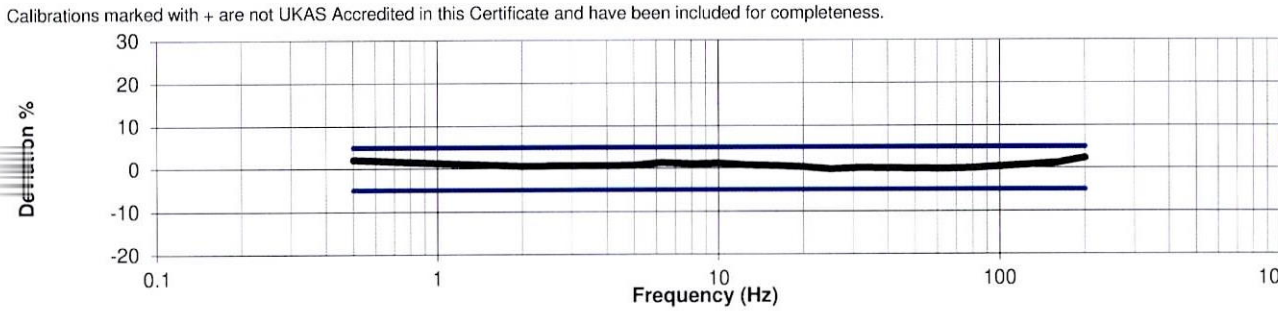
UKAS ACCREDITED CALIBRATION LABORATORY No.: 0654

CERTIFICATE NUMBER
1125398
Page 4 of 4

Freq Hz	Sensitivity V/g	Sensitivity V/m/s²
0.5 +	9.8791	1.0074
1	9.8054	0.9999
2	9.7346	0.9927
3	9.7440	0.9936
4	9.7412	0.9933
5	9.7476	0.9940
6.25	9.8107	1.0004
8	9.7793	0.9972
10	9.7992	0.9992
12.5	9.7476	0.9940
16	9.7330	0.9925
20	9.7091	0.9901
25	9.6564	0.9847
31.5	9.6872	0.9878
40	9.6767	0.9867
63	9.6646	0.9855
80	9.6769	0.9868
125	9.7511	0.9943
160	9.7961	0.9989
200	9.9044	1.0100

Freq Hz	Sensitivity V/g	Sensitivity V/m/s²

Calibrations marked with + are not UKAS Accredited in this Certificate and have been included for completeness.



This curve is for guidance only and does not represent the sensitivity at the frequencies other than those measured, and does not include the uncertainty of measurement.

Test Data	
Nominal Test Level	0.10g
Reference Freq	40 Hz
Axis	Uni-Axial

Notes

Results relate only to the items calibrated.
This certificate may not be reproduced except in full, without written permision.

Method: Calibration is performed in compliance with ISO 9001 and ISO 17025

1g = 9.80665ms-2

TEST ENGINEER: Richard Wade

DATE: 21 March 2022

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

DATE OF ISSUE: 21 March 2022 CERTIFICATE NUMBER: **1125399**

ilac-MRA

UKAS CALIBRATION

11 Frensham Road
Norwich
Norfolk
NR3 2BT

Tel: +44 1603 279557

Approved Signatory
Electronically Authorised Document

- ☐ P K CLARK ☐ J FRYER
- ☐ R J WADE ☐ M FOY
- ☐ M A FROST
- ☒ M S PARDOE

CUSTOMER
PCB PIEZOTRONICS LTD
O/B OF OVE ARUP & PARTNERS
INTERNATIONAL LTD
THE BUSINESS AND TECHNOLOGY CENTRE
BESSEMER DRIVE
STEVENAGE
HERTFORDSHIRE
SG1 2DX
UNITED KINGDOM

MANUFACTURER	**PCB PIEZOTRONICS**
DESCRIPTION	**ACCELEROMETER**
MODEL	**393B31**
SERIAL No.	**44056**
IDENT No.	**AACW 393B31 KIT C**
DATE RECEIVED	**21 MARCH 2022**
DATE OF CALIBRATION	**21 MARCH 2022**
ORDER No	**UKPO001156**

ENVIRONMENT

The instrument was placed in the Vibration Laboratory environment and allowed to stabilise prior to calibration. The laboratory is maintained at ambient conditions of 22°C ±3°C, relative humidity 45% ±15%.

STABILITY

The results contained in this Certificate refer to the measurements made at the time of test and not to the accelerometers ability to maintain calibration.

PROCEDURE

Measurements were performed in accordance with the in house Laboratory procedure No.0169 which conforms to ISO16063-21 back to back comparison method for frequency sweep, and ISO16063-22 for Shock.

The uncertainty evaluation has been carried out in accordance with UKAS requirements.

ACCELEROMETER DATA

Nominal Sensitivity @ 40Hz	9.4737V/g
Temperature	Ambient

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

UKAS ACCREDITED CALIBRATION LABORATORY No. 0654

CERTIFICATE NUMBER
1125399

Calibration Equipment Used:

Cert Number	Ident Number	Model	Serial Number	Test Equipment Calibration Due
1121170IH	185	9155C	19883933	4 Jan 2023

Uncertainties:

Accelerometer Sweep - Ambient Temperature

	Sensitivity Range	Frequency Range	Uncertainty
Charge	0.3 - 1000pC/g	1Hz - 2Hz	3.0%
Voltage	0.3 - 10000mV/g	2Hz - 5Hz	1.2%
Resistive/Capacitive	0.1 - 1000mV/g	5Hz - 5kHz	0.8%
		5kHz - 10kHz	0.9%
Charge	0.04 - 0.3pC/g	20Hz - 10kHz	3.0%
Voltage	0.04 - 0.3mV/g	20Hz - 10kHz	3.0%

Accelerometer Sweep - Temperature -60°C to +180°C

	Sensitivity Range	Frequency Range	Uncertainty
Charge	0.3 - 1000pC/g	20Hz - 630Hz	3.0%
Voltage	0.3 - 10000mV/g	20Hz - 630Hz	3.0%
Resistive/Capacitive	0.1 - 1000mV/g	20Hz - 630Hz	3.0%

Accelerometer Shock - Ambient Temperature

	Sensitivity Range	Shock Range	Uncertainty
Charge	0.01 - 1000pC/g	40g - 10000g	3.0%
Voltage	0.01 - 1mV/g	40g - 10000g	3.0%
Resistive/Capacitive	0.01 - 1mV/g	40g - 10000g	3.0%
Voltage	1.00 - 10mV/g	40g - 1000g	3.0%
Resistive/Capacitive	1.00 - 10mV/g	40g - 1000g	3.0%
Voltage	10.0 - 100mV/g	40g - 100g	3.0%
Resistive/Capacitive	10.0 - 100mV/g	40g - 100g	3.0%

Based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

UKAS ACCREDITED CALIBRATION LABORATORY No. 0654

CERTIFICATE NUMBER
1125399

Notes:

Results given in g are calculated using Standard Gravity $1g_n = 9.80665ms^{-2}$
Estimated Local Gravity for the Calibration Laboratory is $9.81297ms^{-2}$ $\pm 0.00001ms^{-2}$

Reference grade accelerometers are mounted via a suitable thread or thread adapter on to the reference shaker. The transfer standard weighing 10.5 grams is mounted on top of the accelerometer being calibrated to minimise the possibility of differential motion and reduce the affects of mass loading

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

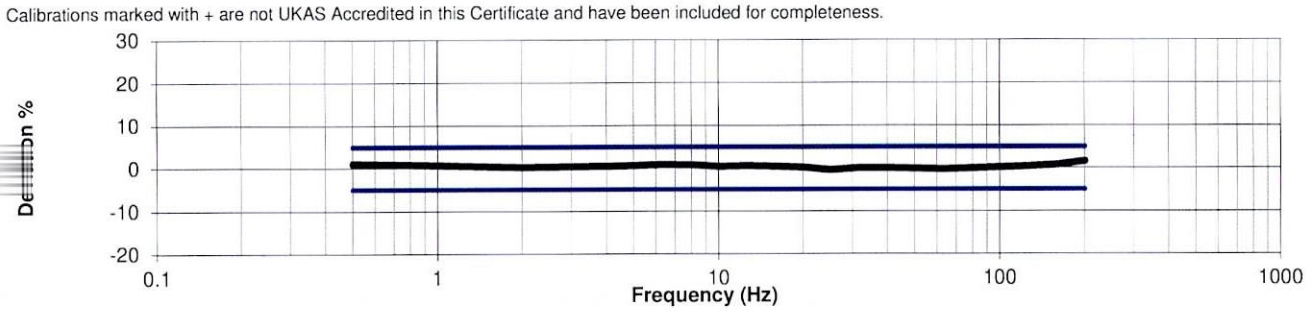
UKAS ACCREDITED CALIBRATION LABORATORY No.: 0654

CERTIFICATE NUMBER
1125399

Freq Hz	Sensitivity V/g	Sensitivity V/m/s²
0.5 +	9.5708	0.9759
1	9.5364	0.9724
2	9.4925	0.9680
3	9.5116	0.9699
4	9.5150	0.9703
5	9.5265	0.9714
6.25	9.5483	0.9737
8	9.5438	0.9732
10	9.5110	0.9699
12.5	9.5198	0.9707
16	9.5057	0.9693
20	9.4916	0.9679
25	9.4313	0.9617
31.5	9.4748	0.9662
40	9.4737	0.9660
63	9.4482	0.9634
80	9.4651	0.9652
125	9.5093	0.9697
160	9.5440	0.9732
200	9.6273	0.9817

Freq Hz	Sensitivity V/g	Sensitivity V/m/s²

Calibrations marked with + are not UKAS Accredited in this Certificate and have been included for completeness.



This curve is for guidance only and does not represent the sensitivity at the frequencies other than those measured, and does not include the uncertainty of measurement.

Test Data

Nominal Test Level	0.10g
Reference Freq	40 Hz
Axis	Uni-Axial

Notes

Results relate only to the items calibrated.
This certificate may not be reproduced except in full, without written permision.

Method: Calibration is performed in compliance with ISO 9001 and ISO 17025

1g = 9.80665ms-2

TEST ENGINEER: Richard Wade

DATE: 21 March 2022

DA20 KIT B.

CERTIFICATE OF CALIBRATION

Date of Issue: 14 December 2021

Certificate Number: TCRT21/1857

Issued by:
ANV Measurement Systems
Beaufort Court
17 Roebuck Way
Milton Keynes MK5 8HL
Telephone 01908 642846 Fax 01908 642814
E-Mail: info@noise-and-vibration.co.uk
Web: www.noise-and-vibration.co.uk
Acoustics Noise and Vibration Ltd trading as ANV Measurement Systems

Approved Signatory

K. Mistry

Client	Ove Arup & Partners International Ltd Parkin House, 8 St Thomas Street Winchester SO23 9HE
Purchase Order No.	AAcW3468
Accelerometer Type	PCB 356B18 Accelerometer
Accelerometer Serial No.	LW123068
Associated Accessory	N/A
Accessory Serial No.	N/A
Client Asset No.	N/A
Procedure ID.	AC80 Tri-Axis Issue 6
Job Number	TRAC21/12501
Date of Calibration	14 Dec 2021
Previous Cert. number	TCRT19/1767
Date of Previous Cert.	09 Oct 2019
Calibration Status	**Passed Calibration**
Rig Number	5
Kit Number	24

This calibration is traceable to National Standards. ANV Measurement Systems sources used to perform calibrations are calibrated at the National Physical Laboratory or by UKAS laboratories accredited for the purpose.

Comment

This certificate reports recorded values for the instrument 'As Received'.

Environment
The ambient environmental conditions at the time of the calibration were;
Temperature: 23.7 ± 1°C, Humidity: 48 ± 5%RH, Atmospheric pressure 101.5 ± 1 kPa

Measurements
The accelerometer was mounted on a traceably calibrated Dytran reference accelerometer type 3123A, which in turn was mounted on a shaker table. The sensitivity was measured at 80 Hz and 1.0 g. The frequency response was then measured at 1.0 g by comparison to the reference accelerometer at standard one-third octave points.

Results
For X-Axis the accelerometer's sensitivity at 80 Hz was 99.59 mV per m/s/s or 976.61 mV per g where g is the acceleration due to gravity, taken as 9.80665 m/s/s.

For Y-Axis the accelerometer's sensitivity at 80 Hz was 98.00 mV per m/s/s or 961.02 mV per g where g is the acceleration due to gravity, taken as 9.80665 m/s/s.

For Z-Axis the accelerometer's sensitivity at 80 Hz was 99.65 mV per m/s/s or 977.20 mV per g where g is the acceleration due to gravity, taken as 9.80665 m/s/s.

The frequency response relative to 80 Hz (as plotted on page 3) was:-

X-Axis	
Hz	dB
20	-0.1
25	0.0
31.5	0.0
40	0.0
50	0.0
63	0.0
80	REF
100	0.0
125	0.0
160	-0.1
200	-0.1
250	-0.1
315	-0.1
400	-0.2
500	-0.2
630	-0.2
800	-0.2
1000	-0.2
1250	-0.2
1600	-0.1
2000	0.1
2500	0.4
3150	0.3
4000	0.9

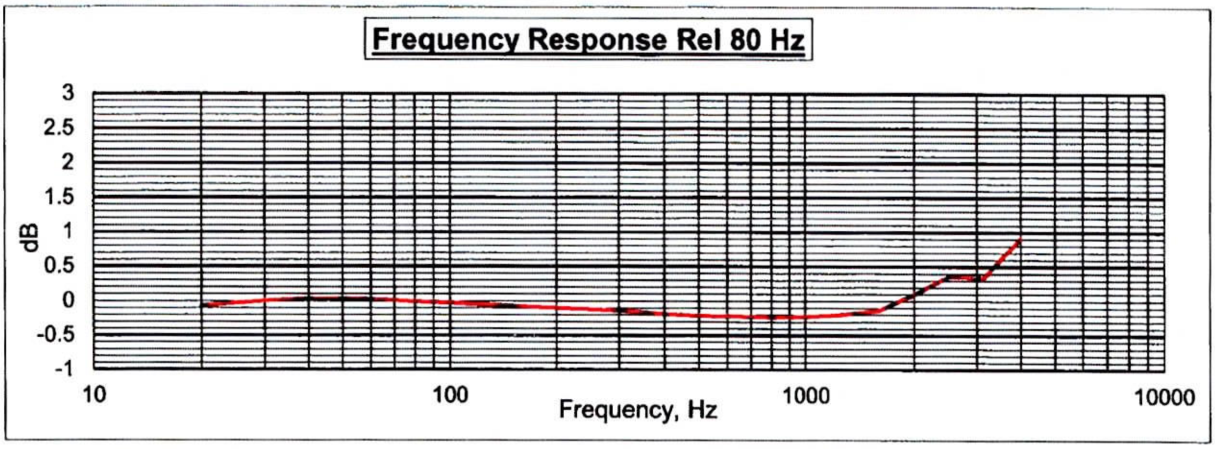
Y-Axis	
Hz	dB
20	-0.1
25	-0.1
31.5	0.0
40	0.0
50	0.0
63	0.0
80	REF
100	0.0
125	0.0
160	-0.1
200	-0.1
250	-0.1
315	-0.2
400	-0.2
500	-0.2
630	-0.3
800	-0.3
1000	-0.3
1250	-0.4
1600	-0.4
2000	-0.4
2500	-0.4
3150	-0.5
4000	-0.3

Z-Axis	
Hz	dB
20	-0.1
25	-0.1
31.5	0.0
40	0.0
50	0.0
63	0.0
80	REF
100	0.0
125	0.0
160	-0.1
200	-0.1
250	-0.1
315	-0.1
400	-0.2
500	-0.2
630	-0.2
800	-0.3
1000	-0.3
1250	-0.3
1600	-0.3
2000	-0.3
2500	-0.4
3150	-0.3
4000	-0.3

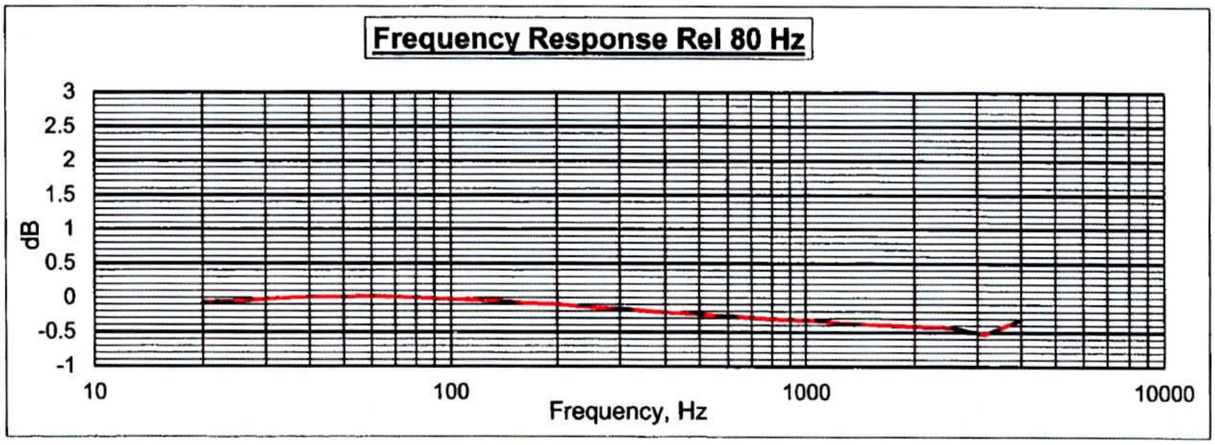
Frequency Responses

Measured at standard 1/3 Octave intervals only

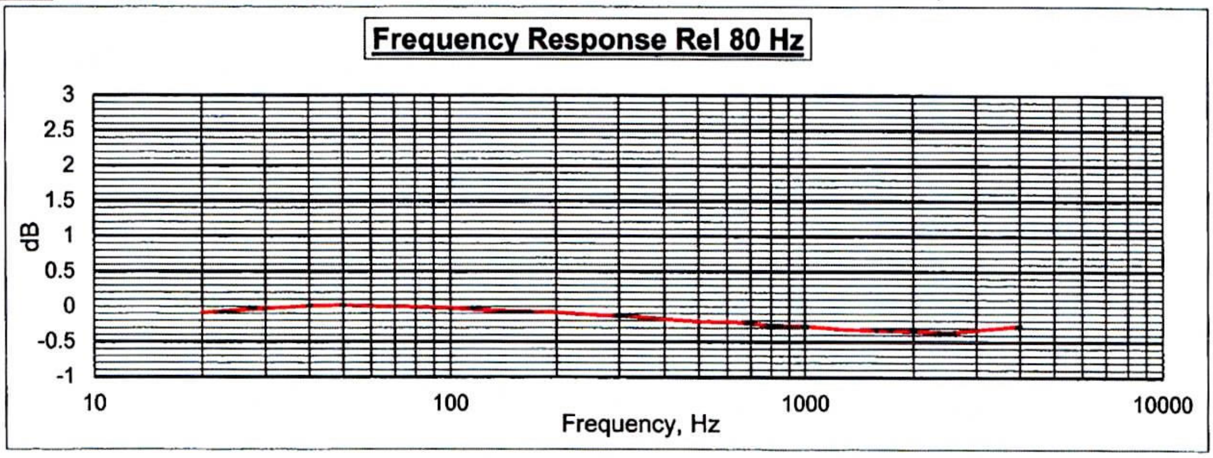
X-Axis



Y-Axis



Z-Axis



The accelerometer appeared to be in good working order.

END OF CALIBRATION

CALIBRATED BY :- A. Lloyd

DA20 KIT B.

CERTIFICATE OF CALIBRATION

Date of Issue: 15 December 2021

Certificate Number: TCRT21/1860

Issued by:
ANV Measurement Systems
Beaufort Court
17 Roebuck Way
Milton Keynes MK5 8HL
Telephone +(44) 1908 642846 Fax +(44) 1908 642814
E-Mail: info@noise-and-vibration.co.uk
Web: www.noise-and-vibration.co.uk
Acoustics Noise and Vibration Ltd trading as ANV Measurement Systems

Approved Signatory

K. Mistry

Customer: Ove Arup & Partners International Ltd
Parkin House
8 St. Thomas Street
Winchester
SO23 9HE

Order No.: AAcW3468

Description: Data Recorder

Identification	*Manufacturer*	*Instrument*	*Type*	*Serial No. / Version*
	Rion	Data Recorder	DA-20	00460342
	Rion	Firmware		1.6

Equipment Used to Carry Out Calibration

Equipment ID.	**Serial Number**	**Date Of Calibration**
Stanford DS360 Function Generator	61900	01 October 2021
Fluke 8845A Multimeter	2230017	09 November 2021

The measurements reported in this certificate were carried out using equipment whose values are traceable to national standards.

Date Received: 10 December 2021

ANV Job No.: TRAC21/12501

Date Calibrated: 15 December 2021

Comments:-

This calibration certificate contains reported values only.

Previous Certificate	*Dated*	*Certificate No.*	*Laboratory*
	09 October 2019	TCRT19/1764	ANV Measurement Systems

Method
Prior to the calibration the instrument was held within the laboratory for a period of not less than 30 minutes.

This calibration certificate covers wav files only, no calibration carried out on the analogue output of the instrument. All results obtained are documented below.

4 Channel BNC Input
DVM and SRS Initial Tests

	Input Volts	Input Hz	DVM Readings Ch1	DVM Readings Ch2	DVM Readings Ch3	DVM Readings Ch4
AC	0.5	1000	0.5018 V	0.5018 V	0.5018 V	0.5018 V
AC	0.5	19.95	0.5004 V	0.5005 V	0.5004 V	0.5005 V
Square Wave	1.26	0.001	1.277 V	1.277 V	1.277 V	1.277 V
Square Wave	0.00	0.001	0.000 V	0.000 V	0.000 V	0.000 V
Square Wave	-1.26	0.001	-1.264 V	-1.264 V	-1.264 V	-1.264 V

Measurement uncertainty for AC Voltage = 0.0013 V
Measurement uncertainty for DC Voltage = 0.0025 V

1.) Frequency Characteristics
Reference Signal = 0.5 Volts

	Frequency Hz	Ch1	Ch2	Ch3	Ch4	Measurement Uncertainty
	0.3162	-3.12 dB	-3.19 dB	-3.17 dB	-3.20 dB	0.19 dB
Reference	1000	0.50 dB	0.50 dB	0.50 dB	0.50 dB	0.19 dB
	19950	-0.16 dB	-0.21 dB	-0.21 dB	-0.24 dB	0.19 dB

2.) HPF 10 Hz
Reference Signal = 0.5 Volts

	Frequency Hz	Ch1	Ch2	Ch3	Ch4	Measurement Uncertainty
	5.012	-2.99 dB	-2.94 dB	-2.92 dB	-2.99 dB	0.19 dB
Reference	1000	0.50 dB	0.50 dB	0.50 dB	0.50 dB	0.19 dB

3.) LPF 100Hz
Reference Signal = 0.5 Volts

	Frequency Hz	Ch1	Ch2	Ch3	Ch4	Measurement Uncertainty
Reference	19.95	0.50 dB	0.50 dB	0.50 dB	0.50 dB	0.19 dB
	199.5	-3.10 dB	-3.14 dB	-3.00 dB	-3.11 dB	0.19 dB

4.) LPF 500Hz
Reference Signal = 0.5 Volts

	Frequency Hz	Ch1	Ch2	Ch3	Ch4	Measurement Uncertainty
Reference	19.95	0.50 dB	0.50 dB	0.50 dB	0.50 dB	0.19 dB
	1000	-3.13 dB	-3.18 dB	-3.04 dB	-3.17 dB	0.19 dB

5.) LPF 1000 Hz

Reference Signal = 0.5 Volts

	Frequency Hz	Ch1	Ch2	Ch3	Ch4	Measurement Uncertainty
Reference	19.95	0.50 dB	0.50 dB	0.50 dB	0.50 dB	0.19 dB
	1995	-3.31 dB	-3.35 dB	-3.22 dB	-3.34 dB	0.19 dB

6.) Offset

Test Carried out with shorting cap on all 4 channels

Voltage Range	Ch1	Ch2	Ch3	Ch4
10	-0.00302 V	-0.00206 V	-0.00181 V	-0.00170 V
3.16	-0.00099 V	-0.00067 V	-0.00062 V	-0.00057 V
1	-0.00033 V	-0.00015 V	-0.00015 V	-0.00020 V

7.) Voltage Range Switching Error

Voltage Range	Ch1	Ch2	Ch3	CH4	Measurement Uncertainty
10	20.15 dB	20.11 dB	20.09 dB	20.07 dB	0.19 dB
3.16	10.10 dB	10.11 dB	10.06 dB	10.03 dB	0.19 dB
1	0.11 dB	0.06 dB	0.07 dB	0.04 dB	0.19 dB
0.316	-9.93 dB	-9.94 dB	-9.95 dB	-9.99 dB	0.19 dB
0.1	-19.95 dB	-19.97 dB	-19.97 dB	-20.02 dB	0.19 dB
0.0316	-29.95 dB	-29.95 dB	-29.95 dB	-30.01 dB	0.19 dB
0.01	-40.00 dB	-39.95 dB	-39.98 dB	-40.00 dB	0.19 dB

8.) Linear DC Input

Input Signal DC Voltage	Ch1	Ch2	Ch3	Ch4
1.2771075	1.27 V	1.26 V	1.26 V	1.26 V
0.00003305	0.00 V	0.00 V	0.00 V	0.00 V
-1.2642425	-1.27 V	-1.26 V	-1.26 V	-1.26 V

9.) Phase difference

Frequency	Ch1-2 Degrees	Ch1-3 Degrees	Ch1-4 Degrees
1	0.07 °	0.08 °	0.05 °
1000	-0.02 °	-0.02 °	-0.01 °
19950	-0.40 °	-0.26 °	-0.10 °

10.) Inherent Noise Level

Voltage Range	Ch1	Ch2	Ch3	Ch4	Measurement Uncertainty
1	-84.67 dB	-84.79 dB	-84.37 dB	-84.84 dB	0.19 dB
0.01	-62.20 dB	-60.50 dB	-62.47 dB	-62.01 dB	0.19 dB

3 Channel Input with 4th Channel Shorted

11.) Voltage Range Switching Error

Range	Ch1	Ch2	Ch3	Measurement Uncertainty
8.3E+4	16.10 dB	16.10 dB	16.10 dB	0.19 dB
2.6E+4	6.07 dB	6.07 dB	6.07 dB	0.19 dB
8.3E+3	-5.91 dB	-5.91 dB	-5.91 dB	0.19 dB
2.6E+3	-15.95 dB	-15.95 dB	-15.95 dB	0.19 dB
8.3E+2	-25.95 dB	-25.95 dB	-25.95 dB	0.19 dB
2.6E+2	-35.97 dB	-35.97 dB	-35.97 dB	0.19 dB
8.3E+1	-45.97 dB	-45.97 dB	-45.97 dB	0.19 dB

Environmental conditions during tests	Start	End			
Temperature	23.63	23.86	±	0.20	°C
Humidity	50.6	49.3	±	3.00	%RH
Ambient Pressure	101.92	101.92	±	0.03	kPa

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

Instrument has Passed

Calibrated by: B. Bogdan

R 2

.... END ....

Additional Comments

None

CERTIFICATE OF CALIBRATION

Date of Issue: 21 March 2022

Certificate Number: TCRT22/1192

Issued by:
ANV Measurement Systems
Beaufort Court
17 Roebuck Way
Milton Keynes MK5 8HL
Telephone +(44) 1908 642846 Fax +(44) 1908 642814
E-Mail: info@noise-and-vibration.co.uk
Web: www.noise-and-vibration.co.uk
Acoustics Noise and Vibration Ltd trading as ANV Measurement Systems

Approved Signatory

K. Mistry

Customer	Ove Arup & Partners International Ltd Parkin House 8 St. Thomas Street Winchester SO23 9HE			
Order No.	AAcW3504			
Description	Data Recorder			
Identification	*Manufacturer*	*Instrument*	*Type*	*Serial No. / Version*
	Rion	Data Recorder	DA-20	34901445
	Rion	Firmware		1.6

Equipment Used to Carry Out Calibration

Equipment ID.	**Serial Number**	**Date Of Calibration**
Stanford DS360 Function Generator	61900	01 October 2021
Fluke 8845A Multimeter	2230017	09 November 2021

The measurements reported in this certificate were carried out using equipment whose values are traceable to national standards.

Date Received	17 March 2022	ANV Job No.	TRAC22/03099
Date Calibrated	21 March 2022		

Comments:-

This calibration certificate contains reported values only.

Previous Certificate	*Dated*	*Certificate No.*	*Laboratory*
	Initial Calibration		

This certificate provides traceability of measurement to recognised national standards, and to units of measurement realised at the National Physical Laboratory or other recognised national standards laboratories. This certificate may not be reproduced other than in full, except with the prior written approval of the issuing laboratory.

MEASUREMENT SYSTEMS

Method

Prior to the calibration the instrument was held within the laboratory for a period of not less than 30 minutes.

This calibration certificate covers wav files only, no calibration carried out on the analogue output of the instrument. All results obtained are documented below.

4 Channel BNC Input

DVM and SRS Initial Tests

	Input	Input	DVM Readings	DVM Readings	DVM Readings	DVM Readings
	Volts	Hz	Ch1	Ch2	Ch3	Ch4
AC	0.5	1000	0.5032 V	0.5032 V	0.5031 V	0.5032 V
AC	0.5	19.95	0.4995 V	0.4995 V	0.4992 V	0.4993 V
Square Wave	1.26	0.001	1.249 V	1.248 V	1.248 V	1.248 V
Square Wave	0.00	0.001	0.000 V	0.000 V	0.000 V	0.000 V
Square Wave	-1.26	0.001	-1.244 V	-1.244 V	-1.244 V	-1.244 V

Measurement uncertainty for AC Voltage = 0.0013 V
Measurement uncertainty for DC Voltage = 0.0025 V

1.) Frequency Characteristics

Reference Signal = 0.5 Volts

	Frequency					Measurement
	Hz	Ch1	Ch2	Ch3	Ch4	Uncertainty
	0.3162	-3.35 dB	-3.33 dB	-3.36 dB	-3.23 dB	0.19 dB
Reference	1000	0.50 dB	0.50 dB	0.50 dB	0.50 dB	0.19 dB
	19950	-0.42 dB	-0.35 dB	-0.33 dB	-0.31 dB	0.19 dB

2.) HPF 10 Hz

Reference Signal = 0.5 Volts

	Frequency					Measurement
	Hz	Ch1	Ch2	Ch3	Ch4	Uncertainty
	5.012	-3.14 dB	-3.08 dB	-3.01 dB	-3.00 dB	0.19 dB
Reference	1000	0.50 dB	0.50 dB	0.50 dB	0.50 dB	0.19 dB

3.) LPF 100Hz

Reference Signal = 0.5 Volts

	Frequency					Measurement
	Hz	Ch1	Ch2	Ch3	Ch4	Uncertainty
Reference	19.95	0.50 dB	0.50 dB	0.50 dB	0.50 dB	0.19 dB
	199.5	-3.32 dB	-3.14 dB	-3.09 dB	-3.17 dB	0.19 dB

4.) LPF 500Hz

Reference Signal = 0.5 Volts

	Frequency					Measurement
	Hz	Ch1	Ch2	Ch3	Ch4	Uncertainty
Reference	19.95	0.50 dB	0.50 dB	0.50 dB	0.50 dB	0.19 dB
	1000	-3.38 dB	-3.18 dB	-3.12 dB	-3.18 dB	0.19 dB

5.) LPF 1000 Hz

Reference Signal = 0.5 Volts

	Frequency Hz	Ch1	Ch2	Ch3	Ch4	Measurement Uncertainty
Reference	19.95	0.50 dB	0.50 dB	0.50 dB	0.50 dB	0.19 dB
	1995	-3.54 dB	-3.35 dB	-3.30 dB	-3.36 dB	0.19 dB

6.) Offset

Test Carried out with shorting cap on all 4 channels

Voltage Range	Ch1	Ch2	Ch3	Ch4
10	-0.00044 V	-0.00016 V	-0.00035 V	-0.00019 V
3.16	-0.00147 V	-0.00051 V	-0.00121 V	-0.00058 V
1	-0.00044 V	-0.00015 V	-0.00035 V	-0.00019 V

7.) Voltage Range Switching Error

Voltage Range	Ch1	Ch2	Ch3	CH4	Measurement Uncertainty
10	19.86 dB	19.96 dB	19.99 dB	20.02 dB	0.19 dB
3.16	9.86 dB	9.95 dB	9.98 dB	9.99 dB	0.19 dB
1	-0.14 dB	-0.06 dB	-0.04 dB	-0.01 dB	0.19 dB
0.316	-10.13 dB	-10.06 dB	-10.04 dB	-10.04 dB	0.19 dB
0.1	-20.14 dB	-20.07 dB	-20.05 dB	-20.07 dB	0.19 dB
0.0316	-30.12 dB	-30.06 dB	-30.06 dB	-30.05 dB	0.19 dB
0.01	-40.12 dB	-40.05 dB	-40.05 dB	-40.03 dB	0.19 dB

8.) Linear DC Input

Input Signal DC Voltage	Ch1	Ch2	Ch3	Ch4
1.24841	1.25 V	1.25 V	1.23 V	1.25 V
0.0000204	0.00 V	0.00 V	0.00 V	0.00 V
-1.244335	-1.26 V	-1.26 V	-1.25 V	-1.26 V

9.) Phase difference

Frequency	Ch1-2 Degrees	Ch1-3 Degrees	Ch1-4 Degrees
1	0.23 °	0.44 °	0.02 °
1000	-0.03 °	0.00 °	0.00 °
19950	-0.63 °	0.09 °	-0.02 °

10.) Inherent Noise Level

Voltage Range	Ch1	Ch2	Ch3	Ch4	Measurement Uncertainty
1	-83.93 dB	-83.92 dB	-83.81 dB	-83.95 dB	0.19 dB
0.01	-61.67 dB	-60.62 dB	-62.00 dB	-62.34 dB	0.19 dB

3 Channel Input with 4th Channel Shorted

11.) Voltage Range Switching Error

Range	Ch1	Ch2	Ch3	Measurement Uncertainty
8.3E+4	15.94 dB	15.94 dB	15.94 dB	0.19 dB
2.6E+4	5.94 dB	5.94 dB	5.94 dB	0.19 dB
8.3E+3	-6.07 dB	-6.07 dB	-6.07 dB	0.19 dB
2.6E+3	-16.08 dB	-16.08 dB	-16.08 dB	0.19 dB
8.3E+2	-26.08 dB	-26.08 dB	-26.08 dB	0.19 dB
2.6E+2	-36.08 dB	-36.08 dB	-36.08 dB	0.19 dB
8.3E+1	-46.07 dB	-46.07 dB	-46.07 dB	0.19 dB

Environmental conditions during tests	Start	End			
Temperature	23.41	23.35	±	0.20	°C
Humidity	37.5	37.0	±	3.00	%RH
Ambient Pressure	101.69	101.66	±	0.03	kPa

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k=2$, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

Instrument has Passed

Calibrated by: B. Bogdan R 2

.... END ....

Additional Comments

None