TRANSPORT AND WORKS ACT 1992

TRANSPORT AND WORKS (INQUIRIES PROCEDURES) RULES 2004

THE NETWORK RAIL (CAMBRIDGE SOUTH INFRASTRUCTURE ENHANCEMENTS) ORDER

MAIN PROOF OF EVIDENCE

ON MATTERS OF NOISE & VIBRATION

RUPERT THORNELY-TAYLOR

ON BEHALF OF THE UNIVERSITY OF CAMBRIDGE

Inquiry Document Reference	[TBC]/OBJ8
Author	Rupert Thornely-Taylor
Date	6 January 2022

Contents

1 SUMMARY

The works proposed and the University's interest

1.1 The Network Rail (Cambridge South Infrastructure Enhancements) Order ("**Order**") seeks powers to construct and operate a new station on the existing main line serving Cambridge ("**Scheme**"). The works involved include, as well as a four platform station and associated structures, the slewing of the existing main line and the installation of two new loop lines connected via new switches and crossings. These works are proposed in the vicinity of the Cambridge Biomedical Campus ("**CBC**"), on which are located a number of buildings sensitive to noise and vibration.

1.2 The Environmental Statement ("**ES**") for the Order reports that there will be significant effects due to noise and vibration on facilities in premises on the CBC owned and operated by the University of Cambridge ("**University**"), namely the Anne McLaren Building ("**AMB**").

1.3 The AMB houses research facilities which are sensitive to noise and vibration. These include sensitive scientific instruments, specifically a Magnetic Resonance Imaging instrument ("**MRI**"), and a vivarium in which there are rodents (mainly mice, but also some rats) and fish. The building also contains personnel engaged in and supporting the research work.

Potential noise and vibration effects

1.4 Noise and vibration effects potentially arise from the construction of the station, the installation of the new loop lines and the associated overhead line equipment and associated works. Additional noise and vibration effects also potentially arise from the operation of the proposed works because (a) the main line will be slewed slightly closer to the AMB (b) the nearest of the proposed new loop lines is closer to the AMB than the existing main line and (c) trains would run over gaps in the rails in the proposed new switches and crossings which would connect the loop lines to the main line.

1.5 There are known limits of acceptability for noise and vibration with regard to the MRI, the rodents and the fish, which are of the species Danio rerio (Zebrafish).

1.6 The AMB was designed and constructed in order that noise and vibration from existing sources, notably the railway line, road vehicles and other external sources in the baseline environment, would not exceed acceptability limits and there are currently no adverse effects of this kind.

1.7 Were acceptable limits for noise and vibration to be exceeded, the following effects would result. In the case of the MRI, image quality would be harmed and therefore research of which it forms part would be disrupted or delayed. In the case of the rodents, the successful breeding of which is essential, the effect of excessive noise or vibration would be behavioural disturbance and interference with reproduction including infertility, abortion, mismothering or cannibalism of pups. In the case of fish the potential effects are behavioural disturbance and hearing damage.

The Environmental Statement

1.8 The ES did not consider all the potential effects of noise and vibration caused by the construction and operation of the proposed works on sensitive receptors in the AMB. With regard to noise, only effects on human beings were considered and were found to be significant during the construction phase. With regard to vibration, effects due to some of the likely sources associated with the Scheme were considered. Adequate mitigation to remove significant effects was not proposed in the ES.

1.9 The noise and vibration chapters of the ES lack sufficient information to enable other than a broad assessment to be made, with no clear indication of locations and durations of many construction activities. Some construction activities are specifically excluded from the assessment. With regard to the operational phase the ES explicitly excludes, for example, vibration from freight trains.

Vibration Thresholds

1.10 While limits of acceptability for the different types of sensitive receptor in the AMB can be expressed using a number of different indices, with regard to vibration the University, in the design of the AMB, reduced these to a set of criteria based on what are known VC curves. For the MRI, the relevant VC curve was what is known as VC-C. With regard to vibration effects on mice the relevant criterion was a modified version of VC-A. The modification was to remove the frequency-dependence of VC-A so that it was equivalent to 50 micrometres/second. If it is so extended to cover all frequencies, conformity to this modified VC-A also results in levels of underwater noise and fluid velocity (the quantities which principally determine adverse effects on fish) which would not result in significant adverse effects caused by noise or vibration.

1.11 In the current baseline conditions, modified VC-A is not exceeded. VC-C is slightly exceeded during the passage of freight trains on the railway, but detailed examination of freight train vibration shows that it is just possible for the specific MRI equipment ultimately installed in the AMB to be used without exceeding its tolerance thresholds, even though the formalisation of those thresholds by the instrument manufacturers in simplified terms results in limits being slightly exceeded.

Further information from Network Rail

1.12 Following receipt of the University's Statement of Case, and commentary on the ES and its shortcomings, Network Rail have engaged in a workshop attended by noise and vibration experts and a one-to-one virtual meeting between vibration (but not noise) experts. Network Rail have provided some additional information, mainly with regard to vibration.

1.13 The current information provided by Network Rail is that vibration may exceed the AMB's VC thresholds during the construction phase of the Scheme. During the operational phase, provided that key assumptions relating to the proposed new track and its operation can be relied on, modified VC-A will not be exceeded during operation but VC-C will be exceeded during the passage of freight trains to a slightly greater extent than is the case for the existing railway. I comment below on the need to consider a related but different approach to VC-C when considering vibration impacts on specific sensitive equipment in the AMB.

1.14 With regard to the construction phase of the Scheme, Network Rail intend to monitor and control noise and vibration through the Code of Construction Practice part B, and through monitoring and limitation of received levels. What is not known is whether it is practicably possible to apply mitigation methods in terms of control of methods of working, selection of machinery and use of mitigation measures including noise barriers so as to comply with acceptability criteria. In the event that there would be periods when those criteria could be exceeded, there is insufficient information to be able to predict when and for how long such exceedances may occur. The proposed structure and details of a monitoring, warning and limitation protocol are not known.

Required mitigation

1.15 Mitigation may be either in the form of physical works, or measures to reduce or limit noise and vibration, including the adoption of an effective protocol for predicting, monitoring and managing (including stopping work) the levels of noise and vibration caused.

1.16 However the nature and degree of mitigation required is currently not capable of assessment in the absence of adequate assessment by Network Rail. As I explain below, I have therefore identified key criteria relating to noise and vibration to avoid disturbance to operations within the AMB.

1.17 Construction and operation of the proposed Scheme in a manner which permits continuance of the research work in the AMB requires (a) that adequate work is completed to enable mitigated levels of noise and vibration to be predicted with evaluated uncertainty margins, such that VC-A (modified as explained above and further below) will not be exceeded; (b) the modified criterion for the MRI developed from VC-C and the manufacturer's stated limits will not be exceeded; and (c) an identified threshold relating to potential noise effects on animals is not exceeded.

1.18 In the case of construction effects (and in relation to operational vibration effects relating to animals), it will also be necessary to establish protocols and method statements which will identify and avoid potential unacceptable interferences with the use of the MRI or research activity. It will also be necessary to secure an identified construction phase noise threshold to mitigate potential effects on human beings using the AMB.

2 QUALIFICATIONS AND EXPERIENCE

2.1 My name is Rupert Maurice Thornely-Taylor.

2.2 I am a Fellow of, and was a founder member of, the Institute of Acoustics, a Member of the Institute of Noise Control Engineering of the USA and a Fellow of the International Institute of Acoustics and Vibration. I have specialised exclusively in the subjects of noise, vibration and acoustics for more than 57 years.

2.3 I am a past President, Honorary Member, and was a founder member of the Association of Noise Consultants and am an officer of the International Institute of Acoustics and Vibration. I was for ten years a member of the Noise Advisory Council chaired by the Secretary of State for the Environment, and was chairman and deputy chairman of two of its working groups. I was a member of the Scott Committee, which drafted the basis of the noise section of the Control of Pollution Act 1974.

2.4 I have been an independent consultant in the subjects of noise and vibration for the past 53 years, and head the Acoustics, Noise and Vibration consultancy practice of Rupert Taylor Ltd.

2.5 I am the author of the Pelican book NOISE, and editor or co-author of many other books including the Association of Noise Consultants Guidelines: “Measurement & Assessment of Groundborne Noise & Vibration”. I was a member of the Working Group that produced BS ISO 14837-1:2005 “Mechanical vibration — Ground-borne noise and vibration arising from rail systems Part 1: General guidance”. BS PD ISO/TS “Mechanical vibration — Ground-borne noise and vibration arising from rail systems — Part 31:2017:Guideline on field measurements for the evaluation of human exposure in buildings”. and BS PD ISO/TS “Mechanical vibration — Ground-borne noise and vibration arising from rail systems — Part 32:2015 Measurement of dynamic properties of the ground”. I am a member of the European Committee for Standardization’s working group developing EN 12354-7 “groundborne sound insulation against outdoor ground vibration”. I am a member of a number of British Standards committees.

2.6 My experience in advising on noise and vibration matters has covered England, Scotland, Ireland, Sweden, Denmark, Hong Kong, Singapore, Taiwan, Thailand, India, China, the USA and Australia and has included residential and commercial development, railways, airports, and container ports. I have been instructed by both private and public sector clients, including in the past by Network Rail.

2.7 I have extensive experience of construction noise and vibration and have carried out construction noise studies of projects including the Jubilee Line Extension, Crossrail, Dublin Metro Link and Thameslink 2000. I have been an expert witness on construction noise in inquiries into several major infrastructure developments including the Victoria Station Upgrade. I was expert witness in the House of Commons Select Committee on the Channel Tunnel Rail Link Bill, and in the House of Commons and House of Lords Select Committees on the Crossrail Bill and on the High Speed Rail Bills.

2.8 I have been consultant to London Underground Ltd and/or Transport for London (and their predecessors) for over 40 years, having advised on projects, in addition to the Jubilee Line Extension, Crossrail and Croydon Tramlink, such as the initial Docklands Light Railway, Green Park Station, Westminster District and Circle Line Station, Camden Town Station, Tottenham Court Road Station, the Northern Line Extension Scheme, and Bank Station. I have also carried out vibration surveys at King's Cross Underground Station.

2.9 In particular, I have had a wide experience in dealing with matters involving heavy rail infrastructure proposals. For Network Rail and its predecessors, in addition to Thameslink 2000, I have been involved in vibration studies at St Pancras Chambers, the Clerkenwell Tunnels, London Bridge, Waterloo International Terminal and the Channel Tunnel. I also presented the noise and vibration evidence before the Select Committees for the HS1 and HS2 Bills and am a consultant to HS2 Ltd. I have also had consultancy commissions from objectors to railway proposals, rolling stock builders and equipment suppliers.

2.10 I was expert witness on behalf of the University of Manchester in the Network Rail (Manchester Piccadilly and Oxford Road Capacity) Order TWAO public inquiry with respect to the effects of noise and vibration on specialist research instrumentation in the North Campus. I have also advised in respect of effects of noise and vibration from railways on highly sensitive equipment in the Francis Crick Institute in London on behalf of Transport for London, and on research facilities at Trinity College Dublin on behalf of Transport Infrastructure Ireland. I have advised on the effects of vibration on sensitive equipment at several hospitals in Dublin and Guy's Hospital in London.

2.11 In the Cambridge area I carried out extensive studies of vibration and groundborne noise at Cambridge North Station as part of the design of the newly opened Novotel, which has been constructed on vibration-isolating bearings.

2.12 I have appeared as an expert witness in many courts of law, both at home and overseas, at various planning and TWAO inquiries, in international arbitration hearings and in both Houses of Parliament.

3 INTRODUCTION

Scope of Evidence

3.1 My Proof of Evidence has been prepared in relation to the University's objection to the Order.

3.2 My evidence concerns the effects on the University's AMB from airborne noise ("**noise**") and from vibration of the construction of the Scheme works and from the operation of the Scheme. I have been instructed to consider, in particular, the effects on occupants and specialist equipment used in the AMB that is sensitive to noise and vibration and effects on animals in the vivarium. The animals consist of rodents and fish, and with regard to fish, effects of noise and vibration would be manifested as underwater noise resulting from groundborne/structureborne transmission of vibration at audible frequencies.

3.3 The University also has an interest in the nearby area of land known as "Plot 9" and I briefly consider the potential effects of the Scheme on the development and use of Plot 9.

3.4 My evidence first considers the adequacy of the information which has been provided by Network Rail, in the documents accompanying the application, the information requested by the University and the response by Network Rail to those requests. Secondly it considers what is required in order to limit potential damage to the University's interests by way of controls either by way of Protective Provisions on the face of the Order and/or in a Land and Works Agreement.

Statement of Matters

3.5 With regard to the Statement of Matters about which the Secretary of State wishes to be informed, my evidence addresses matters raised under items 3, 5, 7 and 10 insofar as they refer to effects of noise and vibration.

The University's Concerns

3.6 The essence of the Scheme is to install additional tracks (loops) and a new four-platform station. The new loops are connected to the main line by way of newly installed switches and crossings. Thus, in the operating phase of the Scheme noise and vibration from the railway as received at the AMB would potentially increase by virtue of the effect of trains, both passenger and freight, running over the new switches and crossings, and the greater proximity of the nearest track. The works required to implement the Scheme will be carried out at varying distances from the AMB which will therefore also be subject to noise and vibration from the construction phase.

3.7 The University is a statutory objector for the purposes of the Transport and Works (Inquiries Procedure) Rules 2004.

3.8 In relation to noise and vibration the following potential effects on the AMB need to be considered:

3.8.1 effects on people using the AMB;

3.8.2 effects on sensitive equipment installed in the building, and on research work dependent on the output from the equipment;

3.8.3 effects on rodents and fish housed in the vivarium in the AMB.

The University's Objection

3.9 Whilst the University supports improvements to public transport provision at Cambridge South, it maintains its objection to the Scheme because it is not satisfied that its effects on the University have been adequately assessed or mitigated and would therefore be harmful to its estate and interests. My evidence develops these concerns with specific reference to the effects of noise and vibration, having regard to the information which has been provided by Network Rail. As I explain below, as matters stand that evidence is deficient and is incapable of assuring the University that its concerns can be overcome.

Structure of evidence

3.10 The structure of my evidence is as follows:

3.10.1 At **Section 4** I will briefly outline the nature of the scales used to quantify noise and vibration to establish the context for my evidence;

3.10.2 At **Section 5** I will outline the relevant legislation, policy and guidance;

3.10.3 At **Section 6** I review methodologies for calculation of noise and vibration;

3.10.4 At **Section 7** I will describe the AMB, the existing sources of noise and vibration, and then the additional sources of these effects arising from the Scheme;

3.10.5 At **Section 8** I review the information in the ES on these issues;

3.10.6 At **Section 9** I review the statement of case on behalf of NR in relation to noise and vibration;

3.10.7 At **Sections 10 and 11** I set out further information which has been provided by Network Rail and its implications. I then set out what further information has been requested by the University and not, at the date of this proof, been received;

3.10.8 At **Section 12** I consider the implication for the University's interest in Plot 9; and

3.10.9 At **Section 13** I give my conclusions and consider what is required by way of controls to protect the position of the University.

4 THE NATURE OF NOISE AND VIBRATION

Introduction

4.1 This section summarises the topic of the measurement and assessment of noise and vibration, both with regard to potential effects on human beings and on animals (including fish).

4.2 In all but a few cases, consideration of noise (defined as unwanted sound) and vibration in the assessment of the effects of a project such as a railway or major infrastructure scheme is devoted to effects on human beings. Policy and guidance on the subjects is also largely focussed on effects on the health and wellbeing of human beings.

4.3 Airborne noise can also potentially have an adverse effect on animals, and underwater noise and associated underwater effects can have an adverse effect on fish. In the recent past, there have been a number of instances where assessment of noise and vibration on species other than human beings has been necessary. Planning applications where adverse effects on horses and farm animals due to helicopter noise have been considered. The Select Committees on High Speed Rail Bills in Parliament heard petitions concerned about railway noise effects on horses, and underwater noise on fish in fish farms. The Environmental Statements for a number of projects including offshore windfarm installations, harbour developments, construction works in the vicinity of aquariums and the boring of tunnels under rivers and estuaries have also considered effects of underwater noise on fish and other sub-aquatic species. While these are slightly different specialisms to the study of airborne and groundborne noise and vibration on human beings, they are nonetheless established disciplines with their own body of literature on which assessments can be based.

Noise Levels and Scales

4.4 The noise levels to which I will refer in my evidence, whether in relation to conventional noise and its effect on human beings, noise as it affects animals, or underwater noise as it affects sub-aquatic species, are expressed using the decibel scale. The decibel scale has the characteristic that it measures proportions rather than absolute quantities, so that, for example, doubling the amount of energy in a sound (for example by putting two identical sound sources close together) always causes an increase of 3 decibels, whether it is a doubling of a large or of a small amount of noise energy. However, to a human being the perceived loudness of a doubling of noise energy is quite small, and much less than a doubling. A tenfold increase in the amount of energy gives an increase of 10 decibels; however, this is not a tenfold increase in loudness as perceived by human beings.

4.5 Because the decibel scale measures proportions, absolute values in decibels have to be stated using a standard reference. In normal airborne acoustics, the reference is 20 microPascals (μPa) when the scale is measuring sound pressure level. However, for underwater sound levels, the established reference is 1 μPa (microPascal or 1 millionth of a Pascal[1]), which results in much higher numerical values for underwater sound levels than are usually seen for airborne sound levels. While for environmental airborne noise it is conventional to state the units as decibels or dB and the reference is usually not explicitly stated, the full terminology is "decibels re *reference*" where *reference* is 20 micropascals or 20 μPa[2]. To avoid confusion, underwater sound levels are almost always stated as decibels or dB re 1μPa.

4.6 The kind of decibel scale most commonly used for overall noise assessment is known as the 'A-weighted decibel' or dB(A). The 'A-weighting' is a method of causing measuring instruments to respond in approximately the same manner as does the human ear, which is comparatively insensitive to low-pitched and very high-pitched sound.

4.7 It is important to take into account the fact that the A-weighting curve only applies to human beings. In cases where animals are affected by noise their significantly different hearing thresholds must be taken into account, as A-weighted sound levels (dB(A)) are not relevant to animals, including fish.There is no equivalent to the 'A-weighting' for those cases; instead, the frequency content of the sound has to be considered as a spectrum rather than as an overall single-number.

4.8 For rodents, hearing thresholds are broadly similar to those of humans but with the frequency scale multiplied by 10 to give maximum sensitivity between 10kHz and 40kHz (compared with 1kHz and 4kHz for human beings). The effect of this is that, while humans hear sounds such as whistles as being the loudest for any given physical magnitude, and hear rumbles and very high pitched hisses at the same physical magnitude as being much quieter, mice are most sensitive to very high pitched sounds right at the top of the hearing range of humans with undamaged hearing, and extending

[1] Pascal is the SI unit of pressure in Newtons per square metre.

[2] When decibels are used to quantify sound power or intensity, the reference will be 1 picowatt in the SI system

up into the ultrasound region, inaudible to human beings. A young human being with undamaged hearing can just hear a sound at 20 kHz, but at half the loudness (or less) than a whistle at 1kHz, and the A-weighting reduces the measured level of a 20 kHz sound by 9.2 dB. This is the upper limit of the frequency range of most sound level meters, although some have ultrasound bands centred on 31.5kHz and 40kHz, and this is the region where mouse hearing is highly sensitive.

4.9 Fish hear underwater sound, which has a different reference to that used for sound pressure levels, but the frequencies of greatest sensitivity do not vary from those of human beings to the extent that is the case with mice. Fish may also perceive vibration as movement of water.

4.10 Fish can sense waterborne noise through both auditory and mechanosensory systems[3]. Hearing threshold curves for various species of fish have been obtained. For Zebrafish[4], their hearing threshold at a frequency of 800Hz is 0.4 Pa or 112 dB re 1 mPa and at 250Hz it is 2 Pa or 126 dB re 1 mPa.

4.11 Most research has centred on the relationship between sound pressure levels and hearing damage in fish. Sounds that were lower than 180 dB (re 1 mPa) and sounds that were not on continuously had no apparent impact on the sensory cells of the ear[5].

4.12 It is not known what effect noise has in the range between 75 and 180 dB, on such matters as the behaviour of fish in, for example, swimming to their spawning grounds. Rivers and oceans are, however, naturally noisy, with heavy rain producing sound pressure levels up to 110 dB. Shipping can produce noise levels over 105 dB.

4.13 Fish species also have pressure-sensitive cells that are sensitive to low frequencies (typically 10 Hz to 30 Hz) and near-field pressure changes, limited to an area immediately surrounding the fish. This allows the fish to detect the presence of other fish in close proximity (such as in schooling behaviour) or assists in predatory avoidance.

---

[3] Clark, Joseph A., Young, Jane A. Bart, Amrit and Zohar, Yonathan, Physiological effects of infrasonic noise on captive fish, Journal of the Acoustical Society of America, October 1996 – Vol 100, Issue 4, p 2709.

4 Bretschneider, F., van Veen, H., Teunis, P. F., Peters, R., & van den Berg, A. V. (2013). Zebrafish can hear sound pressure and particle motion in a synthesized sound field, Animal Biology, 63(2), 199-215. doi: https://doi.org/10.1163/15707563-00002406

[5] Hastings MC, Popper AN, Finneran JJ, Lanford PJ, Effects of low-frequency underwater sound on hair cells of the inner ear and lateral line of the teleost fish Astronotus ocellatus. Journal of the Acoustical Society of America – March 1996, Vol 99, Issue 3. pp1759-1766

4.14 Popper et al[6] groups species of fish according to whether they possess a swim bladder, and whether it is involved in its hearing. Zebrafish have swim bladders. This guidance gives specific criteria, as both SPL_{peak} and SEL_{cum} values, for a variety of noise sources. The modelled criteria are summarised in Table 1. SEL_{cum} is defined as the sound exposure level over a number of individual impulsive sound exposures and is calculated as the logarithmic sum of the squared sound pressure of the individual events. It is primarily applicable to impulsive sound from, for example, percussive piling. SPL_{peak} is the maximum instantaneous value of the sound pressure.

4.15 The Popper data is informative in this case, because it enables the likely impact of underwater noise from construction activity in the project to be considered. Although there are no research data on the effect of underwater noise on Zebrafish, it is important to be able to estimate firstly whether the noise will be audible, secondly its audibility above the fish's hearing threshold and thirdly whether or not it may come close to damage or mortality thresholds.

Type of animal	**Mortality and potential mortal injury**	**Impairment**	
		Recoverable injury	**TTS (Temporary Threshold Shift[7])**
Fish: swim bladder involved in hearing	207 dB SELcum or >207 dB SPLpeak	203 dB SELcum or >207 dB SPLpeak	186 dB SELcum

Table 1 Criteria for assessment of mortality and potential mortal injury, recoverable injury and TTS in species of fish (Popper et al, 2014)

4.16 Popper *et al* also consider behavioural effects in fish, which are defined as "substantial change in behaviour for the animals exposed to a sound. This may include long-term changes in behaviour and distribution, such as moving from preferred sites for feeding and reproduction, or alteration of migration patterns."

4.17 The Popper *et al* (2014) guidelines conclude that there is insufficient data available to apply quantitative thresholds for behavioural effects on fish. Thus, while the criteria in Table 1 are informative, the effects they relate to (mortality and impairment) are far in excess of acceptable effects and cannot be used for limiting exposure to underwater noise in the present case.

6 Popper A N, Hawkins A D, Fay R R, Mann D A, Bartol S, Carlson T J, Coombs S, Ellison W T, Gentry R L, Halvorsen M B, Løkkeborg S, Rogers P H, Southall B L, Zeddies D G, Tavolga W N (2014). Sound exposure guidelines for Fishes and Sea Turtles. Springer Briefs in Oceanography. DOI 10. 1007/978-3-319-06659-2.

7 Short term recoverable deafness

4.18 The results reported below show that underwater sound levels caused by the construction works at Cambridge South Station are likely to be well above the threshold of hearing of fish, and also likely to be well above ambient sound levels although significantly below hearing damage or mortality thresholds. The effect this will have on the behaviour of fish in open water can be assumed to be that they will tend to swim away from the source of the sound. Fish in tanks cannot of course do this.

4.19 To quantify the waveform of a sound (the signal) which is more complex than an unvarying single frequency, a means of obtaining a numerical amplitude is required. Simple averaging is not possible, as a sequence of positive and negative oscillations have an average of zero. All the values are made positive by taking the square of the signal, which can then be averaged. This measurement process involves determination of the “root-mean-square” value (“**RMS**”), which is a form of short-term averaging of the energy in the signal. The measurement of RMS values involves an exponential running average process which takes place over a defined time. In the case of airborne sound there are two standard time constants for this averaging, 1/8 second, known as ‘F' response and 1 second, known as ‘S' response. Longer averaging time constants may be appropriate for vibration measurement. While exponential averaging is the normal way of measuring airborne sound levels, a simpler average which is the sum of the squares divided by the time period is another way of arriving at an RMS value.

4.20 The basic decibel scale can only measure the level of sound at any particular time, and where the level of sound fluctuates up and down, the dB level also fluctuates.

4.21 To measure a fluctuating noise environment by means of single number, an index known as equivalent continuous sound level, or L_{eq}, is employed, also having units expressed in decibels, or dB. L_{eq} is a long term RMS or average of the amount of energy in the fluctuating sound. When expressed in dB(A) the symbol is L_{Aeq}. In the case of a continuous, unchanging sound, its L_{eq} level is the same as its sound level in dB. The L_{eq} scale will measure either the level of sound, or the duration of sound, or a combination of both such as the number and noise level of a series of train passages.

4.22 Another index is the maximum $L_{max.,}$ or, if A-weighting is appropriate, $L_{Amax.}$ Maximum noise levels are measured with either of the two time weightings. F or S, and are labelled L_{Fmax} or L_{Smax}, or L_{AFmax} or L_{ASmax} when A-weighting is appropriate.

4.23 I refer to these indices as relevant below when setting out the proper approach to be taken to measuring and assessing the effects of noise from different sources on different receptors.

Vibration Levels and Scales

4.24 Although low frequency airborne noise from sources such as heavy lorries can cause perceptible movement of building elements, such as rattling of windows, which is described by people as vibration, in my evidence the term ‘vibration' is restricted to displacement of the ground or of structures due to the propagation of waves through the ground.

4.25 The rate of change of displacement is velocity (sometimes called particle velocity to refer to a small point on the vibration surface) and the rate of change of velocity is acceleration. The rate of change of acceleration is jerk, but this quantity is normally only considered in the assessment of vehicle ride quality. Thus the basic units of vibration measurements relating to the movement of the surface that is vibrating are usually either velocity in metres per second (m/s), or acceleration in metres per second per second (m/s^2). For small values, millimetres or micrometres may be used instead of metres. Acceleration may sometimes be expressed in units of “*g*”, by dividing the acceleration in m/s^2 by 9.807. These quantities are precisely convertible from one to another if the frequency spectrum of the vibration is known.

4.26 Vibration from construction plant or trains is transmitted into the ground, via any intervening structure, though which it travels to the receptor location which is typically a building. The vibration enters the building through its foundations, where a “coupling loss” may occur and is then transmitted to different parts of the building via the building’s structure. The building structure has its own dynamic characteristics with the result that amplification or attenuation of incoming vibration may occur depending on the frequencies of modes in the structure and the spectrum of the incoming vibration.

4.27 As in the case of noise, human sensitivity to vibration depends on the frequency of the vibration. There are weighting curves like the ‘A-weighting' of noise measurements in dB(A). There are different weighting curves for vibration in the vertical, horizontal and lateral directions.

4.28 As is the case with noise, it is also necessary to take account of the effect of intermittency on human response, when vibration is not continuous. Whereas with noise this is done using the L_{Aeq} index, for vibration the index used is known as vibration dose value or VDV. Unlike L_{Aeq}, for a constant vibration signal VDV increases over time.

4.29 Short-term vibration levels may be measured using the so-called peak particle velocity (PPV), typically expressed in mm/s. This scale can be used to assess effects on occupiers of buildings or on the structure of a building.

4.30 The effect of vibration on fish occurs after it has been transmitted into the water, when it is perceived as underwater sound/noise, and by many fish species as motion of the water. In the case of zebrafish their sensitivity to underwater noise is greater than their sensitivity to particle motion.

4.31 In the case of open water above a solid surface, the relationship between vibration and underwater sound is obtained by multiplying the vibration velocity in the surface by the density and speed of sound in the water. Where the water is a confined body such as a fish tank, reverberation occurs in the tank resulting in a higher sound level than would be the case in open water.

5 LEGISLATION, POLICY AND GUIDANCE FOR NOISE AND VIBRATION

Legislation

5.1 As part of the Environmental Impact Assessment process the promoter of a scheme must produce an ES which must report the likely significant effects on specific receptors by a range of emissions including noise and vibration[8]. Criteria, which I identify below, must be defined to enable significant effects to be identified.

5.2 The Town and Country Planning (Environmental Impact Assessment) Regulations 2017 also require descriptions of the forecasting methods used to assess the effects and of the measures envisaged to prevent, reduce and where possible offset any significant effects. The requirement to prepare an ES is reflected in the Transport and Works (Applications and Objections Procedure) (England and Wales) Rules 2006.

5.3 Other relevant legislation includes the Control of Pollution Act 1974 ("**1974 Act**") and the Noise Insulation (Railways and other Guided Transport Systems) Regulations 1996 ("**1996 Regulations**"). The 1974 Act uses the concept of "best practicable means" to control construction noise and requires contractors to apply to the local authority for prior consent under section 61. This will generally involve the submission of noise calculations, based on the adopted construction methods, which demonstrate that best practicable means have been adopted, however this does not of itself guarantee or confirm that noise effects would not be significant. The 1996 Regulations set out the requirement on Network Rail to provide noise insulation in respect of operational noise from railways at "eligible buildings" in respect of defined works and according to identified noise criteria. I also return to this below.

Noise Policy Statement for England

5.4 Government policy on noise is primarily devoted to the effects of noise on human beings, and there is no direct guidance on effects on other species or receptors.

5.5 Government policy on noise is set out in the Noise Policy Statement for England ("**NPSE**"), dated March 2010, which is itself referred to in the National Planning Policy Framework (June 2021). The NPSE seeks to "clarify the underlying principles and aims in existing policy documents, legislation and guidance that relate to noise" (paragraph

[8] Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment. 13 December 2011, as amended by Directive 14/52/EU of 16 April 2014.

1.4). The Explanatory Note identifies key concepts to be applied when assessing noise, advising that:

"2.20 - There are two established concepts from toxicology that are currently being applied to noise impacts, for example, by the World Health Organisation. They are:

NOEL – No Observed Effect Level

This is the level below which no effect can be detected. In simple terms, below this level, there is no detectable effect on health and quality of life due to the noise.

LOAEL – Lowest Observed Adverse Effect Level

This is the level above which adverse effects on health and quality of life can be detected.

2.21 - Extending these concepts for the purpose of this NPSE leads to the concept of a significant observed adverse effect level ("SOAEL").

SOAEL – Significant Observed Adverse Effect Level

This is the level above which significant adverse effects on health and quality of life occur.

2.22 - It is not possible to have a single objective noise-based measure that defines SOAEL that is applicable to all sources of noise in all situations. Consequently, the SOAEL is likely to be different for different noise sources, for different receptors and at different times. It is acknowledged that further research is required to increase our understanding of what may constitute a significant adverse impact on health and quality of life from noise. However, not having specific SOAEL values in the NPSE provides the necessary policy flexibility until further evidence and suitable guidance is available".

5.6 The Explanatory Note sets out (at paragraph 2.22-5) its aims to:

5.6.1 avoid significant adverse impacts on health and quality of life from environmental, neighbour and neighbourhood noise within the context of Government policy on sustainable development;

5.6.2 mitigate and minimise adverse impacts on health and quality of life from environmental, neighbour and neighbourhood noise within the context of Government policy on sustainable development; and

5.6.3 where possible, contribute to the improvement of health and quality of life through the effective management and control of environmental, neighbour and neighbourhood noise within the context of Government policy on sustainable development.

5.7 It advises that:

"2.23 - The first aim of the NPSE states that significant adverse effects on health and quality of life should be avoided while also taking into account the guiding principles of sustainable development (paragraph 1.8)…

2.24 - The second aim of the NPSE refers to the situation where the impact lies somewhere between LOAEL and SOAEL. It requires that all reasonable steps should be taken to mitigate and minimise adverse effects on health and quality of life while also taking into account the guiding principles of sustainable development (paragraph 1.8). This does not mean that such adverse effects cannot occur".

5.8 The aims of the NPSE are supported by the National Policy Statement on National Networks ("**NPS NN**"), paragraph 5.195 of which states:

"5.195 The Secretary of State should not grant development consent unless satisfied that the proposals will meet, the following aims, within the context of Government policy on sustainable development:

- *avoid significant adverse impacts on health and quality of life from noise as a result of the new development;*
- *mitigate and minimise other adverse impacts on health and quality of life from noise from the new development; and*
- *contribute to improvements to health and quality of life through the effective management and control of noise, where possible."*

5.9 The NPS NN needs to be considered even in the case of a scheme that does not fall within the definition of a nationally significant infrastructure project, as is made clear by paragraph 1.4 of the NPS NN which states as follows:

"In England, this NPS may also be a material consideration in decision making on applications that fall under the Town and Country Planning Act 1990 or any successor legislation. Whether, and to what extent, this NPS is a material consideration, will be judged on a case by case basis."

Guidance on noise and vibration with respect to human beings

5.10 National Planning Practice Guidance (Paragraph 004, 22 07 2019) identifies three increasing levels of effect ranging from "no observed effect" to "significant adverse effect level".

5.11 Guidance on appropriate noise and vibration levels for different situations may also be found in a range of British and International Standards and other publications which are set out in **Table 4.1**. all confined to the effects of noise and vibration on human beings.

Table 4.1 **Guidance Documents**

Reference	Title	Application
BS 5228-1:2009+A1:2014	Code of practice for noise and vibration control on construction and open sites. Noise	Airborne noise: Construction
BS 5228-2:2009+A1:2014	Code of practice for noise and vibration control on construction and open sites. Vibration	Vibration: Construction
BS ISO 4866:2010	Mechanical vibration and shock. Vibration of fixed structures. Guidelines for the measurement of vibrations and evaluation of their effects on structures	Vibration: Construction
BS 7385-2:1993	Evaluation and measurement for vibration in buildings. Guide to damage levels from groundborne vibration	Vibration: Construction
BS 6472-1:2008	Guide to evaluation of human exposure to vibration in buildigns	Vibration evaluation Construction and Operation
BS ISO 14837-1:2005	Mechanical vibration -- Ground-borne noise and vibration arising from rail systems -- Part 1: General guidance	Vibration and Ground-borne noise prediction: Operation
BS PD ISO/TS 14837-31:2017	Mechanical vibration -- Ground-borne noise and vibration arising from rail systems -- Part 31: Guideline on field measurements	Vibration and Ground-borne noise prediction: Operation

Table 4.1 Guidance Documents

Reference	Title	Application
	for the evaluation of human exposure in buildings	
BS PD ISO/TS 14837-32:2015	Mechanical vibration -- Ground-borne noise and vibration arising from rail systems -- Part 32: Measurement of dynamic properties of the ground	Vibration and Ground-borne noise prediction: Operation
BS 8233:2014	Guidance on sound insulation and noise reduction for buildings	Airborne noise: Construction and Operation
WHO Guidelines 1999 WHO NNG 2009 WHO ENG 2018	Guidelines for Community Noise Night Noise Guidelines for Europe Environmental Noise Guidelines for the European Region	Airborne noise Airborne noise Airborne noise
Building Bulletin 93 (BB93)	Acoustic design of schools: performance standards Department for Education December 2014	Airborne noise
Noise Insulation Regulations for Railways	The Noise Insulation (Railways and Other Guided Transport Systems) Regulations 1996. SI 1996/428	Airborne noise: Operation

Guidance relating to noise and animals

5.12 National Guidance on noise and animals is non-specific in terms of measured levels. As is the *Code of Practice for the Housing and Care of Animals Bred, Supplied or Used for Scientific* Purposes *(December 2014)* published by the Home Office.

5.13 In terms of vibration, the US National Institutes of Health Design Requirements Manual (2016) does set out vibration limits (its Table 5.2.2) for animal research as below:

Animal Research Facility 100 µm/s;

Rodent behavioural and holding rooms 50 µm/s.

5.14 Further, the publication “Noise and Vibration in the Vivarium: Recommendations for Developing a Measurement Plan” by Jeremy G Turner in the Journal of the American Association for Laboratory Animal Science Vol 59, No 6 advises:

"Vibration levels inside the cage should be maintained below

0.025 g RMS. Note that vibration can occur in the x, y, or z axes and can be measured in all 3 axes or the greatest of the 3.

Likewise, vibration levels of only approximately 0.025 g have been shown to increase fecal corticosterone metabolites in female (but not male) mice, and to result in overt behavioral responses in female mice indicative of arousal.

Noise levels inside the cage should be maintained below 70 dB SPL"

As is the case with noise, the effect of vibration on animals is not the same as it is on humans. Research[9] on the effects of vibration on female mice has found the most behavioural responses at 1.0 m/s^2 (0.1g). At intermediate accelerations of 0.5 and 0.75 m/s^2, (0.05 and 0.075g) behavioural responses are most prevalent at frequencies of 70 to 100 Hz.

5.15 A review of published research papers on the effects of vibration on mice, and on the hearing thresholds of fish is given in **Appendix 3**. The papers include work which seeks to establish a broad correlation between noise and vibration and effects on mice[10] and fish. However the papers do not provide any formal recommendations or uniform guidance on criteria to be used in noise and vibration assessments, beyond what I have set out above, and it is also necessary to exercise professional judgment when identifying such criteria based on experience of other projects.

---

[9] Vibration-induced Behavioral Responses and Response Threshold in Female C57BL/6 Mice Angela M Garner,John N Norton,Will L Kinard, Grace E Kissling, and Randall P Reynolds Journal of the American Association for Laboratory Animal Science Vol 57, No 5 Pages 447-455

[10] The published literature focusses specifically on effects on mice, although there is information relating to rats which indicates that conclusions with respect to mice may be extended to include rodents in general, i.e. including rats

6 METHODOLOGIES AND CALCULATION OF NOISE AND VIBRATION

Introduction

6.1 Predictions of noise or vibration start with the source characteristics, *eg* an item of construction plant or a train.

6.2 The level of noise/vibration emitted by a source might be available from published information (*eg*, in a British Standard) for the particular item or one with similar characteristics, or from monitoring undertaken specifically for the project. A further alternative is to determine the levels from the fundamental properties of the source (*eg*, in the case of vibration from railway vehicles).

6.3 The information on source levels may then need to be combined with information on the duration of operation of equipment or the number of times the item operates within a particular period to (*eg*, the day or night) and when it operates (*ie*, the time of year). Information on the operating time is specific to the project and needs to be provided by the promoter of the scheme.

6.4 When the effect under consideration is for receptors other than human beings, standard information about source characteristics may be available solely in terms of A-weighted decibels, dBA. Additional information is required to discover the spectral content of the noise.

6.5 Predictions then determine how the level at the source is changed as the noise or vibration energy travels through the air or ground to the reception point. Thus the characteristics of the transmission path need to be considered.

6.6 The features of the transmission path that affect the change in the level of noise or vibration between the source and receiver include the separation distance and so the locations of the sources must be specified. Source locations are normally project specific and are dictated by the promoter.

6.7 In the case of airborne noise two other relevant features of the transmission path are:

6.7.1 the presence of structures (such as buildings or walls) that can act as barriers to the propagation of the sound, and

6.7.2 the kind of ground surface since there is a greater reduction if the intervening surface is acoustically absorptive (such as tilled soil) compared to acoustically hard surfaces (such as concrete or water).

6.8 Methods for predicting airborne noise that include procedures for accounting for the above features and other relevant factors are provided in BS 5228-1 [11] for construction sites and the Calculation of Railways[12] for railways.

6.9 Relevant features of the transmission path for vibration include the geological composition of the intervening ground. The general nature can be ascertained from maps from the British Geological Survey but there will need to be site investigation by the promoter to determine the local characteristics.

6.10 In the case of trains the transmission path into the ground needs to be specified and that includes the kind of rail and its roughness, the rail fixings, the method of supporting the sleepers and the characteristics of the structure supporting the track bed.

6.11 It is also necessary to consider the relevant receptors. The factors that determine sensitivity of people to noise and vibration include the activity or use of the building which can vary according to the time of day. The sensitivity of equipment depends on the nature of the process (*eg*, an electron microscope) and the resolution of the system (*eg*, 100x or 1000x). The existing level of noise or vibration can also be a relevant factor as can the overall period (*ie*, in terms of weeks etc) for which the noise/vibration will occur. The sensitivity of animals depends on their species and their environment.

6.12 These basic principles of methodology are taken into account, along with relevant legislation, policy and guidance, when determining criteria for assessing noise and vibration from different sources. I turn to this below.

Methodologies and criteria for assessing effects on the AMB

Overview

6.13 In the case of equipment that is sensitive to ambient noise or vibration, account has to be taken of the specific equipment already installed or for which installation is anticipated. The acceptability of a location for the satisfactory operation of vibration

---

[11] BS 5228-1:2009+A1:2014.Code of practice for noise and vibration control on construction and open sites.

[12] Calculation of Railway Noise. Department of Transport 1995. HMSO.

and/or noise sensitive equipment therefore needs to be assessed on a case-by-case basis. There are three approaches to this assessment.

6.14 Two of the approaches are based on published data. Published criteria might be available in a manufacturer's manual for a specific item, or by reference to guidance published by the American Society for Heating and Refrigeration and Air-conditioning Engineers (ASHRAE) or the Institute of Environmental Sciences and Technology (IEST).

6.15 These criteria (which are used internationally) specify a family of curves designated VC-A to VC-E which set levels related to the operational performance of the equipment (*eg* the higher the resolution of an electron microscope the lower the level of acceptable vibration specified in the guidance). The development of more sensitive equipment has led to the adoption of two further curves designated VC-F and VC-G, as published by the IEST. By way of illustration the vibration criteria defined by the VC curves are illustrated in **Appendix 2**.

6.16 It should be noted that while the VC curves are expressed in terms of vibration velocity in units of micrometres/s, equipment manufacturers may state their vibration limits in terms of acceleration in mm/s^2. As I have explained, the three descriptors of vibration, namely acceleration, velocity and displacement are mutually convertible, and VC curves, which are flat in terms of velocity, may be stated in terms of acceleration by multiplying their values at each frequency by 2 x pi x frequency. This is the reason why the VC-C plots in **Appendix 1** and **Appendix 2** appear to be very different, even though they are fundamentally the same.

6.17 However, while the velocity or acceleration are expressed in terms of RMS values, the time constant involved is not specified, as they are primarily intended for the assessment of continuous vibration, the RMS value of which does not vary with time. In the case of vibration which varies with time, the VC curves have no meaning unless the time constant used to determine the RMS value is stated. The original published literature relating to the introduction of the VC system indicated that a time constant of 1 second is appropriate.

6.18 A further consideration relates to the bandwidth of the vibration. Vibration may occur at a single frequency, or predominantly so. This can be the case when the source is rotating machinery. In such a case the vibration spectrum will show a clear peak around a particular frequency, and this can be plotted on a chart of VC curves for evaluation. However, other sources of vibration may contain components at many frequencies, i.e. be broad band in nature. In such circumstances, the vibration spectrum has to be quantified using a defined bandwidth. This can be narrow band (for example a bandwidth of 1Hz) or can group the results into bands such as 1/3 octaves or octaves (where the term octave has its origins in musical acoustics and means that the frequency of the upper limit of the band is twice that of the lower limit). Spectra measured in 1/3 octaves or octaves have numerically greater values than narrow band spectra, for the same vibration signal. Specifications of vibration limits for sensitive equipment seldom specify the bandwidth, but it is common to use 1/3 octave spectra as Network Rail's consultants, Ramboll, have done in the present case.

6.19 The AMB was designed to two vibration criteria on the advice of the consultants (Ramboll) advising the University at the time (who are now Network Rail's consultants). The first related to the MRI installation for which VC-C applies. The second was VC-A which applies elsewhere. The actual MRI instrument installed, manufactured by Bruker, specifies limits for vibration using its own system. Interpreted strictly, at its most sensitive frequency just below 5Hz, the specified limit is equivalent to VC-E. However, the chart reproduced in **Appendix 1** shows that the "Typical distribution of a magnet system's tolerance to floor vibrations" coincides with VC-C at its most sensitive point, i.e.. the lowest point on the tolerance curve. The specification does not enter into the topic of bandwidth or time constant for non-continuous vibration. Based on the tolerance curve, and the minimum uncertainty margin that has been applied by Bruker, it is possible to create a suitable, more detailed, criterion in terms of 1/3 octave bands with a 1 second RMS time constant, and this is also plotted in the graph in **Appendix 1**.

6.20 The third approach to assessment is empirical ie if an item of equipment performs satisfactorily in a given environment then, provided there is no increase in the levels of vibration or noise experienced there, no degradation in performance or usability would be expected. Conversely, if there is an increase in the level of vibration then there is a risk that it will rise to a level where there will be interference or increased interference with the use of that equipment. If an installation already experiences operating difficulties with the existing level of vibration or noise then that problem will be exacerbated by any increase.

6.21 Although, in strict terms, baseline vibration at the AMB exceeds the Bruker specification, the chart in **Appendix 1** shows why it is the case, using the third approach, that the baseline conditions are just tolerable. The sequence of red dots is the measurement of vibration in room 0.24 MRI Control from the passage of a freight train made by Ramboll and reported in the Ramboll Technical Note 5 submitted by Network Rail[13]. The continuous red curve (the lowest continuous curve) is VC-C. The grey-coloured "staircase" curve is the limit stated by Bruker, the manufacturer, which is related to the continuous blue curve representing the "typical tolerance" of the instrument. The continuous blue-grey curve incorporating dots is a more detailed interpretation of the tolerance curve prepared by me including an allowance for minimum-versus-typical – more detailed than the staircase that gives rise to unnecessarily demanding values in its extremes. It is notable that the measured freight train vibration, while it exceeds VC-C, does not exceed the modified Bruker limit curve. This explains why exceedance of VC-C by existing freight trains is acceptable. The VC-C criterion was chosen when the AMB was being designed before the specific manufacturer's limits were known. **Appendix 1** shows it to have been appropriate, but that it is capable of development into a more detailed limit which the University is able to accept should there be an exceedance of the strict VC-C requirement.

6.22 With regard to vibration effects on rodents and fish, while some conclusions derived from the scientific literature are stated in terms of overall acceleration in units of *g*, the University selected the design criterion in terms of VC-A. The relationship between VC-A and values expressed in terms of g depends on the bandwidth of the vibration. Broadband vibration with amplitude just equal to VC-A at every frequency from 8Hz to 80Hz would amount to approximately 0.1g. Vibration at a single frequency at 8Hz just reaching VC-A would be 256 mg.

6.23 Based on the actual characteristics of the installed Bruker MRI instrument, and criteria for noise effects on rodents and underwater noise effects on fish, the vibration criteria which should be applied in order to avoid significant effects on these two classes of receptors can be stated in tabular form as follows:

	MRI	**Animals (rodents and fish)**
1/3 octave band centre frequency, Hz	rms (1 sec) acceleration, mm/s^2	rms (1 sec) velocity, mm/s
1	0.15	0.05
1.25	0.15	0.05

[13] Referred to in the table at paragraph 10.2 below

1.6	0.15	0.05
2	0.15	0.05
2.5	0.15	0.05
3.15	0.2	0.05
4	0.4	0.05
5	1	0.05
6.3	2	0.05
8	4	0.05
10	8	0.05
12.5	16	0.05
16	32	0.05
20 and above	50	0.05

6.24 I return to these vibration criteria below, where I also cover what I consider to be the relevant criteria for airborne noise relating to rodents. It is unnecessary to provide for a discrete criterion relating to underwater noise affecting fish, as the criterion relating to vibration is adequate to address effects arising from underwater noise.

6.25 The AMB is also a place of work for those engaged in the research activities, and guidance on appropriate noise levels in places of work falls under two headings, hearing conservation and appropriate conditions for work in spaces such as offices. Existing and future noise levels in the AMB are well below hearing damage risk criteria, so the latter form of guidance applies. BS8233:2014 is mainly devoted to dwellings but does give some advice on ambient noise levels in non-domestic buildings which should not normally be exceeded. For "study and work requiring concentration" the design ranges are 35-50 $L_{Aeq,T}$[14]. The British Council for Offices specifies levels for external noise intrusion which are equivalent to approximately 40-45 dB $L_{Aeq.T}$ for open plan and cellular offices respectively.

[14] BS 8233 is unspecific with regard to the value of T, and states "The time period,T, should be chosen to cover the normal operation of the source, or particular occupational requirements of the building if more appropriate. If the source level varies, the maximum level having an appreciable duration should be chosen."

7 RECEPTORS AND SOURCES AT THE AMB

Existing sources of noise and vibration

7.1 The principal existing source of noise and vibration at the AMB is the railway running through the campus, together with the movement of road vehicles and activity and plant within the building. These sources were taken into account during the design phase of the building. The building was constructed to a design that does achieve acceptable conditions taking into account the existing sources and the specific requirements of the actual MRI instrument installed.

Receptors in the AMB sensitive to noise and vibration

7.2 There are four classes of sensitive receptor in the AMB: (1) human beings working in the building; (2) rodents, including breeding females; (3) fish; and (4) sensitive instruments, principally a Bruker BioSpec®MR instrument.

7.3 In the case of human beings, the relevant sensitivities are annoyance, interference with task performance, speech interference and indirect health effects[15].These are the principal effects which inform Government planning guidance which is focussed on noise outside homes Other effects such as hearing damage and direct health effects are due to noise levels unlikely to be reached. Sleep disturbance does not arise as there is no overnight accommodation. In the case of rodents the potential effects are behavioural disturbance and interference with reproduction including infertility, abortion, mismothering or cannibalism of pups. In the case of fish the potential effects are behavioural disturbance and hearing damage. Underwater noise can cause fatalities but levels are not expected to be such as to cause fatality in this case. In the case of sensitive scanning instruments the potential effects are reduction in image quality and potential loss of experimental data, and/or programme time and money.

7.4 The broad locations of these receptors (in particular the MRI equipment, rodents and fish) are explained in the evidence of Karl Wilson.

Future sources of noise and vibration

[15] "indirect" means health effects other than direct physical damage (hearing damage or vibratory white finger), e.g. cardiovascular disease found to be more prevalent among noise-exposed populations

7.5 Future sources will include those that are temporary (during construction and any advance works for the Scheme) and new permanent sources (from the operation of the Scheme once completed).

Construction Phase

7.6 Before the new permanent sources of noise and vibration associated with operation of the Scheme, there will be two periods of temporary activity – advance works and the main construction period – when new sources of noise and vibration will occur.

7.7 In each case, a range of construction plant and processes will be used by Network Rail in the vicinity of the AMB, and they will vary depending on the phase of the works being carried out. Construction vehicles will also use the roads near the AMB and other roads on the main network.

7.8 The potential for roads and vehicles using them to be significant sources of vibration depends primarily on the quality of the paving. Second in importance is the nature of the ground supporting the road. A road laid on soft alluvium or peat would give rise to greater vibration than a road constructed on clay, chalk or gravel. With regard to the vehicle itself, the main parameter of importance is the axle load.

Operating Phase

7.9 The passage of trains is the principal source of vibration and groundborne noise in the AMB. The highest levels are caused by freight trains. The installation of the railway infrastructure which would be authorised by the Order would not directly result in any change in the type, length or number of trains although these may change in the future. The potential effects of the Scheme works relate to: (a) a shorter distance from the nearest track to the AMB; and (b) the installation of points and crossings and the possible introduction of welds of a type that cause vibration. This type of weld is known as aluminothermic, and involves the use of an alloy which is softer than steel, causing an impulse when wheels pass over it.

7.10 Network Rail have indicated that the proposed future distance from the nearest rail of the southbound loop to the edge of the AMB is 47.61m, This compares with the existing distance of 53.4m. The nearest of the through tracks will be moved 0.8m nearer to the AMB reducing the distance of 53.4m to 52.6m.

7.11 At present the existing railway is plain line. The Network Rail indicative layout shows a crossing at a distance of approximately 60m from the nearest corner of the AMB. NR have indicated that there are two track layouts under consideration, a temporary layout and a permanent one, with switches in different locations.

Criteria required for the protection of receptors in the AMB

7.12 Having regard to the wider context for noise and vibration assessment and overview of methodologies and criteria that I set out above, in summary, the required criteria necessary to avoid significant effects, avoid harm, and permit the continuance of activities in the AMB without disturbance or interruption are as follows:

7.12.1 **Human beings**: Airborne sound not exceeding 45 dB LAeq,30 minutes inside the building. This may be converted to an external façade level of 80 dB LAeq,30 minutes after allowing for the sound insulation of the façade;

7.12.2 **MRI**: RMS (1 second) vibration not exceeding the limits set out in 6.23 above;

7.12.3 **Rodents and fish**: RMS (1 second) vibration not exceeding the limits set out in 6.23 above; and

7.12.4 **Rodents**: Airborne sound levels not exceeding 45 dB in the ultrasound octave bands centred on 16kHz, 20kHz and 31.5kHz. The sound insulation of the façade can be assumed to be no less than 35 dB at ultrasound frequencies, therefore these values can be monitored using the same system required for airborne sound affecting human beings provided that the sound level meter used has the capability to measure the ultrasound bands, and the processor is programmed to measure separately dBA L_{Aeq} and the ultrasound bands (unweighted).

7.13 These criteria apply to both construction and operation, although only the MRI has the potential to receive levels exceeding them in the operational phase based on current information so far as it is available

7.14 In earlier sections of my evidence, in particular section 4, I have set out the broad context that applies to assessing noise and vibration, including the coverage of these topics within the ES. However, it is not necessary to apply every aspect of this context to the specific receptors in this case. In my view, the above key criteria are those of greatest importance to assessing the impact of the scheme on the AMB. Nonetheless, this does not detract from my criticisms of the ES, which I set out further below.

7.15 If adequate mitigation is not provided, my concern is that there would be likely potential significant effects on the above receptors. The likely effects of the proposals on the AMB are as follows, with regard to each group of receptors:

Construction

7.15.1 **Human beings:** Internal airborne noise levels may disrupt concentration and cause annoyance and interfere with task performance by those engaged in research work.

7.15.2 **Sensitive instruments:** Vibration may invalidate the output of the MRI.

7.15.3 **Rodents:** Noise and/or or vibration may disrupt breeding and general welfare

7.15.4 **Fish:** Underwater noise will be well above the hearing thresholds of Zebrafish, though not at physically harmful levels, with unknown consequences .

Operation

7.15.5 **General:** If key assumptions made by Network Rail do not become reality in the construction and operation of the works, there would be potentially significant noise and vibration effects on all receptors. These assumptions relate to minimum distances, dimensions and speeds.

7.15.6 **Human beings**: Adverse effects due to noise or vibration are not likely.

7.15.7 **Sensitive instruments:** The MRI is already subject to vibration effects which are only just acceptable with regard to error-free operation of the instrument, and any increase may be harmful. An increase is predicted, and no mitigation is envisaged.

7.15.8 **Rodents and fish:** As above in 7.15.3 and 7.15.4.

8 REVIEW OF ES

Introduction

8.1 The Order application was accompanied by an ES which purported to consider the noise and vibration effects of the Scheme. The University was understandably concerned about the potential effects on its interests. As part of my instruction I reviewed the ES to consider the extent to which these issues had been properly addressed before the Order application was made.

8.2 There is very little information in the ES on programming, plant type and location; and it is not sufficient to enable the levels of airborne noise presented in the ES to be verified. The same applies to vibration.

8.3 The assessment of residual effects acknowledges that there will be a “significant negative effect” on the AMB during construction in terms of both noise and vibration.

8.4 The ES therefore acknowledges that significant effects are likely to arise as a result of the Scheme, even after mitigation, but even then the assessment work within that document was fundamentally deficient in its consideration of the effects.

8.5 Some sources are identified and partially assessed. Other sources are referred to and not assessed, such as ground compaction under the new sidings and ballast tamping[16] after the laying of the new track. Some sources are not referred to or assessed, such as the construction of foundations for the gantries to support the overhead line equipment. The potential for vibration to arise from the use of roads, including the temporary haul road, by heavy vehicles is not addressed.

Information not provided in the ES

Construction phase - noise

8.6 The assessment carried out and reported in the ES does not explicitly consider the types of receptor which exist in the AMB. The noise assessment in particular is primarily devoted to effects on human beings. The assessment draws on guidance which is primarily about noise outside people’s homes, and does not consider noise as it affects people in workplaces. Although there is reference in Chapter 5 of the ES (Table 5.3 on page 5-10) to “Sensitive Laboratories and Research Imaging” having

[16] Ballast tamping is the vibration of the ballast to improve its stability

very high sensitivity, the numerical assessment is done using the “ABC Method” from BS 5228 which the Standard describes as “an example of the threshold of potential significant effect at dwellings”. The AMB and other similar buildings on the campus are therefore incorrectly assessed as if they were dwellings. There is no consideration of the effects of noise on animals.

8.7 The ES predicts a major impact on the AMB due to construction noise, yet there is no detailed consideration of mitigation beyond "embedded mitigation" described as site hoarding and the use of Best Practicable Means. It is stated that "Site hoarding of 2.4 m would be installed around the site perimeter, where mitigation is required and practicable. Guidance provided in BS 5228:2009+A1:2014 Annex B, states that a screen can provide 5 dB attenuation for partial line of sight from source to receiver, and up to 10 dB attenuation where there is no line of sight between source and receiver." However where there is a clear line of sight above the hoarding there is zero noise barrier effect, and given the height of the AMB this will be the case for many parts of the building.

8.8 It is necessary to carry out a proper assessment of the potential for mitigation, including more effective noise barriers than standard site hoarding, and the possibility of alternative plant selection.

8.9 In particular an example programme should be provided, based on the construction stages identified in Volume 3: Appendix 5.3 of the ES to indicate the likely periods when the "worst case" prediction will arise and their durations in order that the magnitude of the disturbance to activities in the AMB can be properly assessed.

8.10 The sound insulation of the external facade of the AMB was selected assuming the continuance of the current ambient noise climate, and the predicted exterior construction noise levels are substantially in excess of the pre-existing ambient so that noise criteria for internal spaces will be exceeded.

Construction phase - vibration

Assessment of effects

8.11 The works proposed that would affect the AMB are unclear and contradictory. Page 21 of ES Appendix 6-2 states “Vibratory piling works are to be avoided wherever possible and will not be used except for the OLE works at Shepreth Branch Junction where they may be required due to limited time periods for track possessions.” Yet

Table 6-2-5 presents a prediction of 2.43 mm/s for the AMB due to vibratory piling in the track construction zone and 0.65 mm/s due to vibratory piling in the station area construction zone.

8.12 Sources of vibration are referred to which have not been assessed, "Compaction for the ballasted track will be carried out by means of a Main Line Tamper. This has a negligible impact on induced vibration when compared with other vibratory methods of compaction." (page 21 of ES Chapter 6 Appendices).

8.13 The following information is required as a result:

8.13.1 A prediction of vibration from a main line tamper is required. Tamping will be required not only during construction, but periodically after completion of the works, including tamping on the new loop closer to the building.

8.13.2 A prediction of vibration from each activity and item of plant likely to be used on each site is required. Worst case predictions are insufficient when a significant effect is likely because durations and locations become critical.

8.14 Page 22 of ES Appendix 6-2 states "Where a potential significant impact is predicted for a receptor the likely effect of the building has been taken into account to establish if this would materially affect the assessment." It is unclear whether or how this has been done. Page 28 of Appendix 6-2 make the general statement "Heavyweight building will reduce vibration levels at ground floor but potential for amplification at upper levels to offset benefit. Probable reduction from Moderate to Minor impact but does not alter significance." This is an insufficient level of prediction.

8.15 The following information is required as a result:

8.15.1 Measurements should be carried out on site to establish the local properties of the soil layers and establish a site-specific loss factor for the purpose of predicting the effect of distance.

8.15.2 Measurements should be carried out on site to establish transfer functions between external source locations and internal building structures where sensitive receptors are located.

Mitigation options

8.16 Consideration of mitigation measures is partial and incomplete. Alternatives to vibratory piling are not assessed, such as hydraulic press-in piling. “Low vibration construction techniques” are included on Page 25 of Appendix 6.2 but not explained or assessed.

8.17 The following information is required as a result:

8.17.1 Vibration from all construction activities referred to should be predicted, in a manner suitable for the assessment of effects on all receptors including instruments, workers and animals.

8.17.2 A management, monitoring and control protocol is required.

Management, monitoring and control

8.18 Table 6-2-4 mentions “Vibration monitoring with real-time feedback”. However, a system of continuous monitoring of vibration is required in which warning levels are automatically monitored, so that the approach of critical levels of vibration is detected in advance. It is necessary to establish a site management structure capable of ensuring that work can be stopped immediately when critical levels are approached:

Operational phase

Freight trains

8.19 Although not all timetabled train paths are used, there is a significant number of freight train movements in the Network Rail working timetable. The following issues arise as a result, primarily affecting the vibration thresholds for the MRI:

8.19.1 The baseline vibration currently attributable to freight trains has not been reported in the ES.

8.19.2 The effect of freight trains passing over switches and crossings has not been reported. Measurements have only been made at Shepreth Junction relating to passenger services.

8.19.3 Future intentions regarding use of the proposed loops through Cambridge South by freight trains are unclear, i.e. whether freight trains will use the loops and at what speeds.

Simultaneous train movements

8.20 Table 6-11 of Chapter 6 states "The assessment was based on single train pass-by events. During the baseline surveys, there were periods when trains travelling in opposite directions passed each other in the CBC region, but the frequency of this occurrence was less than 5-10% of all train pass-bys observed. The vibration levels in the as-developed case will be dominated by the S&C locations and hence the chance of trains passing this location at the same time and at the high speeds associated with greatest impact will be lower. However, sometimes trains will pass over S&C simultaneously and may cause higher levels, but this is expected to be sufficiently infrequent to not warrant forming the basis of assessment".

8.21 In the case of sensitive equipment and other receptors in the AMB exceedance of vibration criteria by any combination of train movements is a potential significant effect. The following information is required as result:

8.21.1 Predictions of maximum vibration due to all combinations of train operations should be provided and assessed.

Effects of speeds and distance

8.22 With regard, primarily, to potential vibration effects on the MRI, it is pointed out in the ES that a line speed of 60 mph will apply to the loop lines compared with 90 mph on the current track. However:

8.22.1 Measurements of the relationship between vibration and speed are not reported in the ES and should be provided.

8.22.2 The actual proposed speed profiles that will apply (i) on the loops and (ii) on the through lines should be simulated. The proposed speeds of 60 mph and 90 mph are line speeds for the loops and main line respectively, and these are not necessarily the actual speeds of trains either on the existing line or on the proposed future tracks. Given the proximity of Cambridge Station and associated signalling actual speeds may be lower, and this affects predictions of the relative levels of vibration and noise from trains using the main and proposed loop lines.

8.22.3 While 90 mph will not be reached in the vicinity of the station by stopping trains, the proportion of stopping and non-stopping trains (if any) should be reported, and the likely speeds of trains passing over the crossings should be considered and compared with the speeds of trains measured while passing over the crossing at Shepreth Junction.

8.22.4 The relationship between vibration and distance from the track, measured on site, should have been reported in the ES so that the combined effects of speed changes and distance changes can be accurately predicted.

8.22.5 The use of speed limits as a mitigation measure should be fully considered, including further measurements at Shepreth junction to establish the relationship between speed and crossing vibration.

Vibration prediction location

8.23 It is unclear which vibration predictions in the ES are of ground surface vibration outside buildings and which take account of the transfer function between ground surface and building structure at the location of sensitive equipment. The following information should be provided as a result:

8.23.1 Where it has been previously measured the transfer function should be presented. In other cases site measurements of simultaneous ground surface and internal structural vibration should be made.

The effect of mitigation measures

8.24 The ES lists a number of potential mitigations measures with respect to operational vibration, including resilient fasteners, ballast mats, floating slab track, resiliently supported ties, and switch and crossing design optimisation such as movable frogs. With the exception of movable frogs, these measures are all approaches used in cases where there is a problem of re-radiated groundborne noise as heard by human beings and they are not effective in cases where the sensitive receptor is a laboratory instrument not sensitive to audible groundborne noise.

8.25 VC curves from VC-C downwards have a flat frequency response in velocity terms. Of the operational mitigation measures listed in the ES, all but one have the effect of shifting the peak in the loaded track natural frequency towards a lower point in the spectrum, with no change in amplitude. Thus no improvement in VC levels results. The one measure which does reduce amplitude is the use of swing-nose points or movable frogs. This is dismissed with the comment “This option has been assessed and found not to be feasible given the site constraints” (Table 6-13).

8.26 The following issues arise:

8.26.1 The prediction of vibration in Figures 6-38 and 6-39 of Appendix 6.3 may be exceeded when freight trains have been taken into account and the conclusions of “not significant” on page 6-21 of Chapter 6 does not take freight trains into account. Paragraph 6.2.40 of Chapter 6 states “The south western area of the building at ground floor level requires VC-C to be achieved.” Figure 6-38 shows VC-C reached on the ground floor and Figure 6-39 shows VC-C exceeded for second floor.

8.26.2 A full assessment of the option of installing swing-nose points and movable frogs should be carried out. Where there are site constraints the removal of those constraints should be fully considered.

8.26.3 Table 6-11 states: “It is assumed there are no other track discontinuities such as joints in rails”. In addition to joints, rail welds made using the aluminothermic process also have the effect of discontinuities because the metal used in the weld is softer than rail steel, and impulses occur when axles pass over them. Railway wheels passing over aluminothermic welds may have an effect only slightly less than the “clackety-clack” noise of wheels passing over open joints in the rail. This is in contrast to the case where flash-butt or arc welds are used. The consequence is that higher levels of vibration and noise may result compared with predictions starting from the existing conditions where there are no joints.

9 NETWORK RAIL'S STATEMENT OF CASE

Acoustic Assessment Part I: Noise

Paragraph 9.2.7 states

9.1 *"Any increase in noise and/or vibration during the construction works which may affect particular buildings close to the railway in the CBC will be mitigated through measures set out in CoCP Part B. While significant impacts are anticipated on certain buildings in CBC, these are expected to be temporary and will cease when the operational phase commences. Network Rail is in any event working with affected parties to seek to identify further mitigation that may be employed"*

My Comment

9.2 This statement indicates that after mitigation significant effects will persist until the end of the construction phase. The effect on the research work carried out at the AMB is not evaluated. Insufficient detail on construction works, locations, durations and programming is available. While a detailed programme will not be developed until later in the process, there is no reason why predictions of noise and vibration from specific activities currently unassessed, including OLE gantry constructions, ground consolidation and ballast tamping cannot be carried out. There is also no reason why the effect of basic mitigation measures such as noise barriers or selection of quieter plant cannot be addressed, taking account of the heights of each floor in the AMB and the different barrier attenuations which will result at each level.

Acoustic Assessment Part 2: Vibration

Paragraphs 9.2.9 and 9.2.10 state

9.3 *"Whilst during the construction phase there is the potential for significant adverse effects on scientific and research buildings on the CBC and in residential areas next to the CSIE Project, this would be subject to specific mitigation in the CoCP Part B. In particular, any piling activity would be carefully controlled and a consultation and liaison plan would ensure that stakeholders are given advance notice of works that may affect them*.

9.4 *The CSIE Project has been designed so that new track switches and crossings have been positioned away from sensitive buildings where practicable. No significant vibration effects are predicted in the operational phase, save for only the most sensitive* *imaging equipment within the Laboratory of Molecular biology which will be the subject of a tailored mitigation plan (currently undergoing consultation)."*

My Comment

9.5 Network Rail now consider that because there is an exceedance of the VC-C design criterion for the MRI instrument at the AMB due to the passage of freight trains, the fact that there will be an increase in that exceedance due to the revised track layout may be neglected and no proposals for mitigation are under consideration.

9.6 For reasons that I explain above and further below, the appropriate criterion to apply is, in my view, a more detailed criterion based on the manufacturer's specification, which is not currently being exceeded. In my view, any exceedances of those limits by the scheme are material and so ought to be mitigated.

9.7 In relation to the positioning of switches and crossings, the minimum distances are not limited by the draft Order, nor are the speed limits proposed for the new loop lines.

9.8 The format of the consultation/liaison/mitigation plans is not available to the University.

9.9 If key assumptions used for the assessment of future operational vibration were to be secured, the remaining issue would be exceedance of the vibration criterion I have detailed above by freight trains. Freight train characteristics may change in the future, for example if diesel-electric locomotives were to be replaced by battery-electric locomotives, No mitigation options are proposed. While the mitigation options listed and discarded in the ES may not be appropriate, the principal option, a lower speed limit for freight trains, has not been addressed. The vibration effects during the existence of the temporary track layout have not been assessed.

Conclusions on the Network Rail Statement of case regarding noise and vibration

9.10 The Scheme as presented to the inquiry is stated to be likely to have significant effects on key research facilities including those at the AMB. Full mitigation of those effects is not proposed, and the damaging consequences of interference with research programmes and reduction in the quality of research output are not properly considered, nor weighed against perceived benefits.

10 FURTHER ENVIRONMENTAL INFORMATION PROVIDED BY NETWORK RAIL SUBSEQUENT TO THE ES.

Response following the issue of the University's Statement of Case

10.1 Following the issue of the University's Statement of Case, Network rail responded by issuing documents responding to points raised on both noise and vibration. Two virtual workshops were held, the first including both noise and vibration, and the second attended solely by the Network Rail vibration expert and me.

10.2 Through and after this process some additional information was issued by or on behalf of Network Rail, including an indicative track layout plan, and further technical information relating to omissions in the ES. The relevant documents were as follows.

Drawing: Cambridge South Station, Anne McLaren BuildingmRail Design Impact 158454-JMS-ZZ-ZZZ-DRG-EMF-100000/P01.1	This drawing shows both the temporary and permanent proposed track layout with key distances.
CSIE Project Technical Noise Response To UoC Statement Of Case Technical Note Version 2 Date 13/10/2021	This document provided response to the University's comments on the Noise chapter of the ES, with regard to construction noise effects. The key points were "The significant adverse effects reported in Chapter 5 of the ES are related to potential effects on human behaviour, not on the sensitive research being undertaken in the building". This document includes a discussion on the potential AMB noise criteria for research and their interpretation in respect of construction noise and a discussion of the study presented within the University's Statement of Case that demonstrates that mice behaviour is impacted by high noise levels. The document states. "No significant adverse effects are predicted from noise associated with the construction of the CSIE upon research being undertaken at the AMB."
CSIE Project Technical Vibration Response To Uoc Statement Of Case Technical Note 5 (1620010876-Ram-Csie-Dn-Yv-005) Version 1 Date 14/10/21	This document presents an assessment of vibration from freight trains (absent in the ES) and of the magnitude of vibration from switches and crossings.
CSIE Project Ground Vibration Propagation Parameters Used In Analysis	This document states the assumptions which have been made in calculating vibration propagation through the soil. It includes some information about

Technical Note 8 (1620010876-RAM-CSIE-DN-YV-008) Version 0 Date 2/11/21	local geological conditions, but the main assumption about soil loss factor is taken from other sources
CSIE Project Ground Vibration Propagation Parameters Used In Analysis Technical Note 8 (1620010876-RAM-CSIE-DN-YV-008) Version 0 Date 2/11/21	Key findings were that "The VC-A areas of the building are closest to the railway line. However, there is a significant margin between the baseline vibration levels in the building and the VC-A criterion (a factor of 3-6). The small reduction in distances between the track and the building will mean this is not a critical assessment and the VC-C areas will govern the assessment"; and that "It is seen from the table above that, for the loop line, the most conservative assumptions would result in levels about 11% higher at 12.5Hz and 7% higher at 6.3Hz. However, when the reduced line speed is factored (which would result in a 33% reduction in vibration levels) the net result is that the loop line would have a lower resultant vibration level in the AMB than the current main line track. The main line will stay at 90mph line speed and is proposed to be approximately 1m closer to the AMB. It is seen that this results in a 0.2% to 0.5% increase in vibration levels at 6.3Hz without geometric attenuation and 0.6% to 0.9% with a point source assumption. This is considered to be the most relevant comparison as freight trains govern against the VC-C criterion and their peak vibration frequency is 6.3Hz."

10.3 Network Rail's consultants, Ramboll, were employed by the University during the site selection and building preliminary processes for the AMB. They were able to locate and provide a copy of their report on the site vibration survey which they carried out and this contained information on vibration from freight trains, further information of vibration from passenger trains of a variety of lengths and speeds and on the effect of distance on levels of vibration.

Cambridge Biomedical Campus Plot 8/9 Vibration Survey Report 11/04/2014

10.4 This document was prepared for the University, as Ramboll's then client, at the time when the suitability of the plot for the construction of the AMB was being evaluated. Key findings were "In free field conditions VC-A is typically achieved at all locations (with a risk that some freight services could exceed this) in all axes;" and "VC-C is typically exceeded in free-field conditions except for furthest from the railway." Further, measurements in the LMB building "showed that the building has a significant effect in suppressing ground borne vibration and that at this close distance to the railway line the VC-C criterion was close to being achieved except for a limited number of freight trains".

10.5 Network Rail have indicated that they have now appointed a main contractor, Murphys, who participated in the workshops that took place in November 2021, and that they will be in a position to provide more detailed construction data and programme indications than was the case at the time of the preparation of the ES.

10.6 Network Rail's consultants have declined to carry out an assessment of underwater noise levels.

10.7 Although Network Rail are predicting exceedance of VC-C for the MRI imaging instruments, no mitigation is proposed on the basis that the increase over the pre-existing exceedance is small.

11 CURRENT POSITION REGARDING INFORMATION RECEIVED AND AWAITED FROM NETWORK RAIL

The current position can be summarised as follows.

Construction noise

11.1 There is still no assessment of the noise effects of some of the works, and no information on the locations, timings and durations of activities including those which have been the subject of some assessment. Proposed mitigation is referred to only in broad terms, for example the height of the receptor locations in the AMB has not been assessed and nor has the performance of noise barriers at each level in the building. This remains the case following the provision of the further information listed in section 10.

11.2 The only numerical assessment of effects has been carried out has been done using criteria appropriate for human response. No proper consideration has been given to effects on animals and such text that has been provided makes the error of using the dB(A) scale, notwithstanding the fact that the A-weighting network has no relevance to animals.

Construction vibration

11.3 The ES has the same shortcomings with regard to vibration as for noise, with the addition of the fact that no consideration has been given to underwater noise levels to which fish would be exposed due to vibration at audible frequencies, nor to fish sensitivity to vibration through displacement of the water. Of particular concern is the continuing absence of predictions of vibration from ground compaction in the construction of the proposed new loop lines, rail ballast tamping, and gantry foundation construction.

11.4 Network Rail has not assessed the quality of relevant road surfaces proposed to be used for the construction of the Scheme. Network Rail has taken for granted that the surfaces of all roads to be used by construction vehicles, both roads on the campus and temporary haul roads, will have surfaces without significant irregularities, throughout the construction period. It is necessary for this to be properly considered by Network Rail.

11.5 An assessment of vibration from these construction activities not assessed in the ES is still awaited.

Operational Noise

11.6 The ES assessment of the effects of operational noise presents a “with development” façade L_{Aeq} level that is 0.4 dB lower than the “without development” baseline for rail-only noise. It appears to have assumed that the proposed new switches and crossings will be a greater distance from the AMB than is indicated in the latest track layout received from Network Rail.

11.7 Further, the track layout drawing referred to in section 10 above introduces the temporary track layout whereas only the permanent track layout has been assessed.

Operational Vibration

11.8 Many of the conclusions of Network Rail’s consultants are dependent on assumptions which are not the subject of control through the draft Order. As example is the fact that they are concluding that the distance from the crossing in the turnouts from the main line to the new loop lines is 188m from the centre of the AMB and that at this distance the magnification of vibration and noise from wheels running over crossings is subordinate to the vibration and noise of running on plain line, and can be ignored. The track layout drawing referred to in the table at paragraph 10.2 above introduces the temporary track layout whereas only the permanent track layout has been assessed. It appears that the minimum distance between the AMB and the nearest crossing is shorter in the temporary track layout than in the permanent layout, and that the turnout radius may be significantly shorter, resulting in greater magnification of vibration.

11.9 Network Rail’s consultants conclude that the greater proximity of the nearest rail after the installation of the loop lines is offset by a proposed speed limit of 60 mph on the loop lines. However, they have advised that the turnouts will be “high speed” turnouts. They may be capable of allowing higher speeds than 60 mph and speed limits are not controlled by the Order.

11.10 In calculating the change in the level of vibration from the passage of trains including freight trains, Network Rail have offset the effect of the short distance from the tracks to the AMB by the effect of there being a slower speed limit on the nearest proposed loop line, comparing the main line speed limit of 90 mph with the loop line speed limit of 60 mph. It seems highly unlikely that freight trains pass this location at a speed of 90 mph (many freight trains are limited to 75 mph, and the timetable shows that the lapse of time between a freight train passing Shepreth Junction and Cambridge Station is appropriate for a much lower speed.

11.11 Network Rail's consultants conclude that there will be an increase in vibration from freight trains, but consider that the increase relative to the pre-existing vibration from freight trains, which exceeds VC-C, may be neglected. This is despite the fact that, as shown in the figure in **Appendix 1**, any increase in vibration may be harmful to the correct operation of the MRI instrument. Furthermore the assessment is for a single freight train without allowing for the, albeit rare, occasions when there are two trains passing in opposite directions.

Conclusions regarding information provided

11.12 In my view the above deficiencies mean that ES is inadequate in its assessment of the effects of the Scheme on the University's interests, and despite the provision of some further information there remain important deficiencies. The Order application was therefore made with no proper consideration of how the Scheme might affect an important landowner and stakeholder in close proximity to the construction and operation of this substantial project.

11.13 Discussions are continuing between Network Rail and the University, including their appointed consultants, but there is at the time of writing no agreement on the provision of further information (or on Network Rail avoiding exceedances of the criteria that I have identified above, which I consider further below). I also anticipate that Network Rail may produce evidence which covers some or all the issues I have identified above. I will update my review of the position reached between myself consultants acting for Network Rail following my review of that evidence and prepare rebuttal evidence accordingly.

12 PLOT 9

12.1 The land known as plot 9 is currently undeveloped. The operation (and potentially construction if Network Rail's programme were to be delayed) of the proposed Order works may have similar effects on the Plot 9 building as on the AMB. There are opportunities to incorporate mitigation in the building design to mitigate vibration effects, at some cost. Such mitigation can include, for example, installing massive foundation slabs for sensitive instruments, set on very low stiffness mountings in pits in the foundation slabs. This kind of provision could not realistically be retrospectively installed in the AMB.

13 CONCLUSIONS

13.1 My conclusion is that there is insufficient information to properly assess the effects of the scheme on relevant receptors in the AMB.

13.2 The University have requested further information, some of which has been received, and some of which is awaited.

Outstanding information

13.3 Outstanding information includes a prediction of underwater noise levels and their effects on fish, predictions of vibration amplitudes likely to affect rodents in the vivarium, the likely type and location of rail welds, predictions of vibration and noise from ground compaction for the new track, predictions of vibration and noise from ballast tamping, predictions of noise and vibration from the construction of foundations for the gantries supporting overhead line equipment, properly detailed information on mitigation measures for construction noise, including floor-by-floor predictions taking account of receiver height with respect to noise barriers, and construction programme indications currently envisaged by the contractors.

13.4 A draft construction programme, based on the newly appointed contractor's intentions, is awaited. The basic content of Code of Construction Practice Part B is awaited. The detailed structure of a monitoring and control regime is awaited. While these documents cannot be finalised at the present time, it is essential to place before the Inquiry the fundamental principles on which Network Rail rely in order to make the case that the significant effects can be managed so as to permit continued operation of the affected receptors.

Likely residual significant effects

13.5 The likely effects of the proposals on the AMB are as follows, with regard to each group of receptors:

Construction

13.5.1 **Human beings:** Internal airborne noise levels may disrupt concentration and cause annoyance and interfere with task performance by those engaged in research work.

13.5.2 **Sensitive instruments:** Vibration may invalidate the output of the MRI.

13.5.3 **Rodents:** Noise and/or or vibration may disrupt breeding and general welfare

13.5.4 **Fish:** Underwater noise will be well above the hearing thresholds of Zebrafish, though not at physically harmful levels, with unknown consequences .

Operation

13.5.5 **General:** If key assumptions made by Network Rail do not become reality in the construction and operation of the works, there would be potentially significant noise and vibration effects on all receptors. These assumptions relate to minimum distances, dimensions and speeds.

13.5.6 **Human beings**: Adverse effects due to noise or vibration are not likely.

13.5.7 **Sensitive instruments:** The MRI is already subject to vibration effects which are only just acceptable with regard to error-free operation of the instrument, and any increase may be harmful. An increase is predicted, and no mitigation is envisaged.

13.5.8 **Rodents and fish:** As above in 13.5.3 and 13.5.4.

Securing acceptable conditions at the AMB

13.6 Because of the prediction of significant effects on the AMB made by Network Rail, and the likelihood of significant effects from sources not assessed in the ES or in further environmental information provided, it is essential that provision is made to ensure that key assumptions on which predictions depend cannot be varied so as to invalidate the predictions and cause more adverse effects than those predicted. The matters to be controlled include, for operation, the minimum distance of a rail crossing to the AMB, the absence of other rail discontinuities including aluminothermic welds within the same distance, a speed limit of 60 mph on the loop lines and a minimum radius of 1200m for the turnouts. Provision should be made for mitigation to offset the increase in vibration due to freight trains on the operation of the MRI. This should take the form of applying a speed limit to freight trains such as to avoid exceedance of the modified MRI limits in the event that they are found to be exceeded.

13.7 As I have mentioned, there is insufficient information at this stage to allow the nature and degree of mitigation to be understood and developed in detail. In these circumstances, the University requires that construction and operation of the proposed works permits continuance of the research work in the AMB such that (a) that adequate work is completed to enable mitigated levels of noise and vibration to be predicted with evaluated uncertainty margins, such that VC-A (modified as explained above and further below) will not be exceeded; (b) the modified criterion for the MRI developed from VC-C and the manufacturer's stated limits will not be exceeded; and (c) an identified threshold relating to potential noise effects on animals is not exceeded. The nature and degree of any other detailed mitigation is currently not capable of assessment in the absence of adequate assessment by Network Rail

13.8 In the case of construction effects (and in relation to operational vibration effects relating to animals), it will also be necessary to establish protocols and method statements which will identify and avoid potential unacceptable interferences with the use of the MRI or research activity. It will also be necessary to secure an identified construction phase noise threshold to mitigate potential effects on humans using the AMB. Again I have set out the relevant threshold above.

14 WITNESS DECLARATION

I hereby declare as follows:

14.1 This proof of evidence includes all facts which I regard as being relevant to the opinions that I have expressed and that the inquiry's attention has been drawn to any matter which would affect the validity of that opinion.

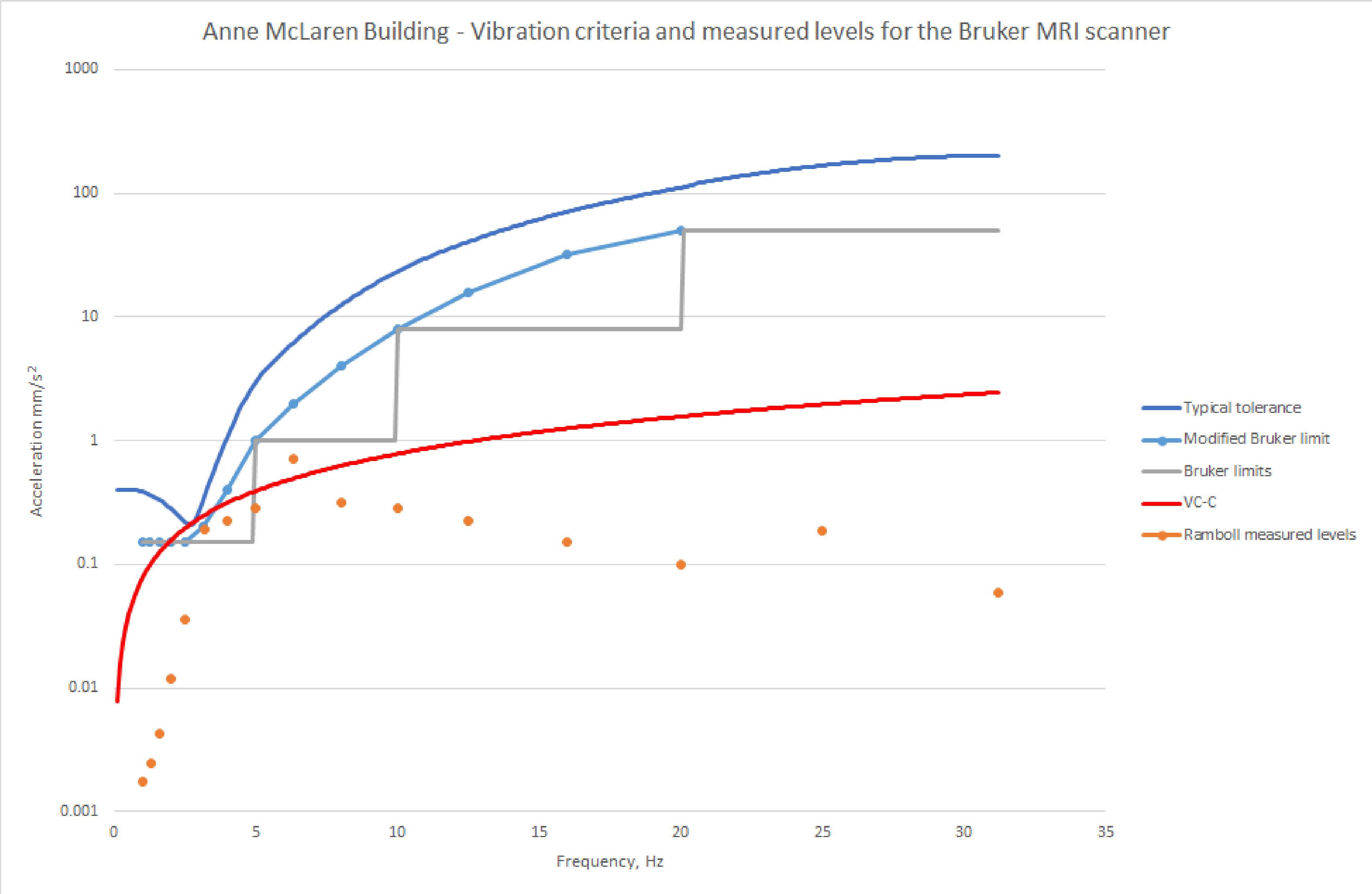
14.2 I believe the facts that I have stated in this proof of evidence are true and that the opinions expressed are correct.

14.3 I understand my duty to the inquiry to help it with matters within my expertise and I have complied with that duty.

Rupert Thornely-Taylor

Head of Acoustics, Noise and Vibration, Rupert Taylor Ltd

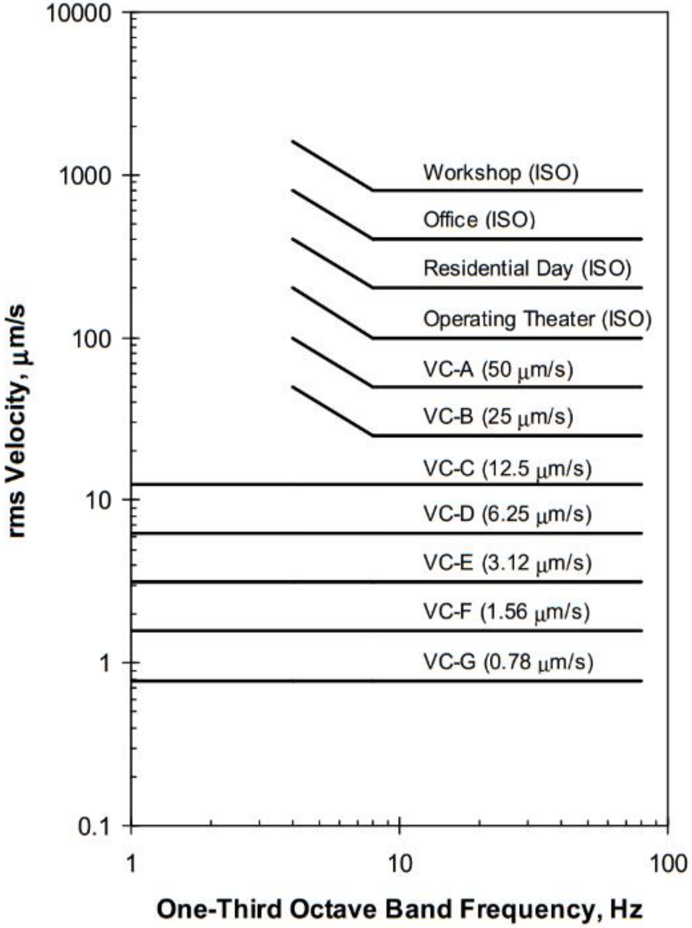
APPENDIX 1 – Vibration Criteria and Measured Levels for MRI



Anne McLaren Building - Vibration criteria and measured levels for the Bruker MRI scanner
Acceleration mm/s^2
1000
100
10
1
0.1
0.01
0.001
0
5
10
15
20
25
30
35
Frequency, Hz
Typical tolerance
Modified Bruker limit
Bruker limits
VC-C
Ramboll measured levels

The source of the "Ramboll measured levels" is Figure 1 in CSIE Project Technical Vibration Response To Uoc Statement Of Case Technical Note 5 (1620010876-Ram-Csie-Dn-Yv-005) Version 1 Date 14/10/21

APPENDIX 2 – VC CURVES



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.

APPENDIX 3 Review of literature on noise effects on mice and fish

The effect of vibration on pregnant laboratory mice Richard A. Carman, Fred W. Quimby, Gary M. Glickman INTER-NOISE 2007

Given the altricial nature of newborn mice we would predict from these studies that exposure of mothers with newborn pups to vibration intensities exceeding 3x10-3 m/s for prolonged periods regardless of the nature of the vibration (i.e., same for continuous and impulse) may lead to newborn mortality. This can be due to lack of milk (resulting in dehydration) and hypothermia when mothers abandon pups in their reaction to the vibration and are distracted by exploring within the cage.

“Warning! Nearby construction can profoundly affect your experiments,”Mary F. Dallman, Susan F. Akana, M. E. Bell, Seema Bhatnagar, Su Jean Choi, Alan Chu, Francisca Gomes, Kevin Laugero, LizaSoriano, and Victor Viau, Vol. 11, No. 2, 111-113 Endocrine, October 1999.

The authors emphasize the potential negative effects of construction noise and vibration on laboratory research animals. Changes in stress hormone levels and physiological indicators such as weight and food intake were observed during construction work. No measurements were obtained, but a “sentinel” rat was observed to decrease food intake and loose weight. The authors warn that, in research that is otherwise tightly regulated, construction activity can introduce environmental factors that cause marked variance from day to day resulting in uncontrolled biological variability.

Effect of animal facility construction on basal hypothalamic-pituitary-adrenal and renin-aldosterone activity in the rat. Raff H, Bruder ED, Cullinan WE, Ziegler DR, Cohen EP. Endocrinology. 2011;152(4):1218-1221. doi:10.1210/en.2010-1432

The study concluded that nearby construction can cause a stress response without long-term effects on hypothalamic-pituitary-adrenal axis gene expression and body weight.

Are investigators aware of environmental noise in animal facilities and that this noise may affect experimental data? Ann Baldwin Gary E Schwartz Douglas H Hopp. February 2007Journal of the American Association for Laboratory Animal Science: JAALAS 46(1):45-51

Control of environmental factors, such as noise, in animal facilities is important to ensure that research animals respond consistently to experimental procedures and that experimental results are not confounded by outside influences. A survey of personnel involved with animal facilities (173 respondents) showed that almost all agreed with this statement. However, 48%

thought that one or more environmental factors in their facilities could be stressing the animals, and a majority of respondents reported generation of audible noise from people (72% of respondents), fans (61%), and squeaky carts (56%). The presence of these noises was correlated with the perception of noise as a problem because of its psychologic and physiologic effects on the animals. The amount of time respondents spent in the facilities was strongly correlated with their perception of noise as a problem, with veterinarians spending the most time and perceiving the most problems, and professors and assistant/associate professors spending the least and perceiving the fewest. Therefore, they may lack key knowledge that can affect their research goals. In addition, because faculty are the least aware of noise as a potential problem but are primarily responsible for designing experiments, research involving animals may be confounded by noise as an unknown variable. This effect may lead to unnecessary numbers of animals being required to achieve statistical significance and possibly to erroneous interpretation of results. On the basis of the findings of this survey, we present recommendations for improving the environment, particularly for decreasing the noise level, in animal facilities.

Comparative Vibration Levels Perceived Among Species in a Laboratory Animal Facility John N Norton, Will L Kinard, and Randall P Reynolds Journal of the American Association for Laboratory Animal Science Vol 50, No 5 September 2011 Pages 653-659

In the current study, vibration from the large jackhammer at various locations was an average of 3.4 times higher at 60 Hz than 20 Hz. In a standing position, human legs have a resonance frequency of about 20 Hz, and the mouse leg has a resonance frequency of approximately 60 Hz. Therefore, vibration again likely would affect mice more than humans. Mouse and human legs may absorb some vibration, because the resonance frequencies for legs are different than those for other body regions. However, the impact of vibration dampening by the legs is complex. Secondary resonances in the legs (a broad spectrum of frequencies produced by the legs when vibrated at the legs' resonance frequency) may coincide with other body resonances. This overlap would cause the legs to amplify, rather than absorb, vibration. The results of this work demonstrate that vibration produced by the same source may have different effects on the abdomen, thorax, and head of various species. The effects of whole-body vibration on these anatomic areas of humans include gastrointestinal alterations, headache, and increased respiratory rate due to oscillation of oxygen in the lungs. Due to the interspecies differences in the susceptibility of body regions to vibration depending on their particular critical frequency values, the physiologic and pathologic effects of vibration from the same vibration source are likely to differ between species. Vibration and noise have long been known to have potentially detrimental effects in rodents, but the relative contribution of each to these adverse effects is unknown. We measured sound at the same time as vibration was measured in the current study. The results of the sound analysis due to the construction equipment indicated that mice actually hear less construction noise than do humans. Therefore, the study in our facility suggests that vibration due to construction equipment would be of greater concern than would the associated noise. Further work needs to be done to determine the resonance frequencies of mice directly and to correlate levels of vibration with physiologic and pathologic effects.

Garner, Angela M et al. "Vibration-induced Behavioral Responses and Response Threshold in Female C57BL/6 Mice." ***Journal of the American Association for Laboratory Animal Science : JAALAS*** **vol. 57,5 (2018): 447-455. doi:10.30802/AALAS-JAALAS-17-00092**

Mice were exposed to frequencies of vibration between 20 and 190 Hz at accelerations of 0.05 to 1.0 m/s^2. Behavioral responses were videorecorded and subsequently scored. Mice showed the most behavioral responses at 1.0 m/s^2. At intermediate accelerations of 0.5 and 0.75 m/s^2, behavioral responses were most prevalent at frequencies of 70 to 100 Hz. In contrast, at an acceleration of 0.05 m/s^2, mice did not show any discernible behavioral response. Behavioral responses induced by the initiation of vibration were transient, generally lasting only 2 to 10 s. When exposed to multiple periods of vibration over a short time, responses seemed to decrease. In summary, mice were particularly sensitive to vibration between 70 to 100 Hz, did not respond to the slowest acceleration (0.05 m/s^2), and exhibited transient responses at the initiation of vibration.

Reynolds, Randall P et al. "Vibration in mice: A review of comparative effects and use in translational research." ***Animal models and experimental medicine*** **vol. 1,2 116-124. 28 Jul. 2018, doi:10.1002/ame2.12024**

The predicted RFRs for mice were 85-92 Hz for the abdomen, 711-727 Hz for the thorax, and 237 to 253 Hz for the head when assuming equivalent inherent stiffness of tissue is similar in mice and humans.

A recent study has demonstrated that mice show more behavioral alterations due to whole-body vibration (WBV) predominantly between the frequencies of 70-100 Hz.[19] Therefore, mice appear to be the most sensitive to vibration between frequencies of 70-100 Hz. Within this RFR, mice should be most susceptible to low level vibration, which would likely most affect an animal's normal physiological and behavioral functions.

Construction Noise Decreases Reproductive Efficiency in Mice Skye Rasmussen, Gary Glickman, Rada Norinsky, Fred W Quimby, and Ravi J Tolwani Vol 48, No 4 July 2009 Pages 363–370 Journal of the American Association for Laboratory Animal Science

Only 1 of the 245 pups born to the control group of 24 mice was stillborn. In comparison, more pups were stillborn when mice were exposed to noise during the first (P= 0.016), second (P= 0.024), or third (P= 0.031) week of pregnancy (Figure 7). Although the effect varied among ex-posure groups, more pups were stillborn from dams exposed to noise of 70 or 90 dBA as compared with the control dams. In particular, the average litter size of the mice exposed to 90 dBA during the peri-implantation period (5.8 pups) was significantly (P= 0.005) smaller than that of controls (10.2 pups). Effect of noise on neonatal growth. During the first 7 d after birth, the pups' weight increased over time as expected and varied depending on litter size. Growth rates of litters exposed to noise did not differ significantly when pooled weights [P= 0.93 (ANOVA)] or individual weights [P= 0.64 (linear regression model)] were compared with those of mice not exposed to noise (Figure 8).

Discussion

Noise limits for construction were established based on the ambient noise levels logged in the rodent housing rooms. Be-cause mice housed within the vivarium were maintained in an environment that routinely exposed them to moderate levels of noise, we predicted that continuous noise below 65 dBA would not have a negative effect. We established that noise should not exceed 75 dBA for 1 h and set a maximum noise allowance of 85 dBA. The 85-dBA noise limit was based on preliminary studies evaluating the behavior of nursing dams: mice exposed to 90 dBA of noise stopped nursing pups during the period of noise exposure (data not shown). Ultrasonic noise measurement data for construction equipment at close range is an area for further study because building elements such as walls, floors, or other potential transmission paths act as a mechanical filter and attenuate higher frequencies more substantially than lower frequencies Canadian Council on Animal Care CCAC guidelines: Mice In general, the audible frequency range for mice at a standard sound intensity of 60 decibels (dB) is 2,300-85,500 Hz, depending on the strain (Heffner and Heffner, 2007); humans have a hearing range of 20-20,000 Hz (Turner et al., 2005). Strains of mice differ in auditory sensitivity, the rate of progressive hearing loss, and susceptibility to noise-induced seizures (Turner et al., 2005).

Mice are very sensitive to ultrasound and use it to communicate. Ultrasonic noise in the environment should be minimized as it can potentially result in adverse health effects for mice and confound research results (Turner et al., 2007). Sources of ultrasonic noise include dripping taps, trolley wheels, computers, light bal-lasts, movement of furniture, vacuum cleaners and cage washers (Turner et al., 2007).

High ambient levels of sound or intense brief sounds may induce hearing loss or damage to the auditory apparatus, depending on the strain and sex of the mice (Willot, 2007). Loud noise may also result in audio-genic seizures (characterized by wild running, convulsions, and possibly death from respiratory paralysis) in some strains of mice (Willott, 2007). Other possible non-auditory impacts of noise include alteration of reproductive efficiency (Rasmussen et al., 2009; Turner et al., 2007; Turner et al., 2005), endocrine and cardiovascular function, and sleep/wake cycles (Turner et al., 2007; Turner et al., 2005). It is particularly important that mouse breeding colonies be located as far away as possible from noise-generating equipment and noisy animals (e.g., dogs and nonhuman primates).

Chronic exposure to moderate levels of low-frequency noise (< 0.5k Hz) at 70 dB has been shown to im-pair balance in mice (Tamura et al., 2012); however, this level of noise may not be detrimental to all strains (e.g., young adult female C57BL/6 mice exposed to the noise of a vacuum cleaner did not show increased concentrations of fecal corticosterone metabolites or express anxiety-related behaviour (Jensen et al., 2010).

Exposure to even a single period of intensely loud noise has been shown to affect learning in young mice (Tao et al., 2015).

Sources of vibration within laboratory animal facilities include the room ventilation system, ventilated racks, and equipment related to husbandry or research activities, as well as activities occurring outside of the room (Reynolds et al., 2018; Norton et al., 2011). Vibrations can result in various physiological and pathological effects, and the impact of vibration caused by a particular source will depend on the species and age of the animal (Reynolds et al., 2018; Norton et al., 2011). In a study involving construction equipment, mice were found to experience more vibration than humans (Norton et al., 2011), and therefore, measures should be taken to dampen all potential sources of vibration.

Norton, John N et al. "Comparative vibration levels perceived among species in a laboratory animal facility." ***Journal of the American Association for Laboratory Animal Science : JAALAS*** **vol. 50,5 (2011): 653-9.**

In the current study, vibration from the large jackhammer at various locations was an average of 3.4 times higher at 60 Hz than 20 Hz. In a standing position, human legs have a resonance frequency of about 20 Hz,and the mouse leg has a resonance frequency of approximately 60 Hz. Therefore, vibration again likely would affect mice more than humans.

The US National Institutes of Health Design Requirements Manual (2016) does set out vibration limits (Table 5.2.2) for animal research as below:

Animal Research Facility 100 µm/s

Rodent behavioural and holding rooms 50 µm/s

Atanasov, Nicholas A et al. "Characterization of Train-Induced Vibration and its Effect on Fecal Corticosterone Metabolites in Mice." Journal of the American Association for Laboratory Animal Science : JAALAS vol. 54,6 (2015): 737-44.

The closest animal room to the train tracks developed problems with abnormally high rates of cannibalism or neglect of pups. After investigating other potential causes such as temperature variations, light–dark cycles, and diet, we hypothesized that the vibrations from the train were a significant factor. The reproductive success of the same set of mice improved after they were moved from a flat wire rack to a single motor-ventilated rack

The greatest vibrations in the test room occurred during the passing of the train. The peak vibrations caused by the passing train were between 0.001 and 0.025 × *g* and had a frequency range of 12 to 16 Hz. Figure 4 represents a typical vibration recording for the test room with mouse cages placed on the flat rack. Trains passed the vivarium for 1 to 4 min, depending on the length of the train. The vibrations produced by the train extend well above the ambient vibrations within the room; a single-factor ANOVA identified a significant difference ($P = 0.001$) between the train-induced and ambient vibrations.

We did not note high rates of preweaning mortality and cannibalism among the ICR and GK mice bred in the test room during this study.

This finding suggests that the vibrations produced by the passage of the train constitute a potential stressor that might introduce nonexperimental variability into research results or negatively influence mouse wellbeing

The preliminary data we gathered indicate that vibrations from passing trains create significant increases in the FCM levels of female mice. Fluctuations in stress may be disruptive to research studies and breeding colonies. Elevated corticosterone levels can induce a variety of negative effects in rodent

Whole-body vibration of mice induces progressive degeneration ofintervertebral discs associated with increased expression ofIl-1bandmultiple matrix degrading enzymesMatthew R. McCanny, Matthew A. Verasy, Cynthia Yeungy, Gurkeet Lalliy,

Priya Pately, Kristyn M. Leitchy, David W. Holdsworthzx, S. Jeffrey Dixonyk, Cheryle A. Seguin http://dx.doi.org/10.1016/j.joca.2017.01.004

Methods: Ten-week-old male mice were exposed to WBV (45 Hz, 0.3gpeak acceleration, 30 min/day, 5days/week) for 4 weeks, 8 weeks, or 4 weeks WBV followed by 4 weeks recovery. Micro-computed tomography (micro-CT), histological, and gene expression analyses were used to assess the effects of WBV on spinal tissues. Results: Exposure of mice to 4 or 8 weeks of WBV did not alter total body composition or induce significant changes in vertebral bone density. On the other hand, WBV-induced intervertebral disc (IVD)degeneration, associated with decreased disc height and degenerative changes in the annulusfibrosus (AF) that did not recover within 4 weeks after cessation of WBV. Gene expression analysis showed that WBV for 8 weeks induced expression ofMmp3,Mmp13, andAdamts5in IVD tissues, changes preceded by increased expression ofIl-1b.Conclusions:Progressive IVD degeneration induced by WBV was associated with increased expression ofIl-1bwithin the IVD that preceded Mmp and Adamtsgene induction. Moreover, WBV-induced IVDdegeneration is not reversed following cessation of vibration

Whole-body vibration of mice induces articular cartilage degenerationwith minimal changes in subchondral boneM.R. McCanny, C. Yeungy, M.A. Pesty, A. Ratneswarany, S.I. Pollmannz,D.W. Holdsworthzxk, F. Beiery, S.J. Dixony, C.A. Seguin http://dx.doi.org/10.1016/j.joca.2016.11.001

Ten-week-old male CD-1 mice were exposed to WBV (45 Hz, 0.3gpeak acceleration; 30 min/day,5 days/week) for 4 weeks, 8 weeks, or 4 weeks WBV followed by 4 weeks recovery. The knee joint was evaluated histologically for tissue damage. Architecture of the subchondral bone plate, subchondraltrabecular bone, primary and secondary spongiosa of the tibia was assessed using micro-CT. Results: Meniscal tears and focal articular cartilage damage were induced by WBV; the extent of damage increased between 4 and 8-week exposures to WBV. WBV did not alter the subchondral bone plate, ortrabecular bone of the tibial spongiosa; however, a transient increase was detected in the subchondraltrabecular bone volume and density. Conclusions: The lack of WBV-induced changes in the underlying subchondral bone suggests that damage to the articular cartilage may be secondary to the meniscal injury we detected. Our findings underscore the need for further studies to assess the safety of WBV in the human population to avoid long-term joint damage.

Noise and Vibration in the Vivarium:

Recommendations for Developing a Measurement PlanJeremy G Turne

Journal of the American Association for Laboratory Animal Science Vol 59, No 6 pp665-672

Vibration levels inside the cage should be maintained below 0.025 g (RMS; see below). Note that vibration can occur in the x, y, or z axes and can be measured in all 3 axes or the greatest of the 3. Likewise, vibration levels of only approximately 0.025 g have been shown to increase fecal corticosterone metabolites in female (but not male) mice, and to result in overt behavioral responses in female mice indicative of arousal.

Noise levels inside the cage should be maintained below dB SPL.

Briese V, Fanghänel J, Gasow H. Untersuchungen zum Einfluss von Reintonbeschallung und Vibration auf die Keimesentwicklung der Maus [Effect of pure sound and vibration on the embryonic development of the mouse]. Zentralbl Gynakol. 1984;106(6):379-88. German. PMID: 6720157.

Studies were conducted about the effects of noise and vibration on the ontogenesis of mouse. Application of noise and vibration was carried out in 340 female mice in the phenocritical phase. The parameters of pure sound were 100 dB and 10.000 Hz. The vibration was carried out with the oscillating velocity of 87,1 mm/s and the oscillating acceleration of 3,45 X 10(4) mm/s2. The duration of noise was 10 hours, of vibration 4 and 8 hours. In an other experiment the animals were exposed to the combination of noise (10 h) and vibration (4 h). 581 fetuses were evaluated by subsequent parameters: Fetal length and weight, placental diameter, resorptions and haematomas. It was concluded that retardations, resorptions and haematomas were results from noise and vibration exposure. A teratogenic effect of these noxes was not evident. Probable the noxes evoked stress reactions in the female animals. Subsequently a constriction of blood vessels impairs the placental function.

Bretschneider, F., van Veen, H., Teunis, P. F., Peters, R., & van den Berg, A. V. (2013). Zebrafish can hear sound pressure and particle motion in a synthesized sound field, Animal Biology, 63(2), 199-215. doi: https://doi.org/10.1163/15707563-00002406

Zebra Fish hearing threshold found to be 0.4 Pa at 800Hz and 2Pa at 250Hz