Best Available Techniques for Control of Noise & Vibration

R&D Technical Report P4-079/TR/1

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Statement of Use

This project has considered the Best Available Techniques for the assessment and control of both noise and vibration from industrial and commercial sources. The information in this document is for use as background information by Agency staff and others involved in the regulation of noise and vibration, however it is not intended to be a replacement for specialist advice. At the date of publication of this report the Agency is consulting upon guidance notes on noise and vibration which describe the application of the general information given herein in a regulatory context.

Keywords
environmental noise, environmental vibration, best available techniques

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EXECUTIVE SUMMARY

This report provides a body of information on the measurement, assessment and control of environmental noise from facilities and activities of the type covered by the Integrated Pollution Prevention & Control (IPPC) Directive and the Waste Management Licensing Regulations, although it could potentially be of wider application. Vibration is also addressed in an environmental context but detailed discussion on the subject is left to specialist publications. This report forms an information source from which the Agency will develop internal guidance and training. The report is not intended to be used in isolation from the relevant Agency guidance for the purpose of regulatory decision-making.

Of necessity, the information is provided in summary form but reference is made to relevant standards and guidance documents for further detail. The main topics covered include:

- an introduction to the effects of noise;
- the measurement of noise and vibration;
- calculation of noise levels;
- prediction and modelling;
- assessment techniques;
- Best Available Techniques (BAT) for noise control, including; .
    - principles of noise attenuation;
    - noise control equipment;
    - noise management practices;
    - planning noise control; and
    - costs, benefits and implications of noise control.

Almost inevitably noise permitting will require the setting of noise limits and there can be complex issues associated with determining where limits should apply and an appropriate level to provide adequate environmental protection. Fortunately there is much existing guidance on noise assessment including British Standards and Planning Guidelines, elements of which are applicable to the Agency's regulatory remit. This report describes the scope and purpose of the more relevant pieces of guidance material, but it has not been possible to extract a prescriptive method for establishing a noise limit as the setting of an appropriate limit will always depend on local factors that cannot be discussed in general terms. *Appendix* D of the report outlines the standards that can be used and some of the additional factors that need to be considered in a given situation.

As part of the permitting process for IPPC the Agency will be involved in determining BAT to prevent or minimise emissions of noise and vibration and balancing this against other emissions or environmental impacts for a particular installation. The following options would normally be considered as part of the determination:

- use of inherently quiet processes
- selection of quiet plant options;
- site layout to maximise screening and separation distances;
- orientation, bunding, barriers for noisy plant;
- phasing of development/ operations (eg landfill filling sequence);
- noise attenuation equipment; and

- noise management - plant maintenance, closing doors, locating mobile plant, restricting hours of operation etc.

Community liaison is also an important element of noise management, and formal systems are required which address complainants concerns and to feed into the central management process for the operation.

Six case studies are included in the report to illustrate noise control in practice. They demonstrate a mixture of innovative and more standard ways to address noise emissions from various facilities, and the difficulties, costs and benefits of each.

CONTENTS

1 INTRODUCTION

1.1 Preamble

Environmental Resources Management (ERM) were commissioned by the Environment Agency under Contract HOC0335 to undertake a technical research study entitled; *Determination of the Latest Best Available Techniques for Control of Noise and Vibration and Their Applicability to Each of the Regimes with Regulatory Responsibility.* The study is a desktop review of current noise assessment methodologies and noise and vibration control practices, including case studies. ERM appointed Acoustic Design Ltd as sub-consultants to assist in the case studies. The findings are presented in this R&D Technical Report in order to assist the Agency in developing guidance material to Agency officers and the Operators of facilities covered by the Regulations.

1.2 Background

EC and UK environmental legislation has generally applied to separate aspects of the environment resulting in solutions for one environmental issue that may in some cases result in adverse effects for another aspect. The Integrated Pollution Prevention and Control (IPPC) directive seeks to harmonise the process for a range of industrial activities.

In the UK noise is not currently considered under Integrated Pollution Control (IPC) except where recovery or disposal of waste is undertaken and, where there is a problem, regulation is dealt by Local Authorities, primarily through nuisance legislation. Noise is however a consideration under the Waste Management Licensing Regulations which cover facilities such as landfills, waste transfer stations and scrap metal processing. Noise is also a Planning consideration and conditions may be imposed as part of the planning permission for a new industrial development.

IPPC takes into account a range of environmental issues, including noise and vibration. As a result of the new PPC Regulations (Pollution Prevention & Control (England & Wales) Regulations 2000), by which means the IPPC Directive is enacted in the UK, operators of a wide range of activities will be required to make careful consideration of the noise emitted from their facilities as a part of the total environmental impact.

In future, permits issued under the PPC Regulations will seek to achieve a high level of protection for the environment as a whole and will require Best Available Techniques (BAT) to be employed. In determining BAT the technical characteristics of the installation, the geographical location and local environmental conditions can, where appropriate, be taken into consideration. The Environment Agency will be issuing guidance on what constitutes Best Available Techniques for different industry sectors and also for cross cutting issues such as noise and vibration.

Permits will be issued according to a rolling timetable such that all industry sectors will be brought under regulation by 2007. Administration of the PPC regime will be split between the Agency and Local Authorities according to sector and, in some cases, throughput. Where the Agency is the primary regulator the view of the Local Authority will be sought as part of the formal consultation process. This is particularly relevant where there are issues relating to noise and vibration. A protocol describing the interaction of the Agency and the Local Authorities at a local level has been drafted.

1.3 Objectives of the Study

The Environment Agency requires an up to date body of knowledge from which it can develop guidance material on how to assess and control environmental noise from facilities covered by the IPPC Directive. This knowledge is to be assimilated into an R&D report describing noise measurement protocols, assessment methodologies, the Best Available Techniques for noise control, and how these techniques fit into the new fully integrated approach to pollution prevention. Whilst this report covers subject matter that is technical in nature, it assumes no prior knowledge of acoustics and is not aimed at qualified acousticians.

1.4 Structure of This Report

The remainder of this report is structured as follows:

> *Section 2* provides an introduction to the effects of noise, describes measurement techniques, and discusses assessment methodologies;
>
> *Section 3* summarises the Best Available Techniques for noise control;
>
> *Section 4* discusses the costs, benefits and environmental implications of noise control;
>
> and
>
> *Section 5* summarises the case studies.

To aid the reader through the substantial volume of information that has been reviewed much of the detailed information is given in the following Appendices:

Appendix A is a glossary of acoustics terminology;

Appendix B gives technical advice on noise measurement and calculations;

Appendix C gives forms for recording noise measurements;

Appendix D gives a review of relevant guidance material;

Appendix E contains 11 noise control information sheets; and

Appendix F gives full accounts of the case studies.

2 REVIEW OF NOISE & VIBRATION ASSESSMENT METHODS

2.1 Introduction

This chapter summarises best practice in noise and vibration measurement, prediction and assessment methodologies. In recent years several organisations have periodically produced guidance material on various aspects of environmental noise assessment, to the extent that there are now numerous guidelines that may be helpful in a given situation. Indeed, there is now a vast extent of knowledge in the field of acoustics, as indicated by the size of the UK's Institute of Acoustics, which now has over 2000 members or associate members. Hence, it is not appropriate to raise new issues in this section, but rather to summarise the consensus view that existing material provides for the situations likely to be encountered in the IPPC permitting process.

There is a common approach that involves, measuring ambient noise levels, measuring or predicting the new or problematic noise, and assessing the new noise against the background noise and/or absolute noise level criteria. However, a view shared by many experts in environmental noise assessment is that the impact of noise on a community, in a particular situation, cannot be assessed by following a series of mechanical procedures. The process by which noise effects people is simply too complex and local conditions will call for flexibility and judgement to be used. Indeed, this is recognised in Planning Policy Guidance 24, Planning and Noise (1994) which introduces the concept of Noise Exposure Categories rather than a simple set of yes/no noise criteria. Hence, this chapter does not include a procedural method of assessing noise impacts, but rather guides the reader to existing guidance material that is particularly relevant in the context of the IPPC/Waste Management Licensing Regulations.

Whilst this chapter aims to provide easily accessible guidance on noise assessment techniques, it should be recognised that environmental noise is a complex scientific subject worthy of further study. For example, the Institute of Acoustics offers a training course leading to a certificate of competence for measuring environmental noise and there are several universities offering Bachelor and Masters of Science courses in acoustics and environmental noise.

A range of guidance has been reviewed during preparation of this document. Since the purpose of this document is to offer the most recent appropriate guidance, sources that are now obsolete have not been discussed in detail. Reference has been made to these documents in the *Bibliography*. For example, guidance from the Institution of Gas Engineers is likely to have been widely used when it was produced in 1990. However, it is now out of print and has largely been superseded by the other more recent national standards that are discussed in the following sections.

2.2 The Effects of Noise

The effects of noise on human beings are summarised in *Figure 2.1*. This illustrates how noise complaints and annoyance can be caused through various effects. When considering a permit level, the potential for complaints should be considered. When complaints about an existing facility that is licensed have been received, the reason for the complaints should be investigated. This is discussed further in *Section 3.5.5*.

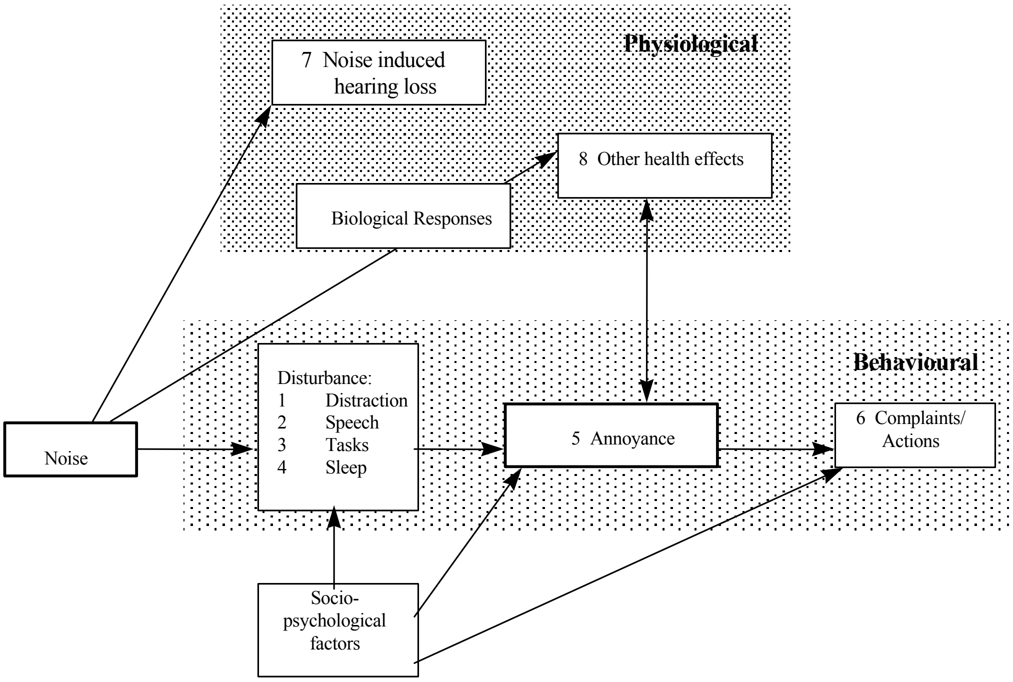

Figure 2.1 Cause and Effect Relationships for Noise

Noise induced hearing loss is not a concern at the levels of noise experienced by neighbours of noise emitting facilities. It is only a potential hazard above noise levels of at least 80 dB(A) and where exposure is over very long periods of time. The potential risk to workers is dealt with by the Health and Safety Executive and in some cases by Local Authorities.

A distinction is made between disturbance and annoyance. Someone is disturbed by noise when it prevents or inhibits them from undertaking an everyday activity such as concentrating while reading (distraction), hearing spoken conversation, listening to the radio or sleeping. The feeling of displeasure caused by noise is annoyance. Annoyance is often a result of disturbance but not necessarily, and it can be influenced by socio-psychological factors, such as a bias for or against the facility or person making the noise, of the environmental expectations of an individual. Whereas disturbance can be assessed analytically, annoyance is measured by social survey questioning, and over the years has been used as a common indicator of overall community noise impact.

Other effects may occur as a result of vibration. These include: perceptible vibration, secondary rattling of windows, items on shelves and pictures hanging on walls. In addition, the sound radiated from vibrating walls may give rise to indirect effects. These effects may contribute to annoyance.

2.3 Measurement of Noise

2.3.1 Noise Measurement Equipment

Various types of noise measurement equipment are commercially available. The range includes equipment that is capable of measuring basic time varying sound pressure level and equipment that is capable of calculating statistical noise indices over time. The first level of sophistication is an *integrating* or *integrating averaging sound level meter* that is capable of measuring the 'A' weighted equivalent sound level, L_{Aeq}. *Appendix A* gives a glossary of acoustic terminology. *Appendix B* describes the decibel scale and provides further details on noise measurements techniques and calculations. The next level of sophistication is a meter that can calculate statistical noise measurement parameters such as L_{A90}, L_{A10}, L_{A01}, the levels exceeded 90, 10 and 1 percent of the measurement period. This type of noise meter is called a *statistical analyser* or a *statistical sound level meter*. A typical example is shown in *Figure 2.2*.

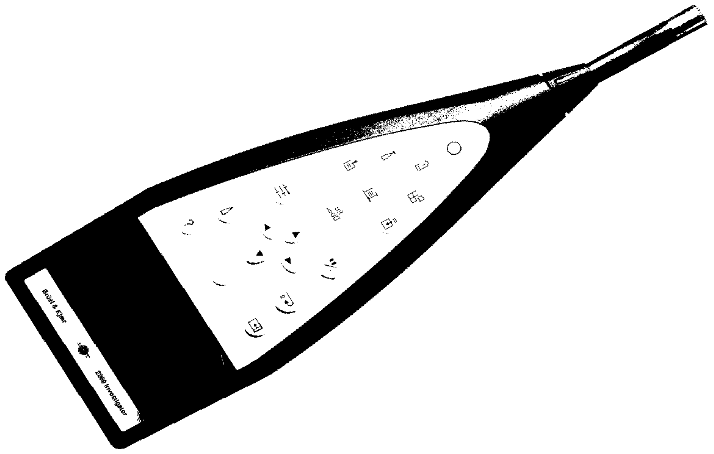

Figure 2.2 A Statistical Sound Level Meter

The equipment may be switched on and off manually when sufficient data has been collected, or may be equipped with a *noise logging* facility. This will allow the meter to be set-up to take one sample over a pre-defined period, store the result in its memory, start another measurement, and repeat the process continuously.

The above meters will all be able to measure in terms of dB(A) noise levels. This is the most commonly used scale for environmental noise studies. More sophisticated noise equipment has additional internal frequency filters that enable measurements to be made in *frequency bands*. The filters can measure the *octave band* components of the sound, and in some cases, the narrower *1/3rd octave bands*. Measurements in these bands can generally be used to determine if noise contains distinctive *tonal* components which can make the noise more annoying and require special attention in one of the most commonly used assessment methods. *Appendix B* gives examples. It is also useful to know the frequency content of a noise source when calculating noise attenuation from screens and enclosures and when considering ground absorption in predictions as these effects are all frequency dependent. In general it is harder to abate lower frequency noise (see *Section 3.3)*

The human ear is an extremely sensitive organ with a very large dynamic range over a wide range of frequencies. To cater for this dynamic range the decibel (dB) scale is logarithmic allowing the full range of audible sound levels to be expressed as a number between 1 dB (the threshold of perception) and about 140 dB (the threshold of pain). The frequency range that most of us can hear falls within the range 20 to 20,000 Hz. Because the ear is much less sensitive to lower frequencies than to higher ones sound level meters are adjusted to mimic this response. This is done by the inclusion of a sound filter, called the *A-weighting*. Using the A-weighting the levels measured by a sound level meter are comparable with the levels we perceive.

In some circumstances, tape recorders provide a useful means of capturing an event for later analysis. This will be useful when the event is rare or when it is expensive to repeat a certain operation for measurement purposes. An audio recording must be calibrated if absolute levels are required. Audio recording for analytical purposes is probably best left to an experienced consultant. Even an un-calibrated recording can be a useful memory aid when writing a report following a site visit. Generally, DAT recorders have now replaced traditional tape machines. The use of mini-disk recorders is becoming more common in the acoustics industry, although care may be required if the equipment uses a signal compression system.

Some meters are able to switch a tape recorder into record mode, and to start internal analysis software, during noise events above a specified noise level. This again allows measurements to be made of occasional events without an operator present during the measurements.

It is often useful to record the variation in noise over time in a graphical form. This has been traditionally done by calibrating a paper trace so that it displays a time history of the sound pressure level. However, with advances in electronics, noise graphs showing noise variation over time can be made electronically for presentation in reports (see *Appendix B*). The most advanced of the electronic systems allow individual events to be marked to identify the noise source responsible for a particular noise level.

When it is important to isolate the contribution from a particular plant item to the total noise output more complex measurements may be required. Sometimes a combination of measurements with a sound level meter made close to different plant and calculations, can be used to predict the contributions. In a crowded plant area, an *intensity meter* may be used. An example of a situation in which this technique may be useful would be to estimate the effect of silencing a particular machine. The advantage of this type of meter in this situation is that noise in only a particular direction can be measured. The noise contributions from other plant in the area can be virtually eliminated. This type of meter is now generally available but is expensive and complex to use. However, in the hands of a skilful user intensity meters can be used to identify the noise output of plant items in terms of their individual sound power level and to demonstrate that it would be useful to focus noise control effort on certain key sources. The accuracy of results in all cases will also depend on practical measurement constraints such as access limitations to key plant that could make it difficult to take appropriate measurements.

2.3.2 Vibration Measurement Equipment

Vibration measurements are unlikely to be required in the majority of environmental assessment situations since the vibration sensitive buildings are likely to be far enough from the plant to avoid vibration impacts.

However, equipment is available to carry out measurements in cases where vibration is perceptible off-site. The equipment used for an investigation should either be capable of measuring *peak particle velocity* (ppv) or *vibration dose values* (VDV). The former is normally used to assess the potential for building damage and the latter is used to assess the potential for annoyance. VDV suffers from inherent complexities and a simpler approach may be appropriate to establish if there is potential for perceptible effects in the first instance. It is possible to establish if vibration would be perceptible by a simpler measurement of either *ppv* or *rms velocity* (root mean square velocity). Since the assessment of vibration is more complex than airborne noise, it is recommended that a subjective judgement is made regarding perceptibility. If vibration may be an issue, then expert advice should be sought.

2.3.3 Measurement Techniques

Where to Measure

The choice of measurement location is often not straightforward where noise permitting is concerned. Clearly as a general principle we are interested in the noise level that is experienced by the effected person or people. This usually implies we would like to measure outside the window to the buildings that they occupy. But there can be reasons why this is not practical and measurement must be taken elsewhere. BS4142 Method for Rating industrial noise affecting mixed residential and industrial areas, is relevant, and states:

> *Choose measurement positions that are outside buildings that will give results that are representative of the ... levels at the buildings where people are likely to be affected.*

Clearly when investigating a complaint of excessive noise, measurements should be taken at the complainants property, and access will not be a problem. Measurements may be taken inside and outside the building. Permit levels will be set outside the windows to noise sensitive rooms, on the basis that the attenuation through an open window will be approximately equal for any noise sensitive building (this is the basis of applicable noise standards for environmental noise). But it will not always be possible to carry out noise monitoring at the receiver's building because access may not be available.

The site boundary is a readily available location for setting a permit level which can be checked. If receivers are close to the boundary the situation is straightforward, but if not it would imply calculating noise levels at the receivers. *Appendix B* gives some examples of how this can be done, but calculation will not be as accurate as measurement and it should always be considered preferable to enforce noise limits by measurement at sensitive receivers.

A planning condition may already have been set limiting noise emissions beyond the site boundary in order to safeguard future noise sensitive development in the vicinity. In cases where new noise sensitive development is possible then enforcing noise levels at the site boundary may be appropriate.

There can be problems with measuring at site boundaries due to local screening effects, for example by a boundary wall. In these cases the monitoring location should to chosen to best mimic the screening effect at the nearest receivers, so that any interpolation by calculation is as simple as possible, in order to minimise the error in the calculation process. Judgement will be required to determine the best compromise location to the adopted, but it should always be chosen to be as representative of the levels at noise sensitive buildings as possible.

BS 7385 (1) describes a measurement method for vibration. Locations for measurement are recommended. BS 6472 (2) relates to measurements affecting human exposure to vibration. The guidance in this standard suggests that measurements should be made at the locations where people will be affected by the vibration eg living or sleeping areas.

Measurement Procedures

Measurement microphones are prone to slight changes in sensitivity under changing climatic conditions and it is important that all equipment is calibrated so that measurements are robust. The equipment will need to be returned to a laboratory for full calibration at intervals of one to two years. Equipment should conform with the relevant standards (including BS EN 60651: 1994, BS EN 60804: 1994 and BS EN 60942: 1998). The calibration of noise measurement equipment should be checked on-site before and after measurement with an acoustic calibrator. Vibration calibrators are also available for some equipment which can be used in an equivalent way.

Standard measurement methodologies, for noise measurement, are contained in BS 7445 (3) (which is equivalent to ISO 1996) and BS 4142 (4). The relevant conditions can be summarised as follows:

- measurements should be taken between 1.2 to 1.5 m above the ground;
- measurements should either be taken under free-field conditions (more than 3.5 m from any reflecting surface) or at 1 m from the facade of a building and results treated accordingly (when a noise source is incident on a facade, the effect of reflected noise from the facade is generally to increase the 'facade level' measured at 1m by 3 dB); and
- measurements should not be made if average wind speed exceeds 5 m/s.

Appendix C contains standard forms that can be used for recording noise complaints and measurements.

Environmental noise measurements are subject to an unavoidable tolerance that may be due to:

- weather;
- source term variation;
- ground attenuation effects; and
- time of measurement and duration.

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(1) BS 7385 Evaluation and measurement for vibration in buildings Part 1 Guide for measurement of vibrations and evaluation of their effects on buildings, BSi, 1990.

(2) BS 6472 Guide to Evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz), BSi, 1992.

(3) BS 7445 Description and measurement of environmental noise Parts 1 to 4, BSi, 1991.

(4) British Standard BS 4142 Method for rating industrial noise affecting mixed residential and industrial areas, Bsi (1997).

These are discussed below.

Weather - Noise propagation can be affected by wind and temperature gradients and changes in relative humidity. Fog, snow and thick mist may also affect the noise levels that are recorded. Wind may affect the results by causing rustling of foliage, buffeting the microphone or enhancing or inhibiting the propagation or sound. Wind speeds above 5 m/s should be avoided. Measurements over large distances can show substantial variations with wind direction, with typically 2dB increases downwind and up to 10dB decreases upwind being possible. Dry weather and calm conditions are preferred.

Source Strength Variation - Variations in operating patterns of the licensed facility should be considered when taking measurements. The measurement should be taken over a period that is sufficient to obtain a representative sample. If the noise is intermittent or cyclic, a number of cycles may need to be recorded including the noisiest operational modes. Records of operational conditions during measurements should be obtained from the operator of the facility.

Ground Attenuation Effects - The presence of acoustically *soft* ground can lead to a reduction in noise level at the receptor due to absorption of noise energy reflected from the ground particularly where propagation distances are high. Examples of acoustically *Soft* ground are grassed areas, areas under crops, and forests with ground covering vegetation. Areas that are concreted or otherwise sealed, or areas of water are acoustically *hard.* The presence of soft ground between the facility and the receptor point should be noted. If the effect is seasonal due to variations in ground cover, measurements may need to be taken at a time when ground cover is at a minimum if this corresponds to a time when public reaction is likely to be highest. Alternatively, measurements could be made close to items of plant and a prediction could be made with no attenuation factor for ground attenuation included. This would indicate the highest likely noise levels that would be experienced at the receptors. Extrapolated levels may be subject to some uncertainty and it is not uncommon for predicted results to be quoted along with an estimate of accuracy.

Time of Measurement and Duration - The time at which measurements are made may affect the noise levels that are measured. If a survey is intended to establish background noise level from which noise limits will be derived for a new facility the following should apply:

- the survey should include night-time measurements unless the facility will not operate at night;
- night-time measurements will normally take place between midnight to 0400 hours (when traffic noise and other human activity is at its lowest);
- if the maximum difference between the noise level from the facility and the background noise level is expected to occur during a time other than the night, a further survey should be carried out during that period.

When a survey is designed to check ambient noise levels with a facility operating, the survey should include night-time measurements when background noise levels are normally at their lowest so that the noise contribution from the plant is at its highest.

Measurements should be carried out over a sufficient period of time to establish typical average noise levels, and if necessary, maximum noise levels, from the facility. *Appendix B* gives further information on measurement periods. It is good practice to repeat measurements to gain extra certainty in the results because of all the factors described above.

Noise measurements made within buildings may require different considerations, and various guidelines are available, such as those produced by the Association of Noise Consultants (5).

2.4 Prediction of Noise

2.4.1 Why Are Predictions Necessary?

Noise predictions are useful in two main situations:

- At a proposed facility where noise must be quantified before construction to ensure that no noise problems will result from the facility and to allow a permit noise limit to be set.

- At existing sites where there is a need to review the effectiveness of various noise control techniques and to enable a reasonable permit level to be established that takes into account the Best Available Techniques to limit noise.

It should however be noted that a predicted noise level will not be as accurate as a measured one.

2.4.2 How Are Noise Predictions Carried Out?

Common prediction methods are discussed in this section. The main methods that are used to predict noise in the UK are CONCAWE (6) , EEMUA (7) , and BS 5228 (8). Other standards also exist for prediction.

For complex sites computer programs are useful. These implement a range of standards which is often dependent on the country of origin of the prediction program. Standard computer programs implement:

- ISO 9613 Part 1 /Part 2 (9)
- CONCAWE
- EEMUA
- standards for industrial noise from Germany, Scandinavia, and Austria.

Whilst noise from mechanical plant can generally be quantified quite reliably, the prediction of variable source noise from gas flares etc can only be achieved by consulting the methods developed in specialist research papers. These specialist areas are not generally included in the computer programs.

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(5) Association of Noise Consultants Guidelines – Noise measurements in buildings (ANC-C9801) – Part 2: Noise from external sources (eg traffic noise) within buildings, 1998, Association of Noise Consultants.

(6) The propagation of noise from petroleum and petrochemical complexes to neighbouring communities, CONCAWE, Den Haag, 1981.

(7)Guidance on the use of noise specification EEMUA publication 141, The Engineering Equipment and Materials Users Association (EEMUA), 1985

(8) Noise control on construction and open sites: BSi, 1997.

(9) ISO9613 Acoustics - Attenuation of sound during propagation outdoors, ISO, 1993.

The basic method in BS 5228 can be implemented at a simple level if the factors such as ground absorption and air absorption are not critical to the assessment. This will often provide a quick method of carrying out an initial assessment. Care must be taken to apply correction factors that are appropriate to the source involved. For instance, the ground absorption factors in BS 5228 are intended for use with construction plant and should not be used without checking that the frequency content of equipment under investigation is likely to be consistent with the construction plant in BS 5228. BS 5228 does not include a method of predicting noise from plane or line sources, such as buildings louvres and large plant.

2.4.3 Advantages and Disadvantages of Noise Predictions

Table 2.1 shows some advantages and disadvantages of various aspects of noise modelling.

Table 2.1 Advantages and Disadvantages of Prediction

Advantage	Disadvantage	Comment
Cost		Reduces abortive/ineffective noise control spend
	Cost	Expensive to set up accurate prediction for small sites. Cost of software can be significant.
Strategic information		Focuses effort on important sources
	Uncertainty in output	Any noise prediction is subject to variation due to uncertainty in input parameters. Measurement may be required to supplement the modelling approach.
	Complex	The complexity of a model will depend on various factors. Suitable qualified practitioners should be consulted before establishing modelling technique.

At existing plants, a combination of modelling and measurement can be the most effective approach. Measurements can be made to establish the noise output from the facility. If changes to a particular plant item are being considered, the effect of replacing it with a quieter item can be predicted. Predictions are only required for the equipment items that may be subject to change using this method.

2.5 Assessment of Noise

2.5.1 Introduction

The licensing system applies to two situations:

- *greenfield* sites where no industrial noise is currently audible and a new facility is proposed; and

- areas where noise from industrial and commercial facilities has been a significant feature of the environment for a long period.

- There is a need to consider the relevant assessment approach. In the UK, some guidance (eg BS 4142 (10)) compares background levels with the new noise from a plant. Absolute levels can also be considered, for example to assess the effect on sleep which is triggered at an absolute level independent of the location. Even when a noise limit is set as an absolute level, one may need to consider the existing ambient levels if they are already close to the limit that is to be set.

In all cases, it will be important that the local conditions are taken into account. Consultation with the Local Authority will be helpful when determining the approach to be adopted.

2.5.2 Relevant Methodologies

Guidance that is applicable to the IPPC and the waste management licensing regime are summarised below. *Appendix D* gives a fuller explanation of each document.

Planning Policy Guidance PPG24

PPG24 outlines the Government's view on noise and planning. The guidance focuses on the planning of new noise-sensitive development in already noisy environments (PAN 56 (11) in Scotland and TAN11 in Wales are very similar). In the case of proposed noise-producing development affecting existing noise-sensitive premises, PPG24 advises that British Standard BS 4142 can be used, within its own terms of reference, to predict the likelihood of complaints. PPG24 draws attention to the greater potential for complaints to arise if industrial noise has tonal or impulsive characteristics.

British Standard BS 4142

The test that is generally applied to assess the potential for noise from fixed installations to give rise to community response is contained in British Standard BS 4142: 1997. BS 4142 describes a method for desegregating industrial and background noise levels outside residential buildings and for assessing whether the industrial noise is likely to give rise to complaints from the occupants.

The BS 4142 assessment methodology involves comparing the existing background level with the noise from the industrial development. The industrial noise level is adjusted to allow for any tonal or impulsive characteristics (+ 5 dB), and is called the *Rating Level*. The difference between the two levels can be used to indicate the likelihood of complaints arising. *Appendix D* gives further details.

There is a feeling within the industry that a revision to BS 4142 should be considered after it comes up for review in 2002, particularly with regards to the rating method.

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(10) British Standard BS 4142 (1997) Method for rating industrial noise affecting mixed residential and industrial areas.

(11) Planning Advisory Note 56 Planning and Noise, Scottish Office, 1999.

World Health Organisation

WHO published their latest guidelines on noise in December 1999 as the WHO Guidelines for Community Noise (12). The guidance quotes over 300 bibliographical references and forms an authoritative summary of scientific knowledge on the health impacts of community noise.

The document covers many aspects of community noise, the most relevant of which may be guidelines noise values for dwellings. The guidance suggests that for continuous noise an internal L_{Aeq} below 30 dB is required if negative effects on sleep are to be avoided, and where the background noise is low levels above L_{AMax} 45 dB should be limited. Information on the complex nature of sleep disturbance due to noise is given as background to these values and others.

It is important to note the declared scope of WHO's efforts is to consolidate actual scientific knowledge on health impacts rather than to set standards that might be applicable to given situations.

British Standard 8233

Planning Policy Guidance PPG24 suggests that BS 8233(13) should be used if it is necessary to consider noise levels within buildings. This may be the case if the affected buildings are non-residential or if external areas are not of concern and for some reason acoustic insulation packages are already installed at a building.

BS 8233 gives recommendations for the control of noise in and around buildings, and suggests appropriate criteria and limits for different situations. The standard makes it clear that **these criteria and limits are primarily intended to guide the design of new or refurbished buildings, rather than to assess the effects of changes in external noise level**. The criteria and limits given are therefore of limited relevance to IPPC or waste management permitting situations. However, the standard contains other general information on noise control and noise calculations that may be useful.

British Standard BS 5228

BS 5228 (14) provides guidance on the control of construction and open site noise. It provides:

- a prediction method for construction plant noise;
- standard sound power levels for a wide range of construction plant; and
- some advice on appropriate noise levels during construction.

The prediction method is the most helpful part in terms of IPPC and waste management licensing and could be used to predict noise at open sites, particularly landfill and quarry sites.

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(12) Guidelines for Community Noise , WHO, 1999.

(13) BS 8233: Sound insulation and noise reduction for buildings – Code of practice, BSi, 1999.

(14) Bs 5228: Noise control on construction and open sites, BSi, 1997.

Minerals Planning Guidance MPG11

Minerals Planning Guidance MPG11 (15) describes the government's policy on noise from Surface Mineral Workings. MPG11 notes that waste disposal sites share many common features with surface mineral working, and much of the advice contained in these guidelines will be appropriate to noise control for such operations. As such, MPG11 is useful for assessing the noise from landfill operations. MPG11 recommends the use of BS 5228 to predict noise levels. This document is under review at the date of writing.

The *Engineering Equipment and Material Users Association Guide to the Use of Noise Procedure Specification EEMUA* publication 141 (1985).

The EEMUA method describes measurement of noise from plants, and using prediction to investigate the effect of implementing noise control. It also suggests low frequency noise limits that may be appropriate for some sources.

British Standard BS 6472.

This standard gives a method of assessing vibration effects on human beings. Criteria are included that indicate likely levels of annoyance from vibration exposure.

Institute of Environmental Assessment and the Institute of Acoustics Guidelines on Environmental Impact Assessment

An important UK guidance document on assessment methods is expected to be published by the Institute of Environmental Assessment and the Institute of Acoustics. This document will cover the main features of an environmental noise assessment.

- baseline;
- prediction;
- assessment;
- mitigation;
- presentation; and
- follow up.

It will provide sufficient guidance to enable a reviewer to check that everything has been properly carried out in an environmental noise study. It is also likely to highlight that one single assessment method is not appropriate to all situations.

Further details of the above guidance documents are presented in *Appendix D*.

2.5.3 Future Trends

The European Commission published a Green Paper on Future Noise Policy in 1996. As part of the closer co-operation with other European countries, harmonisation of noise assessment methods is currently being investigated by European Commission Working Groups drawn from EU Member States. Prospective EU legislation concerning this Policy is likely to be implemented between 2002 and 2003. The draft European Directive for the Assessment and

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(15) The control of Noise at Surface Mineral Workings, DoE, 1993.

Reduction of Environmental Noise (July 2000) is currently being progressed by the European Parliament.

It is likely that the Directive will encourage environmental noise measurements to be based on a variation of L_{Aeq} with adjustments made to the noise level if the noise occurs during sensitive periods such as evening or night. Such standardised units will be used for reporting noise exposure at a national level, but are unlikely to be appropriate to setting noise permit levels in given situations.

It is also possible that the EC will propose noise targets. However, these will be long term national population noise exposure targets, and are unlikely to have a major influence on limits for industrial noise set in given situations. The new Directive is likely to raise public awareness of noise pollution and could conceivably raise public expectations in the long term and add weight to the noise permitting process.

Part of this legislation will require ‘noise mapping’ of urban areas. The intention will be to highlight sensitive urban/suburban areas that are affected by high ambient noise levels, and to help develop suitable mitigation procedures to help safeguard human health and reduce levels of annoyance and disturbance. In the first instance, it is likely that the proposed legislation will require conurbations with a population greater than 250,000 to be noise mapped by 2005. Noise Abatement Plans would then be produced to tackle the issues identified for these areas by 2006 (these dates are subject to revision). This requirement would also be applied to conurbations with a population greater than 100,000 a few years later.

By preparing a noise level map based on all noise sources information would be available about the effect of strategic changes on total noise levels. Local noise effects around particular facilities will always need specific studies. The results of IPPC and waste management licensing may be useful input to local authority efforts to carry out noise mapping and to progress abatement plans to improve overall noise exposure in the long term.

2.5.4 Conclusions/Setting Targets

The guidance that is summarised above can be used to establish suitable design targets for the permit. Different guidance documents are most applicable to different situations. Much of this guidance is aimed at avoiding nuisance, and it should be noted that Best Available Techniques may go beyond the requirements for avoiding nuisance.

It is generally better to set noise permit levels at the nearest noise sensitive buildings, but it may be appropriate to set them at the site boundary, for example for access reasons.

The inspector will need to take local circumstances into account in setting this target and consultation with the Local Authority should be carried out at an early stage.

The target will also need to be reasonable and will need to take into account noise reductions that are achievable using Best Available Techniques. These are described in the following section.

3 BEST AVAILABLE TECHNIQUES FOR NOISE CONTROL

3.1 Introduction

This chapter summarises the multitude of techniques that are available to control noise emissions from the range of noise sources that are likely to be encountered at the type of facilities that will require licensing under the IPPC and Waste Management Regulations. Many of these noise sources can be controlled using common techniques such as noise barriers or enclosures, others require unique solutions. This chapter gives an overview of the most commonly used techniques, many of which are applicable to numerous situations. Active noise control, the latest hi-tech noise control technique, is described separately.

This chapter also provides a discussion of administrative noise control options under the headings *Noise Management Practices and Alternatives to Noise Control.*

In order to understand what constitutes the best noise control technique in a given situation, and the shortcomings of some techniques, it is helpful to have a general understanding of the mechanisms through which noise can be attenuated. The following sections offer an introduction to the general principles of noise control.

3.2 How Sound is Attenuated

Sound passes through the air as a pressure wave. The amplitude of that pressure wave can be reduced by several means. In open space a sound wave will naturally reduce in amplitude as it moves from source to receiver through two principal mechanisms; spherical spreading - the natural dilution of the sound energy as it is spread over a widening area, and absorption - due to frictional forces in the air. Spherical spreading reduces the sound level radiating away from a point source at the rate of 6 dB for every doubling of distance from the source. Over small distances (up to a few hundred meters) absorption can generally be ignored as its effect is minor compared to that of spherical spreading. If the level of noise generation at source cannot be reduced, two methods of noise control are commonly used; increasing distance or increasing attenuation. Increasing distance from source to receiver is usually only possible at the planning stage, and can be extremely effective, but in many cases the sound wave must be attenuated through additional means. This usually involves blocking the sound path with a solid structure of some kind.

3.3 Sound Attenuation Through Structures

Sound incident on a solid structure, such as a wall, has one of four paths to follow. It is either reflected back away from the wall, it passes directly through the wall or it passes along the wall and may be radiated away from its structure somewhere else (the so called *re-radiated* noise path). Noise may also pass around the end of the wall or over the top to form another *flanking path*. Let us consider each of these paths in turn, and how they effect the attenuation that is achieved by the structure.

3.3.1 Reflected Sound

The reflection of sound back from a structure is useful in reducing the level of sound that passes through, but there is a potential disadvantage too. If the noise source is enclosed, reflected sound will be trapped within the enclosure and will result in *reverberation* of sound.

This *reverberant* sound may build up within the enclosed space and increase the apparent strength of the sound source. This can be combated by adding acoustic absorption to the enclosed space, for example with mineral fibre quilting in acoustic panels. Barriers may also be covered in absorptive material on the side facing the source to increase their effectiveness.

3.3.2 Flanking Paths and Re-radiated Noise

There are various types of flanking paths. Sound may pass along a structure for some distance and radiate away from it somewhere else, for example as a result of vibration being transmitted through the plant supports into the floor, along the floor into the walls and radiating away from the walls to the outside of a building. Or sound may simply diffract around the edge of the structure, for example under the eaves of a roof. Flanking paths can reduce the acoustic performance of the structure and should not be ignored when a high performance is needed.

3.3.3 Transmitted Sound

The portion of the incident sound wave that passes through the structure is first converted into vibrational energy in the structure and then back to air-borne vibrational energy as it is radiated away from the far side. The extent to which this process attenuates the sound depends on two key characteristics of the structure; its mass and its stiffness.

3.3.4 The Effect of Mass

It is mass that attenuates sound through frictional losses, the greater the mass the greater the attenuation. This attenuation depends on the frequency of the sound, higher frequencies are absorbed more easily than low frequencies. As a result, a common feature of noise control is that it is nearly always more difficult to attenuate low frequency noise than high frequencies. This problem is accentuated when a long propagation distance is involved because air absorption will effect higher frequencies far more than lower frequencies. The result is that low frequency noise tends to ‘travel’ more than high frequency noise.

Mathematically, the relationship between sound reduction, mass (M), and frequency (f) are given in the ‘Mass Law’ of sound insulation as follows:

- Sound Reduction = $20 \log Mf - 43$

Or, stated in words:

- At a given frequency, sound reduction increases by about 6 dB for each doubling of mass; and
- For a given mass, the sound reduction increases by about 6 dB for each doubling of frequency.

These are idealised relationships that ignore other mechanisms that may effect attenuation in given materials, such as the effect of stiffness, discussed below.

3.3.5 The Effect of Stiffness

The stiffness of the structure will control the extent to which it flexes under the influence of the incident sound wave. A structure that is flexing will radiate sound as it oscillates at the frequency of that oscillation. If a structure has very low stiffness this can form a very efficient route for sound to pass through. Even heavy walls can allow sound to pass through them in this way because flat structures such as walls or windows have a natural frequency at which they will oscillate easily if energy of that frequency if put into them. Hence, only very specific frequencies of sound are transferred through structures in this way. Nonetheless because the process transfers noise very efficiently it can lead to substantial losses of attenuation performance at given frequencies.

3.3.6 Holes, Openings, and Barriers

For a noise attenuating structure to be effective it must completely block the sound transmission path. Any hole or opening in the structure will greatly reduce its acoustic performance. For example, if a wall or partition capable of attenuating sound by 25 dB has an opening in it with an area that is 10% of the area if the wall, its performance will be reduced from 25 dB to about 10 dB. Sound can be thought to behave rather like a liquid in such cases, it will simply pour through the easiest route it can find. Similarly sound will flow round a structure if allowed to do so. More correctly speaking sound will diffract around the edge of a structure. It is the ease with which sound diffracts around structures that limits the performance of noise barriers which only partly block the sound transmission path. This is also the reason why tree planting is not usually an effective noise control technique. Sound does not move in straight lines.

3.4 Noise Control Equipment

3.4.1 Introduction

This section provides a description of noise control equipment that is available to attenuate noise from commonly encountered sources of noise found at facilities covered by the regulations. The equipment is divided into two types; ‘conventional or passive noise control equipment’ such as acoustic enclosures and barriers, and ‘active noise control’ which uses modern electronics to produce an acoustic signal that partly cancels out the unwanted noise. Active systems are also available for vibration cancellation.

3.4.2 Conventional Noise Control Equipment

Noise control is a highly developed industry and there are numerous manufacturers producing a huge range of equipment designed for particular applications. However, there are common types of equipment that use particular techniques and materials to attenuate noise. This section provides descriptions of 11 generic types of noise control equipment that account for the majority of the equipment used by the noise control industry.

The description of each type of equipment is presented in *Appendix E* as a one page information sheet giving:

- a photograph or picture;
- description - including some of its advantages and/or limitations;

- the application - a list of the noise sources to which it can be applied;
- the acoustic performance; and
- the cost.

The use of this standard information sheet format is intended to make the information concise and accessible.

Table 3.1 cross-references the 11 types of noise control equipment with a list of noisy plant that may commonly be encountered at regulated facilities. For many noise sources there are more than one noise control option.

The costs, benefits and other implications of these types of noise control equipment are discussed in *Section 4*.

Table 3.1 Noise Control Equipment Applications

Noise Source	**Acoustic Enclosure**	**Acoustic louvre**	**Noise Barrier**	**Acoustic Panelling**	**Acoustic Lagging**	**Acoustic Damping**	**Impact Damping**	**Attenuator**	**Steam Trap Diffuser**	**Vibration Isolation Mount**	**Inertia Bases**
Information Sheet No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Boiler		X		X	X	X		X	X	X	X
Chiller		X	X	X	X			X		X	X
Conveyor	X		X	X	X	X	X				
Compressor	X	X	X	X	X				X	X	X
Duct					X	X		X		X	
Fan	X	X	X	X	X	X		X		X	X
Generator	X	X	X	X	X			X		X	
Hopper			X	X	X	X	X				
Lorry/digger etc			X		X	X	X	X			
Materials handling		X	X	X		X	X				
Pump	X	X	X	X	X	X				X	X
Press	X		X	X	X	X	X			X	X
Gas discharge			X					X	X		

3.4.3 Active Noise Control

Active noise control is the term used to describe the process through which noise is reduced by introducing a sound wave that is an inverse, or mirror-image of the unwanted noise. This cancellation wave, which is of equal amplitude and frequency, but of opposite phase, destructively interferes with the noise without physically blocking the sound path. It is therefore fundamentally different from conventional noise control techniques and has potential advantages. But is also has limitations and is expensive. The main applications of active noise control up to now have been ear defenders, fan and pump noise in industry, noise from air-conditioning systems and aircraft interior noise.

A typical active noise control system consists of an input microphone that detect the unwanted noise, a controller system that generates the 'anti-noise', a loudspeaker that emits the anti-noise and a further error microphone that is used to refine the anti-noise signal via the controller. The main limitation of the process is the speed at which the system can react to a rapidly varying noise signal. So, it is most effective for noise signals that are predictable like pure tones, and it is less effective on higher frequency noise because the higher the frequency, the more rapid the signal fluctuates and the electronics cannot keep up. Attenuations of 25 dB or more are achievable for pure tones, whilst 15-20 dB is a more realistic upper limit for broad band noise (ie noise consisting of acoustic energy in a wide range of frequency bands).

A well developed and effective application of active noise control in industry is for in-duct fan noise attenuation. The earliest applications were built about 10 years ago. The problem of poor performance at higher frequency can sometimes be overcome by adding a conventional duct silencer that is inherently more effective at the higher frequencies. Active noise control has one notable advantage in ducted fan noise application. Conventional silencers restrict airflow, which produces an additional load on the fan that drives the air and thus increases the energy consumption of the fan. The active control system itself uses very little power and overall power consumption savings can be 10-20%.

Active control systems can be damaged by high temperatures or wet conditions and are therefore less suited to outside applications. Furthermore external applications tend to require high levels of acoustic energy at the source and there are limitations as to how much anti-noise energy can be generated at low frequencies. Nonetheless active noise control is used for reducing noise emissions from industrial sites, and is effective particularly where low frequency tonal noise cannot be attenuated by other means. In Case Study 3 active noise control was considered but it was discarded largely because of costs which are typically about £4,000 for a single fan.

3.5 Noise Management Practices

3.5.1 Introduction

For some operational facilities there are effective ways of reducing noise simply by being aware of its presence as an issue for the site, and by adopting appropriate procedures when carrying out every day activities. Such procedures can be collectively called 'noise management' and can be particularly important where substantial noise control has been incorporated in a plant design. Noise management may be part of an overall Environmental

Management System, in which case it may be subject to routine auditing and reporting requirements.

3.5.2 Routine Maintenance of Plant

Noise is usually generated in mechanical plant by the interaction of moving, and often rotating, parts. Over time these parts tend to wear, stretch or become distorted in some way and the levels of noise generated tend to increase. Common examples include bearings, gear chains, rollers and engines. Routine maintenance or servicing of such equipment can have a significant effect on noise output.

Noise control equipment can also degrade with time and require servicing or replacement. Engine silencers are a prime example. Acoustic panelling can become clogged, waterlogged and distorted and hence will become less effective.

3.5.3 Good Operational Site Practices

There are a number of common sense procedures that can help to reduce noise emissions. Although these tend to be specific to operations at particular facility some common examples are listed as follows:

- closing doors and windows in noisy buildings and acoustic enclosures;
- ensuring that generator or vehicle engine hatches are kept closed;
- locating mobile plant away from noise sensitive receivers where possible;
- avoiding dropping metallic materials from a height;
- switching off plant when not in use;
- stock piling materials (eg containers) so as to provide acoustic screening between noise sources and receivers; and
- arranging delivery or on site vehicle routes away from sensitive receivers.

Although the noise reduction benefits of these practices can be difficult to quantify, they should form a routine part of best practice to reduce overall noise emissions.

3.5.4 Restricting Operating Hours

The sensitivity of neighbouring areas to noise impacts will vary with the time of day and on different days of the week/weekend. Much of the guidance material described in *Section 2* recognises this by applying more stringent standards for the evening (generally taken as 1900 to 2300 hours) and night (2300 to 0700 hours) compared to daytime. The Irish EPA IPC licensing guidelines on noise (16) are in line with other guidance in suggesting a 10 dB differential between day and night in the absence of more detailed information. Restricting the operating hours of noisy activities can be an extremely effective way of mitigating community noise impacts and is often used, to great effect, in planning conditions for new facilities. Restricting operating hours can of course reduce productivity and create operational difficulties, but it need not necessarily require a complete cessation of all activity on the site. In some cases it will be possible to schedule noisy operations to the less sensitive daytime, weekday periods in order to keep noise emissions to a minimum at night.

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(16) Integrated Pollution Control Licensing, Guidance Note for Noise In Relation to Scheduled Activities, Irish Environmental Protection Agency, 1995.

3.5.5 Community Liaison

Some plants require occasional unavoidably noisy procedures to be followed such as 'blowing down' pressurised systems and testing emergency generators. There is evidence that the impact of noise from such activities can be reduced simply by warning the community beforehand. Often, the fact that a member of the public has been informed, and is aware that the operator is being as considerate as possible will reduce the level of disturbance caused. For one thing people will tend to schedule particularly noise-sensitive activities away from such periods. Of course the operator should try to schedule the noisy operations sympathetically too. An example of this is the testing of emergency generators in commercial areas where there are no residential buildings, on Sundays. More generally, keeping the community aware of noise control activities and plans will offer long term benefits to all parties, and should be encouraged.

Complaints due to noise should be treated in a constructive manner. They can often provide the operator with guidance on the main source of concern and the best approach to mitigating the problem. *Appendix C* provides a standard form to illustrate the key information that should be sought from a complainant. A general procedure for handling a noise complaint is as follows:

1. The complaint is logged.

2. The facility under consideration is visited immediately to inquire:
    - if the operator knows what the source of the noise could be; and
    - if the noise could be due to an unusual activity.

3. The source of excessive noise is investigate by inspection to see if there is an obvious remedy, if so it is implemented and the complainant is updated.

4. If no remedy is implemented, and excessive noise is suspected, noise monitoring is carried out to help identify the source and the extent of any noise impact.

5. If monitoring identifies a noise impact remedial work is planned and implemented, the complainant is advised of progress.

6. Repeat monitoring is carried out to establish whether the remedial work has been successful.

7. The complainant is advised and the logged complaint is signed-off as having been properly addressed.

It is important that throughout this process the complainant is kept updated of progress, particularly if the investigations take some time.

3.6 Planning Noise Control

The ideal time to consider noise control is at the initial planning stage of a new facility. Similar opportunities may arise during the lifetime of a facility when planning an extension or when old plant is being replaced (see Case Study 1). At this stage potential noise problems can be 'designed out' rather than being left to be addressed later through a bolt on, end of pipe solution. This approach can not only produce more effective noise control but tends to be more cost effective too.

In some cases there will be planning restrictions governing what can be done on the site and these can limit the options for noise control, but in general consideration should be given the following general principals:

- use of inherently quieter processes (eg Case Study 1, see *Appendix F*);
- selection of inherently quiet plant or 'low noise options';
- site layout to maximise natural screening, screening by buildings, and separation distances;
- orientation of directional noise sources away from sensitive receivers; and
- noise barriers and bunding.

In the particular case of landfill sites the design of the filling sequence can influence the extent of noise screening by filled material, and hence can be used to maximise screening for particular noise-sensitive areas.

Tree planting may provide effective mitigation of visual impacts but rarely reduces noise. For trees to have significant attenuation benefits they will need to be planted very close together and to cover a substantial propagation distance, for example a substantial mature woodland.

4 COSTS, BENEFITS AND IMPLICATIONS OF NOISE CONTROL

4.1 Introduction

This section discusses the overall implications of the various noise control techniques that have been described above. In addition to the acoustic benefit achieved, long-term costs in both monetary and environmental terms are considered. It is not appropriate to attempt a cost benefits analysis of different noise control techniques because in most remedial situations the choice of noise control options will be limited by practical operational factors and there may be only one feasible solution.

4.2 Cost Benefits

4.2.1 Summary of Benefits

The methods of noise control described in this report have generally been in widespread use for many years (with the exception of active noise control). It is because acoustic hardware provides tangible noise benefits for modest costs that it used so commonly. The installation of a suitable piece of acoustic hardware typically provides several decibels of attenuation and can achieve up to about 50 dB, although this is rare in practice. Of course, the reduction in the overall noise level from a facility tends to be less because there are usually many sources of noise that add up at the receiver point, all of which may potentially need acoustic treatment. Nonetheless, in environmental terms the noise benefits achieved represent significant improvements in the noise climate experiences by local communities (*Appendix B* describes how changes in noise are perceived, eg a 10 dB reduction is perceived as a halving of noise level). Such reductions are commonly achievable through tried and tested techniques. There are also benefits to the workforce who will experience a more pleasant work environment.

4.2.2 Costs

The cost of acoustic hardware varies hugely depending on the application. A simple fan silencer may cost a few hundred pounds, whereas it is not uncommon for power stations to incur noise control costs measured in millions of pounds (see Case Study 5). Compared to initial construction costs and ongoing operational costs, the costs of noise control are usually affordable, except to businesses operating on very low margins where only the cheaper methods can be used.

Noise control through good planning generally has minimal costs and potentially substantial noise reduction benefits. Ongoing noise management has minimal costs but generally the benefits are smaller. *Figure 4.1* summarises, in general terms, the relative cost benefits of some of the noise control methods that have been discussed in this report.

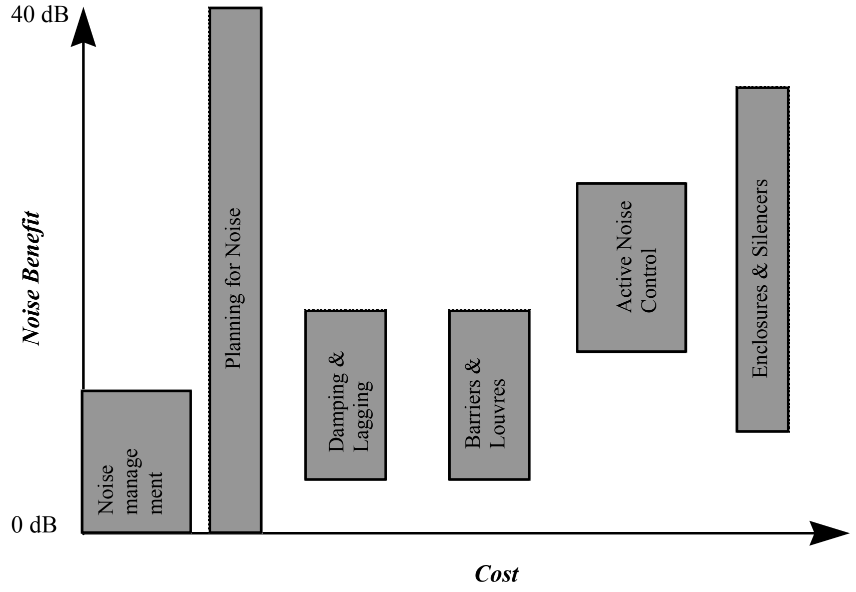

Figure 4.1 Cost Benefits of Noise Control

Noise management may be cost effective, but will rarely offer a complete solution to a serious noise problem. Low cost acoustic hardware, represented in the central part of the figure, may be affordable and may offer sufficient noise reduction in many cases, but in severe cases where acoustic enclosure and silencers are required costs will be higher. Active noise control is a relatively expensive method, but can provide a solution where other techniques cannot, ie for severe low frequency noise problems. This figure illustrates once again that planning for noise control will invariably offer the most cost-effective solution.

4.3 General Implications

For an operational facility there will usually be restrictions as to which choice of noise control method to pursue because of the practicalities of retrofitting equipment and the long term implications of having it in place. There may be a lack of space, insufficient access for maintenance, safety implications or any number of difficulties to contend with.

Noise control equipment may also interfere with the correct operation of the plant, for example by placing it under increased load. Most noise control equipment works by blocking the path by which noise is emitted. This will tend to also block airflow and cooling which could increase wear in the plant and have long term maintenance and cost implications. These problems are not incurred by active noise control, although some maintenance will be required and speakers do wear out.

Noise management practices will rarely conflict with the safe operation of the plant as they are aimed at ensuring operatives use noise control features as they were designed to be used.

When planning a site layout with noise control in mind there will be numerous other considerations that will require careful consideration in achieving an optimal site and plant layout. However, in the past noise control has tended to be left until last and it should be considered along with all other factors in a balanced way during the conceptual and detailed design process.

4.4 Environmental Implications

4.4.1 Energy Consumption

Passive equipment added to a plant has the capacity to increase energy consumption by adding mass and restricting the free operation of the plant. Attenuators fitted to fans impede air flow and hence put additional load on the fan. This increased load, quantified as ‘pressure drop’ can be minimised by using a silencer with more open splitters but of greater length if there is space. Sometimes performance is increased by using two silencers in series. However, inevitably some extra load is created and more energy is required to drive the air flow. This effect is more severe when adding attenuators to high velocity air flows, such as in the inlet and discharge stacks to gas turbines in power stations. In high velocity air flows attenuators produce higher pressure drops which can have an appreciable effect on the efficiency of the gas turbine and hence the whole power generation process. For example, a stack silencer producing a pressure drop of 30 millibars can reduce overall power generating efficiency by 2%. Consequently acoustic engineers work to tight guidelines when designing and selecting such attenuators.

4.4.2 Raw Material Usage

The manufacture, servicing, replacement and decommissioning of acoustic hardware all require natural resources. There are clear advantages in choosing an inherently quiet process or low noise plant option rather than bolting on noise control equipment. Where acoustic hardware creates additional mechanical or heat load the life of the plant may potentially be shortened which will also have resource implications. These will not be major concerns for smaller installations, but they may be more important in sectors such as the power industry where more substantial resources are involved.

Acoustic hardware generally has a lifetime of many years and is largely maintenance free. As such it generates very little waste when operational. Acoustic panels can degenerate under adverse conditions, for example if they became very wet the infill material may need replacing from time to time. There has been concern that very fine mineral fibres can be hazardous, but safer products have been developed.

5 CASE STUDIES

5.1 Introduction

The Study Brief put a clear emphasis on case studies to illustrate how noise control is used in practice. In particular case studies were requested to:

- demonstrate cost-effective solutions;
- show simple 'low tech' but effective solutions;
- show novel or innovative solutions;
- explain how difficult issues have been tackled;
- give examples not limited to heavy industry;
- include photographs and diagrams; and
- demonstrate co-operation of the operator.

This chapter describes how six case studies were selected, summarises each and how it demonstrates Best Available Techniques, and then draws conclusions from all six. A fuller account of each case study is provided in *Appendix F*.

5.2 Selection of Case Studies

Case studies were selected based on the following criteria.

- industries and processes that are covered by the IPPC and Waste Management Regulations;

- preference to industries and processes that are most common in the UK in order to make the case studies as relevant to as many sites as possible;

- a mix of new facilities and remedial situations; and

- the inclusion of a wide range of noise control techniques and solutions.

5.3 Overview of Case Studies

The case studies provide descriptions of how various noise control techniques were employed in real situations. In most cases a combination of techniques was used. In order to help locate an example of a particular technique *Table 5.1* gives a summary of the techniques applied in each case.

Table 5.1 Noise Control Techniques Covered in Each Case Study

Case Study Facility	Noise Control Techniques Covered
1. Foundry	Change of process used to re-house noisy plant in acoustically designed building. Use of building screening.
2. Maltings	Fan attenuators. Acoustic damping to conveyor systems. Acoustic enclosures on conveyor drive engines.
3. Paper Products Factory	Partial acoustic enclosure. Helmholtz resonators for elimination of tonal noise.
4. Mineral Fibre Factory	Vibrating screens adjusted to reduce low frequency tonal noise.
5. Combined Heat and Power Plant	Acoustic design of a new power station. Building design, acoustic enclosures, doors, specialist attenuators, plant planning.
6. Landfill	Noise bunding. A Noise Management System for a Landfill.

5.4 Summary of Case Study 1

Case Study 1 concerns a foundry run by a company that produces malleable metal casings. Noise from a cupola furnace system, scrap metal handling operations, and dust and fume extraction systems was apparent in residential areas some distance from the site. Measured noise levels were up to 20 dB above background noise in nearby residential areas and low frequency tonal noise was clearly audible.

For various reasons it was decided to replace the existing cupola melt facility with a new electric melt operation. During the pre-planning stage a decision was made to address the noise concerns early in the design. Acoustic consultants were employed to assist in the design of a new building to contain the electric melt furnaces and the raw materials store, which included an area for lorries tipping scrap metal, an overhead crane and the furnace charger.

The noise reduction achieved following the opening of the new furnace system was 12 dB(A). This case study illustrates how the incorporation of noise control within the design of an updated process on the site was successful in achieving a substantial noise improvement for the local community.

5.5 Summary of Case Study 2

Case Study 2 concerns a large Maltings operating near a rural community where the Local Authority were investigating reports of noise nuisance. The main noise sources that were addressed included tonal fan noise, clatter, screeches and clonks from conveyor systems, and high frequency hissing sounds from grain chutes.

Fan noise was addressed using in-line absorptive silencers. Noise reductions of about 5 dB(A) were achieved and tonal noise was eliminated. Some fans also required acoustic lagging to reduce noise breaking out from the fan casings.

Conveyor and elevator casings were fitted with a dense PVC matting to provide acoustic damping. A grain chute treated in this way showed a noise reduction of over 10 dB(A). Drive mechanisms forming particular noise sources were boxed in with small local enclosures manufactured on site from sheet steel and mineral fibre board.

An overall noise reduction of 7 dB(A) was achieved and whilst noise levels remained significantly above the background noise they were reduced to below recognised absolute noise standards. This case study is an example of how acoustic treatments can be built by an operator to fit a particular situation without the need of expensive high-tech equipment.

5.6 Summary of Case Study 3

Case Study 3 concerns an international paper product manufacturer who was experiencing neighbourhood noise problems, and reduced tonal noise from air-handling material transport systems and impulsive noise from high pressure blow-off exhausts, using low cost, innovative technology.

The factory is located in a rural setting but two neighbours had complained of tonal, intermittent, impulsive noise. The main source of the problem was identified as a series of fans used to drive air through a system that transports paper pulp around the site. For safety reasons (fear of fire ignition) standard attenuators could not be used and several other alternatives were ruled out, including active noise control. A solution was finally found using Helmholtz resonators. The Helmholtz principle uses a vessel, or side branch, to produce an air spring which absorbs energy from sound waves in the main duct. Although resonators cannot operate over wide bandwidths, they control pure tones effectively. As the materials handling system emitted a tone at 160 Hertz, this option was considered to be a suitable one.

Following research into a suitable design a simple Helmholtz resonator was fabricated in-house using a 250 mm steel tubing, 1 metre in length. This was attached to the 600 mm duct by a 75 mm right angled branch, bolted directly to the duct. An adjustable piston was fitted inside the resonator operated by a screw thread in the closed end.

Eventually four Helmholtz resonators were manufactured on site at a total cost of less than £1,000. A noise reduction of 10 dB(A) was achieved and the tonal noise was eliminated.

This case study illustrates an innovative low-cost solution that was extremely effective with no long-term disbenefits.

5.7 Summary of Case Study 4

Case study 4 concerns a mineral fibre manufacturing factory which was reported to be producing very low frequency noise at unacceptable levels in a nearby house. Several sources of noise were audible at the site boundary, including noise from various process fans, pumps, and a low-frequency rumble from the filter plant. Noise also arises from lorry traffic servicing the plant. However, the source of the low frequency noise was traced to some recently installed vibrating screens used to process the fibres.

The screens were driven by an eccentric weight which produces an out of balance force and rotates at low frequency. Detailed 1/3rd octave band analysis in the complainant's house showed a tonal peak in the 20 Hertz 1/3rd octave band, but during the survey it could not be heard above background noise.

The solution was to reduce the speed of rotation of the driving motor from 1450 rpm to 825 rpm. This solution took some time to find, but reduced the offending tone by 10 dB. There were no long-term implications to the plant and minimal cost in making the required adjustment.

5.8 Summary of Case Study 5

Case Study 5 describes some of the acoustic design work undertaken for a new Combine Heat and Power (CHP) plant. The plant was to be located 200m from housing and the Local Authority set a stringent noise criterion in order to prevent ambient noise levels 'creeping' over time. This is a reasonably common practice where there is concern that multiple developments in the future could each add incrementally to background noise levels and together produce significant increase in ambient noise levels in the future.

It was decided that the best approach to attenuating the numerous major noise sources was to house them together in a single acoustically designed building. Turbines and major plant required substantial acoustic enclosures. Conventional attenuators were used extensively and specialist attenuators were required in the exhaust stack to cope with very high temperatures.

On commissioning of the plant, noise surveys at the nearest residential dwellings demonstrated that there had been no increase in ambient noise. In addition, noise from the CHP building was not detectable at the noise sensitive location previously identified during the initial noise survey.

This case study illustrates the extent of noise control measures that may be required for a major plant such as a power station.

5.9 Summary of Case Study 6

Case Study 6 concerns a Landfill operation in the vicinity of two properties at which the Local Authority had prescribed noise limits. The noise limits were set in accordance with MPG11 and modelling of possible future noise levels using BS 5228 methodologies suggested that substantial noise control was required.

Two bunds were constructed of soil removed from the site for cell construction. During their construction, noise levels at the two receptors occasionally reached levels of 70 dB(A) for short periods. Noise impacts arising from the construction of bunds in this way is identified in MPG 11, which also points out the necessity to construct bunds in such cases. As a result, an agreement was reached with the Planning Authority regarding the exceedance of noise limiting criteria whilst bund construction took place.

A package of noise management practices was developed including maintenance and switching off of equipment, limiting plant sound power levels, restricted operating time, limited use of audible warning alarms, and noise monitoring.

The overall noise reduction achieved was about 10 dB(A) and although levels were still above background noise levels they met the requirements of the Local Authority.

5.10 Conclusions From Case Studies

The six case studies illustrate a wide range of noise control techniques applied to a variety of situations. The fuller account of each study given in *Appendix F* describes the reasons behind the choice of noise control method in each case and the difficulties that had to be overcome.

Where possible cost information has been provided. In some cases the costs involved are surprisingly low, particularly where innovative solutions have been found and the required hardware has been built on site. Also discussed in *Appendix F* are some other costs and benefits associated with the noise control that was undertaken.

The case studies also illustrate how noise limits were set for two new facilities and how Best Available Techniques were used to reduce noise from existing facilities such that acceptable outcomes were reached.

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LIST OF FIGURES

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Appendix A - Glossary of Acoustics Terminology

Sound Power Level and Sound Pressure Level	Any source of noise has a characteristic *Sound Power*, a basic measure of its acoustic output, but the *Sound Pressure Levels* it gives rise to depend on many external factors, which include the distance and orientation of the receiver, the temperature and velocity gradients in the medium, and the environment. *Sound power* on the other hand is a fundamental physical property of the source alone, and is therefore an important absolute parameter which is widely used for rating and comparing sound sources.
dB (decibel)	This is the scale on which sound pressure level is expressed. It is defined as 20 times the logarithm of the ratio between the root-mean-square pressure of the sound field and the reference pressure (0.00002 N/m^2).
dB(A)	This is a measure of the overall noise level of sound across the audible spectrum with a frequency weighting (i.e. \`A' weighting) to compensate for the varying sensitivity of the human ear to sound at different frequencies.
$L_{Aeq,T}$	This is the equivalent steady sound level in dB(A) containing the same acoustic energy as the actual fluctuating sound level over the given period, T.
Background Noise Level	The A-weighted sound pressure level of the residual noise in decibels exceeded for 90% of a given time
$L_{A90,T}$	This is the dB(A) level exceeded 90% of the time, T.
$L_{A10,T}$	This is the dB(A) level exceeded 10% of the time, T.
$L_{A50,T}$	This is the dB(A) level exceeded 50% of the time, T.
L_{Amax}	This is maximum dB(A) level
Residual Noise	The noise level in the area without the noise source under investigation.
Facade	Noise levels at locations 1m from the facade of a building are described by the term *Facade* and are subject to higher noise levels than those in open areas (*Free-field* conditions) due to reflection effects.
NR	Noise Rating curves, similar to Noise Criteria (NC) curves form a set of noise criteria given in octave bands which are set with similar frequency weightings as the A-weighting.
PPV	Peak Particle Velocity - vibration measurement parameter that corresponds to the highest speed in a given direction during a sample period. Often used to assess the potential for building damage but sometimes used to establish if vibration will be perceptible.
VDV	Vibration Dose Value - vibration measurement parameter that combines the magnitude of vibration and the time for which it occurs. The measurement is based on a form of acceleration which is frequency weighted to reflect human sensitivity to various frequencies (see BS 6472).

Appendix B - Noise Measurements & Calculations

B1 INTRODUCTION

B1.1 The Scope of this Appendix

Section 2.3 of this report, Measurement of Noise, outlines some of the principles of measuring and calculating levels of noise in the environment, and *Appendix A* gives definitions of some of the terminology used. This Appendix provides further description of how to carry out noise measurements and calculations, giving examples and formulas applicable to the most commonly encountered situations. BS 4142 and BS8233 give further guidance.

B1.2 The Decibel Scale of Sound

Before going into the detail of noise measurement it is useful to have a feel for the scale on which all measurements are made.

Noise levels are measured using the decibel scale. This is not an additive system of units (as, for example, metres or kilograms are) but a proportional system (a logarithmic progression). Measurements in dB(A) broadly agree with people's assessment of loudness. A change of 1 dB(A) is only perceptible under controlled conditions. A change of 3 dB(A) is the minimum perceptible under normal conditions, and a change of 10 dB(A) corresponds roughly to halving or doubling the loudness of a sound.

Noise levels of some common sounds are shown in *Table B1.1.*

Table B1.1 Approximate Noise Level of Common Sources of Noise

Noise Level - dB	Noise Source
80	Heavy road traffic at 10m
70	Car at 60 km/h at 7m or loud radio indoors
60	Busy general office or restaurant and normal conversation at 1 m
50	Quiet conversational speech at 1m
40	Whispered conversation at 2m
30 to 35	Quiet bedroom or living room

Notice that in *Table B1.1* the distance from the source to the receiver is given in cases where the source may be mobile. This is because as sound propagates away from a source its intensity decays rapidly as the acoustic energy is spread more and more thinly. For a small (point) source, the rate of decay is about 6 dB for each doubling of distance (see *Section B4.4* below). So it is important to note the measurement distance in any case where the source may move or where the receiver point is not clearly defined.

The noise levels of some everyday situations are shown in *Figure B1.1*. These are for typical source to receiver separation distances, and hence the precise level in any particular case will vary around the levels indicated.

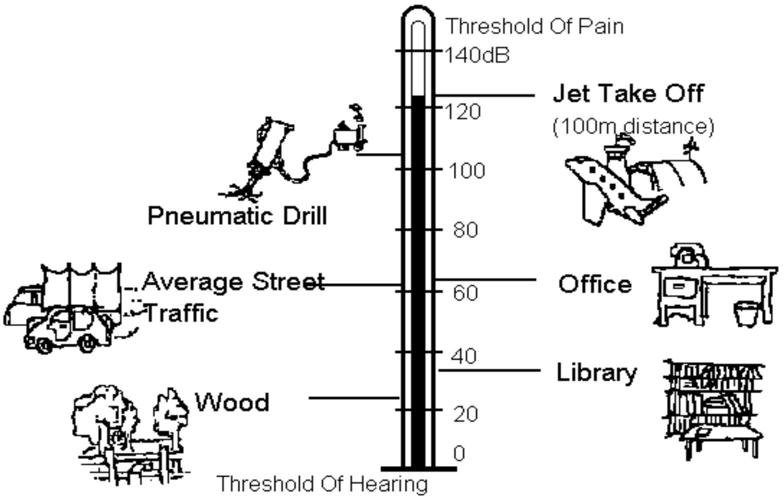

Figure B1.1 Noise Levels in Everyday Situations

B2 QUANTIFYING A VARYING SOUND LEVEL

The sound levels we hear are rarely constant. This is because the sound pressure arriving at our ears is usually the result of numerous different sources of noise, each of which may be varying in strength from one second to the next. Exceptions tend to be when one particularly constant source is very loud compared to the rest (eg close to a extract fan in a factory wall) or when all noise sources are at large distances from the receiver (eg in the bedroom of a remote house at night). So, to quantify a noise level we tend to measure it over a period of several minutes by taking numerous very short samples (typically half a second long) and we report a statistical analysis of sampled levels.

The simplest statistical metrics we can report include the level of the highest noise sample (L_{Max}, the maximum level), the level of the lowest sample (L_{Min}, the minimum level), and the median (L_{50}). These are commonly used, particularly L_{Max}, as it a measure of the most obtrusive facet of the noise, even though it may only occur for a split second. L_{Min} is rarely used, but can be a powerful way of measuring a constant noise in amongst other intermittent noises.

L_{50}, the median level, or 50th percentile, is hardly ever used. Instead, another form of 'average' level is more common, L_{eq}, the equivalent level. L_{eq} is indeed an average of all the sampled levels, but to take account of the logarithmic nature of the decibel scale of sound, it is not the arithmetic mean, it is the logarithmic mean.

The L_{90} level will be a little above the L_{Min}, and has been adopted as a good indicator of the 'background' noise level. Whilst it is not the absolute lowest level measured in any of the short samples, it gives a clear indication of the underlying noise level, or the level that is almost always there in between intermittent noisy events.

L_{10}, the tenth percentile, or the level which 10% of the samples exceed, has been shown to give a good indication of people's subjective response to road traffic noise, and in this country is used in assessments of road traffic noise impact. This is presumably because it is the general peakiness of road traffic noise that people notice, but not the absolute peaks (L_{Max}) that occur only occasionally. It is relevant here, to reiterate the importance of always noting the measurement duration - an L_{Max} measured in a two minute sample of road traffic may be lower than an L_{Max} measured over a one hour period, depending on the frequency of vehicle pass-bys. Indeed, for low traffic flows, L_{10} may be different too. The Calculation of Road Traffic Noise gives the following equation for determining the shortest measurement period that will give reliable L_{10} levels for a given traffic flow.

- Minimum period = (4000/hourly flow) + (120/sampling rate).

Usually a measurement period of 15 minutes is adequate to obtain repeatable results. If the objective of the measurement is to measure the level of a noise source underlying road traffic at low flows (or some other intermittent noise event), a useful technique is to 'pause' the sound level meter during noisy events. Clearly, only part of the noise climate is being quantified when using this technique.

Road traffic noise is by far the most common source of environmental noise. It varies through the time of day and the day of the week as the traffic flow varies. Other factors effect traffic noise level, but in general there is a familiar pattern of noise levels through the day. *Figure B2.1* gives a plot of noise level against time for a period of one week at a location about 10m from a busy main road within a city.

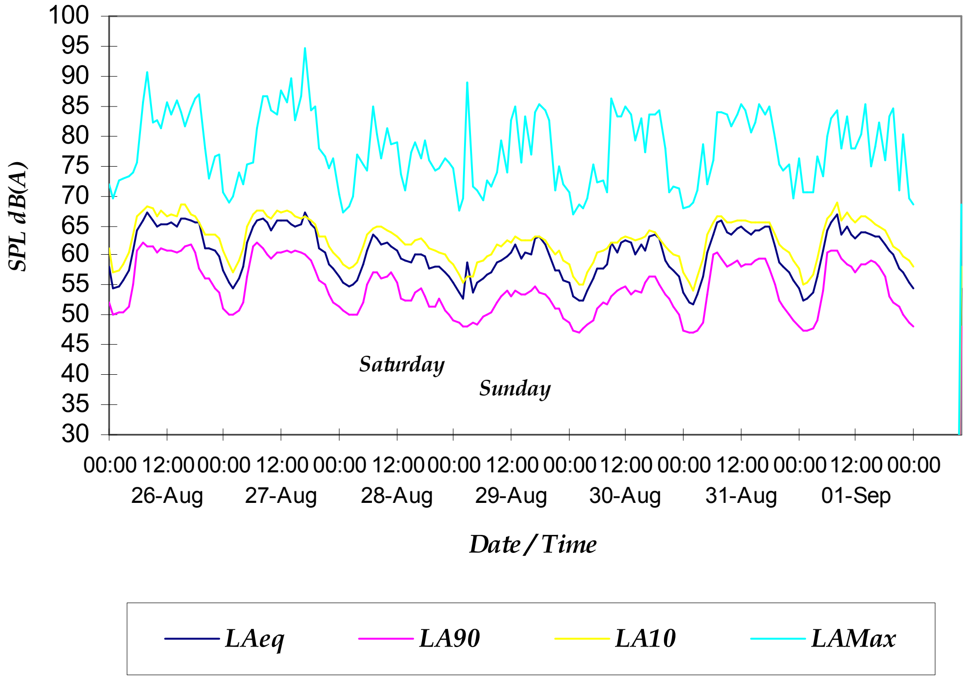

Figure B2.1 A Time History Plot for Road Traffic Noise

Figure B2.1 gives the values of L_{A10}, L_{Aeq}, L_{A90}, and L_{Amax} for each hour of the day and night. The following typical observations can be made:

- On weekdays the morning and evening peak rush hours are visible.
- At night noise levels drop by about 10 dB.
- L_{Amax} levels vary over a wide range from hour to hour.
- Saturdays and Sundays are generally quieter during the day, but not at night.

Whilst these are typical observations, they are by no means predictable and the pattern of noise levels will depend on local conditions. This figure does however illustrate the relationship between the different noise metrics, and also some of the factors to be considered when carrying out a noise measurement which will include road traffic noise.

So, there is a range of noise metrics to choose from to meet the needs of any particular measurement situation. Criteria used to assess noise impact have historically used various metrics, but in recent years there has been a move towards using $L_{Aeq,\ T}$ wherever possible. This trend is continuing with the European Commission's work on future European noise policy.

B3 FREQUENCY ANALYSIS

Introduction

Just as a given noise is characterised by the way in which it varies over time, it will also be made up of a wide range of different frequencies of noise. The spread of noise energy across the audible frequency 'spectrum' (about 20Hz to 20,000 Hz) is one factor that helps to make it identifiable to the human ear.

Tonal Noise

Often the highest levels of sound energy will be spread over a wide band of frequencies ('broad-band' noise) and the frequency spectrum will follow a smooth curve. Sometimes, however, a noise source will emit noise that is concentrated in a 'narrow band' of the spectrum and contains a high proportion of energy at a single frequency (a 'pure tone'). Examples of sources that can give rise to tonal noise include fans, compressors, motors, and transforms. Most have moving parts that rotate or vibrate at a given, audible frequency.

For example, a fan with four blades, rotating at 600 revolutions per minute (10 times per second) has a fan blade passing frequency of 40 Hz. Whilst noise from fans is commonly the result of complex aerodynamic effects, this fan could potentially produce tonal noise at 40 Hz. Mains electrical power is a common source of tonal noise, for example in transformers. The 'fundamental' frequency (ie the frequency of the driving force that generates the noise) for main electricity is 50 Hz. Other 'harmonics' may also be produced, at multiples of 50 Hz, (100 Hz, 200 Hz etc) as a result of further modes of vibration being set up in structures or in the air.

Tonal noise is generally more noticeable and more annoying than non-tonal noise of the same level and can be penalised in assessments of noise impact, usually by 5 dB. Whilst tonality can be judged subjectively, it will often be useful to measure it. This is achieved through 'frequency analysis'. The most common technique is 'third octave band analysis' whereby the sound level meter divides the sound signal into band-widths of 1/3rd of an octave. Each band is described by its centre frequency. Conventionally up to 10 octaves are covered, centred on 32, 63, 125, 250, 500, 1000, 2000, 4000, 8000 and 16000 Hz. Often the first and last are not used. Third octaves split each octave into three, thus they centred at 32, 40, 50, 63 Hz etc.

Figure B3.1 gives an example of a 1/3rd octave band spectrum from a cooling plant inside a plant room.

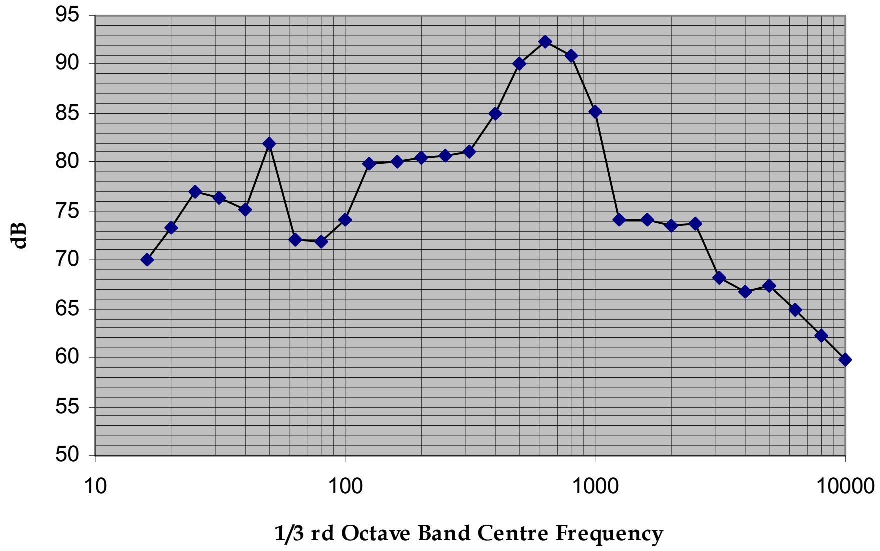

Figure B3.1 Noise Spectrum from Cooling Plant

A distinct peak can be seen at 50 Hz which would be judged as tonal. BS 7445 gives guidance on tonality, and suggests that where a single 1/3rd octave band level is at least 5 dB higher than the level in both of the two adjacent bands, then tonal character may be present. The broader peak around 700 Hz would not be judged as tonal.

Conditions or permit levels should require that tonal noise or noise with any other clear character (see BS 4142) is avoided.

Low Frequency Noise

The A-weighting frequency network applies the highest attenuation to low frequencies (eg 26 dB at 63 Hz) and when measuring noise with a high content of low frequency energy A-weighting can give non-representative results. There is a recent trend to use ‘linear’ noise levels (ie with no frequency weighting at all) when quantifying a low frequency noise source. This is a valid technique but would generally require specialist advice.

Noise Rating (NR) Curves

Noise Rating (NR) and Noise Criterion (NC) curves were developed for setting noise limits in internal rooms. The curves specify limiting sound pressure levels in each separate octave band, but unlike A-weighting the levels in different bands are not summed in any way. Instead the NR level is taken as the highest NR level in any separate octave. *Figure B3.2* shows NR 35, 40, 45, and 50 dB curves and a spectrum from a noise source. This source has its highest NR level of 45 dB in the 1000 Hz octave band and so is rated as NR 45.

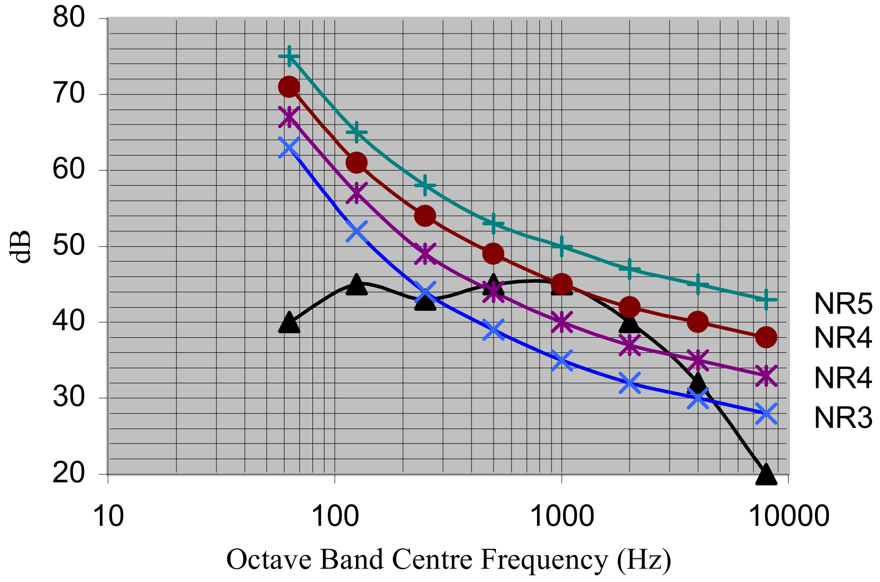

Figure B3.2 Sample NR Curves

NR curves are rarely used for environmental noise but have in the past been considered as a way of attempting to apply a tighter limit than a dB(A) so as to provide extra assurance that tonality will not be audible. However, even if an NR limit is set below the A-weighted background noise level it is still possible that a distinct tone in the new noise source will be discernible. It is more usual to set noise limits in dB(A) and to specify that the noise should have no discernible tonal character.

B4 CALCULATING NOISE LEVELS

B4.1 Introduction

The best way to establish the noise level in a particular place is to go there and measure it. Similarly, if a particular source of noise is of concern, it is best if there are no other significant noise sources to be heard when measuring it. Of course, in reality these ideal conditions are not always possible. In these cases it may be necessary to adjust a measured level by calculation to determine the level that is actually of interest. Some of the calculations that can be used are explained below.

B4.2 Adding and Subtracting Noise Levels

In some situations it is possible to deduce the noise level you are interested in by adding of subtracting noise level from two or more measurements. For, example, a good way to measure the noise level from a piece of building serviced plant is to measure the total noise level at the receiver first with the plant running, and then with it switched off. The noise level of the plant is then calculated by subtracting the second level from the first. This subtraction must be done logarithmically, and can be looked up on *Figure B4.1* below.

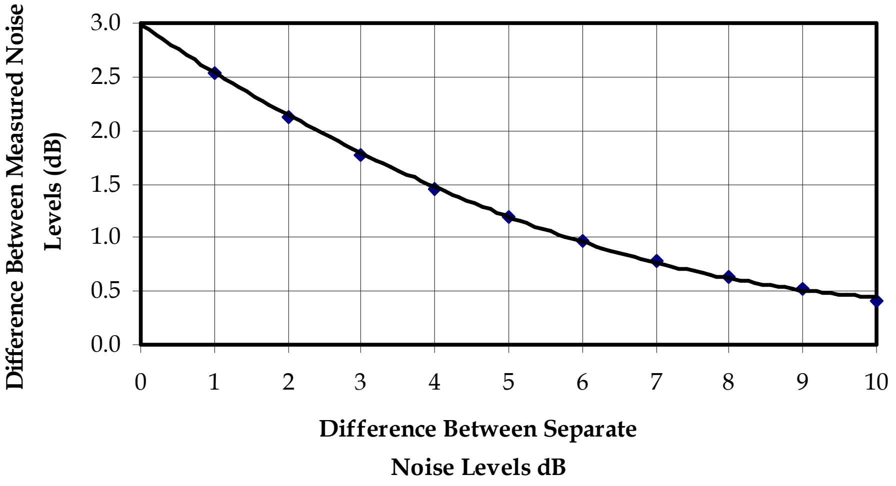

Figure B4.1 Subtracting Noise Levels

For example, if the difference between the second and the first measured levels is 1.5 dB then the plant noise must be at a level 4.0 dB lower than the first measurement.

This chart can be used similarly to add noise levels logarithmically. For example if the difference between two separate noise levels is zero, then the additive effect is plus 3 dB.

The effect of multiple sources, each of equal level is calculated as
+10 Log (number of sources).

B4.3 Façade Effects

When sound is incident on a building (or any acoustically 'hard' surface) the majority of it is reflected back off the façade. Thus a measurement made close to the façade will record the summation of the noise incident on the façade and the noise reflected away from the façade. The reflected noise is rather like a second source of the same magnitude, and the effect is to add approximately 3 dB to the level of the incident sound. Measurements should be made either at a façade location, approximately 1m from the façade, or in a 'free-field' location, at least 4m away from any reflective surface (apart from the ground). If the receiver is the occupant of a building it is better to measure at the façade, since façade effects can be less than 3 dB, for example if the noise is not incident perpendicular to the building.

B4.4 Distance Attenuation

Where it is not possible to measure at the receiver it may be necessary to calculate the level at the receiver from the level measured somewhere else. In general if a parallel location can be used that is the same distance from the source, and is next to the receiver (so it has the same screening effects etc), then no correction will be needed. If measurements are made on the site boundary it may be necessary to correct for the additional distance to the receiver. This is usually straight-forward.

The general relationships between noise level and distance from source for a point and line source are as follows.

For a point source:
Level at distance B = Level at distance A – (20 x Log (distance B / distance A)).

For a line source:
Level at distance B = Level at distance A – (10 x Log (distance B / distance A)).

When measuring at the site boundary a relatively small piece of plant will general be a point source. A conveyor or road may be a line source if there is an unobstructed field of view of it from the measurement point.

So, for example, if a measurement of noise from a chiller on top if a building gives 60 dB at the site boundary which is at a distance of 100 m, and the receiver is a further 50 m away, then the calculated level at the receiver is 60 - 20log(150/100)= 56.5 dB.

These simple relationships do not follow where there is significant levels of acoustic screening or acoustically 'soft' ground. BS 5228, Part 1 gives a simple method of calculating these effects. Soft ground effects can produce additional attenuation of up to about 3 dB(A) over distances of 100m and up to about 9 dB(A) over 1000m. ISO 9613 gives a more detailed method that allows for weather conditions.

The more complex the calculation, the lower the certainty in the predicted level, so complex interpolations of measured levels should be avoided wherever possible.

Appendix C - Noise Complaint and Noise Measurement Forms

Table C.1 Typical Form for the Reporting of a Noise Complaint

Sheet No

Noise Complaint Report Form

Date	Site	Grid Reference

Name and address of complainant

Tel no. of complainant
Time and date of complaint

Date, time and duration of offending noise

Weather conditions (ie, dry, rain, fog, snow)

Wind strength and direction (ie, light, steady, strong, gusting)

Complainant's description of noise (ie, hiss, hum, rumble, continuous, intermittent)

Has complainant any other comments about offending noise?

Any other previous known complaints relating to installation (all aspects not just noise)

Any other relevant information

Type of installation

Plant and equipment installed

Items working at time offending noise occurred

Operating condition at time offending noise occurred
(eg Flow rate, pressure at inlet and pressure at outlet) ______________________

____

____

Form completed by ______________________ Signed ______________________

Table C.2 Noise Measurement Form

Sheet No. of		Project No. and Name:						Date: / /
Location	Time	Weather	L_{Aeq}	L_{A90}	L_{A50}	L_{A10}	L_{AMax}	Comment
Filters: OFF/ 1/1/1/3		Frequency Weighting: Lin/A			Time Weighting: PK/I/S/F			Signature:

Appendix D - Summary of Relevant Guidance Documents on the Assessment of Noise and Vibration

D1 INTRODUCTION

This *Appendix* summarises and comments on key guidance documents that can be used to assess noise impacts from new and existing facilities.

The key features of each guidance document and their relevance to IPPC and waste management licensing are highlighted in *Section 2*. This Appendix gives a fuller description of each in order to offer further guidance of their applicability. However, if in doubt the reader should refer to the full document. A bibliography of all the guidance relevant to this report is given prior to the Appendices.

There is a need to consider the relevant assessment approach. In the UK, some guidance (eg BS 4142(17)) compares background levels with the noise from a plant. Absolute levels can also be considered, for example to assess the effect on sleep which may be triggered at an absolute level. Even when a noise limit is set as an absolute level, one may need to consider the existing ambient levels if they are already close to the limit that is to be set. Across Europe the more common approach is generally to use absolute levels, and European noise policy is likely to follow this approach.

In all cases, it will be important that the local conditions are taken into account. Consultation with the Local Authority will be helpful when determining the approach to be adopted.

The Institute of Acoustics and Institute of Environmental Assessment working group on noise assessment is also likely to make some important recommendations in their guidance on noise assessment which is currently being developed. It has not been published at the time of writing but a description of the likely scope has been discussed in S*ection 2*.

D2 RELEVANT NOISE GUIDELINES

D2.1 Planning Policy Guidance PPG24

D2.1.1 Introduction

PPG24 (18) establishes Noise Exposure Categories which are applicable when planning new residential developments affected by transport noise or by mixed noise sources in which industrial noise does not dominate. In the case of proposed noise-producing development **affecting existing noise-sensitive premises, PPG24 advises that British Standard BS 4142 can be used, within its own terms of reference, to predict the likelihood of complaints. As such PPG24 is not as relevant as BS 4142 in most cases that will be encountered in the permitting** process under the IPPC and waste management licensing regime.

PPG24 also introduces the concept of Noise Exposure Categories (NECs). These categories are intended to be used to provide guidance on the levels of acceptable noise for new housing

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(17) British Standard BS 4142 (1997) Method for rating industrial noise affecting mixed residential and industrial areas.

(18) Planning Policy Guidance 24 Planning and Noise, 1994, DoE

developments that should be taken into account when determining planning permission conditions relating to noise insulation. The NECs are not intended for use in reverse, ie for assessing noise impacts of new noise sources on existing housing. However, the derivations of these are explained and this background research is often used to develop absolute criterion for noise levels.

D2.1.2 Noise Exposure Categories

PPG24 does not offer a single set of criteria, but introducing the concept of Noise Exposure Categories (NECs) that provide flexibility to take account of local conditions and the needs of the local community and economy. There are four NECs:

A. Noise need not be considered as a determining factor in granting planning permission, although the noise level at the high end of the category should not be considered as desirable.

B. Noise should be taken into account when determining planning applications and, where appropriate, condition imposed to ensure an adequate level of protection against noise.

C. Planning permission should not normally be granted. Where it is considered that permission should be given, for example because there are no alternative quieter sites available, conditions should be imposed to ensure a commensurate level of protection against noise.

D. Planning permission should generally be refused.

Table D2.1 reproduces the table in PPG 24 that gives the noise levels for each NEC for each source of noise.

Table D2.1 Recommended Noise Exposure Categories for New Dwellings Near Existing Noise Sources.

Noise levels (a) Corresponding to the Noise Exposure Categories for New Dwellings $L_{Aeq,T}$ dB				
		Noise exposure category		
Noise source	**A**	**B**	**C**	**D**
Road traffic				
07.00 - 23.00	<55	55 - 63	63 - 72	>72
23.00 - 07.00(b)	<45	45 - 57	57 - 66	>66
rail traffic				
07.00 - 23.00	<55	55 - 66	66 - 74	>74
23.00 - 07.00(b)	<45	45 - 59	59 - 66	>66
air traffic(c)				
07.00 - 23.00	<57	57 - 66	66 - 72	>72
23.00 - 07.00(b)	<48	48 - 57	57 - 66	>66
Mixed sources(d)				
07.00 - 23.00	<55	55 - 63	63 - 72	>72
23.00 - 07.00(b)	<45	45 - 57	57 - 66	>66

D2.1.3 Derivation of Noise Exposure Categories

The type of noise source covered by PPG24 that is most relevant to the IPPC and the waste management licensing regime is 'mixed sources', ie a combination of road, rail, air an industrial noise. PPG24 explains how the NEC levels for noise from mixed sources are set at the lowest numerical values of the single source limits, reproduced in *Table D2.1* above.

Annex 2 of PPG24 offers explanations of the how the NEC levels are set for each source of noise. It explains how for road and rail noise there is no recent major research from which to obtain the scale of noise effects. For aircraft noise several major studies have been undertaken by the Department of Operational Research and Analysis (DORA) of National Air Traffic Services. However, for all types of noise source a common rationale separates the NECs, and this provides a useful indication of the magnitude of the noise impact that can be expected in each category.

Boundary of NEC A/B : Taken as the onset of noise impacts taken from World Health Organisation research (see *Section D2.3* below).

Boundary of NEC B/C : Based on the levels that trigger noise insulation for transportation noise. Hence indicative of the threshold at which the severity of noise impacts become very undesirable.

Boundary of NEC C/D : Taken as the level above which noise insulation becomes insufficient to mitigate noise impacts. Hence indicative of the level at which noise impacts become very severe.

The day/night levels of $L_{Aeq,\ period}$ 55/45 dB used as the boundary of NEC A and B have been widely adopted as the levels which represent the onset of community noise effects. Under developing EU noise policy, for example, they are the long-term target noise levels for Member States to aim for. Whilst levels lower than this are frequently enjoyed in more rural locations, it can be argued that even if noise levels in such areas are increased, provided they remain below these levels a good standard of noise climate will be maintained. However, there are initiatives to preserve quiet. Evolving European noise policy is recognising the value of quiet or tranquil areas and the need to maintain them. Also the Council for the Protection of Rural England (CPRE) has defined tranquil areas and produced maps of them.

D2.2 British Standard BS 4142

Planning Policy Guidance PPG24 suggests that the approach in BS 4142 should form the basis of the operational noise assessment. BS 4142 describes a method for determining industrial and background noise levels outside residential properties and for assessing whether the industrial noise is likely to give rise to complaints from the occupants.

The BS 4142 assessment methodology involves the following procedure:

- background (L_{A90}) noise levels (BNL) in the absence of the new noise source are measured at noise-sensitive receptors;

- noise levels due to the facility are then quantified, ie predicted in the case of proposed developments, for the receptor location as an L_{Aeq} (using the procedures set out in the standard);

- noise levels are corrected, if appropriate, for duration and character, with the corrected noise levels being termed the *rating levels* and expressed in L_{Aeq}; and

- *rating levels* are then compared with the BNLs for the area.

The correction for tonal, impulsive or any distinctive character in the noise source is +5dB.

The interpretation of the difference between the *rating level* and the BNL is shown in *Table D2.2.*

Table D2.2 Interpretation of Noise Level Difference

Difference in noise level (dB)	Significance
Around +10	Complaints are likely
Around +5	Marginal
<+5	Decreasing likelihood of complaint with decreasing difference in levels
-10	Positive indication that complaints are unlikely

BS 4142 requires that daytime assessments are based on the highest L_{Aeq} from the noise source over a period of 1 hour, while at night-time an assessment period of 5 minutes is specified.

Table D2.2 is useful in determining the likelihood of complaints in a given situation, but if it is to be used to determine an acceptable noise permit level then great care is needed. This British Standard is commonly misused in this way. When used for assessing acceptable noise limits several factors that are unique to the local situation must be considered, including:

- the absolute levels of ambient noise in the area;
- the types and characteristics of noise present;
- the planning setting with regards to other future noise sources; and
- local opinion on the noise environment.

Taken on face value *Table D2.2* could be interpreted to indicate that if a new noise source is at a level between 10 dB below and 5 dB above the existing background noise level then complaints are not likely and hence such a level is 'acceptable'. In this sense BS4142 offers limited guidance because this range of levels is large. It is the local conditions that will help determine where in this range 'acceptability' lies. The following examples illustrate some situations where certain interpretations of BS 4142 could be misleading.

Where background noise levels are very low, below L_{A90} 30 dB, BS 4142 warns that the guidance may not apply. Applying a -10 dB limit of below $L_{Aeq,\ night}$ 20 dB to ensure a positive indication that complaints are unlikely would therefore be inappropriate.

A new type of noise may be clearly more discernible above a very different type of background noise, for example distant traffic that tends to form a steady broadband noise. In such cases a limit of background +5 dB for a new source may not be appropriate.

Adopting the +5 dB 'marginal' case as acceptable can be inappropriate if there is a likelihood of other future developments adding further to ambient noise levels in the future. This is the so-called 'creeping background' concern that sometimes arises around developing industrial areas. This concern can be valid in some cases, but in others it my not be so serious, for example if road traffic noise is the main source of noise actually experienced by the receiver locations, and changes in industrial noise will have little effect on total noise levels at the receivers. In some cases theoretical calculations of additive noise effects from future developments can be misleading. Noise levels from different sources may not add according to simple theory (see *Appendix B*). For example if they have different frequency components, different temporal patterns, different screening effects, or arrive at a property from different directions and so effect different facades or will not peak under any one set of meteorological conditions.

If little future development is expected adopting a cautious approach of setting permit level at -10 dB may be unnecessary, depending on other local factors, particularly if ambient nose levels are low in absolute terms.

Finally, in situations where there is a history of noise disturbance from whatever source, the local community may have become 'sensitised' to noise impacts. In such cases the 'average' dose-response relationships which form the basis of noise standards may not hold and there may be more complaints. In such cases limits at the lower end of the BS4142 range may be more appropriate, depending on other local factors.

Of course all these local factors interrelate, and for this reason it is not possible to offer prescriptive guidance on how to apply BS 4142. Indeed there is much criticism of the way the standard is applied and this may lead to a revision after 2002. In the meantime BS 4142 must be used with care when setting noise permit levels.

D2.3 World Health Organisation

In 1980 the World Health Organisation (WHO) proposed environmental health criteria for community noise (19). In 1995 Stockholm University and Karolinska Institute published the essentials of WHO's revised guidelines (20) and in December 1999 the latest guidance was published as the WHO Guidelines for Community Noise (21). The guidance quotes over 300 bibliographical references and forms an authoritative summary of scientific knowledge on the health impacts of community noise. It is important to note the declared scope of WHO's efforts is to consolidate actual scientific knowledge on health impacts rather than to set

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(19) Environmental Health Criteria - 12 Noise, WHO, 1980

(20) *Community Noise*, Archives of the Centre for Sensory Research, Stockholm University, Vol 2. Issue 1. Berglund & Lindvall, 1995.

(21) Guidelines for Community Noise , WHO, 1999.

standards that might be applicable to given situations. The document is arranged in five main chapters, the contents of which are discussed below.

Chapter 1 introduces the guidelines. It includes information on current levels of noise exposure, and notes that in the European Union about 40% of the population is exposed to road traffic noise with an equivalent noise level exceeding 55dB(A) during the day.

Chapter 2 discusses noise sources and measurement techniques.

Chapter 3 describes the adverse health effects of noise, such as hearing impairment, sleep disturbance, physiological functions, social and behavioural effects, and vulnerable groups.

Chapter 4 gives guideline noise values for health effects and specific environments. Those of most relevance to this R&D report will generally be those that relate to dwellings and residential areas, and are summarised in *Table D2.3*. Guidelines for other areas are also given.

Table D2.3 Guideline Values for Community Noise in Residential Environments

Specific environment	**Critical health effect(s)**	**L_{Aeq} [dB(A)]**	**Time base [hours]**	**L_{Amax} fast [dB]**
Outdoor living area	Serious annoyance, daytime and evening	55	16	-
	Moderate annoyance, daytime and evening	50	16	-
Dwelling, indoors	Speech intelligibility & moderate annoyance, daytime & evening	35	16	
Inside bedrooms	Sleep disturbance, night-time	30	8	45
Outside bedrooms	Sleep disturbance, window open (outdoor values)	45	8	60

The guidance suggests that for continuous noise an internal L_{Aeq} below 30 dB is required if negative effects on sleep are to be avoided, and where the background noise is low levels above L_{AMax} 45 dB should be limited. Information on the complex nature of sleep disturbance due to noise is given as background to these values and others.

The guideline values given in this chapter can be converted to external noise levels, and applied to industrial noise, say as limits at the nearest receptor, thus fulfilling the WHO's objective of avoiding health effects, but whether or not such limits would be appropriate and reasonable, and whether they would ensure BAT is employed to control noise emissions from a given site, will depend on the many local factors that should also be carefully considered in setting a permit level.

Chapter 5 offers general guidance on noise management, but is necessarily concerned with the general situation rather than specifically with noise permitting for new or extended industrial facilities.

D2.4 British Standard BS 8233

Planning Policy Guidance PPG24 suggests that BS 8233(22) should be used if it is necessary to consider noise levels within buildings. This may be the case if the affected buildings are non-residential or if external areas are not of concern and for some reason acoustic insulation packages are already installed at a building.

BS 8233 gives recommendations for the control of noise in and around buildings, and suggests appropriate criteria and limits for different situations. The standard makes it clear that **these criteria and limits are primarily intended to guide the design of new or refurbished buildings, rather than to assess the effects of changes in external noise level**. The criteria and limits given are therefore of limited relevance to IPPC or waste management licensing situations. However, the standard contains other general information on noise control and noise calculations that may be useful, including:

- Sound insulation data for various building elements.
- General noise calculation methods, such as adding and subtracting noise levels and calculating noise insulation of composite building facades.
- A-weighting corrections and Noise Rating (NR) curves.
- Discussion on the Mass Law and special noise insulation problems that may require expert advice.

D2.5 Minerals Planning Guidance MPG11

Minerals Planning Guidance MPG11 (23) describes the government's policy on noise from Surface Mineral Workings. MPG11 notes that waste disposal sites share many common features with surface mineral working, and much of the advice contained in these guidelines will be appropriate to noise control of such operations. As such, MPG11 will be useful for assessing the noise from landfill operations that are covered by IPPC. MPG11 recommends the use of BS 5228 to predict noise levels.

This planning guidance document adopts the approach of a single absolute noise limit. The basic criterion it recommends for daytime operations is a nominal noise limit of 55 dB $L_{Aeq,1\ hour}$ (free-field) at noise sensitive properties used as dwellings. In this case, 1 hour means any of the one-hour periods during the defined working day.

However, it is recognised that in the case of quieter rural areas, where a 55 dB $L_{Aeq,1\ hour}$ (free-field) limit would exceed the existing background level by more than 10 dB(A), a lower limit may be appropriate. It is recommended that a limit below 45 dB $L_{Aeq,1\ hour}$ (free-field) is not normally used since 45 dB $L_{Aeq,1\ hour}$ (free-field) should prove tolerable to most people in rural areas.

MPG11 also states that it will often be necessary to raise the noise limits to allow temporary but exceptionally noisy phases in the mineral extraction operation which cannot meet the

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(22) BS 8233: 1999 Sound insulation and noise reduction for buildings – Code of practice, BSi, 1987

(23) The control of Noise at Surface Mineral Workings, DoE, 1993.

limits set for routine operations. It is suggested that any higher noise limit as well as the duration of any such temporary phases is agreed between the Mineral Planning Authority (MPA) and the mineral operators taking account of local circumstances.

The guidance suggests that noise limits of 70 dB $L_{Aeq,1\ hour}$ (free-field) for temporary operations may be appropriate.

D2.6 British Standard BS 5228

British Standard 5228 (24) *Noise and vibration control on construction and open sites* has four parts:

- Part 1. Code of practice for basic information and procedures for noise and vibration control (1997).

- Part 2. Guide to noise and vibration control legislation for construction and demolition including road construction and maintenance (1997).

- Part 3. Code of practice applicable to surface coal extraction by opencast methods (1997).

- Part 4. Code of Practice for noise and vibration control applicable to piling operations (1992).

The standard forms a series of codes of practice for construction sites. However sections of Part 1 provide useful guidance for any situation where noise is generated by plant outdoors, for example on landfill sites. The bulk of Part 1 provides a method of calculating noise from construction plant, including:

- tables of source noise levels;
- a methods for summing up contributions from intermittently operating plant;
- a procedure for calculating noise propagation, over ‘soft’ or ‘hard’ ground;
- a method for calculating noise screening effects; and
- a way of predicting noise from mobile plant, such as those on haul roads;

Part 1 also provides guidance on the following subjects for construction sites that may also be useful in other outdoor situations;

- legislative background;
- community relations;
- training;
- noise and vibration neighbourhood nuisance;
- project supervision; and
- control of noise and vibration.

On the last subject, the standard gives examples of the noise control achievable through various methods (such as exhaust silencers and enclosures) and also gives diagrams

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(24) BS5228, Noise and vibration control on construction and open sites, parts 1,2,3 and 4: BSi, 1997.

illustrating simple designs of noise enclosures and barriers that can be built and used on construction sites.

In summary, BS 5228 provides guidance that may be useful when predicting noise and considering noise control techniques for plant operating outdoors, in particular for landfills and waste transfer stations.

D2.7 The Engineering Equipment and Material Users Association Guide to the Use of Noise Procedure Specification EEMUA publication 141 (1985)

The EEMUA method describes measurement of noise from plants, setting noise limits, and using prediction to investigate the effect of implementing noise control. A method for establishing frequency band noise limits is also proposed to limit the potential for tonal elements in the noise that may be more distinctive than a broad-band noise. An absolute low frequency limit is proposed in the 31.5 Hz band to enable low frequency combustion sources (such as gas turbines and boilers) to be controlled.

D3 VIBRATION CRITERIA

D3.1 British Standard BS 5228

BS 5228 Part 4 (25) is strictly applicable to control of vibration from piling operations and not operational facilities. However, it describes parameters to be measured during a vibration assessment at various facilities and states that the human threshold of perceptibility range from 0.15 to 0.3 mm/s (ppv) at frequencies between 8 to 80 Hz.

D3.2 British Standard BS 6472.

BS6472 (26) is a method of assessing vibration effects on human beings. Criteria are included that indicate likely levels of annoyance from vibration exposure. ppv curves are shown that indicate the point at which low probability of complaints will be expected. The lowest value in any of the assessment curves, at any frequency, is 1.41 x 10^{-4} m/s. Significant human vibration issues should not be expected at this level. This level is slightly lower than the threshold of perceptibility described in BS 5228.

Vibration disturbance assessments are complex and they require the use of specialised equipment (particularly to measure VDV). A screening assessment could be carried out to establish if there is a potential for a vibration problem. If the following two conditions are met, it may be appropriate to commission a detailed survey:

- the vibration is perceptible at the sensitive off-site areas; and
- a ppv vibration measurement shows that the levels are higher than 1.41 x 10^{-4} m/s.

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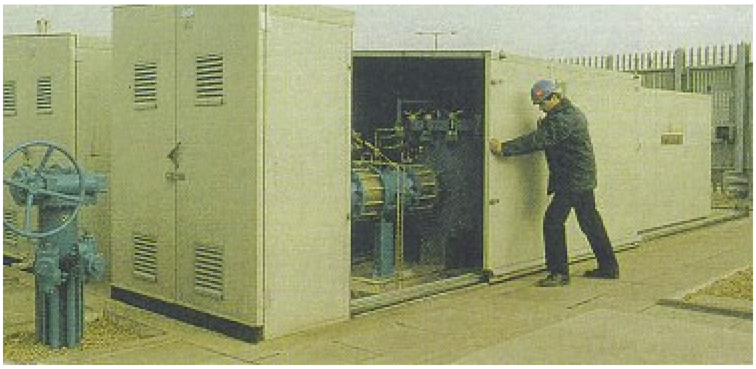
(25) Noise control on construction and open sites: part 4. Code of practice for noise and vibration control applicable to piling operations, BSi, 1992.

(26) Guide to Evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz), BSi, 1992.

Appendix E - Noise Control Equipment Information Sheets

Sheet 1 Acoustic Enclosures



Picture used with the permission of Industrial Acoustics Ltd

Acoustic enclosures form a complete box around a piece of equipment and include acoustics doors, windows and attenuated ventilation or cooling systems.

Description

Where equipment can operate in a confined space it can be completely enclosed by high performance metal acoustic panels. Doors, windows and other openings require special attention and proprietary enclosures ensure optimal design. Openings to provide adequate air flow for cooling are usually the acoustically weak points and high performance attenuators are required.

Vibration isolation is usually required between the equipment and the floor.

Application

Generators, compressors, pumps, process equipment requiring substantial attenuation but minimal access and maintenance.

Performance

20-30 dB(A) limited mainly by silencing of openings and doors.

Cost

Enclosures with surface areas of 30 m^2, installed with attenuators:

20 dB - £5,000
30 dB - £7,000

Sheet 2 Acoustic Louvres

Acoustic Louvres are similar to weather louvres but provide additional attenuation of noise that passes through them.

Description

Acoustic Louvres can be used to replace weather louvres in building openings to reduce noise transfer to outside. Alternatively free-standing acoustic louvres can be placed around external equipment that requires air flow for cooling. Air is allowed to flow between the louvre blades, but noise is attenuated by absorptive material within each blade.

Acoustic louvres can produce high pressure drops to the air flowing through them which may create heat load problems to the plant.

Application

Chillers, compressors, pumps, heat pumps, other external equipment requiring air flow.

Performance

Low frequency performance in limited. The noise path over the top of a louvre screen will usually limit performance to up to about 10 dB(A). Back to back acoustic louvres (ie two louvres fixed together) can increase performance to about 15 dB(A).

Cost

Single acoustic louvres - £300 / m^2
Back to back louvres - £400 / m^2

Sheet 3 Noise Barriers

Picture used with the permission of Industrial Acoustics Ltd

Acoustic Barriers are solid structures located close to equipment to provide acoustic screening between source and receiver.

Description

Noise barriers can be made from acoustic panels, but usually brick/ block walls or solid wooden fences are adequate unless reverberation behind the barrier is a concern. Barriers require a minimum density so that noise passing through the barrier is attenuated to below that passing over the top. Barriers are most effective when located close to the noise source and can be painted or landscaped to minimise visual impact. Transparent materials have also been used. Earth bunds can be effective barriers, trees cannot. Barriers must be solid without any holes or openings.

Application

Most equipment whose noise sources are close to the ground or a flat roof.

Performance

Performance increases with the 'path difference'; the difference between the direct path (through the barrier) and diffracted noise path over the top edge of the barrier. A path difference of zero (ie when the line of sight from noise source to the receiver is just broken) implies 5 dB(A) attenuation. In practice a performance of greater than about 15 dB(A) requires very large barriers and is rarely practicable.

Cost

Noise barrier fences can cost as little as £150 per linear meter but can be considerably more expensive if they are tall or made from superior materials.

Sheet 4 Acoustic Panelling

There are many types of acoustic panel, but most are designed to absorb sound incident from one side.

Description

Acoustic panels are generally between 40 and 200 mm thick and are made from a sandwich of coated steel sheets, with a mineral fibre in-fill. On one side of the panel the metal sheet is perforated to allow sound to pass inside where it is absorbed by the in-fill material. Acoustic panels can be designed to offer very high attenuation to noise transmission that is better than an equivalent solid structure of the same weight. Also, their absorptive properties are used to control reverberation in confined spaces.

Application

Acoustic Panels are the building blocks of many acoustic products. Used alone they can replace conventional walls or partitions, or used to line plant rooms within existing structures.

Performance

Attenuation to sound transmission can be up to about 40 dB(A).

Absorption can be over 90% at middle and high frequencies.

Cost

Acoustic panels need not be expensive, but prices increase if attractive finishes are required.
£100-150 / m^2

Sheet 5 Acoustic Lagging

A flexible material wrapped around noise sources in the same way as thermal lagging.

Description

Acoustic lagging is generally made of a laminated quilt comprising a tough outer skin, mineral fibre quilting and a heavy (often lead) internal layer providing mass. Such lagging is flexible and can be fitted around complex shapes and is ideal for sealing holes and gaps around solid acoustic elements. A similar product can be hung as acoustic curtain around plant that is moved frequently of in very confined spaces.

Application

Lagging to pipes and ducts. Sealing around most acoustic installations.

Acoustic curtain for pumps, fans, hand tools etc.

Performance

10 to 15 dB(A)

Cost

Relatively expensive per unit area, but generally used in small quantities.

£15-30 per m^2

Sheet 6 Vibration Damping

Damping materials applied as an adhesive, flexible 'putty' or sheeting to vibrating metal sheeting.

Description

Metal sheeting, has a tendency to 'ring' when vibrated by heavy machinery. Large unsupported areas of metal can be very efficient at converting vibrational energy into audible frequencies and radiating noise, rather like a loud speaker cone. Casings and guards can be damped using various damping or 'anti-drumming' compounds.

Application

Casings and guards to most machinery, eg conveyors, pumps. Rotating parts.

Performance

Performance varies, but 10 dB(A) is achievable. Damping of machinery casing is most effective on large areas of thin gauge metal.

Cost

Variable depending on product.

Sheet 7 Impact Deadening

Noise generated by impacts on metal surfaces such as loading material into dump trucks, can be reduced by applying a resilient surface treatment.

Description

Deadening materials can be useful on metal floors, chutes or containers, but there are practical problems with wear and tear. For metal floors blended resin compounds have been developed that damp noise generated by trolley wheels and foot falls whilst offering adequate grip, strength and weatherproofing. Metal chutes and lorry holds can be surfaced with abrasion-resistant rubber to reduce noise generated by material impacts. Resilient materials can also be used to help reduce noise generated by inherently noisy material, eg barrels, scrap metal and pipes.

Application

Metal floors or wall coverings in warehouses or industrial stores.

Lorries, metal chutes, hoppers.

Performance

Impact noise can be reduced by 10 dB(A) or more.

Cost

Metal floor treatment - approximately £66 per m^2.

20 Tonne Dump Truck - £26,000.

Sheet 8 Attenuators

Attenuators are designed to allow air to flow between a series of *splitters* which absorb noise. They come in all shapes and sizes.

Description

Attenuators can be part of a ducted air flow system or can be inserted in a wall, partition or enclosure opening. Several splitters divide the air flow. Splitters comprise perforated metal or rigid mesh enclosing an acoustic in-fill which is generally some form of mineral fibre. Problems include degradation of the in-fill material and pressure loss (energy consumption) due to restricting the air flow. Excessive air flow speed can regenerate noise. These problems do not prevent attenuators being very widely used in industry.

Application

Standard attenuators : heating, ventilation and air conditioning systems, fans.

Specialist attenuators: as used on motor vehicles, modified materials allow high temperature and corrosive gas discharges to be silenced.

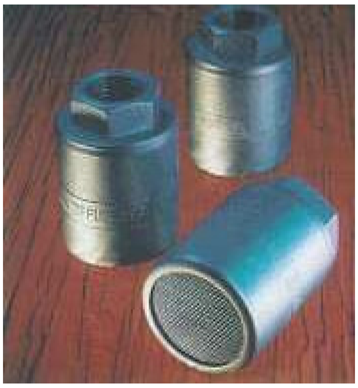
Performance

Performance is a function of attenuator length and the ratio of the cross-sectional areas of the splitters and the whole attenuator. Up to 45 dB(A).

Cost

Approximately £250-400 /m^3. Specialist applications can be very expensive.

Sheet 9 Steam and Air Diffusers



Metal fittings attached to the outlets of high pressure steam or air discharge.

Description

Steam traps and compressed air valves, used in petrochemical, food and other process plants to release excessive pressure, generate noise because of the high pressure and velocity of the discharge. The discharge flow can be passed through a diffuser of enlarged diameter filled with a flow resistant material such as stainless steel wool to slow down the gas speed, thus reducing noise generation.

Application

Steam and high pressure air system discharges.

Performance

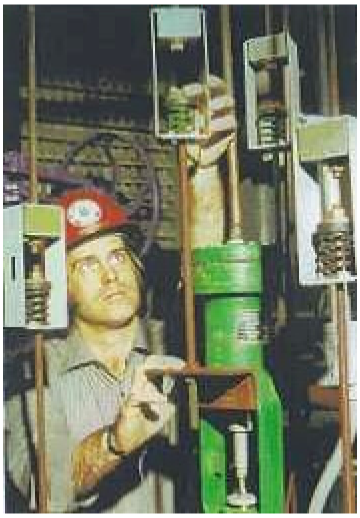
Performance is best at mid to high frequencies and typically gives up to about 15 dB(A).

Cost

Simple steam trap diffuser - Approximately £20 each.

Specialist compressed air attenuators can be expensive.

Sheet 10 Vibration Isolation Mounts



Spring or rubber mounts located between vibrating plant and their supporting structure reduce the transfer of vibrational energy into the structure where it may transferred and re-radiate as unwanted noise.

Description

Stiff springs or low compliance rubber/neoprene pads are housed in metal retaining fittings forming a mount or hanger to which the plant is bolted. The mount is designed to be deflected under static load and to absorb the predominant frequencies at which the plant oscillates. In practice this means selecting a mount whose natural frequency is well below the driving frequencies in the plant. Poor installation can lead to flanking paths, poor performance or amplification.

Application

Vibration isolation mounts can be fitted to most mechanical equipment, including pumps, fans, generators, compressors, and also to pipes, and ductwork.

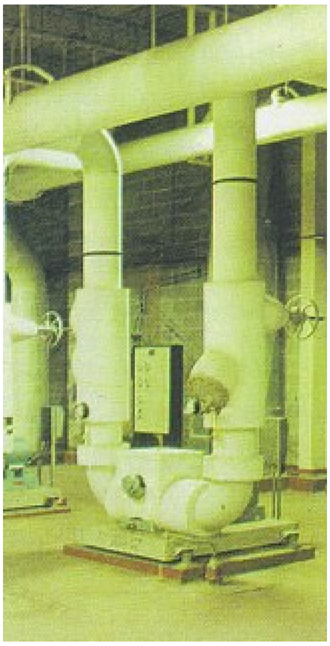
Performance

Vibration isolation can be almost complete for correctly selected mounts. Installation is harder for large heavy plant and performance can be compromised at lower frequencies. Noise reduction performance will depend on the surrounding structure and its noise transfer and radiation characteristics.

Cost

Modest costs for simple installations requiring typically 4 to 10 mounts, depending on loading and support requirements (see Sheet 11).

Sheet 11 Inertia Bases



A massive, usually concrete, block onto which the plant is mounted via anti-vibration mounts or pads.

Description

Mounting equipment on spring or rubber isolators makes the system inherently unstable and can compromise the safe operation of the plant. These problems can usually be overcome with inertia bases which provide the following benefits; lower centre of gravity, reduced movement during start up, and even spreading of load.

Where plant is permitted a degree of freedom to move on such systems, flexible connectors may be required in pipework or other services to prevent fatigue and vibration transfer via flanking paths.

Application

Mainly applicable to large heavy machinery in combination with vibration isolation mounts or sometimes rubber/neoprene pads for extra stability.

Performance

See vibration isolation Mounts (sheet 10).

Cost

Inertia bases can increase the cost of vibration isolation, particularly if one-off design is required.

Appendix F - Case Studies

F1 CHANGE OF PROCESS IN A FOUNDRY

F.1.1 Background

The organisation described in this study produce malleable metal castings for fluid movement systems. For many years their foundry has been operating using a coke fired cupola furnace to melt scrap metal and limestone to produce molten raw material.

A cupola furnace operates by melting metal in a large bowl or crucible which is heated, in this case by solid fuel burnt in the crucible. Metal and other raw materials are added at regular intervals, melt in the heat produced by the solid fuel and form a flux which then runs out in a continuous stream of molten metal. The heating and melting of the various materials produces a large amount of fume which is drawn off by extraction systems and treated to reduce its toxicity before being discharged to atmosphere.

Noise from the cupola system and associated operations was apparent in residential areas some distance from the site. Concerns over noise emission from the site affecting both the existing residential areas and proposed new developments prompted a comprehensive noise survey. A strategy to develop a noise control programme resulted which addressed both existing noise sources and future projects including a New Electric Melt Facility to replace the old cupola system. The development of the Electric Melt significantly reduced the impact of site noise in residential areas.

F1.2 Description of the Site

Originally a green field development, the 20 acre site produces castings for pumps and valves using scrap metal from local sources. A large number of dust and fume extraction systems are located close to the boundary. Over many years residential developments have taken place around the site, some of which are adjacent to the site boundary, with further residential developments planned (see *Figure F1.1*).

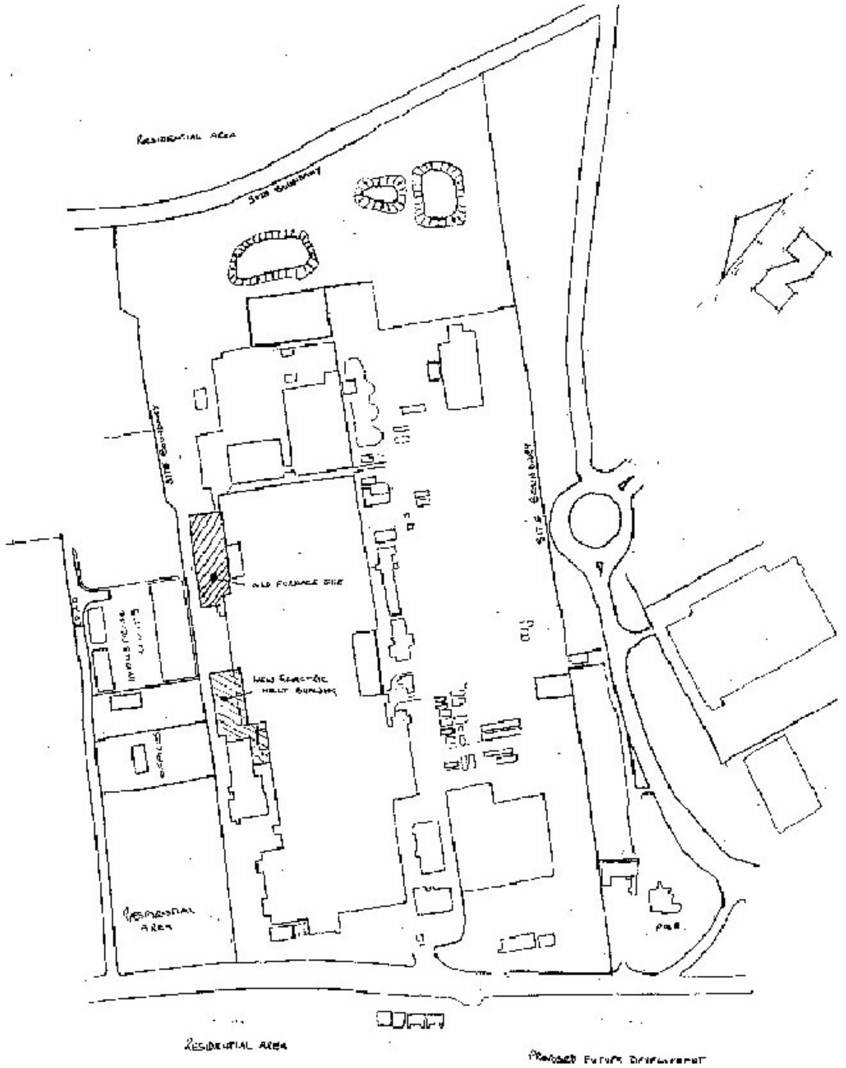


Figure F1.1 Site Location Plan showing Noise Sources and Noise Sensitive Areas

F1.3 Planning the New Electric Melt Facility

It was decided to replace the existing cupola melt facility with a new electric melt operation for the following reasons:-

- to reduce solid waste in the form of clinker and slag and associated waste disposal costs; and

- to reduce emissions to atmosphere together with associated costs of meeting increasingly more onerous IPC limits.

To achieve this without disrupting production, the new facility was built in parallel with, and adjacent to, the existing cupola.

During the pre-planning stage a decision was made to address the noise considerations early in the design. Acoustic consultants were employed for initial advice and subsequently to assist in the design of a new building to contain the Electric Melt furnaces and the raw materials store, which included an area for lorries tipping scrap metal, an overhead crane and the furnace charger.

F1.4 Assessment of Noise Impact at Receivers

Noise from the existing stock yard, including handling of scrap metal, overhead crane and charger operations and noise emission from the extraction systems, resulted in adverse noise impacts on nearby residential areas. Noise from the site included continuous tonal noise and high levels of intermittent impulsive noise.

Measurements of noise from the extraction systems taken at the adjacent site boundary showed the frequency spectrum given in *Table F1.1*, with a clear tone apparent at 250 Hertz:

Table F1.1 Measured Noise Frequency Spectrum at Site Boundary

Frequency	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**Hertz**
Decibels	68	66	74	63	57	54	50	DB

Impulsive noise was apparent at the site boundary when the overhead crane dumped metal into the feeder for the cupola charger. This operation took place every 45 minutes and lasted for approximately 10 minutes. Other intermittent impulsive noise in the stock yard adjacent to the charger was produced by forklifts discharging coke, limestone and metal returns, and delivery lorries tipping their loads of raw materials and scrap metal. These operations typically produced L_{Amax} levels 20 dB above the general site noise.

An environmental noise survey carried out in and around the foundry indicated L_{Aeq} noise levels of 17dB above background in the nearby residential areas, a situation which was clearly unacceptable.

Tonal noise from the cupola wet scrubber discharge chimney was apparent at a distance of over 500 metres. Impact noise from lorries discharging metal was distinct at a greater distance. Low frequency noise from the dry dust extraction systems associated with the cupola melt was also apparent in nearby residential areas.

F1.5 Identification of Noise Sources

Following initial discussions to identify the requirements for noise control and possible methods of meeting those requirements, a further noise survey was conducted specifically to identify noise levels associated with the operation of the cupola melt system. The survey comprised of a number of measurements made near to the main noise sources in order to identify their relative contribution to the overall noise level experienced at receivers outside the site. The noise survey was followed by a BS4142 noise assessment which showed Rating Levels 22dB(A) above daytime background noise levels, and 14dB(A) above night-time background noise levels, at the boundary adjacent to nearby noise sensitive receivers. As part of the on-going noise reduction programme, a target for total site noise emission at these boundaries had been set. This target required an overall reduction in site noise L_{eq} levels of 17dB(A).

The cupola operated on a continuous 24 hour basis. It was fed with raw materials by a vibrating conveyor charger and an overhead gantry crane, both of which were located externally in a stock yard. The cupola extraction system operated through a wet scrubber which discharged at high level, with a secondary dry dust extraction system outlet exhausting at low level.

Melt operations consisted of three distinct phases with the following associated levels of noise emission:

- Delivery lorries arriving and discharging scrap metal during the day producing maximum noise levels during tipping of L_{Amax} 110dB at 10m.

- Charger filling with the overhead crane dropping scrap metal into the charger producing intermittent noise levels of L_{Amax} 96dB at 10m, and the vibrator conveyor producing a continuous noise level of L_{Aeq} 78dB at 10m.

- Furnace operation with a continuous noise level of L_{Aeq} 79dB at 10m from the wet scrubber system with a distinct tone at 250 Hertz, and L_{Aeq} 73dB at 10m from the dry dust extraction system with large low frequency components at 63Hz and 125 Hz

The resultant cumulative noise level at the site boundary adjacent to the cupola stock yard was L_{Aeq} 78dB with distinct tonal characteristics and intermittent high levels of impulsive noise.

F1.6 Noise Control Techniques

The design of the new electric melt facility had to achieve the desired level of noise reduction whilst addressing a number of operational requirements, including:

- the requirements of overhead crane movements for handling raw materials;

- access for delivery vehicles and forklifts;

- weather shielding for the electric furnaces; and

- the provision of a good working environment for employees.

With existing boundary noise levels from cupola melt operations of L_{Aeq} 78dB and a final target for site noise at the boundary of L_{Aeq} 58dB, an overall reduction of melt operation noise of L_{Aeq} 20dB was necessary.

It was decided to house the complete facility in a building giving adequate reduction of noise to meet the requirements of the noise reduction programme.

The new building was constructed on a steel portal frame with dense concrete blockwork to a height of two metres and double skinned composite profiled metal cladding above to the eaves. The roof of the building was also constructed of double skinned composite metal cladding.

The main access door was designed to be large enough to allow an articulated lorry with a tipping trailer to exit with the trailer raised. This presented technical problems due to the effects of wind on such a large area, and for sealing the door when closed. The solution was to fit a top-hung door with flexible rubber strip seals all around the perimeter.

A new dust extraction plant was installed for the Electric Melt facility. During the design and planning stage, noise emission limits based on predetermined targets, were set for this extraction system. The system was placed where it was screened from nearby noise sensitive receptors by the new Electric Melt building. *Figure F1.2* shows the layout of the buildings. This resulted in a reduction of fan noise L_{Aeq} of 10dB at affected receptors.

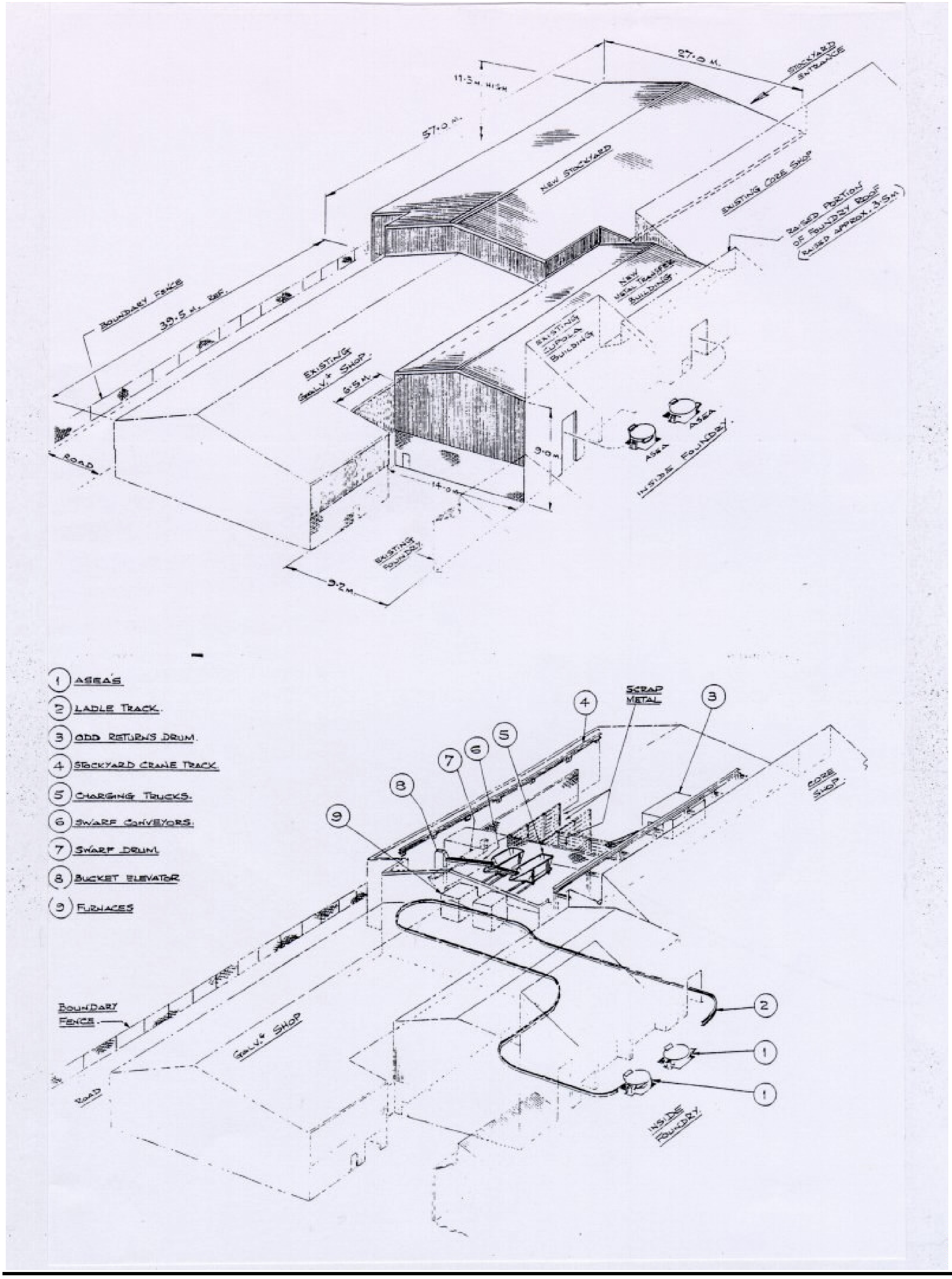


Figure F1.2 Building Layout

F1.7 Overall Improvement Achieved

The average sound reduction performance of the new building was estimated at 40dB dB(A). Subsequent noise measurements have shown that overall site L_{Aeq} noise levels have been effectively reduced by 12dB at the boundary adjacent to the new facility indicating a significant improvement gained by the development of the Electric Melt. *Figure F1.3* gives the results of the 24 hours noise surveys before and after work.

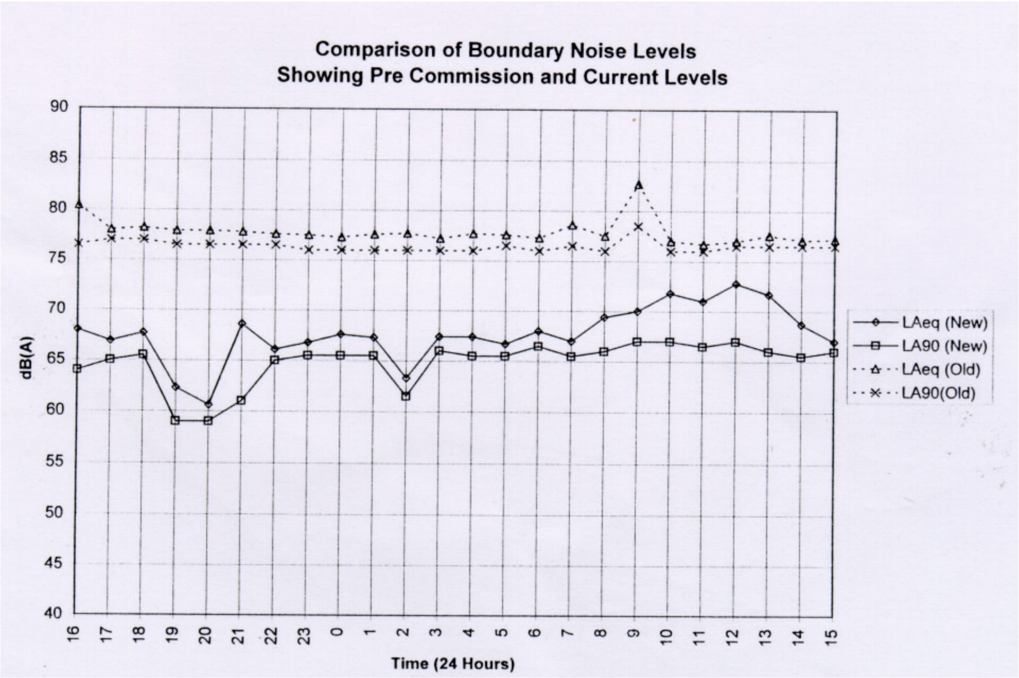


Figure F1.3 Before and After Noise Survey Results

The noise reduction achieved was due to:-

- the enclosure of the melt process and scrap handling in an acoustically designed building;
- the redundancy of the wet scrubber system;
- the replacement of old dry extraction systems with new low noise systems; and
- the location of noisy plant where it is screened from noise sensitive receptors by on-site buildings.

F1.8 Outcome of Noise Control Measures

A number of significant benefits have been realised with the change from coke firing to electric melt.

F1.8.1 Environmental Benefits

- Reduction of solid waste in the form of slag and clinker;
- reduction of emissions to atmosphere;
- discontinuation of the use of coke and limestone as raw materials;
- reduction in road traffic related to import of raw materials;
- increased recycling of local waste materials in the form of high quality scrap metal;
- transfer to cleaner power (electricity) from fossil fuel; and
- substantial reduction in environmental noise emission;

F1.8.2 Financial benefits

- Reduction in the cost of raw materials (coke and limestone).
- reduction of waste disposal costs.
- reduction of energy costs due to negotiation of favourable terms with the electricity supply company.

The change from coke firing to electric melt has had two short-term disbenefits.

- Cost of building new facility.
- disruption of site during construction.

F2 A MALTINGS REDUCES ENVIRONMENTAL NOISE IMPACT USING LOW COST, LOW TECH SOLUTIONS

F.2.1 Introduction

A large maltings facility, operating in a rural community, was advised by their Local Authority that a possible noise nuisance existed due to high levels of noise arising from the site. A large number of individual sources were found to be responsible for the alleged nuisance, which were effectively attenuated using 'low tech' and cost effective solutions.

F2.2 Description of the Site

The maltings facility covers an area of approximately 20 acres (8 hectares), and is situated in a rural location which is subject to very low background noise levels. The original facility was developed over 100 years ago when local housing for employees was provided in the immediate vicinity of the site. However, these properties are no longer owned by the company, and are now occupied by residents who have recently moved into the area. Due to a lack of other industrial activities in the village, noise arising from the maltings makes a significant contribution to ambient noise levels in the area.

Over the past 20 years, processes at the site have been modernised and levels of production increased. As a result, noise levels have also increased, causing disturbance to local residents in the surrounding community.

F2.3 Assessment of Noise Impact at Receivers

Low background noise levels in the area, coupled with the nature of the noise, which included discrete screeches and clatters from conveyor systems, hissing from grain chutes and fan noise, led to a number of complaints from local residents. As a result, the matter was taken up by the Local Authority.

A noise survey and subsequent BS 4142 assessment carried out by the Local Authority indicated that noise arising from the site exceeded background noise levels by around 26 dB at the nearest noise-sensitive dwellings, a situation which was clearly unacceptable. This noise level was adjusted to take into account the tonal and impulsive nature of the noise, which can cause greater annoyance, and is called the *Rating Level*. A prominent tonal component can be detected in one-third band spectra, if the level of one band exceeds the level in adjacent bands by more than 5 dB. The presence of a distinct tone like this can result in a noise which is particularly annoying and intrusive.

To avoid the service of a *Noise Abatement Notice* under Part III of the *Environmental Protection Act 1990*, the company were advised by the Local Authority that prompt action should be taken to reduce site noise.

F2.4 Identification of Individual Noise Sources

A large number of individual sources were identified on the site, including noise arising from fans, conveyors, elevators and grain chutes. The sources were categorised as follows:

- continuous, tonal fan noise;
- clatter, screeches and clonks from conveyor systems; and
- high frequency hissing sounds from grain chutes.

Noise arising from fan systems was considered to be the most significant source, although intermittent, mechanical noise from grain transfer systems was found to be the cause of most community annoyance. Continuous fan noise from the drying and aeration plant was also audible at the site boundary and contributed significantly to noise levels in the area. This source of noise was considered to be responsible for the underlying noise impact.

A specific noise survey of the site identified high levels of noise, with tonal characteristics, arising from three individual fan systems.

In the first fan system two fans (illustrated in *Figure F2.1 Centrifugal Blower*) operated an air drying system which discharged directly into a small building containing the drying plant. Silencers were not fitted to the fan exhausts.

A noise level of 101 dB L_{Aeq} was measured at a distance of 1 metre from the fan exhausts, with a level in excess of 70 dB L_{Aeq} at the boundary of the site, around 30 metres away. Strong tonal characteristics of 107 dB at 250 Hertz and 99 dB at 1000 Hertz were also identified.

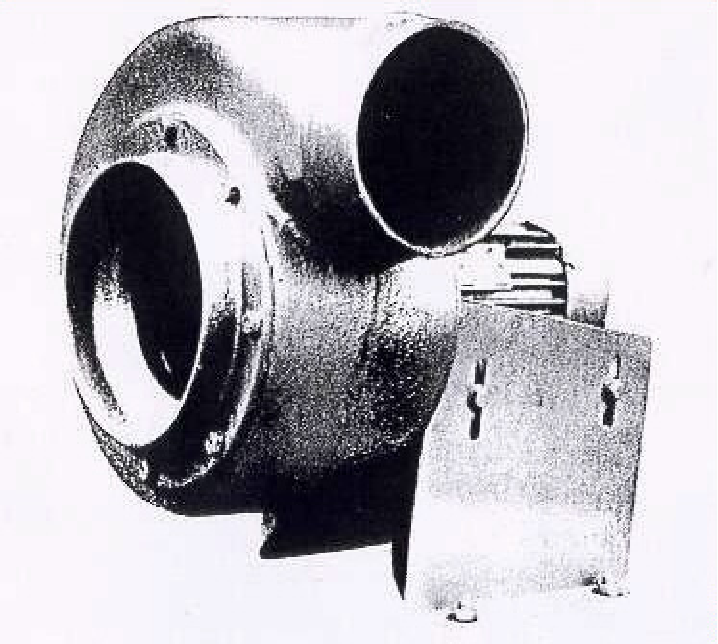


Figure F2.1 Centrifugal Blower

The maltings building, which is constructed from brickwork, with a corrugated sheet roof and open eaves, provided little reduction in the noise arising from the plant.

For the second system, which operated a dust extraction unit for the main grain input from delivery lorries a noise level of 86 dB L_{Aeq} was measured at a distance of 5 metres. As the filter unit was located in an open loading bay, no attenuation was provided by enclosure. The dust extraction system bag filter utilised a self-cleaning mechanism which operated when the fan was switched off. As a result, when large volumes of dust built up in the bag filters, fan noise would increase by 5 dB(A) with a distinct tone of 84 dB at 1000 Hertz.

The third fan system operated an aeration plant for the fermentation process. Although the intake was fitted with an attenuator, noise levels in excess of 95 dB(A) were measured at a distance of 1 metre, with distinct tones of 93 dB at 250 Hertz and 96 dB at 500 Hertz.

Secondary noise sources were associated with grain transfer systems. Much of the plant on site operates for 24 hours a day on a batch process system, with batches starting or finishing late at night and early in the morning. At the start and finish of each batch conveyors and associated equipment run empty without their loads of grain. As a result, mechanical noise which was reduced or *damped* when grain was in the system, often became more apparent. This included creaks and groans from the conveyor chains, clonks and clatters where chains rounded conveyor ends and bearing/motor noise from conveyor and elevator drives. The nature of this noise, in addition to the time of its occurrence, resulted in a number of complaints from the local community.

When operated with a full load, many of the mechanical noises experienced when the transfer system was empty, were reduced. However, mid to high frequency noise produced by grain dropping down elevator towers and into chutes, became more apparent. Noise levels at around 81 dB L_{Aeq} at a distance of 1 metre from the chutes, with tones of 72 dB at 2000 Hertz and 78 dB at 4000 Hertz were measured. The resulting hissing noise was apparent over much of the site and audible at nearby residential properties.

F2.5 Noise Controls and Techniques

Each source of noise was addressed in terms of the significance of its impact on the local community. Two factors influenced the resulting noise control programme:

- the results of the BS 4142 assessment which showed that there was a high level of noise at the site boundary; and

- the addition of a 5 dB penalty to the *Rating Level* due to the intrusive characteristics of mechanical noises.

Initially, a reduction in the overall level of noise arising from the site was achieved by silencing the three major fan systems. Because only a small number of secondary sources were audible at nearby residential properties, attenuation of grain transfer systems was considered to be unnecessary.

A target to reduce fan noise at the site boundary by at least 5 dB L_{Aeq} was established. Once achieved, secondary noise control operations addressed the most significant mechanical noises individually, until they were no longer causing noise problems in the community.

F2.5.1 Fan Systems

In-line absorptive silencers costing around £250 each were fitted to the exhausts of the *Centrifugal Blower*, reducing noise levels by 20 dB L_{Aeq}.

A reduction in the level of noise arising from the dust extraction system bag filter unit, was achieved through the use of a timer in the electrical control circuit, which switched the system off at hourly intervals, thus engaging the self cleaning mechanism. Overall noise levels from the dust extraction system were reduced by 5 dB L_{Aeq} and the tone at 1000 Hertz was eliminated.

Reducing noise levels arising from the aeration fan was more difficult. High noise levels were emitted from the air intake, in addition to secondary noise which radiated from the fan casing. An additional splitter silencer was fitted to the fan intake, with an insertion loss (*ie* the amount by which noise is reduced) of around 10 dB at 500 Hertz. The fan casing was fitted with an acoustic enclosure constructed from 16 gm sheet steel on a steel framework, with an internal sound absorption quilt of 50 mm thick *Rockwool* and an inner skin of perforated metal. The resultant reduction in fan noise of around 10 dB L_{Aeq}, reduced boundary noise levels by 7 dB L_{Aeq}.

F2.5.2 Grain Transfer Systems

Following this reduction in site boundary noise levels, attention was turned to controlling mechanical noise from the grain transfer systems. Noise consisting of clonks and hissing, arising from around 20 grain transfer systems on the site, and had been a source of complaint in the local community.

A night time survey identified the systems responsible for the most intrusive noises. Where conveyor and elevator casings were transmitting noise, acoustic damping material in the form of dense PVC matting was attached to the outer surface of the casing with adhesive. Where conveyor and elevator drive mechanisms were directly responsible for high noise emission, small local enclosures were fabricated around the noisy area. These were constructed from 18 g steel sheet on angle iron frames, lined internally with 50 mm of dense *Rockwool* held in place by a perforated metal inner skin.

This reduced mechanical noise by between 5 dB(A) and 10 dB(A) at each grain transfer system.

Grain transfer noise was also audible from several of the high level chutes. These were treated in similar manner, by applying PVC matting to elevator casings. High frequency noise, of the type arising from the chutes, is treated effectively by damping, and as a result, a significant reduction in excess of 10 dB(A) from each treated chute was achieved.

F2.6 Overall Improvement Achieved

Mechanical noise from the grain transfer systems was controlled to the extent where the formerly intrusive clonks and groans were barely audible off-site. In addition, hissing from grain chutes was no longer audible at the site boundary.

A noise survey carried out following fan noise control demonstrated a reduction of 7 dB L_{Aeq} at the site boundary, reducing the BS 4142 *Rating Level* to 14 dB above background. This represented a major achievement in noise control for so large a site, although it did not meet Local Authority's expectations. Furthermore, residual noise impact at nearby residential properties were below that recognised by the World Health Organisation as likely to cause interference with amenity.

F2.7 Outcome of Noise Control Measures

There have been no significant disbenefits to this exercise, with the exception of the costs required for equipment and in man hours for installation. Most of the work was carried out in-house with local enclosures manufactured on site.

The employees' working environment was also improved through a reduction in noise levels in the drying shed and loading bay. Relations with the community and the Local Authority have also improved and the threat of Statutory Noise Nuisance action was withdrawn.

F3 A MANUFACTURER OF PAPER PRODUCTS REDUCES MATERIALS HANDLING NOISE USING INNOVATIVE TECHNIQUES

F.3.1 Background

An international paper product manufacturer experiencing neighbourhood noise problems reduced tonal noise from air-handling material transport systems, and impulsive noise from high pressure blow-off exhausts, using low cost, innovative technology.

F3.2 Description of the Site

The production facility is housed in a single factory building, covering some 14 acres. Fifteen production lines, running continuously, produce consumer goods manufactured from paper pulp. Each production line is fed by one of two materials handling systems which transfer pulp pneumatically. There are over 30 paddle bladed axial fans in each system, ranging in size from 1.5 kW to 55 kW.

The facility is located in a coastal area, some distance from any major residential development, although two farm houses are situated within 500 metres of the factory. The site lies in a natural depression which generally gives good acoustic screening. However, the two nearby farm houses are on high ground and have a direct line of site to the factory building, which exposes them to noise arising from the site.

F3.3 Assessment of Noise Impact at Receivers

Complaints had been received from residents at both properties, one complaining of tonal noise, and the other, of intermittent, impulsive noise.

A prominent tonal component can be detected in one-third band spectra, if the level of one band exceeds the level in adjacent bands by more than 5 dB. The presence of a distinct tone like this can result in a noise which is particularly annoying and intrusive.

A night time noise level of 53 dB L_{Aeq} with a prominent tone of 63 dB at 160 Hertz was measured at the boundary of one property. This was compared to noise levels measured as part of a BS 4142 assessment and environmental noise survey, carried out during an Environmental Impact Assessment conducted prior to the development of the factory. An increase in ambient noise levels of 10 dB(A) since the last noise survey were identified. When a 5 dB penalty for tonal characteristics, in line with the BS 4142 assessment, was added to the measured level (called the *Specific Noise Level*), the resultant *Rating Level* of 58 dB(A) exceeded the background noise level by 15 dB(A), a situation which was considered to be unacceptable.

At the second property, impulsive air exhaust noise was measured at 12 dB above ambient noise levels with a peak of 68 dB at 2000 Hertz. This noise continued throughout the night and created a severe disturbance to the residents.

F3.4 Identification of Individual Noise Sources

The factory operates over 24 hours, seven days a week and the materials handling systems run continuously throughout the week.

These systems transfer dry paper pulp between the raw materials input area and the production lines in a airborne suspension, via 600 mm ducting. The system is driven by a large number of staging fans, with pressure fans at the input end and vacuum fans past the production lines. Surplus material is recycled via an in line reclaim facility. At the end of the system waste air is discharged through two large dust collection units containing standard bag filters.

The 55 kW paddle bladed system exhaust fans produced noise levels of 67 dB L_{Aeq} at a distance of 100 metres from the exhaust louvres, with a distinct tone of 75 dB at 125 Hertz. Narrow band analysis was used to define the tone further, which was then identified at 160

Hertz, with associated harmonics at 250 and 500 Hertz. Calculations showed that this tone was related to the blade passing frequency (27) of the exhaust fan.

Noise arising from two air pressure blow-off exhausts serving the reclaim area baler which discharges through the roof of the factory building were also identified. Because the exhausts were screened by the roof line of the factory, exhaust noise was not audible at ground level on the factory site. However, the exhausts produced distinct intermittent impulsive noise around 12 dB above ambient levels in the 2000 Hertz Band, at one of the local farmhouses which is situated on high ground.

F3.5 Noise Controls and Techniques

A number of factors influenced the choice of noise control for the materials handling system exhaust.

The systems handle dry paper pulp with a high dust content, which has the potential to cause a dust explosion. The bag filter systems include a spark suppression system and it was important to ensure that this was not compromised. Consequently, standard end of line absorptive attenuators could not be fitted to the bag house exhaust louvres. In line absorptive and reactive silencers were considered but rejected due to the risk of clogging with paper residues.

Reducing the fan speed, which would have reduced the noise output, was also rejected. Reworking the control systems would be expensive in terms of man-hours and would require the complete system to be shut down for a number of days while the new control systems were installed. In addition, there was concern that a reduction in fan speed and associated reduction in air flow, would have affected the efficiency of the system. Fan replacement with quieter centrifugal fans was dismissed as too costly.

Re-working the blades of the 55 kW exhaust with 600 mm ducting fans was also considered, but as the maximum reduction in noise levels was estimated at only 3 dB(A), this option was not considered to be cost effective.

The possibility of applying active noise control (ANC) to the exhaust fans was also examined. A reduction of 10 dB at low frequencies was predicted, but due to the costs associated with ANC (in the region of £4,000 per fan system) which would be required for a minimum of four fans, other methods of noise control were investigated.

A solution was finally found using Helmholtz resonators. The Helmholtz principle uses a vessel, or side branch, to produce an air spring which absorbs energy from sound waves in the main duct. Although resonators cannot operate over wide bandwidths, they control pure tones effectively. As the materials handling system emitted a tone at 160 Hertz, this option was considered to be a suitable one.

A simple Helmholtz resonator was fabricated in-house using a 250 mm steel tubing, 1 metre in length. This was attached to the 600 mm duct by a 75 mm right angled branch, bolted directly to the duct. An adjustable piston was fitted inside the resonator operated by a screw thread in the closed end.

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(27) The blade passing frequency is calculated by multiplying the number of fan blades by the fan speed in revolutions per second.

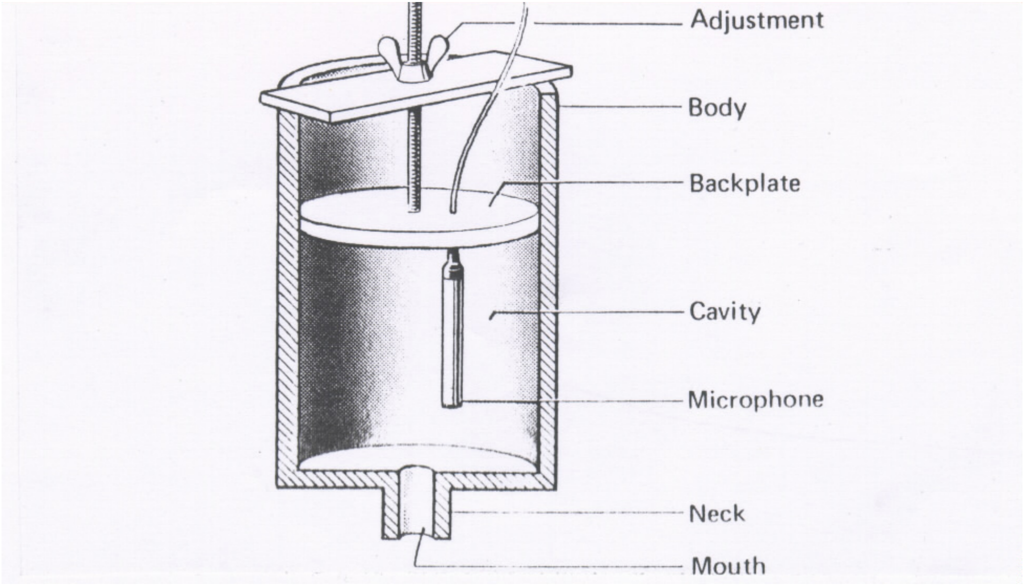

Figure F3.1 Helmholtz Resonator Design

The assembly was bolted to the main duct and in-duct noise levels measured with the resonator piston fully retracted, using a narrow band analyser. The piston was then screwed down until the 160 Hertz tone was reduced to its lowest measurable level at 16 dB. The operation was successful and as a result, more resonators were fitted to the trial system to reduce harmonics. In total, 4 resonators were used resulting in an overall reduction of 10 dB(A) and the elimination of the tonal component.

For the baler exhaust noise, a partial acoustic enclosure made from sheet metal with an internal liner of mineral fibre behind perforated metal, was constructed for each exhaust. The enclosures were designed so that they formed a box over each exhaust, without touching them. Open side vents (situated such that they were directed away from residential dwellings) were included to ensure that exhaust air flow was not restricted.

F3.6 Overall Improvement Achieved

On completion of the installation of the Helmholtz resonators, a follow-up noise survey was undertaken to determine the reduction in noise at the affected residential property. The survey showed that overall site noise had been reduced by 2 dB L_{Aeq} at the boundary of the residential properties, and the 160 Hertz tone eliminated.

Noise from the baler exhausts was reduced to a level where it was no longer audible at the farmhouse boundary.

F3.7 Outcome of Noise Control Measures

To date there have been no adverse operational side effects with either the Helmholtz resonators or the enclosures around the baler exhausts.

In this case there were a number of benefits associated with the use of Helmholtz resonators. The costs for standard silencers or ANC systems were at least 5 times that required for the installation of the resonators. The costs associated with the original proposals for ANC were in excess of £5,000 for each installation with an expected reduction in tonal noise of 6 dB at the relevant frequencies. Total installation costs for the Helmholtz resonators, including research and fabrication were less than £1,000.

The tonal reduction resulting from the use of each resonator, measured in-duct, was approximately 16 dB at 160 Hertz, reducing overall duct noise levels by 3 dB(A). This is approximately 7.5 times more cost effective than ANC for the same tonal reduction.

The performance of Helmholtz resonators is also considered to be more reliable than ANC, as neither computer software, nor moving parts are used in resonators. The ANC system relies on a series of in-duct microphones measuring noise before and after the control system and using the data gained to adjust the output of a series of loudspeakers in the duct. Consequently there are a number of components which can potentially be subject to damage.

In past applications using ANC, component failure has resulted in the system becoming unserviceable. Helmholtz resonators do not suffer any similar mechanical failures and once adjusted to give optimum noise reduction, remain stable. Tuneable resonators manufactured to a standard configuration can be fitted to the materials handling systems in a number of places, progressively reducing tonal noise. Although no calculations have been carried out to determine the total noise reduction possible, it is estimated that an overall reduction in fan exhaust noise of 10 dB(A) is achievable.

The simplicity of the Helmholtz resonator system means that less energy and fewer resources are used in their manufacture than for either standard silencers or ANC systems. The overall environmental impact of producing the resonators was therefore substantiality less than would have been the case with any other system.

In addition, the use of a standard attenuator would have resulted in the expenditure of extra energy to maintain efficient air flow. No loss of airflow occurred using the resonators. Although not impeding airflow, the ANC system would have required a continuous energy source to run the monitoring system and to power the loudspeakers.

However, considerable research was required initially to determine the optimum dimensions for the resonators. Virtual modelling, which took several man-hours to complete, was carried out using state of the art computer technology, although a similar amount of time would have been required to perfect the ANC system for configuration to this specific application. The manufacture and supply of conventional splitters or absorptive silencers would have reduced development costs as these items are readily available 'off the shelf' or are produced to standard designs.

F4 MINERAL FIBRE MANUFACTURING PLANT REDUCES LOW FREQUENCY AIRBORNE NOISE BY EQUIPMENT MODIFICATION

F.4.1 Background

In 1995 a factory which produces mineral fibre received complaints from a local resident, regarding low frequency night time noise. Investigations revealed that very low frequency noise, below the level which can normally be heard by human beings, was detectable inside the complainant's house. The noise was traced to two vibrating screens, which had recently been installed at the factory (illustrated in *Figure F4.1*).

Following the complaint and on the basis of a background noise survey, the Local Authority determined that a statutory noise nuisance existed. Simple modifications to the equipment reduced the low frequency noise to a more acceptable level.

Figure F4.1 Northern Boundary of the Site Adjacent to the Residential Area

F4.2 Description of the Site

The site covers an area of approximately 20 acres and is situated in an urban area on the coast. To the north and east, are established residential developments, with the closest dwellings situated within approximately 100 metres of the site boundary (illustrated in *Figure F4.2*). The factory produces fibreglass insulation materials, using a continuous process, and comprises a number of large buildings which are inter-linked in the centre of the site with a perimeter road for service vehicles and HGVs.

Several sources of noise were audible at the site boundary, including noise from various process fans, pumps, and a low-frequency rumble from the filter plant. Noise also arises from lorry traffic servicing the plant.

Buildings and embankments located near to the site serve to screen many residential dwellings from plant noise. Although this type of screening can help to reduce high frequency noise, it is less effective at screening lower frequencies. Due to its long wavelength characteristics, low frequency noise travels further and penetrates building structures more readily than noise of a higher frequency.

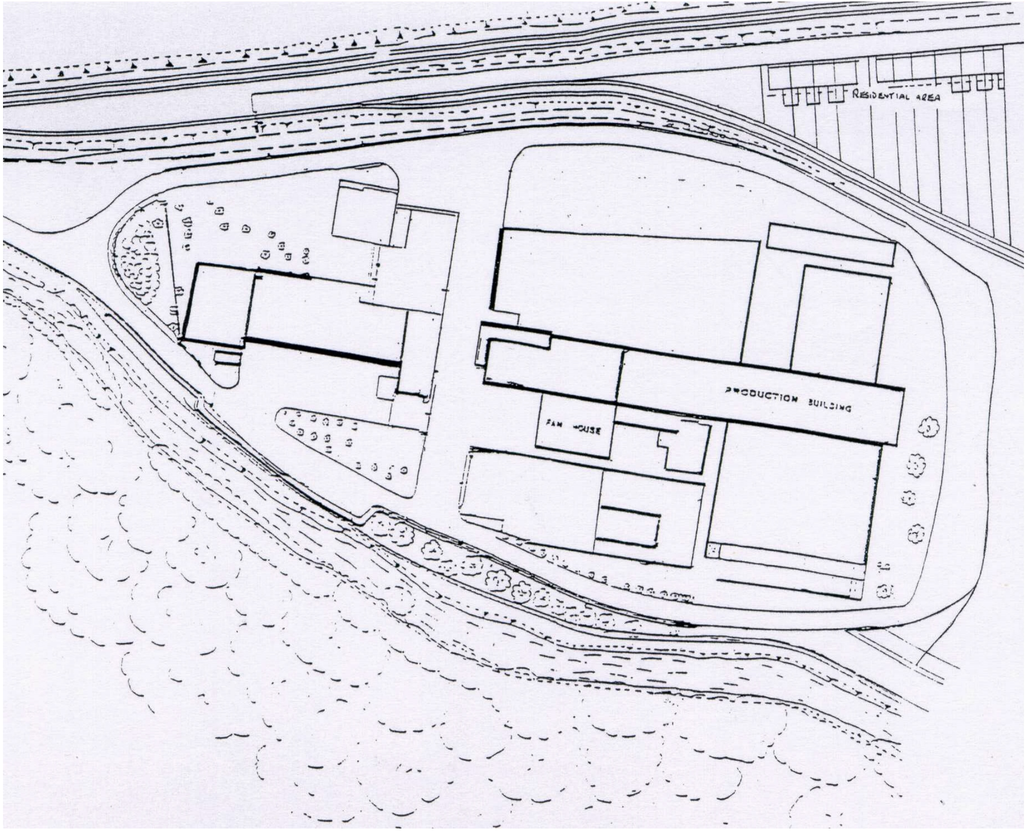

Figure F4.2 Site Plan Showing Residential Area to the North West

F4.3 Assessment of the Noise Impact at Receptors

A noise survey was conducted to determine the level of the low frequency noise outside the nearest residential dwelling from which complaints had been made. Noise from the screens was not audible during the survey, but could be detected by the measuring instruments, at a very low frequency, which was identifiable in the linear and $^{1}/_{3}$ octave band levels, as detailed in *Table F4.1* below.

Table F4.1 Noise Levels Measured Outside the Property of Concern

		Octave Band Centre Frequency							
dB (A)	**Linear**	**31**	**63**	**125**	**250**	**500**	**1k**	**2K**	**Hz**
19	49	46	38	25	18	11	10	10	**DB**
		1/3 Octave Band Centre Frequency							
		20	**25**	**31**	**40**	**50**	**63**	**Hz**	
		40	49	34	26	61	< 25	dB	

Because the noise was of such a low frequency, and varied over time, it was only audible under certain conditions within the dwelling. The noise was most discernible in the complainant's bedroom, and was of a very low frequency, accompanied by a distinctive 'beat'. It was not possible to record internal levels during the survey due to other sources of noise in the area, and as a result, the assessment could only relate to external conditions where the noise was inaudible, but measurable. The 'A' weighted sound levels at the house were dominated by local traffic and railway noise.

When dealing with environmental noise complaints such as this, the methodology outlined in British Standard BS 4142 in generally used. Noise levels outside the complainant's property are measured with the offending plant switched on and off. By applying corrections to take into account any tonal components or impulsive characteristics which can cause greater annoyance, the two levels are compared. The difference between the two levels can then be used to indicate the likelihood of complaint, *eg* a difference of 10 dB indicates that complaints are likely, and an increase of 5 dB is of marginal significance.

Modern, integrating sound level meters can record levels below the threshold of human hearing, so it is important to relate noise levels to reasonable criteria in addition to subjective comment. Noise levels arising from the screens were predicted using the methodology outlined in BS 4142. The predicted *Rating Level* of 34 dB L_{Aeq} was at a level which should not normally give rise to complaints.

F4.4 Identification of Noise Sources

The recently installed vibrating screens were identified as the cause of the low frequency noise problem (illustrated in *Figure F4.3*). The screens are operated by an eccentric weight which creates an out of balance force. This causes the screens to vibrate, exciting the surrounding air at the same frequency. It was this low frequency component arising from the screens which excited the complainant's building, causing disturbance.

Figure F4.3 The Vibrating Screens Installed at the Factory

Noise measurements were repeated outside the property with the vibrating screens running at high speed (1450 rpm), at low speed (850 rpm), and with the screens switched off. During the survey it was not possible to detect changes in noise levels as the screen speed was varied, although it was possible to measure them.

The octave and $^1/_3$ octave band levels showed a clear increase over background when the screens operated at 1450 rpm, but not when they operated at 825 rpm. Because the noise levels were extremely low, *ie* less than 20 dB (A), measurement was very difficult. Any increase in background noise levels for example, from the passage of a distant vehicle, meant that measurements had to be repeated.

When the screens operated at 1450 rpm, the noise was just audible in the complainant's bedroom, but at 825 rpm, it was impossible to detect.

F4.5 Noise Controls and Techniques

A noise level at 25 Hz was measurable at the complainant's property. As a result it was possible to estimate overall noise levels based on measurements made at the screens. On-site recordings were made close to and opposite the screens to determine the reduction in noise levels resulting from changes in screen speed. As the plant was capable of operating with a single screen, the tests were repeated with only one screen in use.

Following the measurements, a variable speed controller was fitted, the speed of the screens was reduced, and the vibration isolation was adjusted. The operation of only one screen at a reduced speed, compared with two at the original speed, reduced the overall noise level and removed the beating effect.

Table F4.2 below details the $^1/_3$ octave band width analysis at 1450 rpm and 850 rpm, illustrating how frequency effects vary with speed.

Noise levels in the dominant frequency (20 Hz) are reduced by over 10 dB by changing to the third screen speed. It was considered that the plant could operate with a single screen running at a motor speed of 825 rpm.

Table F4.2 Variation in Noise Emission at Different Operating Speeds

Frequency	**20**	**25**	**31**	**40**	**50**	**63**	**Hz**
1450 rpm/1 screen	82	78	67	75	71	73	**dB**
1000 rpm/1 screen	66	70	66	68	66	70	**dB**
825 rpm/1 screen	59	67	62	65	62	66	**dB**

F4.6 Overall Improvement Achieved

Noise levels from the modified screen were re-measured on site and within the complainants house. When only one screen operated at 825 rpm, the linear noise levels were reduced by 10 dB, and the strong tonal component removed, as indicated in *Table F4.3*. Furthermore, the noise was no longer audible in the complainant's bedroom and recorded levels were below the threshold of audibility. No further noise control was considered to be necessary.

Table F4.3 Comparison of Measured Noise Levels in the Bedroom with the Screen at Various Speeds

Motor Speed			**Octave Band Centre Frequency (Hz)**								
rpm	**dB A**	**Linear**	**31**	**63**	**125**	**250**	**500**	**1k**	**2k**	**4k**
1450	19	49	46	38	25	18	11	10	10	11
825	18	37	35	30	24	16	11	10	10	11
off	18	40	35	30	24	17	11	10	10	11

	1/3 Octave Band Centre Frequency (Hz)					
	20	**25**	**31**	**40**	**50**	**63**
1450	40	49	34	26	31	< 25
825	35	31	32	33	31	< 25
off	35	33	29	29	32	< 25

F4.7 Outcome of Noise Control Measures

Noise levels were reduced to below those measured by the Local Authority at the time of the complaints. This was due almost entirely to the reduction in screen speed. As a result, the disturbance was effectively eliminated at a very low cost. Overall savings on energy required to run the single screen at low speed also compensated for the man-hours taken to resolve the problem.

As the projected life of the screen has increased following the changes, further savings have been identified as a result of reduced maintenance time and lower maintenance costs. Total estimated costs were £1,500 (1999) which includes the fees for acoustic consultancy.

F5 COMBINED CO-GENERATION GAS TURBINE (CHP) FOR HEAT AND POWER AT A FOOD PRODUCTION PLAN

F5.1 Background

On a major food manufacturing site steam requirements had historically been met by a boiler system comprising five coal-fired units, and electricity requirements, via a connection to the national grid. The 60 year old boiler system was subject to air pollution control under Part I of the *Environmental Protection Act 1990* and required retrofitting with flue gas treatment if it was to continue to operate.

As an alternative the owners proposed to install a cleaner, more energy efficient combined co-generation gas turbine facility, to provide steam and heat for the site. However, the proposed location of the Combined Heat and Power (CHP) facility adjacent to noise sensitive residential dwellings, meant that careful selection and design of noise control equipment was necessary to ensure that local planning conditions were met. Enclosure of all plant associated with the facility in a single building was proposed to ensure optimum noise reduction.

F5.2 Description of the Site

The 140 acre site operates continuously over 24 hours, and is the largest industrial site in the area. The location of the proposed CHP installation is approximately 200 metres away from the nearest residential properties, (illustrated in *Figure F5.1*).

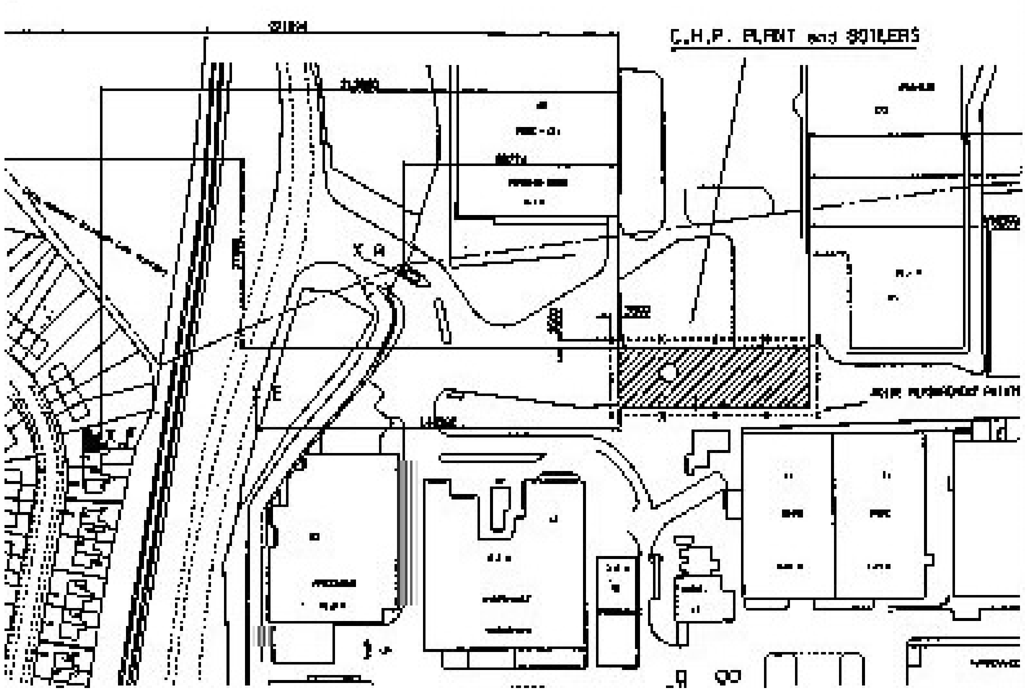

Figure F5.1 Plant Layout Plan

F5.3 Assessment of Noise Impact at Receivers

Prior to the development of the CHP facility, the Local Authority advised that an environmental noise survey should be carried out in surrounding residential areas. The survey identified an existing night-time background noise level of Noise Rating 35, which is roughly equivalent to 40dB(A) at the nearest residential properties.

Noise Rating (NR) curves are often used to assess the acceptability of a noise to ensure preservation of hearing, speech and communication, and to avoid annoyance. Because noise limiting criteria based on NR specify noise limits at each octave band between 63 Hz to 8 kHz, they can be more onerous than criteria based on BS 4142, where an equivalent continuous noise level (dB L_{Aeq}) is specified, which is averaged over each octave band.

A background noise level of 40 dB L_{Aeq} is typical of night time noise levels in mixed industrial and residential areas in large conurbations. In this case, the dominant source of noise in the area was due to the 24 hour production facility on the site and associated site traffic.

The Local Authority also expressed concern over 'creeping' background noise levels in the area. This can occur when noise criteria applied to new development allows background noise levels to be exceeded by 1 or 2 dB, which although imperceptible, causes noise levels to rise incrementally over time. Consequently, noise control measures for the proposed CHP plant were required such that noise levels arising from the facility were lower than existing background levels, to prevent any increase in ambient noise.

F5.4 Identification of Individual Noise Sources

The proposed CHP facility included two 4.8 MWe Centrax KB7 gas turbines and associated heat recovery boilers and gas compressors. Ancillary plant included three Wellman Robey gas fired Euronox boilers, a water treatment plant and a stand-by diesel generator to ensure a back-up supply of electricity in the event of a failure.

The following sources of noise from the proposed plant were considered to be significant:

- gas turbine combustion air intakes;
- gas turbine exhausts;
- breakout from the body of the gas turbines and ducting;
- gas compressors cooling air intakes and exhausts;
- stand-by diesel generator cooling and combustion air intake;
- stand by diesel generator aspiration and cooling air inlets and exhausts;
- stand-by diesel generator engine exhaust;
- direct breakout from the stand-by diesel generator; and
- gas turbine oil cooler fans intakes and exhausts.

F5.5 Noise Controls and Techniques

Whilst not wishing to set too onerous noise limits on the design of the new CHP system, site management were nevertheless keen to ensure that any noise nuisance problems were avoided.

Achievement of NR 35 at the closest noise sensitive receptor would require noise levels to be reduced to a maximum of 60dB(A) at a distance of 1 metre from the CHP installation. Two possible noise control options were considered:

- *Option 1* - to house each of the turbines in weather proof enclosures with additional noise controls for ancillary plant; and

- *Option 2* - to house the turbines, associated ductwork and all ancillary plant in a single acoustically designed building, which would achieve the required reduction in noise levels.

Costs for Option 1 were estimated at around £40,000 per enclosure with a further £15,000 to £20,000 for secondary noise controls (at 1993 prices).

However, due to the complexity and number of noise sources arising from the facility and the technical problems associated with the treatment of each source individually, Option 2 was considered to be more cost effective. This would involve housing the complete turbine/boiler installation in a single building and providing attenuators for supply air intakes and exhausts, (illustrated in *Figure F5.2*).

As result, noise emissions from the proposed facility would be limited to the following sources:

- gas turbine air intakes;
- gas turbine exhausts;
- oil cooler air intake;
- diesel generator air intake;
- gas compressor air intake and exhaust;
- building ventilation intake and exhaust;
- breakout from the building structure; and
- noise emission from the combined exhaust stack.

Figure F5.2 Turbine and Boiler Installation

F5.6 Gas Turbine Air Intakes

A sound power level (SWL) of 137 dB was predicted to arise from the gas turbines. The octave band frequency spectra arising from the turbines is illustrated below in *Table F5.1*.

Table F5.1 Gas Turbine Air Intake Sound Power Level

Frequency Hz	31.5	63	125	250	500	1k	2k	4k	8k
SWL dB	113	113	113	116	119	121	127	132	134

The reduction in noise levels, or insertion loss, required by the gas turbine air intake attenuators (when corrected for distance attenuation and duct losses) to meet the environmental noise criteria of NR 35, are specified below in *Table F5.2*.

Table F5.2 Gas Turbine Air Intake Attenuator Insertion Loss

Frequency Hz	31.5	63	125	250	500	1k	2k	4k	8k
SWL dB	-7	-15	-28	-50	-50	-50	-50	-50	-48

F5.7 Gas Turbine Exhausts

In a CHP system, the gas turbines discharge through two separate exhausts. One passes through the heat recovery boilers and the other operates in a by-pass mode when the boilers are off-line. Both exhausts vent through a common stack. Levels of noise arising from the by-pass exhaust were around 20 dB higher than those arising from the gas turbine heat recovery boiler exhaust. Consequently, primary attenuators were required for the by-pass exhausts and secondary silencers for the boiler exhausts in order to reduce turbine exhaust noise to a level which would meet environmental noise criteria.

Pressure and heat in the exhaust system also required consideration. Losses in the gas turbine heat recovery boilers reduce heat and pressure to levels where standard splitter attenuators can be used at the base of the exhaust stack. However, higher pressures and temperatures occur in the by-pass duct which prevented the use of standard splitter attenuators. This problem was addressed through the use of specialised stainless steel hot gas attenuators, with purpose made infills manufactured from basaltic mineral fibre.

F5.8 Oil Cooler Air Intakes

The gas turbines require efficient oil cooling which is provided by supplementary oil coolers. Air flow over the coolers in this installation was maintained by axial flow fans with a SWL of 104 dB. Noise arising from the fan intakes were reduced to a level of 60 dB(A) externally at 1 metre, using standard splitter attenuators.

F5.9 Stand-by Diesel generator

In order that maximum benefit of the acoustic properties of the turbine building could be realised, the stand-by diesel generator was located in a purpose built enclosure inside the turbine building. The enclosure was constructed from 140 mm dense concrete blocks with acoustic access doors to RW 45 (28). The aspiration air and cooling air intakes and the cooling air exhaust were fitted with standard splitter attenuators to reduce noise emissions from the generator to 65 dB(A) at 1 metre from the relevant louvres. The engine exhaust was fitted with a conventional absorptive silencer which vented through the main stack.

F5.10 Gas compressors

The gas compressors were housed in a separate blockwork building. Intakes and exhausts were fitted with standard splitter attenuators.

F5.11 Building Ventilation Intakes and Exhausts

A noise level of 83 dB (A) with a high mid frequency component was predicted to occur inside the gas turbine building. Standard splitter attenuators on supply air and ventilation fans were used to prevent internal noise breakout via the ventilation louvres. As a result, noise levels were reduced to 60 dB(A) externally at 1 metre.

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(28) This describes the acoustic performance or weighted sound reduction index of the door as measured under laboratory conditions.

F5.12 Breakout from the Building Structure

By combining all major sources of noise within one building, it was possible to control overall noise levels from the CHP plant using standard building construction methods. In order that the environmental noise criteria of NR 35 could be achieved at the nearest noise sensitive receptors (when corrected for distance attenuation, directivity and surface transmission area), a noise level of 45 dB(A) was required at the facade of the CHP plant building. This was achieved through the use of 140 mm dense (2,000 kg/m^3) blockwork in the building wall construction.

The sound reduction index (SRI) provided by this type of wall construction is detailed below in *Table F5.3*. The SRI or transmission loss of a wall or partition describes its effectiveness as a sound insulator.

Table F5.3 Wall Sound Reduction Indices

Frequency Hz	**31.5**	**63**	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**
SRI dB	15	20	27	33	40	50	57	56	59

For the roof, composite metal cladding materials were used comprising:

- 0.7 mm outer steel panel;
- 200 mm cavity with 80 mm glassfibre quilt infill at a density of 12 kg/m^3; and
- 0.7 mm steel inner liner panel.

The SRI provided by this type of roof construction material is detailed below in *Table F5.4*.

Table F5.4 Roof Sound Reduction Indices

Frequency Hz	**31.5**	**63**	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**
SWL dB	7	12	17	25	32	38	41	41	39

F5.13 Noise Emission from the Combined Exhaust Stack

The gas turbine by-pass exhausts, the heat recovery boiler exhausts and the standby diesel generator were all designed to vent through a single stack. To reduce regenerated noise in the stack, a limiting gas velocity of 20 metres per second was specified. Calculations based on the combined noise emission from all flues indicated a noise impact of less than 30 dB(A) at 200 metres.

F5.14 Internal Noise Levels

To reduce internal noise levels to below the First Action Level of 85 dB(A) specified under the *Noise at Work Regulations 1989*, purpose built acoustic enclosures were provided for the turbine bodies. These were constructed from an inner and outer skin of 3 mm steel with an infill of 80kg/m^3 density mineral wool. High levels of noise breakout from the ductwork between the turbines exhausts and the stacks were reduced by lagging the ductwork in an envelope of mineral wool (128 kg/m^3 density) clad with aluminium sheet to a thickness of 0.5 mm.

F5.15 Overall Improvement Achieved.

Although the CHP plant has not replaced other noise making equipment, the predicted noise impact arising from the installation without the benefit of the turbine building, would have resulted in noise levels of NR60 or approximately 65 dB(A) at the nearest residential dwellings. This level exceeds environmental noise criteria specified by the Local Authority by around 25 dB(A).

On commission of the CHP facility, noise surveys at the nearest residential dwellings demonstrated that there had been no increase in ambient noise as a result of the plant. In addition, noise from the CHP building was not detectable at the noise sensitive location previously identified during the initial noise survey.

F5.16 Outcome of Noise Control Measures

The approximately cost of the noise control measures was £8m at 1993 rates.

Combined Heat and Power involves the simultaneous generation of electricity and useful heat as a single process. By using the heat produced in electricity generation, CHP can operate at efficiency levels of up to 85%, compared to approximately 35% for conventional power stations. In addition, CHP schemes typically use around one third less fuel than conventional, separate methods of electricity and steam generation. As a result CHP plants commissioned in the UK since 1990 have reduced the UK's carbon dioxide emissions by the equivalent of over 1 million tonnes per year.

The CHP facility generates most of the electricity and steam required for the whole site, producing 9.6 MWe of electricity and 22 tonnes of steam per hour.

Costs associated with energy consumption have been reduced by the equivalent energy needs of 5,000 homes.

Back-up power and steam are guaranteed if primary supplies are interrupted or fail. In addition, electricity can be exported and/or imported to the national grid via the 11 kv substation which is linked to the CHP system.

F6 LANDFILL SITE OPERATIONS EFFECTIVELY CONTROLLED BY LOW COST BEST PRACTICABLE MEANS

F6.1 Background

The operators of a mineral extraction quarry located in a rural environment, applied to the Local Planning Authority for permission to import commercial and industrial waste for infill and restoration purposes. During the planning process a number of noise sensitive receptors were identified at adjacent farms and cottages.

Permission was granted subject to certain environmental controls which included control of noise arising from infilling and compacting operations. A noise control and mitigation scheme was required to enable planning conditions to be discharged.

An overview of the construction and waste infill operations at the site are illustrated in *Figure F6.1* below.

Figure F6.1 Overview of Cell Construction and Waste Infill Operations at the Site

F6.2 Description of Site

The 35 hectare site, formerly used for extraction of sand and gravel lies in an agricultural area at distance from any large residential development. However, a number of farms and cottages are situated within 300 metres of the site (refer to *Figure F6.2* below). As a result, ambient noise levels are low. The only significant noise sources in the area are those associated with agricultural operations, the existing mineral extraction operations, and local traffic.

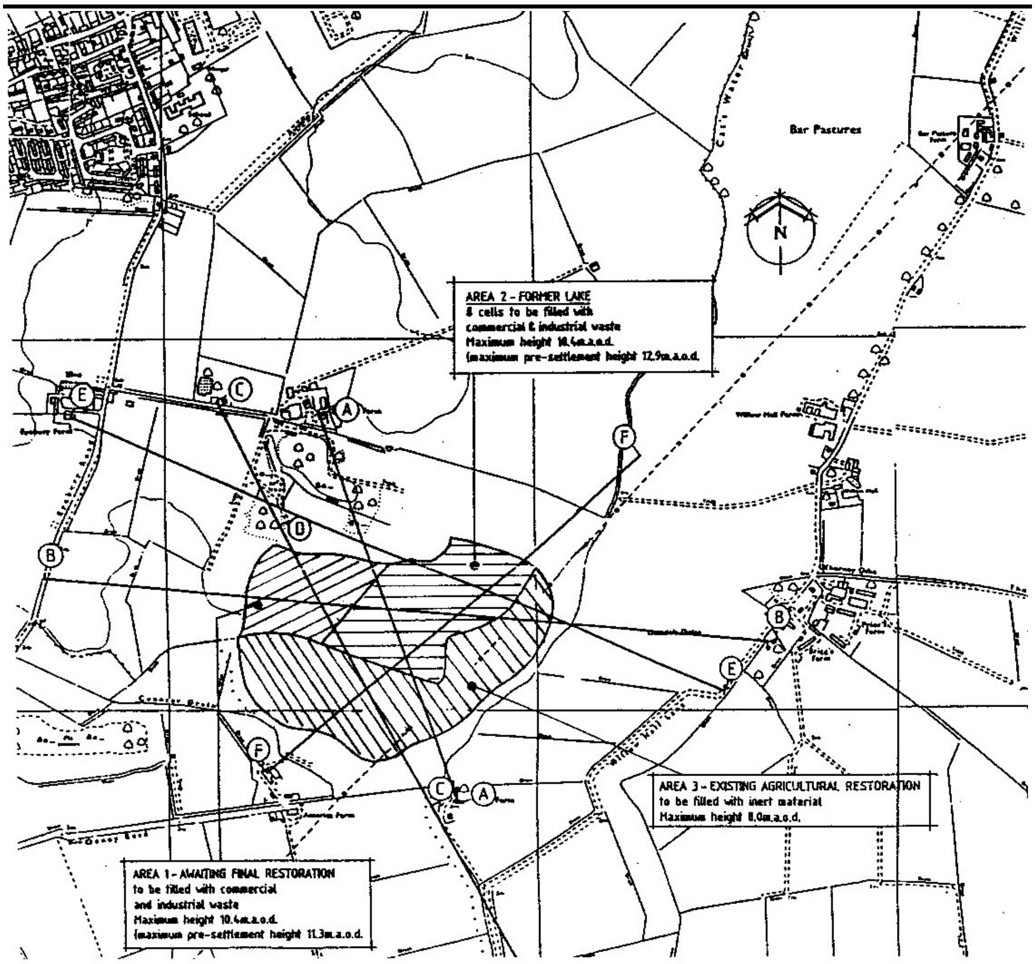

Figure F6.2 Map of the Site Showing Workings and Nearby Noise Sensitive Receptors

F6.3 Assessment of Noise Impact at Receivers

To ensure compliance with the planning conditions, an acoustic consultancy company was approached and instructed to carry out a noise survey and modelling exercise, and to provide recommendations for noise control and mitigation.

F6.3.1 Noise Survey

In order to establish the potential noise impact at nearby noise sensitive properties, an environmental noise survey was conducted to identify existing background noise levels. Noise measurements were taken over a period of 3 days in two areas representative of the closest dwellings. Daytime background levels of 35 dB L_{A90} and 39 dB L_{A90} respectively, were measured.

F6.3.2 Prediction of Noise Impact

Potential noise impacts were predicted by modelling the main elements of the landfill operations, as detailed below:

- lorry movements to and from the site importing waste materials and tipping waste on site;
- the excavation of clay for cell construction;
- cell construction by bulldozers and dumpers;
- waste compaction; and
- cell capping.

The basis of the prediction method used is described in British Standard (BS) 5228. This method enables an hourly A-weighted L_{eq} (the L_{Aeq}, 1 hour) to be calculated for each operation or item of plant at varying distances and for varying proportions of the time.

Studies of similar operations and noise data for the types of vehicles to be used on site were also utilised in the model, including that relating to:

- haul routes;
- distances and speeds travelled by on-site vehicles;
- the number of hourly tipping operations;
- areas of work and progression of that work;
- topography of the site and the level of workings;
- the duration of each operation;
- the type and number of vehicles used on the site; and
- noise levels for each type of vehicle, as Sound Power Levels, or Sound Pressure Levels at a determined distance.

The Planning Authority required that operations should be carried out in accordance with current Minerals Planning Guidance, in particular MPG 1 and MPG 11: which refer to the use of mineral extraction sites for waste disposal, and give advice for the control of noise at such sites. MPG 11 recommends that noise from site operations should not exceed 55 dB $L_{Aeq\ 1hr}$ at noise sensitive receptors, or where the background noise level is below 45 dB L_{A90}, that site noise should not be greater than 10 dB L_{Aeq} above the existing background noise level.

Noise limiting criteria of 45 dB L_{Aeq} and 49 dB L_{Aeq} respectively, were determined based upon these recommendations and measured background noise levels. Predicted operational noise levels of 49 dB $L_{Aeq\ 1\ hr}$ and 57 dB $L_{Aeq\ 1\ hr}$ at each receptor were also determined, indicating that background noise levels would be exceeded by 4 dB L_{Aeq} and 8 dB L_{Aeq} respectively. As a result, significant noise control measures were required. Infill and restoration operations were expected to continue for around 10 years, so any noise control schemes needed to be durable and capable of being maintained at low cost.

F6.3.3 Identification of Individual noise sources

A number of noise sources, and in particular those associated with on site vehicle movements were identified as detailed below in *Table F6.1*.

Table F6.1 Identification of Individual Noise Sources

Site Operation	Noise Level at 10 metres dB (A)
Road vehicles delivering waste (measured during drive-by)	76
Excavator removing clay	77
Dump trucks transporting clay and soil	80
Bulldozers/dumpers constructing cells	83
Levelling and capping	77
Compactors traversing waste cells	77
Soil screening	70
Diesel water extraction pump	70

The most significant noise sources were those associated with the use of bulldozers and dumpers, which would be required to operate throughout much of the day. Cell construction activities utilising this type of equipment are illustrated below in *Figure F6.3*.

Figure F6.3 Cell Construction with Dumper and Bulldozer

F6.4 Noise Control and Mitigation

Two methods of noise control were utilised:

- screening through the use earth bunds and natural features; and
- operational restrictions.

F6.4.1 Screening

Calculations based on initial modelling indicated that a 5 metre high earth mound or bund, which visually screened the noise sensitive receptors from the site, would reduce noise levels by around 6 dB(A).

Two bunds were constructed of soil removed from the site for cell construction, one along the southern boundary of the site and one along the western boundary (illustrated in *Figure F6.4* below). During construction, noise levels at the two receptors occasionally reached levels of 70 dB(A) for short periods. Noise impacts arising from the construction of bunds in this way is identified in MPG 11, which also points out the necessity to construct bunds. As a result, an agreement was reached with the Planning Authority regarding the exceedance of noise limiting criteria, whilst bund construction took place.

Soil screening and grading plant and the diesel powered water extraction pump were located as far away from noise sensitive properties as possible, and additional screening provided through the construction of soil mounds.

Figure F6.4 Typical Earth Bund

F6.4.2 Operational restrictions

As far as possible, site traffic was directed away from noise sensitive receptors on main roads. Vehicles entering the site were directed along specially constructed haul routes which were aligned such that they were out of site of noise sensitive receptors. The condition of the haul routes was maintained to reduce noise arising from body crash of empty trucks leaving the site.

All earth-moving equipment was required to comply with a maximum sound power emission of 108 L_{wA} in accordance with BS 6812 / ISO 6395 '*Airborne noise emitted by earth-moving equipment'*. In addition, the following recommendations were made:

- all equipment to be switched off or idled when not operating and engines not revved unnecessarily; and
- equipment to be maintained in good condition (including silencers) to minimise noise emission during operation.

F6.4.3 Operating Times

To ensure that disturbance did not occur during unsociable hours *ie* in the evening and at weekends, landfill operations were limited to between 0730 and 1900 Monday to Friday and 0700 to 1300 on Saturday. No working was permitted on Sundays or Bank Holidays. Soil replacement and capping operations, which take place at elevated levels were restricted to between 0800 and 1700 Mondays to Fridays.

F6.4.4 Audible Warning Devices

Further planning conditions related to the use of audible reversing alarms or warning devices, which should not be used except where agreed with the Planning Authority.

F6.4.5 Other Noise Mitigating Measures

In order to minimise the noise impact of the proposed operation as a whole, a number of additional, more general measures were identified:

- sub-contractors to use equipment which complies with EC Directive noise emission limits;
- equipment to be maintained in good working order;
- engines to be switched-off or left in idle when not in use;
- access hatches and engine door panels on the plant to be kept closed as far as possible; and
- regular monitoring of noise levels to be carried out.

F6.5 Overall Improvement Achieved

The predicted noise impact at the two reference noise sensitive receptors, after construction of the earth bunds along the site boundaries, was estimated at 38 dB $L_{Aeq\ 1hr}$ and 48 dB $L_{Aeq\ 1\ hr}$ respectively. At the former site, the predicted noise impact was some 7 dB(A) below the noise limiting criterion, but exceeded existing background noise level by 3 dB.

At the second location, the predicted noise impact approached the noise limiting criterion of 49 dB L_{Aeq} but was still within prescribed limits. Here noise from landfill operations would be apparent but at a level which was considered to be acceptable to local residents. In addition, other local sources of background noise would serve to mask site noise at certain times of the day.

F6.6 Outcome of Noise Control Measures

The noise controls used at this landfill site were low cost or no cost options. Construction of bunds using topsoil and overburden enabled the use of material, which would otherwise be transported from the site or dumped elsewhere, for noise screening, thus saving the cost of acoustic fencing at around £150/linear metre at 1999 prices.

Regular maintenance of haul routes and plant also benefits the efficiency and reliability of equipment, which may otherwise be subject to costly repairs and overhauls. Switching off engines when not in use can also provide significant fuel savings.

The costs incurred in the noise control scheme included fees for the noise survey and noise modelling of approximately £1,500, and man hours and fuel costs for bund building. However, the costs of bund construction were equal to those associated with the removal of the bund material from the site, which would have been required with or without the noise control operations.

During bund construction noise levels from the site were significantly higher than the existing background noise levels at noise sensitive receptors. However, in light of this unavoidable noise impact, the Local Planning Authority allowed noise limiting criteria to be exceeded for a maximum duration of eight weeks for soil/overburden removal and bund construction.