

THE ENGINEERING EQUIPMENT AND MATERIALS USERS ASSOCIATION

NOISE PROCEDURE SPECIFICATION

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THE ENGINEERING EQUIPMENT AND MATERIALS USERS ASSOCIATION

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FOREWORD

This specification defines the procedures for controlling noise in plant and equipment for use in the petroleum, petrochemical and allied industries; it applies both to the design and construction of new plants and to the modification of existing plants where noise reduction is required. Noise control is a continuing process which starts at the earliest stage of design and carries on throughout the operation of the plant; it is a process which requires close co-operation between the Principal, Contractor and Equipment Vendor. Essentially, the specification deals with the stages up to the commissioning of the plant or equipment, but it is sufficiently comprehensive to provide guidance on noise control during operations, particularly in the diagnosis of sources of neighbourhood nuisance.

The acquiring and reporting of noise data in a standard manner is a key feature of design for noise control and is a field in which there is an urgent need for uniformity. This specification is therefore intended to provide standard methods for doing this.

Although the measurement and calculation procedures in this specification are practicable and adequate for use in most cases, special situations may be met where they cannot be employed precisely as specified. In such cases it may be necessary to modify the procedures. An explanation of the theory and philosophy behind the procedures is therefore included so that a consistency of approach and accuracy can be maintained. Some special cases of noise-level prediction - particularly indoor situations where enclosures or screens are to be employed - are beyond the scope of this specification, and the methods of calculation described in standard texts must be employed.

This document is Revision 2 of the OCMA Specification originally published in 1971 with the title "Procedural Specification for Limitation of Noise in Plant and Equipment for use in the Petroleum Industry". It contains many changes in text and replaces Revision 1 issued in October 1972. These changes are the result of experience in the use of previous documents in the petroleum and petrochemical industries and the publication of new technical material in the intervening years.

The aim of this revision has been to present a more complete version of the measurement and calculation procedures, and this has extended the document so that it may appear complicated to newcomers to the subject. OCMA has therefore prepared a further document, NWG-3, which gives a guide to the use of the specification. It describes the principles to be applied in selecting noise limits and gives worked examples of the calculation methods.

The member companies of OCMA declare that they are at liberty to buy goods which do not comply with this specification whenever they desire to do so.

Part 1 defines the scope of the specification and the division of responsibilities between the three main parties in a construction project; the Principal, Contractor and Equipment Vendor. In any given project there may be contractual requirements which define in detail the relationship between these parties, particularly with reference to performance guarantees, and it is not within the scope of this specification to provide a precise legal contract for the project. Nevertheless, the general framework given here defines the essential features of any such contract.

The notation and terms used in this specification have been chosen as far as possible to be in accordance with current international practice.

Part 2 defines the measurement and reporting of equipment noise; its aim is to specify measuring procedures which can be used in the practical situations encountered in plants and factories. These procedures are based on the use of a precision sound-level meter equipped with octave-band filters and an accelerometer; equipment which could be readily available in plants and factories.

They include a correction for semi-reverberant environments; for small sources this is derived from readings on two measuring surfaces (so that no special equipment is required). Where this is not practicable, alternative methods are proposed which are based on the use of a partial second surface or the Room Constant, in descending order of merit.

The preferred measuring surface is a hemisphere in which the source is small in relation to the measuring distance; this is called the "small-source method". The use of this method is not determined by the physical size of the source but by the nature of the environment - the absence of high background noise and of physical obstructions, so that measurements can be made sufficiently far from the source.

Where it is not possible to get far enough away from the source - because of background noise or physical obstructions - it is necessary to measure in the geometric near field of the source. This means that the source dimensions are large compared with the measuring distance, so it is called the "large-source method". The preferred measuring surface is then the conformal surface (a cuboid with rounded corners and edges). But if the source radiates unevenly it is necessary to divide this into separate surfaces (called "measuring-surface zones"), to calculate their sound-power levels individually, and then to add them up. There are still some sources which do not suit this method - usually they have identifiably separate radiating components - and these have to be treated as a composite of sources, using the small-source or large-source methods as appropriate. A procedure is also given for determining the sound-power levels of linear sources.

When using the large-source method, a correction must be applied for the geometric near-field error of the sound-pressure level measurements and suitable values are given for this correction. For convenience these are quoted in terms of the ratio of surface areas rather than the angular terms from which they were calculated.

The preferred method for determining sound-power levels is from measurements of sound-pressure level, but where this is not possible - due to high background noise - a procedure is proposed for using vibratory - velocity levels, derived from measurements of vibratory velocity or acceleration.

Fig. 9 gives a flow chart for the various choices in the determination of sound-power level.

Part 3 describes the calculation methods to be used for handling the test data. This includes the derivation of sound-power levels to define the noise emission of equipment items and the use of this information to estimate noise levels in the work area and the neighbourhood.

It is considered that the procedures described in this specification will determine the sound-power level with an accuracy of $\pm 3\text{dB}$ at the 95% confidence limits. This is likely to be acceptable for most engineering purposes. Where a higher precision is required the procedures of ISO 3741 to 3745 should be used.

Appendix F provides a standard procedure for calculating neighbourhood noise which can be used as the basis for a contractual guarantee on whether the plant has met the neighbourhood-noise requirements. Other methods of assessing attenuation from ground and weather effects are currently available, or may be developed; but measurements around a number of plants indicate that this procedure estimates the long-term median (L_{50}) noise level in the neighbourhood to $\pm 5\text{dB(A)}$ with about 90% confidence.

Part 4 describes the procedure for specifying the noise limits for a complete plant. This would be used by the Principal as part of the general plant specification for the Contractor. Appendix D gives a model format for specifying noise limits for a plant.

Part 5 describes the procedure for specifying noise limits for individual items of equipment and would be used by the Contractor in ordering equipment. He would derive the equipment noise limits from the complete plant limits specified by the Principal on the basis of his general design for noise control. Appendix D gives a model format for specifying equipment-noise limits.

Part 6 defines the requirements for assessing equipment sound-power levels and the noise levels of a complete plant for acceptance purposes.

OCMA PUBLICATIONS ON NOISE

Specification NWG-1 (Rev. 2)	Noise Procedure Specification.
Specification NWG-2	The Measurement and Reporting of Equipment Noise (Equipment Vendor's Abstract from NWG-1). WITHDRAWN (now incorporated in Specification NWG-1)
Publication NWG-3 (Rev. 2)	Guide to the Use of Noise Procedure Specification NWG-1
Specification NWG-4	General Specification for Silencers and Acoustic Enclosures.

These documents have been prepared by the Industrial Noise Committee of the Oil Companies Materials Association who would welcome comments from users on their application. Comments should be sent to:-

Oil Companies Materials Association,
14, Belgrave Square
London, SW1X 8PS, UK

Where an OCMA Specification includes details of tests to be carried out by manufacturers or others, those tests must be strictly adhered to if the conclusions to be drawn from them are to be valid.

PART 1: INTRODUCTION AND USE OF SPECIFICATION

1.1 Scope

1.1.1 This is a specification of the procedures which shall apply to noise control in the selection and installation of all plant equipment. It indicates the method of specifying maximum acceptable noise levels for plant and equipment, describes acceptable methods of test for determining noise emission from equipment, and gives a guide to methods of calculation and presentation of data. It does not set noise limits because the acceptable limit for any location will depend on factors relevant to that location; noise limits may also be varied in the course of time as new information becomes available on the physiological effects of noise. The choice of noise limits is the responsibility of the Principal.

1.1.2 Noise levels shall be considered under the following headings:-

- (a) Hearing Conservation
- (b) Speech and Work Interference
- (c) Community Reaction
- (d) Accommodation

1.2 Division of Responsibilities

The division of responsibilities in the application of this specification shall be as stated in this section unless otherwise specified in the contract or agreed by the Principal.

1.2.1 The Principal

For the purpose of this specification the Principal is defined as that party responsible for placing the order for a plant, specifying the technical requirements of the plant, and ultimately paying for its design and construction.

The Principal shall be responsible for the following:-

1.2.1.1 Specifying the following requirements for the complete plant:

- (a) The broad-band noise limits and the required additional restrictions for noise character under the headings in 1.1.2. He may specify community-noise levels as sound-power levels for the complete plant or as sound-pressure levels at designated locations.
- (b) ~~Any special noise limits which may be required for certain abnormal operating conditions of limited duration. These may include construction, start-up and emergency conditions.~~
- (c) The areas and times in which the noise limits are to be met.
- (d) Whether compliance with the noise limits shall be determined by direct measurement or by calculation. Where test measurements are to be made, the Principal shall provide information on any background noise from sources outside the plant under consideration or agree a method for determining this and correcting for its effect. Unless otherwise specified by the Principal, the procedures and values in this specification are to be used for all measurements and calculations.

1.2.1.2 Specifying the procedure and requirements for the acceptance testing of the complete plant.

1.2.2 The Contractor

For the purpose of this specification the Contractor is defined as the party which carries out the design, engineering, procurement, construction and commissioning of a plant on an order from the Principal. In some cases the Principal may undertake all or part of the responsibilities of the Contractor.

The Contractor shall be responsible for the following:-

1.2.2.1 Obtaining necessary information relating to the noise levels generated by equipment in the contract. This information may be derived from one or more of the following sources:

- (a) Calculation based on theoretical or standard procedures.
- (b) Test and calculations carried out by the Equipment Vendor.
- (c) Test carried out by, or on behalf of the Contractor.
- (d) Test and calculations from other sources agreed by the Principal to be reliable

1.2.2.2 The accuracy of the data and calculations based thereon. The Principal's approval must be obtained for any deviation from the procedures prescribed in Parts 2 and 3 of this specification and the relevant appendices.

1.2.2.3 The determination of all areas where the relevant noise limits would be exceeded if standard equipment were used, and in all such areas the selection of the most economic method of meeting the limitations, subject to the approval of the Principal. The Contractor shall take into consideration the effects of reverberation, equipment mounting, and neighbouring equipment to ensure compliance with the Principal's noise limits. He shall also take into consideration the requirements for dealing with narrow-band and impulsive noise. Corrective action may take one or more of the following forms:-

- (a) Selection of low-noise equipment.
- (b) Modification of design to reduce the noise at source.
- (c) Alteration of plant layout and orientation of directional sources.
- (d) Enclosure of equipment or working areas.
- (e) Screening equipment from the working areas.
- (f) Fitting silencers.
- (g) Acoustic lagging.

1.2.2.4 The determination of suitable sound-power level limits for equipment items where appropriate (see Part 5) in order to achieve the work-area and community limits set by the Principal, subject to the requirements of 1.2.2.3.

1.2.2.5 The preparation of noise data sheets for the requisition of equipment and the checking of noise data supplied by Equipment Vendors.

1.2.2.6 When required by the Principal, the preparation of reports giving sufficient data and calculations to demonstrate to the satisfaction of the Principal that the plant design meets the requirements of his specification. Such reports shall define the measures proposed for reducing noise and shall include all the noise-test data obtained, together with data received from other sources. They shall also indicate clearly those areas where it does not appear practicable to meet the noise limits.

1.2.2.7 Ensuring that the noise levels from any reasonable operating condition up to the maximum design load shall meet the noise limits. These conditions shall include regeneration, low load, recycle, start-up, shutdown and other abnormal but expected modes of operation.

1.2.2.8 Estimating the sound levels radiated from piping and vessels connected to noisy equipment such as valves or compressors.

1.2.2.9 Taking corrective action if the acceptance tests for the plant show that the specified noise levels have not been met. Such action shall have the approval of the Principal.

1.2.3 The Equipment Vendor

For the purpose of this specification the Equipment Vendor is defined as the party which manufactures or supplies equipment to perform the duties specified by the Contractor. He may manufacture the equipment himself or assemble packages of equipment from other suppliers.

The Equipment Vendor shall provide the following information:

- 1.2.3.1 Sound-pressure levels at 1m from the surface of his equipment under free-field conditions, and at the operator's position, if any. This information is to include both average and maximum noise levels.
- 1.2.3.2 The sound-power level of his equipment under agreed operating conditions. This shall be determined by the test methods in Section 3 or by a test method agreed with the Principal. The determination may be affected by the equipment mounting or by associated equipment and details of this shall be provided.
- 1.2.3.3 Any special characteristics of the noise emission such as narrow-band or impulsive noise.
- 1.2.3.4 Where noise tests can only be made under semi-reverberant conditions, the test data shall be corrected to free-field data. If this is not possible, a note shall be made that the data provided may be higher than free-field data. The corrections used and the method of calculation shall be given in the test report.
- 1.2.3.5 For equipment such as compressors or valves where a considerable portion of the noise it generates is radiated by the connected piping, the Equipment Vendor shall quote the sound-power level per unit length of pipe upstream and downstream of the equipment, together with the diameter and schedule of the pipe for which the data apply. Alternatively he shall quote the in-pipe sound-power levels at the suction or discharge of his equipment.

For tests on pipes connected to pumps or compressors it is necessary to ensure that the measurements are not influenced by noise from external loads such as valves; for example, by using low-noise valves.
- 1.2.3.6 He shall indicate all modifications to standard equipment necessary to meet the noise limits set by the Contractor. Alternatively he shall advise the Contractor on appropriate methods for reducing the noise from standard equipment when this does not meet these noise limits. Any modifications to the equipment shall not conflict with the requirements of other specifications for the equipment.

1.3 Special Consideration

- 1.3.1 In certain circumstances the available noise data may be inadequate for detailed calculations and design. In such cases, provided that there is no reasonable method of obtaining the required data, the Principal shall approve a particular design and layout and equipment selection, and be responsible for the resulting noise levels.
- 1.3.2 When it is necessary to make use of data obtained from another test method (1.2.3.2) it must be at least as accurate as the corresponding measuring procedure in this specification and the results must be given in octave bands. In particular, the relevant near-field and environmental corrections must be applied, and the operating conditions of the equipment under test must be appropriate. These must be agreed with the Principal.

1.4 Notation and Definitions

- 1.4.1 The following notation is used in this specification:-

d	Measuring distance	(m)
D	Directivity index	(dB)
D ₀	Typical source dimension	(m)
E ₁	Geometric near-field correction	(dB)
E ₂	Environmental correction	(dB)
E ₃	Conformal-surface correction	(dB)
f	Frequency	(Hz)
F	Correction for area of conformal surface	

K	Attenuation factor	(dB)
L_{eq}	Equivalent continuous sound level	(dB)
L_p	Sound-pressure level	(dB)
$\bar{L}_p$	Mean sound-pressure level	(dB)
L_p^*	Directional sound-pressure level	(dB)
L_v	Vibratory-velocity level	(dB)
$\bar{L}_v$	Mean vibratory-velocity level	(dB)
L_w	Sound-power level	(dB)
I_n	Dimension of reference surface	(m)
$\log$	Logarithm to base 10	
p	Sound pressure	(N/m ²)
p_0	Reference sound pressure	(N/m ²)
Q	Ratio of the measuring surface to the reference surface	
r	Radius	(m)
R	Room constant	(m ²)
t	Time period	
T	Total observation time	
S	Surface area	(m ²)
v	Vibratory velocity	(m/s)
v_0	Reference vibratory velocity	(m/s)
W	Sound power	(W)
W_0	Reference sound power	(W)
σ	Radiation ratio	
α	Sound absorption coefficient	
θ	Angle	(rad)
λ	Wave length	(m)

1.4.2 The following definitions apply to this specification:-

Acoustic near field

is defined as the region near a noise source where particle velocity and pressure are not in phase.

Conformal surface

is a form of measuring surface which is at a distance, d , from all points on the reference surface.

Crude sound-power level	is the sound-power level obtained from a measuring surface before the application of the environmental correction.
Cuboid	is a rectangular parallelepiped.
Directional sound-pressure level	is the sound-pressure level in free field at any distance from the equipment in the specified direction.
Directivity index	of a small source in a particular direction is the difference between the directional sound-pressure level L_p^* and the mean sound-pressure level $\bar{L}_p$ at the same distance. $D = L_p^* - \bar{L}_p$ For a large source it is the difference between the sound-power level in a particular direction and the total sound-power level of the source.
Equivalent continuous sound level	is the level of a steady sound that has, over a given period, the same energy as the fluctuating sound in question.
Free field	is defined as that part of the sound field where the effects of its boundaries are negligible. (Note: where the effects of the boundaries are constant, such as above a continuous reflecting plane, the sound levels may be treated as if in a free field and corrections made as necessary.)
Geometric near field	is defined as the region near a noise source where the measuring distance from the reference surface is less than the maximum linear dimensions of the source or reference surface element.
Impulsive noise	When a noise contains significant irregularities, such as bangs, clanks, or thumps, or if the noise is only existent momentarily and is of a character to attract attention, then it shall be considered as impulsive for the purpose of this specification.
Measuring distance	is the distance between the point on the measuring surface where the measurement is made and the nearest point on the reference surface.
Measuring surface	is an imaginary surface on which measurements are made. Its relation to the reference surface is defined in the appropriate test procedure.
Measuring-surface zone	is that part of the total measuring surface of a source over which the variation in sound pressure level is less than 6 dB(A). It may consist of one plane surface or a continuous group of plane or curved surfaces.

Narrow-band noise

When the noise from a source contains a pure tone or narrow-band component which is noticeable to the ear as a noise of distinguishable pitch, and which represents a dominant feature of the total source noise, then the source noise shall be regarded as containing narrow-band noise for the purpose of this specification.

Note: Where there is doubt about the subjective assessment of narrow-band noise it shall be resolved by narrow-band analysis, using an instrument with a band width not more than 10 Hz or 1%, whichever is the less (See Appendix E).

Octave bands

refer to the preferred octave frequency bands of BS 3593 or ISO 266.

Reference surface

is the smallest possible imaginary parallelepiped enclosing the source and terminating on the ground (excluding re-entrant sections and minor protruberances which are not significant emitters of noise).

Sound level

is the A-weighted overall sound-pressure level.

Sound-power level

is defined as $10 \log (W/W_0)$ in dB where W is the sound power in watts, and W_0 is the reference sound power of 10^{-12} watt.

Sound-pressure level

is defined as $20 \log (p/p_0)$ in dB where p is the measured sound pressure in N/m^2 and p_0 is the reference sound pressure of $2 \times 10^{-5} N/m^2$.

Vibratory-velocity level

is defined as $20 \log (v/v_0)$ where v_0 is the reference velocity of 5×10^{-8} m/s.

Note: This is not the preferred reference velocity required by ISO 1683 but it is the most suitable value for relating vibratory-velocity levels with sound-power levels.

Work area

is any position not less than 1 m from equipment surfaces which is accessible to personnel, or any position where an operator's ear may be exposed to noise in the normal course of duty. It includes any platform, walkway or ladder.

1.5 References

1.5.1 Standards

Reference is made to the following standards:-

BS 2475	Octave and 1/3 octave-band-pass filters.
BS 3593	Preferred frequencies for acoustical measurement.
BS 3489	Sound-level meter (Industrial Grade).
BS 4197	Precision sound-level meter.

IEC 651	Recommendations for sound-level meters (draft).
IEC 225	Octave, half-octave and third-octave band filters intended for the analysis of sound and vibrations.
ISO 266	Acoustics - Preferred frequencies for measurements.
ISO/DIS 1683	Preferred reference quantities for acoustic levels.
ISO 3741	Precision methods for broad-band sources in reverberation rooms.
ISO 3742	Precision methods for discrete-frequency and narrow-band sources operating in reverberation rooms.
ISO 3743	Engineering methods for special reverberant test rooms.
ISO 3744	Engineering methods for free-field conditions over a reflecting plane.
ISO 3745	Precision methods for anechoic and semi-anechoic rooms.
ISO 3746	Determination of sound-power level of noise sources: Survey method.

1.5.2 Other References

CONCAWE Report No. 2/76 — Determination of sound-power levels of industrial equipment, particularly oil industry plant.

CONCAWE Report No. 8/77 — Measurement of vibrations complementary to sound measurements.

CONCAWE Report No. 3/77 — Test method for the measurement of noise emitted by furnaces for use in the petroleum and petrochemical industries.

CONCAWE Report No. 2/79 — Method for determining the sound-power levels of flares used in refineries, chemical plants, and oil fields.

CONCAWE Report No. 5/78 — Method for determining the sound-power levels of air-cooled (air-fin) heat exchangers.

L.L. Beranek — Noise and Vibration Control, McGraw Hill, 1971.

G.M. Diehl — Sound power measurements on large machinery installations. Sound and Vibration 8, 32-36, May 1974.

Z. Maekawa — Noise reduction by distance from sources of various shapes. Applied Acoustics 3, 225-238, 1970.

I. Sharland — Practical Guide to Noise Control, Woods, 1972.

J.E. Hawkins, S.S. Stevens — The masking of pure tones and of speech by white noise. Jour. Acoust. Soc. Amer. 22, 1st January, 1950.

VDI 2714 (draft) Schallausbreitung im Freien. Verein Deutscher Ingenieur. December 1976.

PART 2: MEASUREMENT AND REPORTING OF EQUIPMENT NOISE

2.1 Measuring Equipment

Measurements shall be made with a sound-level meter to BS 4197 (Precision) or IEC 651, Grade 1, equipped with band filters to BS 2475 or IEC 225.

Measurements made with instruments to BS 3489 (Industrial Grade) or IEC 651 Grade 2 or 3, may be accepted only if the Principal agrees that it is unreasonable or impracticable to obtain readings with a precision instrument.

The 'slow' meter response setting shall be used.

More sophisticated equipment may be used provided that it can give equivalent readings to those of a precision sound-level meter and octave-band analyser; for example, a narrow-band analyser may be required in some circumstances (see Appendix E).

The microphone shall be orientated so that the angle of incidence of the sound waves is that for which it is calibrated, as specified by the manufacturer.

When measurements are made outdoors or around ventilation equipment, the use of wind screens on the microphone is recommended. An appropriate correction to the readings shall be made according to the manufacturer's instructions.

2.2 General Requirements for Measurements

The following points shall be observed at all times when noise measurements are made:-

2.2.1 Measurements

The terms 'readings' or 'measurements' will at all times imply separate measurements in each of the eight octave frequency bands centred on 63, 125, 250, 500, 1k, 2k, 4k and 8k Hz and in overall dB(A). Additional readings shall be made in the 31.5 and 16k Hz bands if required by the Principal. The readings in octave bands shall be unweighted.

(Note: In some countries it is the practice to use weighted octave-band levels and such values should be corrected for use in calculations according to this specification.)

2.2.2 Sound-Level Meter Calibration

The sound-level meter shall be calibrated immediately before and after use, using a standard acoustic calibrator approved for the meter. A maximum difference of 1dB between the two calibration readings and an error of not more than ± 1 dB between each and the quoted sound level of the calibrating source shall be deemed acceptable.

2.2.3 Measurement of Background Noise

Whenever possible, measurements of background noise shall be made when the equipment under test is not operating. A minimum of four measurements of background noise, spaced equally around the equipment at approximately the same distance as for the source noise measurements, shall then be made.

When any background measurement is within 6dB of the total-noise level (background plus equipment), an individual background-noise level measurement should be made for each point of total-noise measurement.

2.2.4 Measurement of Fluctuating Noise Levels

Where the sound-pressure levels fluctuate, the average or most common level with the meter on "slow" response shall be recorded. If the range of fluctuation is greater than 6dB, the maximum and minimum levels shall also be recorded and a level 3dB below the maximum shall be used for design purposes. For slow fluctuations (for example, where there are discrete modes of operation) or for intermittent noise the equivalent continuous sound level (L_{eq}) shall be derived (see 3.1.6).

2.2.5 Test Conditions

Operating conditions for the tests shall be selected beforehand and shall be kept constant during each test.

2.2.6 Precision

Measurements shall be recorded to the nearest 1dB.

2.3 Sound-Pressure Level Measurements

For the purpose of calculating work-area noise limits (see Part 4) sound-pressure levels shall be measured at 1 m from the equipment surface and at the operator's position where applicable. Readings shall be taken at a minimum of four positions equally spaced around the equipment at 1.5 – 2 m above the working floor level. The positions chosen shall include the position of the highest noise level. These sound-pressure level measurements and any others made around the equipment to determine sound-power levels can be used directly for determining work-area noise levels near the equipment (see 3.3.1.4).

2.4 Sound-Power Level Determination for Equipment

The procedures in this section are based on the use of a portable precision sound-level meter and are intended for use in industrial conditions such as factories or open-air plants. It is assumed that the use of special anechoic or reverberant test chambers is not practicable. Where these special chambers are available the procedures of ISO 3741, 3742, 3743, or 3745 should be used, as appropriate.

The sound-power level of a noise source is normally determined from sound-pressure level measurements on an imaginary surface enveloping the source, defined as the "measuring surface". In order to define the measuring surface a "reference surface" is established which is the smallest possible imaginary cuboid just enclosing the source and terminating on the ground on which the source is mounted. Elements protruding from the source which are not major radiators of sound may be neglected.

The preferred measuring surface is a hemisphere and measurements should ideally be made under conditions of "free field above a reflecting plane". This means that the ground is assumed to be a flat continuous reflecting surface from the source to the measuring points; it should preferably be concrete, steel plate or wood. If such a surface is not available and the source has to stand on an absorbing surface such as gravel or grass, a note shall be made in the test report. Also, there should be no reflecting surfaces present, apart from the ground, and no other sources to cause high background levels. In these circumstances, measurements can be made at such a distance from the source that its linear dimensions are small in relation to the measuring distance (see 2.4.1.1); the acoustic details of the source are then insignificant. Measurements made in these conditions are defined in this specification as the "Small Source Method" and are described in 2.4.1.

There are, however, many practical situations in which reflecting surfaces and high background noise cannot be eliminated and to minimise their influence it is necessary to make measurements at distances smaller than those prescribed in the small-source method; the source will then be large relative to the measuring distance. Measurements made under these conditions are defined in this specification as the "Large Source Method" and are described in 2.4.2.

It is important to verify that the test environment has met the above requirements and this must be checked as part of the procedure. This should preferably be done by using the noise emission of the source itself so that no special equipment is required; but where this is not possible a correction may be made by other methods (see 2.4.1.5 for the small-source method and 2.4.2.6 for the large-source method). If the environment is semi-reverberant an indication of sound-power level may be obtained by the procedure described in Appendix A.

In addition there are some special techniques for determining sound-power levels which do not fall into these two categories and these are described in 2.4.3.

Fig. 9 gives a flow chart for determining the appropriate procedure to be used.

2.4.1 The Small Source Method

This is to be used for sources whose linear dimensions are small in relation to the radius of the measuring surface as defined in 2.4.1.1. The source should be mounted away from other reflecting surfaces and a check on the suitability of the environment shall be made as in 2.4.1.5. The background noise should be measured, if possible, as described in 2.2.3 and the test measurements corrected as in 3.1.4.

The calculation of the sound-power levels is described in 3.2.1.

2.4.1.1 The Measuring Surface

For the small-source method the measuring surface is a hemisphere terminating on the ground. The radius of the hemisphere is at least twice the typical source dimension D_0 , defined as

$$D_0 = \sqrt{[(l_1/2)^2 + (l_2/2)^2 + l_3^2]}$$

where l_1 , l_2 and l_3 are the length, width and height of the reference surface. The radius shall be such that the hemisphere is at least 1 m from the reference surface (see Fig. 1(a)).

2.4.1.2 The Microphone Positions

Before selecting the microphone positions a preliminary survey shall be made over the measuring surface with the sound-level meter set to dB(A) in order to determine whether the source has any directivity.

The microphone positions are situated on the measuring surface and a minimum of 5 positions shall be used. One of these shall be vertically above the source and the other 4 positions should preferably be on a circle of radius 0.92 times the radius of the hemisphere and at a height above the ground of 0.4 times the radius, spaced at 90° intervals around the source (see Fig. 1(b)). If the radius is large and this microphone height is impracticable a lower height may be used with a correspondingly larger measuring circle. In any case the microphone positions shall not be less than 1 m above the ground.

2.4.1.3 Omission of the Overhead Microphone Position

If it is impracticable to make a measurement in the position vertically above the source it may be omitted. 4 additional microphone positions on the measuring surface shall then be used which shall be at heights which are one half or double the height of the corresponding positions defined in 2.4.1.2. They shall be at least 1 m from the ground and shall be rotated 45° about the vertical axis with respect to the original positions.

2.4.1.4 Additional Microphone Positions

If the preliminary survey shows that the difference in sound level between any two points on the measuring surface exceeds 6dB(A), one microphone position shall be situated at the maximum and four additional positions shall be used so that the positions are equally spaced around the equipment. They should preferably be at a different height from the first 4 positions and rotated 45° about the vertical axis (see Fig. 1(c)). The purpose of these extra positions is to weight out the effect of the maximum on the mean sound-pressure level.

Note: These four positions may be the same as those in 2.4.1.3 if the overhead microphone position cannot be used.

The position of the maximum shall be noted and used to derive the directivity index as described in 3.2.7.1.

2.4.1.5 Test Environment Correction

The measurements described in 2.4.1.1 to 2.4.1.4 shall be repeated on a second hemispherical measuring surface of area approximately 4 times that of the first measuring surface. It shall not be less than 3 times the area. A second set of sound-power levels shall be derived from these measurements and compared with the first. For distances greater than 25m a correction for air absorption will be necessary (see Fig. F1 and CONCAWE Report 5/78 for flares).

If the second estimate of sound-power level exceeds the first estimate by more than 2dB in any octave band, the correction of 3.2.3 shall be applied to the first estimate (in the relevant octave band). If the difference is 2dB or less, the first estimate shall be used for sound-power level. Otherwise a correction to the measurements shall be made which is derived from the mean absorption factor of the test environment (the Room Constant). This correction is based on ISO 3746 and is described in Appendix A.

When it is not possible to make a correction for reverberation a second estimate of the sound-power level shall be derived from the methods described in 2.4.2 or 2.4.3. The smaller of the two estimates shall be taken as the best value of sound-power level but both shall be quoted in the Test Report.

2.4.2 The Large Source Method

This method shall be used for sources whose dimensions are large relative to the measuring distance, but only when circumstances do not allow the use of the small-source method of 2.4.1. The near-field corrections of 3.2.2.3 shall be applied to readings where appropriate.

2.4.2.1 The Measuring Surface

For the large-source method the shape of the measuring surface should preferably be a conformal surface which envelopes the reference surface (see Fig. 2(a)).

The preferred and minimum measuring distance is 1 m from the reference surface. Where it is not possible to use a single enveloping surface, other surfaces shall be used as described below.

The calculation of the sound-power levels is described in 3.2.2.

2.4.2.2 Preliminary Survey

Because of the relatively small measuring distance a preliminary survey will be necessary to determine the radiating properties of the source in some detail. This survey shall be done over the measuring surface with the sound-level meter in the A-weighting position, and a subjective assessment of the noise field should be made by ear.

Three cases can be distinguished:

- Sound is radiated evenly by all equipment surfaces: the variation of sound level over the measuring surface is smaller than 6dB(A) (see 2.4.2.3).
- Sound is not radiated evenly: some equipment surfaces are louder than others. This may be taken to apply when well defined parts of the measuring surface have sound levels 6dB(A) or more above those in other parts (see 2.4.2.4).
- There are discrete parts of the equipment or unit which radiate most of the noise (see 2.4.2.5).

In the last two cases the choice of measurement procedures will depend on the nature of the equipment. This specification provides an outline procedure and more detailed procedures consistent with it may be used for certain items of equipment (see, for example, CONCAWE Reports 3/77 and 6/78 for furnaces and air-cooled heat exchangers).

2.4.2.3 Source with Evenly Distributed Radiation

When the preliminary survey shows that the variation of sound level over the measuring surface is smaller than 6dB(A), a minimum of five measuring positions shall be chosen on the measuring surface, one near the centre of each side surface and one vertically above the equipment (see Fig. 2(b)).

If it is impracticable to make a measurement in the overhead position, 4 additional measuring positions shall be used in the vertical sections of the measuring surface. These shall be at a different height from the other positions and above the mid point of the vertical section.

When it is not possible to make measurements on a second measuring surface as in 2.4.2.6, further measuring positions shall be chosen such that there are 3 evenly spaced positions on each vertical part of the measuring surface.

Note: This ensures that the points are more representative of the source when there is no check from the second surface but it does not correct for environmental errors.

The calculation of the sound-power levels is described in 3.2.2.1.

2.4.2.4 Source with Some Surfaces Louder than Others

When the preliminary survey shows that the variation in sound level over the measuring surface is 6dB(A) or more and that some surfaces radiate significantly more noise than others, the choice of microphone positions shall be related to the different source surfaces. The measuring surface shall be divided into separate zones corresponding to the various radiating areas of the source, so that the variation in sound level across each measuring-surface zone is less than 6dB(A).

The dB(A) measurements in the preliminary noise survey shall be included in the Test Report. They shall be made at sufficient positions to indicate how the measuring-surface zones have been chosen. The measuring-surface zones on the second surface (used to check the suitability of the environment) may not be similar in shape and number to those of the first surface.

There shall be at least 3 microphone positions on each measuring-surface zone and these should be evenly spaced over the zone (see Figs. 2(c) and 2(d)).

The calculation of the sound-power levels is described in 3.2.2.2.

2.4.2.5 Equipment with Discrete Radiating Parts

When a preliminary survey shows that most of the radiated noise originates from discrete parts of the equipment (such as openings in enclosures), these shall be treated as separate sources and their sound-power levels calculated separately. The procedures described in 2.4.1, 2.4.2, and 2.4.3 shall be applied to the various parts of the equipment where appropriate.

In this case there may not be a continuous measuring surface enveloping the equipment, and where parts of the reference surface have been neglected this shall be indicated in the report of the preliminary survey.

These discrete parts of the equipment may be treated as separate noise sources with different heights in subsequent noise calculations. For example, a brick-walled building with a metal roof, a large opening on one side, and a ventilating fan in the opposite wall will consist of three separate sources. The opening will be treated as a measuring-surface zone as in 2.4.2.4 with measuring positions in the plane of opening. The fan will be treated as a small source with the wall as the reflecting plane. The radiation from the roof may be treated as a measuring-surface zone, or may be measured by vibration methods as in 2.4.3.2.

Where the source consists of an opening which radiates sound energy from a diffuse noise field (such as a window or the imaginary surface between the pillars of a floor-fired furnace) the measuring surface shall be taken in the plane of the opening. It is then coincident with the reference surface and the near-field correction described in 3.2.2.3 is given by $E_1 = 3\text{dB}$.

If there is an air flow through the opening (such as the inlet or discharge of a fan duct) this will influence the noise measurements. The nearest measuring position shall then be at least 1 m from the opening. If the opening is in a large wall which acts as a reflecting surface, the small-source method of 2.4.1 should be used to derive the sound-power level (using a hemispherical measuring surface based on the wall). But where this is not practicable, measurements shall be made on a line extending from the centre of the opening and perpendicular to it. They shall be made at two distances and a sound-power level shall be derived from each measurement according to 3.2.6. The mean of the two sound-power levels shall be used.

2.4.2.6 Test Environment Correction

The measurements described in 2.4.2.3, 2.4.2.4 and 2.4.2.5 shall be repeated on a second measuring surface. This should preferably be geometrically similar to the measuring surface of the first test but in some cases it may be necessary to use a second surface of different shape. The measuring distance shall be chosen such that the surface area is approximately four times the surface area used in the first test. If a smaller ratio of areas is used, it is important to ensure that the difference in sound-pressure levels is significant compared with the precision of the sound-level meter.

Sound-power levels shall be derived from each surface and compared with each other. Where the first and second surfaces have been divided into measuring-surface zones, the sound-power levels derived from the zones shall be added and the totals for each surface compared.

If the difference in the sound-power levels from the two surfaces is 2dB or less, the estimate from the inner surface shall be taken as the sound-power level. If the difference is greater than 2dB, an environmental correction, E_2 , shall be derived from the procedure of Appendix A and applied to the sound-power level from the inner surface (in the relevant octave band). A note shall be made in the Test Report to indicate that this procedure has been used.

Where a complete test on a second surface is not practical, useful information on the accuracy of the first test may be obtained from a partial second test. This could be made, for example, on a part of the second measuring surface which is not affected by background noise or encumbrances such as neighbouring structures, or where background noise affects only some of the octave bands.

The accuracy of the test procedure will be reduced if no test-environment qualification can be made and a note shall then be made in the Test Report. The sound-power levels from the first test are then likely to be an upper estimate of the true sound-power levels.

2.4.3 Special Techniques for the Determination of Sound-Power Level

2.4.3.1 Groups of Sources

When sources are close together it may not be possible to use either the small-source method or the large-source method on each source individually. In such cases the group may be treated as a single source and either method may be employed to obtain the sound-power levels. This procedure shall only be used for small groups of sources; for measurements on large groups of sources, such as complete plants, see Appendix C.

2.4.3.2 Vibration Measurements

It is possible to estimate the radiated sound-power of an equipment surface by using vibration measurements. The vibration quantity relevant to sound radiation is the vibratory-velocity and the calculation of sound-power levels from vibratory-velocity levels is described in 3.2.4. It is important to measure vibrations at more positions than for noise in order to obtain a representative value of the mean vibratory-velocity level.

In some cases the vibratory-velocity level can be read directly from the sound-level meter (see CONCAWE Report No. 8/77). A summary of this report is given in Appendix B.

Note: Vibration measurements do not usually give the same precision as sound-pressure level measurements and they should preferably be used to supplement information from noise measurements; they should only be used for the direct determination of sound-power level when there is no alternative (for example, when the background noise is too high).

2.4.3.3 Composite Sources

When a source consists of several well-defined components it may be necessary to obtain separate measurements of the components. This will be necessary when some driven equipment is tested with a driver which is not the same as that to be used ultimately in the plant. It is then important that the measurements on the equipment are not affected by the driver. A correction for the background noise due to the driver may be made from measurements when it operates on its own, but if this is too high it will be necessary to separate the driver acoustically by means of acoustic screens or walls.

Another important case is that of equipment such as pumps, compressors, valves and ejectors, where there is associated pipework. The noise generated by the equipment may then be transmitted by the fluid and radiated by the pipework. The noise radiated by the pipework is frequently greater than that radiated by the equipment itself and must be measured separately. Pumps and compressors, for example, should be treated as three separate sources comprising the suction piping, the machine casing and the discharge piping. The sound-power levels should preferably be determined from noise measurements. Where this is not practicable they should be determined from vibratory-velocity measurements. The relevant sound-power level of the piping is that of the complete run from the equipment to the next plant item. Consideration should also be given to the noise radiated by vessels attached to the piping.

It is necessary to ensure that the measurements are not influenced by noise from external loads such as valves, preferably by using low-noise valves.

2.4.3.4 Linear Sources

Linear sources are typified by pipes or rows of closely-spaced burners in wall-fired furnaces and the measurement of sound-power level is based on the large-source method but the geometry is that of cylindrical propagation.

The reference surface is a cylinder or semi-cylinder which just encloses the source, ignoring protruding elements which are unlikely to be major radiators of sound. The measuring surface is a cylinder or semi cylinder, depending on whether the source radiates freely in all radial directions or whether it is near a reflecting surface. If the source is near to a reflecting surface it shall be taken to be a semi cylinder having the same length as the source. The minimum measuring distance is 1 m. (See Fig. 3).

A preliminary noise survey shall be made to examine the sound field on the measuring surface. If the variation in sound level is less than 6dB (A) the measuring positions shall be situated at the middle of the source. There shall be 4 positions at an angular separation of 90° for a source in free field (see Fig. 3(a)). For a source near a reflecting plane there shall be 2 positions at 45° to the normal to the surface (see Fig. 3(b)). Where this is not practicable 3 positions shall be chosen along the axis of the source on radii perpendicular to the reflecting surface (see Fig. 3(c)).

If the variation in sound level over the measuring surface is greater than or equal to 6dB (A) the measuring surface shall be divided into separate zones such that the variation across each zone is less than 6dB (A). There shall be 2 or 4 measuring positions in each zone, depending on the presence or absence of a reflecting surface.

The measurements shall be repeated on a second measuring surface such that the surface area is approximately four times that of the first measuring surface. The ratio of the areas shall not be less than three. A second set of sound-power levels shall be derived from these measurements and compared with the first. All measurements shall first be corrected for background noise as in 2.2.2.

If the difference in the sound-power levels from the two surfaces is 2dB or less, the estimate from the inner surface shall be taken as the sound-power level. If the difference is greater than 2dB and can be attributed to the effect of reverberation, an environmental correction, E_2 , shall be derived from the procedure of Appendix A and applied to the sound-power level from the inner surface (in the relevant octave band). A note shall be made in the Test Report to indicate that this procedure has been used.

Where a second measuring surface is not practicable additional sets of 4 (or 2) measuring positions shall be selected at two other positions along the pipe such that the three positions are equally spaced (see note in 2.4.2.3).

Vibratory-velocity measurements may be used to estimate sound-power levels where the background noise precludes the measurement of sound-pressure levels.

2.5 Modifications to these Procedures

The above paragraphs of Section 2 specify procedures which will enable adequate sound-level measurements to be made in most cases. There may, however, be cases where none of these procedures can be applied precisely but where it is still possible to obtain data which will enable the necessary calculations to be made with an acceptable degree of accuracy.

Such cases may arise for example where background noise is high and cannot be measured separately. Instances might be:-

- (a) Background noise is high on one side of the source, but the source is known to radiate noise symmetrically. If the two-surface comparison indicates that the sound levels measured on one side of the source are valid, the sound-power level may be deduced from a minimum of one half of the measuring surface.
- (b) Background noise is high in some octave bands. If the two-surface comparison shows that sound levels measured in some octave bands are valid, sound power levels can be derived for these bands.

Observations by ear may sometimes be sufficiently conclusive to deduce whether sound-level measurements are valid. Wherever possible, such subjective conclusions must be supported by objective data.

In such cases, the measurement procedures in Section 2 and the calculation procedures in Section 3 may be modified as appropriate, and a clear explanation must then be included in the Test Report to justify the modifications. Data thus derived may be used in later calculations subject to approval by the Principal. Such modifications can be accepted only if it is impracticable to follow the full specified procedures.

2.6 Test Reporting

The Test Report shall incorporate the following information:-

- (a) Results of the preliminary survey and reasons for the choice of measuring surfaces.
- (b) All readings taken.
- (c) Relevant data on the corrections made to the recorded readings for background or environmental effects.
- (d) Directivity index.
- (e) Presence of any impulsive or narrow-band noise components.
- (f) A scaled drawing or dimensioned sketch showing the locations of readings for the equipment under test, and any features of the test environment capable of affecting the sound field around the equipment.
- (g) Operating conditions of the equipment under test.
- (h) The derived sound-power levels together with the relevant calculations.
- (i) Notes indicating deviations from the specified procedures and the reasons for them.

PART 3: CALCULATION METHODS AND PROCEDURES

3.1 General Calculations

3.1.1 General

- 3.1.1.1 The readings for each of the octave bands shall be considered separately.
- 3.1.1.2 All readings shall first be adjusted for background noise and then for reverberation.
- 3.1.1.3 Directivity index shall be taken into account when calculating sound-pressure levels, unless otherwise stated by the Principal. It will, however, be frequently found that reverberation in the environment or reflection from nearby surfaces will negate the effect of source directivity.
- 3.1.1.4 Calculations shall be performed to an accuracy of 0.1 dB and the final result shall be rounded to the nearest 1 dB.

3.1.2 Addition and Subtraction of Sound-Pressure Levels or Sound-Power Levels

The values in the following table may be used for adding sound levels obtained from measurements:

Difference in levels	0	1	2	3	4	5	6	7	8	9	10
Addition to higher level	3	2.5	2.1	1.8	1.5	1.2	1.0	0.8	0.6	0.5	0.4

In calculations, where levels are expressed to 0.1 dB, Fig. 8 (a) and (b) may be used for adding or subtracting sound levels. They are derived from the following equations:

$$L = 10 \log \left[\text{antilog} (L_1/10) + \text{antilog} (L_2/10) \dots + \text{antilog} (L_i/10) \dots + \text{antilog} (L_n/10) \right] \quad (\text{dB})$$

$$L = 10 \log \left[\text{antilog} (L_1/10) - \text{antilog} (L_2/10) \right] \quad (\text{dB})$$

Where L is the total or difference of the sound-pressure or sound-power levels, L_i , and n is the number of levels to be added.

3.1.3 Calculation of Mean Sound-Pressure Level

The mean sound-pressure level is calculated from the measurements at all relevant test positions by means of the equation:

$$\bar{L}_p = 10 \log \left\{ \frac{1}{n} \left[\text{antilog} (L_{p1}/10) + \text{antilog} (L_{p2}/10) \dots + \text{antilog} (L_{pi}/10) \dots + \text{antilog} (L_{pn}/10) \right] \right\}$$

Where L_{pi} = sound-pressure level at position i (dB).

n = number of test positions considered.

If the range of sound-pressure levels is less than 6dB, the arithmetic mean may be used:

$$\bar{L}_p = \frac{1}{n} (L_{p1} + L_{p2} + \dots + L_{pi} \dots + L_{pn})$$

3.1.4 Correction for Background Noise

Corrections may be made for background noise by subtraction employing Fig. 8, or by the approximate table:-

Increase in L_p with equipment operating	Correction to measured total L_p
dB	dB
3	-3
4-5	-2
6-9	-1
10-	0

When corrections of 3 dB are applied, the corrected levels shall be reported in brackets.

If the increase in L_p with the equipment operating is less than 3 dB, the measurements may be used only to indicate that the equipment noise level is below the background level.

3.1.5 A-Weighting

The values in the table below shall be used to convert linear octave-band levels to A-weighted levels.

Octave-band centre frequency (Hz)	31.5	63	125	250	500	1k	2k	4k	8k	16k
A weighting	-39	-26	-16	-9	-3	0	+1	+1	-1	-7

3.1.6 Calculation of Equivalent Continuous Sound Level

The following equation may be used to calculate the equivalent continuous sound level, L_{eq} , from a fluctuating series of sound-pressure levels or from an intermittent source.

$$L_{eq} = 10 \log \left\{ \frac{1}{T} [t_1 \cdot \text{antilog} (L_1/10) + \dots + t_i \cdot \text{antilog} (L_i/10) \dots + t_n \cdot \text{antilog} (L_n/10)] \right\}$$

Where,

L_i is a discrete noise level lasting for a period, t_i

$T = t_1 + \dots + t_i + \dots + t_n + t_0$ (the total observation time)

t_0 = the total period of silence for intermittent noise

3.2 Calculation of Sound-power Level

3.2.1 Small-Source Method

When sound-pressure levels have been measured according to the small-source method (2.4.1) the mean sound-pressure level (A-weighted and octave bands) is calculated according to 3.1.3. The sound-power level is calculated from the mean sound-pressure level by means of the equation:

$$L_w = \bar{L}_p + 10 \log S - E_2 = \bar{L}_p + 10 \log 2\pi r^2 - E_2$$

where the correction for reverberation E_2 is derived from 3.2.3 or Appendix A.

3.2.2 Large-Source Method

3.2.2.1 Calculation of Sound-power Level for a Conformal Surface

When sound-pressure levels have been measured on a conformal surface according to 2.4.2.3, the sound-power level L_w is calculated using the following equation:

$$L_w = (\bar{L}_p - E_1) + 10 \log S - E_2$$

Where,

L_w is the sound-power level.

$\bar{L}_p$ is the mean sound-pressure level over the measuring surface.

S is the area of the measuring surface.

E_1 is the near-field correction (see 3.2.2.3).

E_2 is the correction for reverberation (see Appendix A).

The near-field correction shall be applied first to estimate the crude sound-power level before deriving the correction for reverberation.

3.2.2.2 Calculation of Total Sound-power Level from Measuring-surface zones

When sound-pressure levels have been measured on several measuring-surface zones according to 2.4.2.4, the sound-power level L_{wi} for each zone i is calculated, using the following equation:

$$L_{wi} = (\bar{L}_{pi} - E_{1i}) + 10 \log S_i$$

where,

$\bar{L}_{pi}$ is the mean sound-pressure level over the zone, i .

S_i is the area of the measuring-surface zone.

E_{1i} is the near-field correction for the zone (see 3.2.2.3).

The total sound-power level for the equipment, L_w shall be obtained by summing the values of L_{wi} for each zone using 3.1.2. A reverberation correction, E_2 , derived from Appendix A shall be applied to L_w when necessary.

3.2.2.3 Near-Field Correction

When sound-pressure levels have been measured according to the large-source method (2.4.2) a geometric near-field correction has to be applied because of the small measuring distance relative to the source dimensions (see CONCAWE Report 2/76).

The correction depends on the angle subtended at the microphone by the source surfaces but, for convenience, it can be determined from the value of the quotient, Q , which is defined as the area of the reference surface divided by the area of the measuring surface.

The value of the near-field correction, E_1 , to be subtracted from the sound-pressure level can be read from the following table:

Q	E_1
$0.9 < Q < 1$	3 dB
$0.7 < Q < 0.9$	2 dB
$0.4 < Q < 0.7$	1 dB
$0.0 < Q < 0.4$	0 dB

3.2.2.4 Deriving a Conformal Surface from a Cuboid

When the measuring surface is a conformal surface which envelopes the source, as in Fig. 2(a), it may be convenient to locate the measuring positions on a cuboid as in Fig. 2(b). The corresponding conformal surface has rounded corners and edges and its area can be obtained from the area of the cuboid, S_c , by using the correction factor, F . The area, S , in the equation of 3.2.2.1 is then given by:

$$S = S_c F$$

where,

$$S_c = (l_1 l_2 + 2l_2 l_3 + 2l_1 l_3) + 4d(l_1 + l_2 + 2l_3) + 12d^2$$

$$F = (l_1 + l_2 + 2l_3 + 6d)/(l_1 + l_2 + 2l_3 + 10d)$$

and l_1, l_2, l_3 are the length, width and height of the reference surface and d is the measuring distance. The first term in brackets is the area of the reference surface.

(Note: The surface S is equivalent to the conformal surface in ISO 3744.)

Alternatively S_c may be used directly in the equation in conjunction with an additional correction factor, E_3 , so that the sound-power level is given by:

$$L_w = (\bar{L}_p - E_1 + 10 \log S_c - E_3) - E_2$$

where,

$$E_3 = -10 \log F$$

Values for E_3 may be derived from Fig. 7 but for sources where the ratio, Q , of the reference surface area to the area of the measuring-surface cuboid is less than 0.7, it is found that the sum of the corrections E_1 and E_3 is approximately 2 dB. The above equation can then be simplified to:-

$$L_w = (\bar{L}_p + 10 \log S_c - 2) - E_2 \quad (\text{for } Q \leq 0.7)$$

and where the ratio, Q , is greater than 0.7

$$L_w = (\bar{L}_p + 10 \log S_c - 3) - E_2 \quad (\text{for } Q > 0.7)$$

The corrections E_1 and E_3 shall be applied first to estimate the crude sound-power level before making the check for reverberation.

3.2.3 Correction for Semi-reverberant Test Environment (Two-surface Method)

If the check on the suitability of the test environment indicates that the sound-power levels from the larger measuring surface, S' , are more than 2dB higher than those from the smaller measuring surface, S , a correction term, E_2 , may be calculated by the following method (Ref: Diehl).

- (a) Determine the crude sound-power levels L_{wa} and L'_{wa} from the two measuring surfaces:

$$L_{wa} = \bar{L}_p + 10 \log S - E_1 \quad (\text{smaller surface})$$

$$L'_{wa} = \bar{L}'_p + 10 \log S' - E'_1 \quad (\text{larger surface})$$

- (b) Determine the ratio of the areas of the larger to the smaller surface, S'/S .
 (c) Determine the difference of the sound-power level on each surface $L'_{wa} - L_{wa}$
 (d) Enter the values of S'/S and $L'_{wa} - L_{wa}$ into Fig. 4 and determine the environmental correction factor, E_2 .
 (e) Subtract E_2 from the sound-power level calculated from the smaller surface.

$$L_w = L_{wa} - E_2$$

This correction is not valid when both measuring surfaces lie in the reverberant-field region of the room so that $\bar{L}_p$ and $\bar{L}'_p$ represent estimates of the same reverberant noise field. It shall not be applied, therefore, when the difference $\bar{L}_p - \bar{L}'_p$ is less than 2dB.

To obtain a greater difference it may be necessary to decrease the distance of the first measuring surface below the minimum of 1 m. This will introduce errors due to the acoustic near field and a note shall therefore be made in the Test Report. In any case measurements shall not be made at a distance of less than 0.25m. If the difference in sound-pressure levels is still less than 2dB, an approximate estimate of the sound-power level can be obtained by the method described in Appendix A.

3.2.4 Calculation of Sound-Power Level from Vibration Measurements

The sound-power level radiated from a vibrating surface can be estimated by means of the equation:

$$L_w = \bar{L}_v + 10 \log S + 10 \log \sigma$$

where $\bar{L}_v$ is the mean vibratory-velocity level (dB)

S is the area of the vibrating surface (m²)

σ is the radiation ratio

In many practical situations the radiation ratio is nearly unity and these are indicated in Appendix B; the above equation then simplifies to:

$$L_w = L_v + 10 \log S$$

When the radiation ratio is less than unity there will be an over-estimate of the sound-power level (because $\log \sigma < 0$). It is not within the scope of this specification to prescribe rules for determining the radiation ratio so sound-power levels derived from such vibratory-velocity measurements shall be recorded in the Test Report with a note that they may be higher than the true sound-power level.

3.2.5 Calculation of the Sound-Power Level of Linear Sources

The sound-power level radiated from a linear source can be estimated from the following equation:

$$L_w = (\bar{L}_p - E_1 + 10 \log S + 10 \log l) - E_2$$

where,

$\bar{L}_p$ is the mean sound-pressure level measured at a radius r from the axis of the source.

S is the area of a measuring surface of unit length given by $2\pi r$ for a cylinder and πr for a half cylinder.

l is the length of the source.

E_1 is the near-field correction (see below).

E_2 is the correction for reverberation (see Appendix A).

The correction for near-field error depends on the ratio of the radius, r , and the source length, l , and the following values shall be used:

r/l	E_1
$r/l < 0.08$	2dB
$0.08 < r/l < 0.24$	1dB
$0.24 < r/l < 0.40$	0dB
$0.40 < r/l < 0.58$	-1dB
$0.58 < r/l < 0.80$	-2dB

Note: For ratios of r/l greater than 0.8 the source can be treated as a small source.

The near-field correction shall be calculated for each measuring surface to derive the values of sound-power level used to check for reverberation.

The above table is based on the following equation:

$$L_w = \bar{L}_p + 10 \log 2\pi r l - 10 \log \theta$$

where,

$$\theta = \arctan (l/2r)$$

$$r/l < 0.8$$

3.2.6 Calculation of Sound-Power Level at a distance from an Opening or Fan Intake or Discharge

When measurements are made at a distance, d , from an opening, or fan intake or discharge, to minimise the effect of air flow, the area of the opening is no longer appropriate for the area of the measuring surface. The following equation shall then be used to derive the required surface area,

$$S = \pi (a^2 + d^2)$$

where a is the radius of a circular opening or half the diagonal of a square opening.

The near-field correction, E_1 , may be derived from the following table:

a/d	E_1
$a/d < 0.8$	0dB
$0.8 < a/d < 2.3$	1dB
$2.3 < a/d < 8.2$	2dB
$8.2 < a/d$	3dB

The above table is based on the following equation:

$$L_w = \bar{L}_p + 10 \log \pi (a^2 + d^2) - 10 \log (2 (1 - \cos \theta) / \sin^2 \theta)$$

where,

$$\theta = \arctan a/d$$

Note: This procedure is not applicable to duct openings of small diameter relative to the wavelength where $a/\lambda < 1$. Nor can it be used when the air velocity is too great to allow measurements on the axis. In these cases an approximate estimate of sound-power level must be obtained from measurements on a hemispherical surface centred on the opening, applying the principles of the small-source method.

3.2.7 Calculation of Directivity Index

3.2.7.1 Small Sources

The directivity index D for a small source in a given direction is calculated from

$$D = L_p^* - \bar{L}_p$$

The value of D and the approximate angle over which it extends can be derived directly from the measurements made on the two measuring surfaces, provided they are made in the free field (this is the case where the environmental correction in 2.4.1.5 is zero).

The directivity index shall be quoted whenever the variation in sound pressure around the equipment is in excess of 6dB. The directions of the index shall be clearly identified relative to the equipment concerned.

3.2.7.2 Large Sources

The measuring surfaces around large sources are too close for a consistent radiating pattern to be established from measurements of sound-pressure level. This means that the directivity index cannot be derived directly from these measurements as with a small source. Nevertheless, large sources are commonly the major individual contributors to the total sound-power level of a plant so their directivity index is likely to be important. It must therefore be derived from the differences in sound-power level in various directions, using the method given in Appendix G.

3.3 Calculation of Sound-pressure Levels from Sound-power Levels

3.3.1 Aspects of Sound Propagation

3.3.1.1 Hemispherical Radiation

As sound propagates from the source its intensity decreases in inverse proportion to the surface area over which the energy is distributed. On the basis of this "geometrical attenuation" the sound-pressure level L_p at a distance r from a source on a reflecting surface (such as the ground) with sound-power level L_w can be calculated as follows:

$$L_p = L_w - 10 \log (2\pi r^2) = L_w - 20 \log r - 8$$

Implicit in this formula is the assumption that the source is small relative to the measuring distance, that it is on the ground, that it radiates evenly in all directions (hemispherical radiation) and that the environment is free from reflecting surfaces other than the ground.

The value of $(20 \log r - 8)$ is given by the straight line plotted in Fig. F1 for octave bands 1-3.

3.3.1.2 Spherical Radiation

For elevated sources where the sound waves are not influenced by reflections (such as reflected waves from the ground, for example) the following equation must be used to calculate the sound-pressure level at a distance, r .

$$L_r = L_w - 10 \log (4\pi r^2) = L_w - 20 \log r - 11$$

3.3.1.3 Reverberation Effects

When a source is mounted in an enclosed or semi-enclosed space, sound will reflect from the walls. The space can be divided into two regions: the free-field region near the source, where the contribution of the reflected waves is negligible; and a reverberant region farther from the source, where the level of its direct radiation is low compared to that of the reflected waves. Where the transition occurs depends on the total surface area of the "room" and its average sound-absorption coefficient.

At any point in the room a distance r from a noise source, the sound-pressure level is a function of the direct radiation and the reverberant noise and is calculated from:

$$L_p = L_w + 10 \log (1/(2\pi r^2) + 4/R)$$

where,

L_p is the sound-pressure level at the distance, r

L_w is the sound-power level of the source (assumed to be on the ground)

r is the distance from the source

R is the room constant defined by $R = S \bar{\alpha} / (1 - \bar{\alpha})$

S is the total area of the room surface

$\bar{\alpha}$ is the average absorption coefficient.

The average absorption coefficient of the room is calculated from the absorption coefficients of the various surfaces (see Appendix A). For partly enclosed spaces the opening should also be counted as surface areas with an absorption coefficient of unity. The difference $L_p - L_w$ may be calculated from the above equation, but for many purposes it will be sufficient to obtain it from Fig. 5. This gives the differences for various values of the room constant, R and distance, r.

When there are several noise sources in the room their contributions to the sound-pressure level at any point are added according to 3.1.2.

It should be noted that the above equation is based on the assumption of point sources on a reflecting plane and gives reduced accuracy in the near field of large sources.

Full details of the calculation method are given in Beranek (Chapter 9) and Sharland (Chapter 4).

3.3.1.4 Sound-pressure Levels near a Large Source

When sound levels are to be calculated at a distance smaller than twice the typical source dimension D_0 , the formula of 3.3.1.1 cannot be used. Maekawa has published a rigorous method for determining the sound-pressure level at points within the geometric near field of a large source; but in many cases an approximate method may be sufficient. This is illustrated in Fig. 6 and makes use of an interpolation between the noise level variation with distance in the near and far field of the source.

Near the source, the sound-pressure level does not vary much with distance and may be represented as a horizontal line on the graph. The level is taken as the sound-pressure level measured near the source (say, at a distance of 1 m). If this is not known, it may be calculated from the relation.

$$L_p = L_w - 10 \log S + E_1$$

where,

S is the area of the measuring surface on which the point lies (see 3.2.2.1).

In the far field, at a distance of $2D_0$ or greater from the centre of the source, the noise level varies as the inverse-square law and the source can be treated as a point source with a directivity index according to Appendix G. The sound-pressure level can be calculated according to 3.3.1.1 and the sloping section of the graph is drawn so that there is a 6dB decrease for each doubling of distance.

The two linear parts of the graph are then joined with a curved line which is used for estimating sound-pressure levels at intermediate distances.

3.3.2 Estimation of Noise Levels within the Plant Area

When estimating the noise at any given position of the site plan, the following should be observed:

3.3.2.1 If the position lies within a distance smaller than twice the typical source dimension D_0 , estimates of the noise level shall be made using the procedure of 3.3.1.4 and the relevant directivity index in that direction. In all other cases, and for small sources, hemispherical (or spherical) propagation may be assumed, and the values modified according to the directivity index.

3.3.2.2 The effect of reverberation and reflection shall at all times be allowed for (see 3.3.1.3).

3.3.2.3 Allowance must be made for the effects of barriers and reflecting surfaces. The method of calculation shall be agreed with the Principal.

3.3.2.4 It is not practicable to estimate the noise at all points within the site. The worst conditions in those areas likely to be in general use by personnel shall be considered.

3.3.3 Estimation of Noise Levels at Remote Areas

The estimation of noise levels at remote areas shall be made using the following procedure:

- (a) The sound-power levels of all items of equipment, groups of items, or units are to be considered.
- (b) The sound-pressure level contribution from each source shall be calculated for the point in the neighbourhood by using the appropriate attenuation for the distance from the source to the point.

The equation for geometrical attenuation is only valid for distances up to about 25m and beyond that distance other factors affect the attenuation. These must be taken into account in the calculation of the neighbourhood noise due to a source, and the sound-pressure level at a distance, r , must be calculated from the following equation:

$$L_p = L_w + D - K$$

where,

D is the directivity of the source

K is the sum of the attenuations due to geometrical, meteorological, and ground effects.

For the purpose of this specification the appropriate value of K shall be derived from the procedure given in Appendix F.

- (c) The total noise level is determined from the sum of the sound-pressure level contributions from each source.
- (d) The directivity index is to be taken into account as follows, unless otherwise specified by the Principal:
 - (i) for small sources within the plant it is to be ignored.
 - (ii) for small sources on the edge of the plant and for all large sources it is to be ignored if negative but taken into account if positive.

PART 4: NOISE LIMITS FOR COMPLETE PLANT

4.1 Broad-band Noise

The Principal shall specify separate noise limits for hearing conservation, speech and work interference, neighbourhood areas and accommodation according to the requirements of the plant. These limits shall be for steady broad-band noise and shall be specified as sound-pressure levels in octave bands and/or dB (A). For the neighbourhood-area noise control, the Principal may alternatively specify sound-power levels at his discretion. In each of these categories more than one set of limits may be specified for different areas or for different times of the day; in addition, separate limits may be specified for special operations of limited duration. These special operations may include:-

- (a) construction
- (b) pre-commissioning
- (c) start-up
- (d) infrequent operations of limited duration
- (e) emergency operations.

A model format for specifying noise limits for a complete plant is given in Appendix D.1.

4.2 Modifications for Narrow-band or Impulsive Noise

The Principal shall specify the modifications to the broad-band limits which are required when there is equipment in the plant with annoying characteristics such as narrow-band or impulsive components. The modifications for narrow-band noise refer only to the octave band or bands in which the characteristics occur.

There are three general methods for reducing the annoyance from narrow-band and impulsive noise and the Principal shall specify which of the following cases apply to the plant:-

- (a) Masking by broad-band noise from the plant under contract.
Where the characteristic noise can be masked by broad-band noise from other equipment in the plant under contract, the Principal shall specify the amount by which the noise contribution from the equipment emitting the characteristic shall be reduced below the broad-band noise. The relevant noise level below which the characteristic is to be reduced is the actual noise in the area (calculated or measured) and not the noise limit. This broad-band noise will relate only to the equipment in the contract.
- (b) Masking by broad-band noise from the plant under contract and other plants.
Where the characteristic noise can be masked by the combined broad-band noise from equipment within the contract and other equipment outside the contract, the Principal shall specify the amount by which the noise contribution from the equipment emitting the characteristic shall be reduced below the combined broad-band noise. In this case, the Principal shall specify the noise levels in the relevant areas due to equipment outside the contract. The Contractor shall be responsible for estimating the total noise resulting from the existing noise level and the actual noise level due to the plant in the contract.
- (c) Reduction of characteristic noise below noise limits.
Where the characteristic noise cannot be masked by broad-band noise, or it is undesirable to use masking, the Principal shall specify the amount by which the noise contribution from the equipment emitting the characteristic shall be reduced below the specified plant-noise limit for each area.
In cases (a) and (b) Appendix E gives the basis for setting limits for narrow-band noise where masking noise is available.

PART 5: EQUIPMENT NOISE LIMITS

5.1 Contractor's Specifications

The format given in Appendix D2 is recommended for use by the Contractor for specifying noise levels for individual items of equipment; it indicates the basic requirements for the noise specification and for the information to be provided by the Equipment Vendor and may need to be extended for large items of equipment. It may be applied to the separate components of a unit, such as the driver, gearbox and driven machine, or to the complete unit. When limits are specified for separate components they should be selected so that the combined noise does not exceed the appropriate work-area limits.

5.2 Locations for Limits

The sound-pressure levels will normally be specified at a minimum distance of 1 m from the equipment surfaces but greater distances may be specified for remote equipment such as vents. In some cases it may be required to specify the noise level at a specific location where an operator works. These limits will normally apply to all components of the equipment.

5.3 Equipment Components

Different sound-power levels may be specified for individual components, depending on the most economical and practical balance to meet the requirements for the whole equipment. The choice may be influenced also by the height of the components and its influence on the propagation of noise to neighbourhood areas.

5.4 Noise Control

Where standard equipment does not meet the Principal's noise limits the Equipment Vendor shall state what noise-control methods shall be used to modify the equipment. He shall be responsible for ensuring that the modified equipment still meets the other specifications for its operation, particularly with regard to temperature rise, ventilation, purging and fire safety.

5.5 Narrow-band and Impulsive Noise

Where the equipment emits narrow-band or impulsive noise the Contractor shall modify the noise limits in the relevant octave bands so that the Principal's requirements for narrow-band and impulsive noise are met. For work-area noise the modifications take the form of reductions in the sound-pressure level limits. For neighbourhood noise the modifications may take the form of specifying maximum sound-power levels in the relevant octave bands and these would apply to all items of equipment. These would be derived from the modified neighbourhood sound-pressure levels after applying the narrow-band reductions to the masking noise as described in 4.2 (a) and (b) (see Appendix D2).

5.6 Fluctuating or Intermittent Noise

For equipment emitting fluctuating or intermittent noise the equivalent continuous sound level, L_{eq} , over the most noisy consecutive 8 hours shall meet the specified limits. The maximum level shall not be more than 10dB higher than the limit for continuous noise.

5.7 Special Limits

Special limits shall be set for relief valves and vents which only operate occasionally. These shall be based on the need to control the noise exposure of adjacent personnel until they can move to a quieter area. However, the limits for items which operate infrequently but as part of normal plant operations (for example, depressurising valves) shall not exceed the general work-area limits.

PART 6: ACCEPTANCE TESTING

6.1 Noise Levels

6.1.1 General

The procedures used for the noise acceptance testing of completed plant shall conform with the requirements of this specification.

All measurements used for acceptance testing shall be made with a precision-grade sound-level meter (BS 4197 or IEC 651 Grade 1) unless otherwise agreed by the Principal and Contractor.

All such measurements shall be made with the relevant equipment operating under design operating conditions unless otherwise agreed by the Principal and Contractor.

The plant shall be deemed to meet the requirements of this specification if the noise levels measured, or calculated from measurements, do not exceed the appropriate limits. No excess is allowed for meter tolerance.

6.1.2 Work-Area Noise

The measured sound-pressure level in any work area shall not exceed the limit specified for the area at any position 1 m or more from the equipment surfaces, or at operators' work positions.

When noise from equipment for which the Contractor is not responsible affects the work-area noise level, the effect of this shall be determined and suitable corrections made to the measured total sound-pressure level. Such corrections shall be made using procedures in accordance with this specification.

6.1.3 Neighbourhood Noise

The noise level at a point remote from the source varies widely with meteorological conditions. Direct measurement of the sound-pressure levels in the appropriate area therefore should not be used as the basis of acceptance unless agreed by the Principal and Contractor.

For acceptance, the sound-pressure level at any distant location shall be calculated from equipment noise measurements. The procedure for such calculations shall be in accordance with this specification. The plant shall be deemed to meet the requirements if the calculated sound-pressure levels meet the specified limits.

If the Principal has specified sound-power level limits to control neighbourhood noise, the total sound-power levels of the individual equipment items shall be required to meet these limits.

6.2 Equipment Sound-Power Levels

The equipment shall be deemed to meet the noise limits set for it when the sound-power levels derived for it meet the limits. No excess is allowed for meter tolerance or for the reproducibility of the test method.

Where the Principal or Contractor has agreed to accept the results of test procedures other than those in this specification no excess is allowed for the quoted precision of the test procedure.

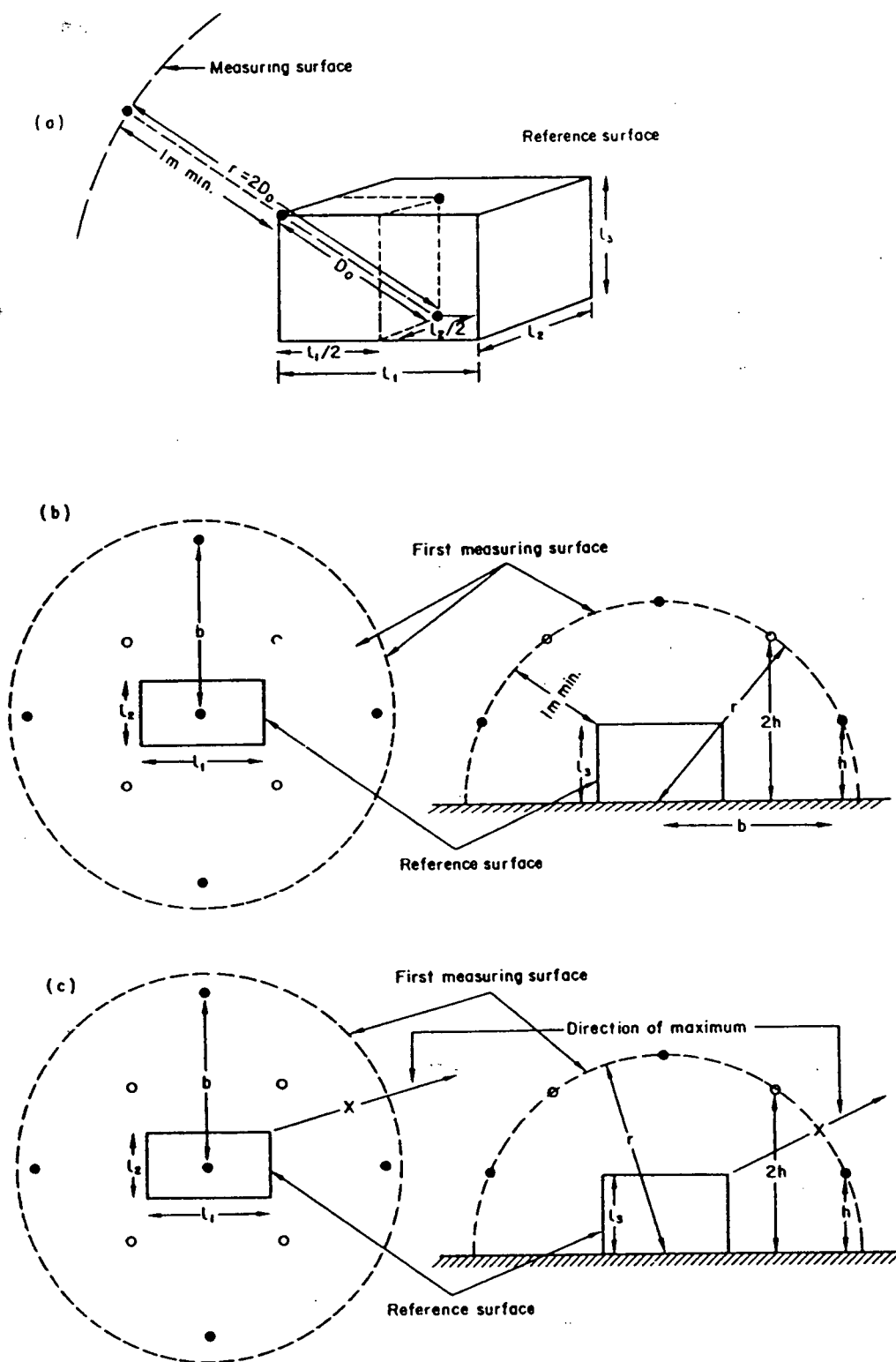


Fig. 1. Small-source method. (a) Determination of radius r of measuring surface. Minimum radius of measuring surface

$$r = 2D_0 = 2\sqrt{[(l_1/2)^2 + (l_2/2)^2 + l_3^2]}$$

(b) Measuring points. • Measuring points with overhead point. Preferred positions: $h = 0.4r$, $b = 0.9r$. ○ Additional measuring points to replace overhead point.

(c) Small-source method: measuring points for source with directivity. • Basic measuring points. Preferred positions: $h = 0.4r$, $b = 0.9r$. ○ Additional measuring points. X Point to measure maximum.

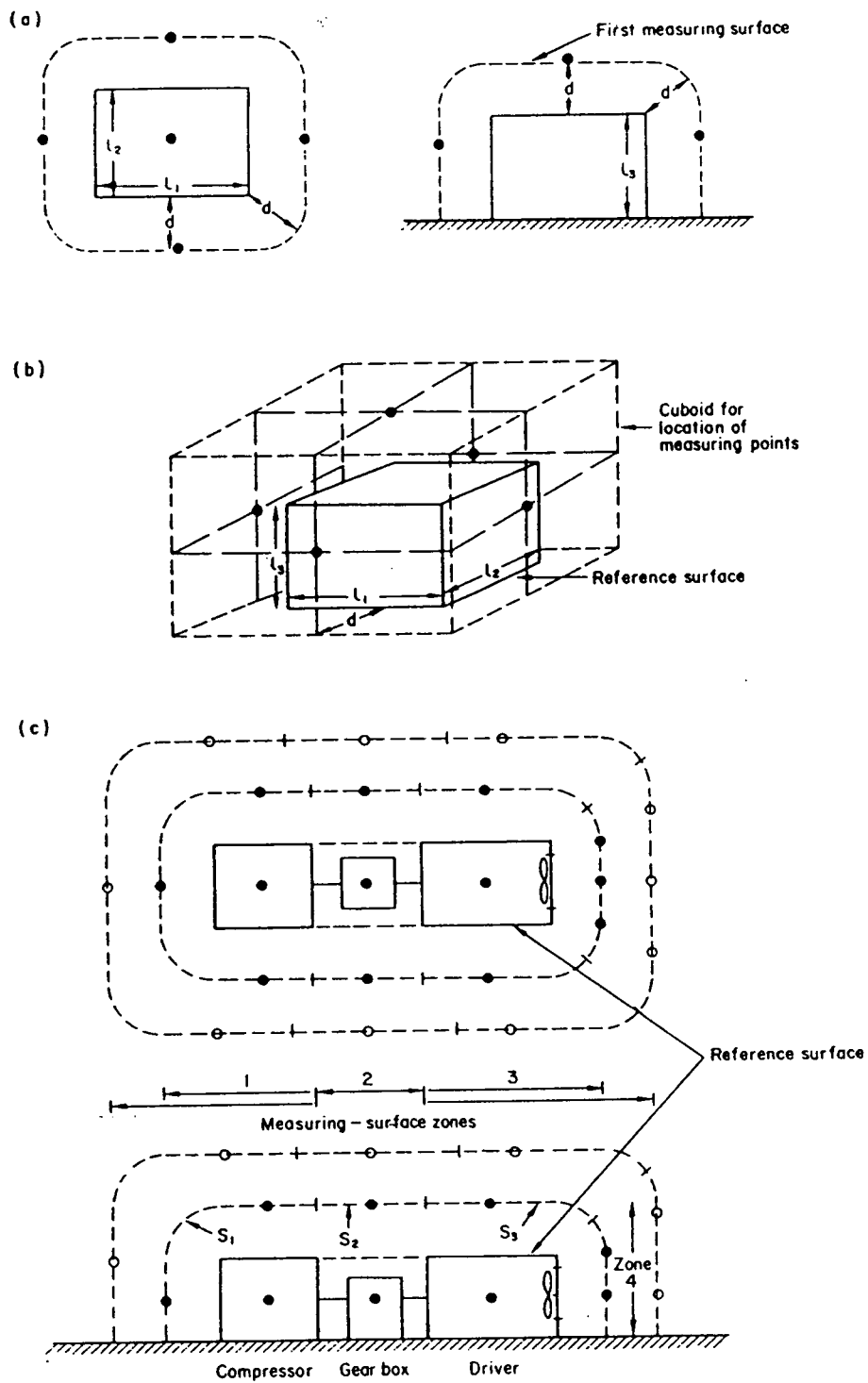


Fig. 2 — continued on next page.

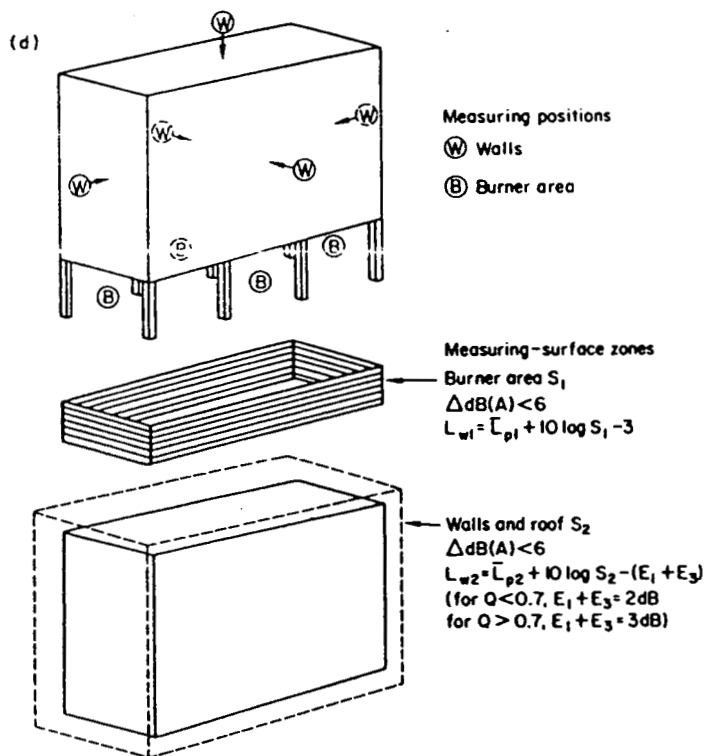


Fig. 2. Large-source method: source with evenly distributed radiation. (a) Conformal surface. (b) Measuring points. (c) Source requiring 4 measuring-surface zones, typified by compressor set with gearbox (with acoustic lagging on piping). • Measuring points - inner surfaces.

$$\left. \begin{aligned} L_{w1} &= (L_{p1} + 10 \log S_{p1} - 2) \\ L_{w2} &= (L_{p2} + 10 \log S_{p2} - 2) \\ L_{w3} &= (L_{p3} + 10 \log S_{p3} - 2) \\ L_{w4} &= (L_{p4} + 10 \log S_{p4} - 2) \end{aligned} \right\} \text{ for } Q < 0.7, \begin{cases} |L_{p1} - L_{p2}| > 6 \text{ dB} \\ |L_{p4} - L_{p3}| > 6 \text{ dB} \end{cases}$$

S_{p1} etc. = area of outward-facing surfaces of cuboid.

○ Measuring points - outer surfaces. Note: the measuring-surface zones on the outer surface may not be similar to those on the inner surface. (d) Source with unequal radiating surfaces, typified by floor-fired furnaces.

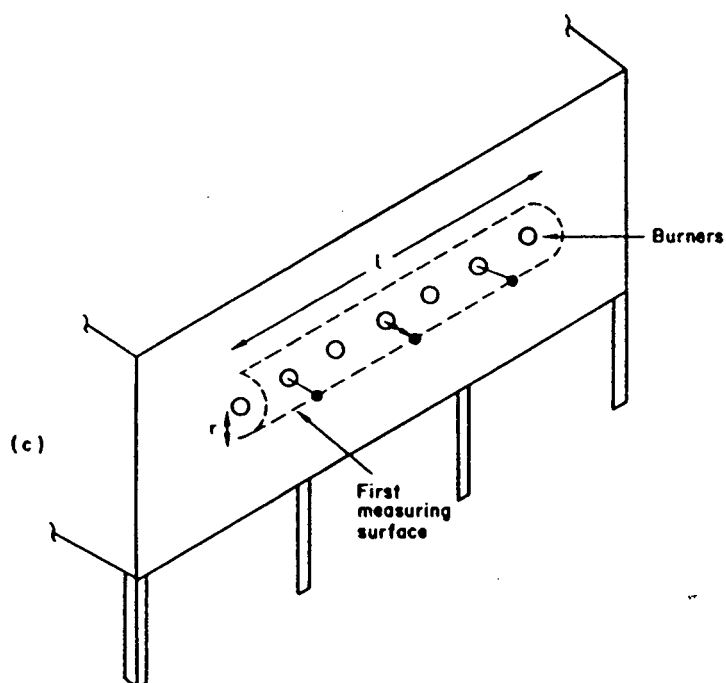
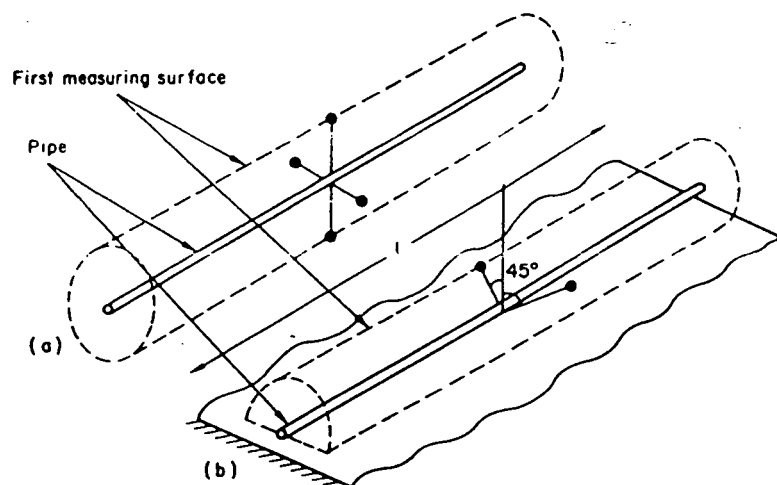


Fig. 3. Linear sources: typical measuring positions. (a) Overhead pipe (no reflecting surface), $S = 2\pi r$. (b) Pipe near reflecting surface, $S = \pi r$. For (a) and (b), $\Delta dB(A) < 6$. (c) Row of burners in wall-fired furnace (wall acting as reflecting surface). $\Delta dB(A) < 6$, $S = \pi r$. • Measuring positions.

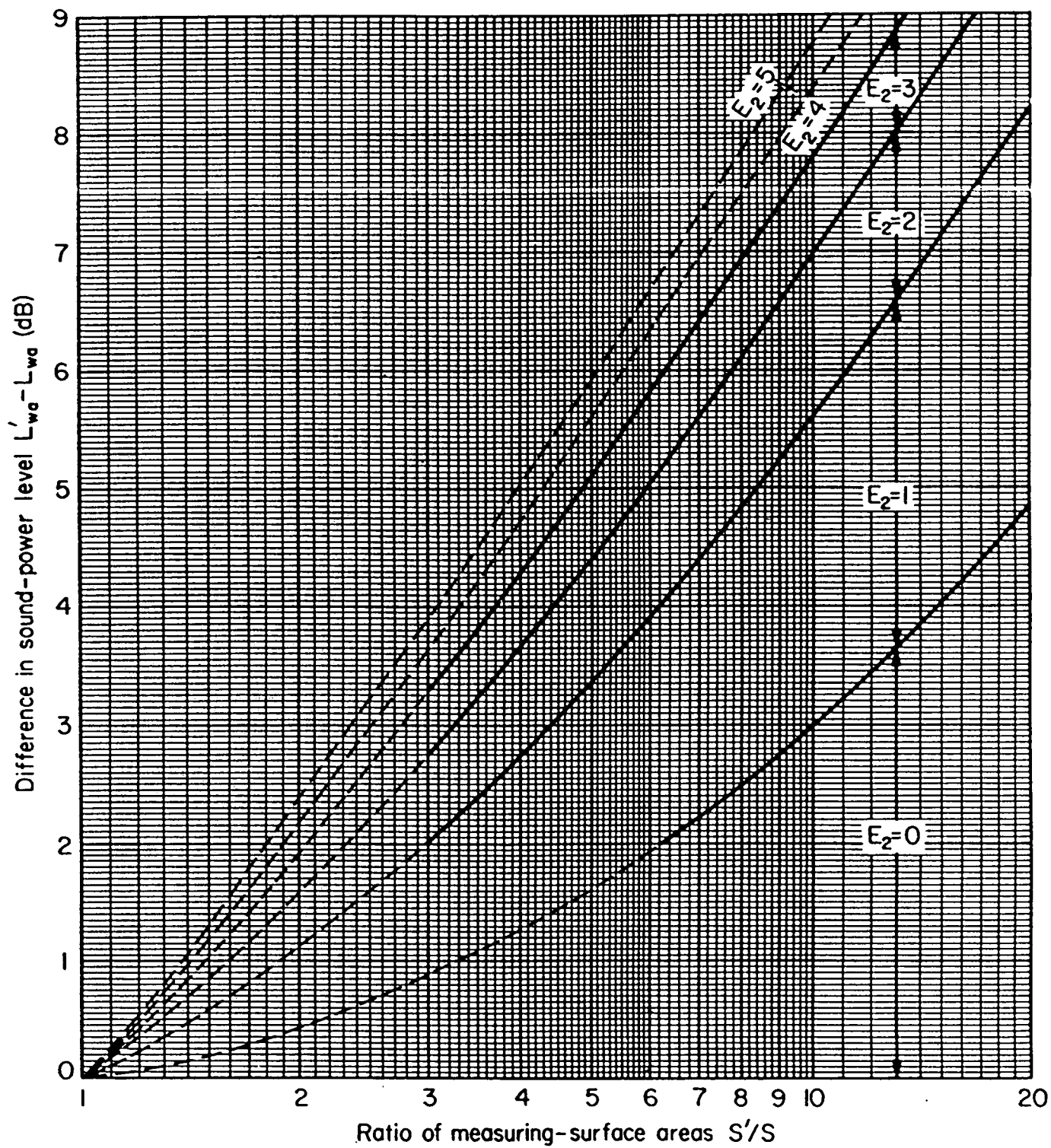


Fig. 4. Correction for semi-reverberant test environment (two-surface method).

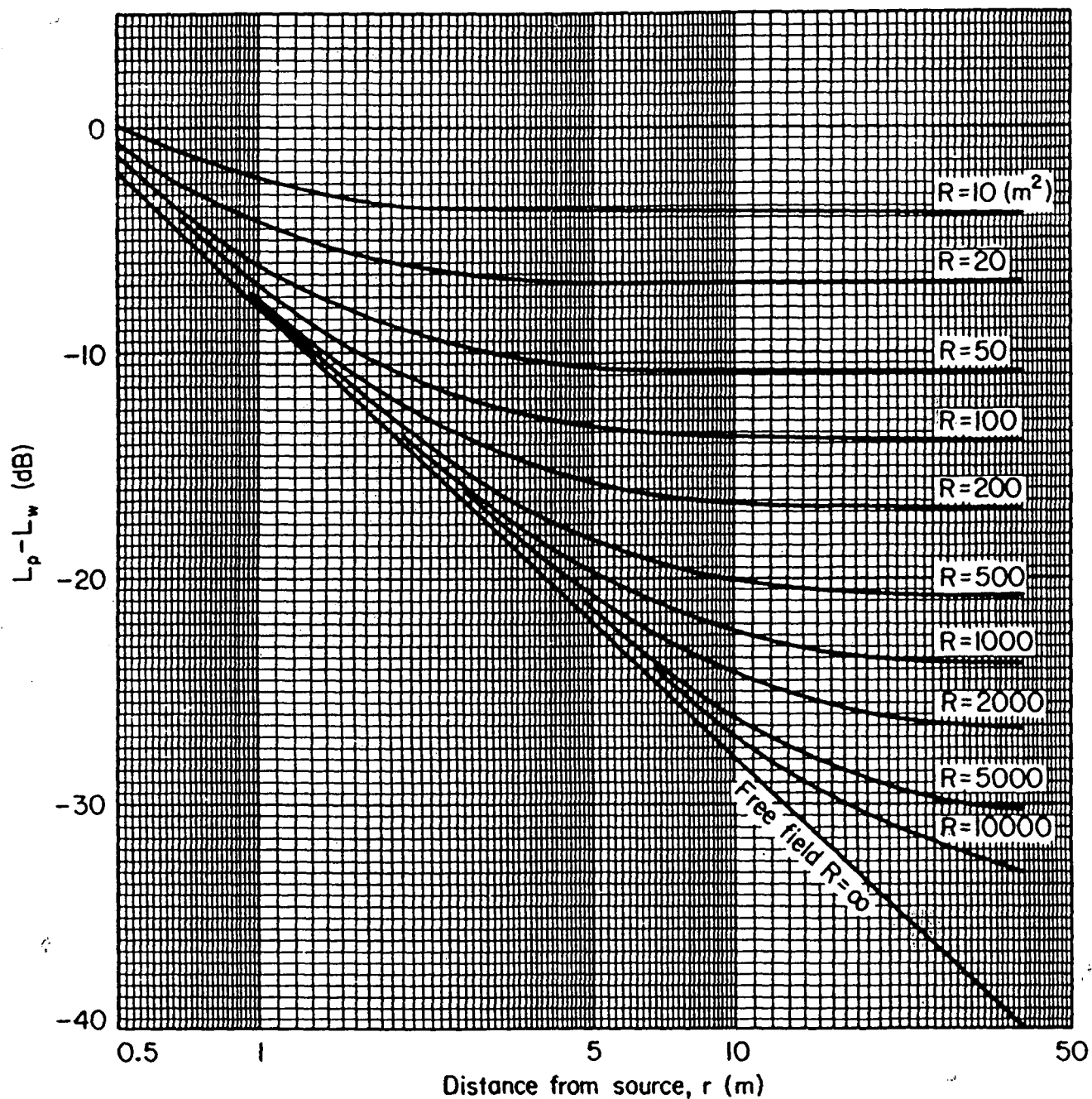


Fig. 5. Graphs for determining sound-pressure levels in a semi-reverberant room. Derived from $L_p - L_w = 10 \log (1/2\pi r^2 + 4/R)$, where L_p = sound-pressure level (dB) at distance r from source; L_w = sound-power level (dB) of source on reflecting surface; R = room constant (m^2).

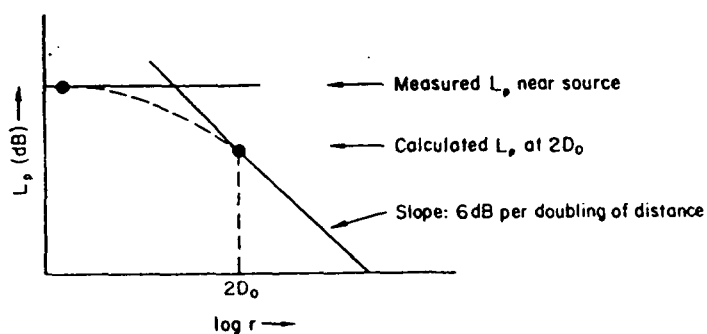


Fig. 6. Estimation of sound-pressure level near large sources (approximate method).

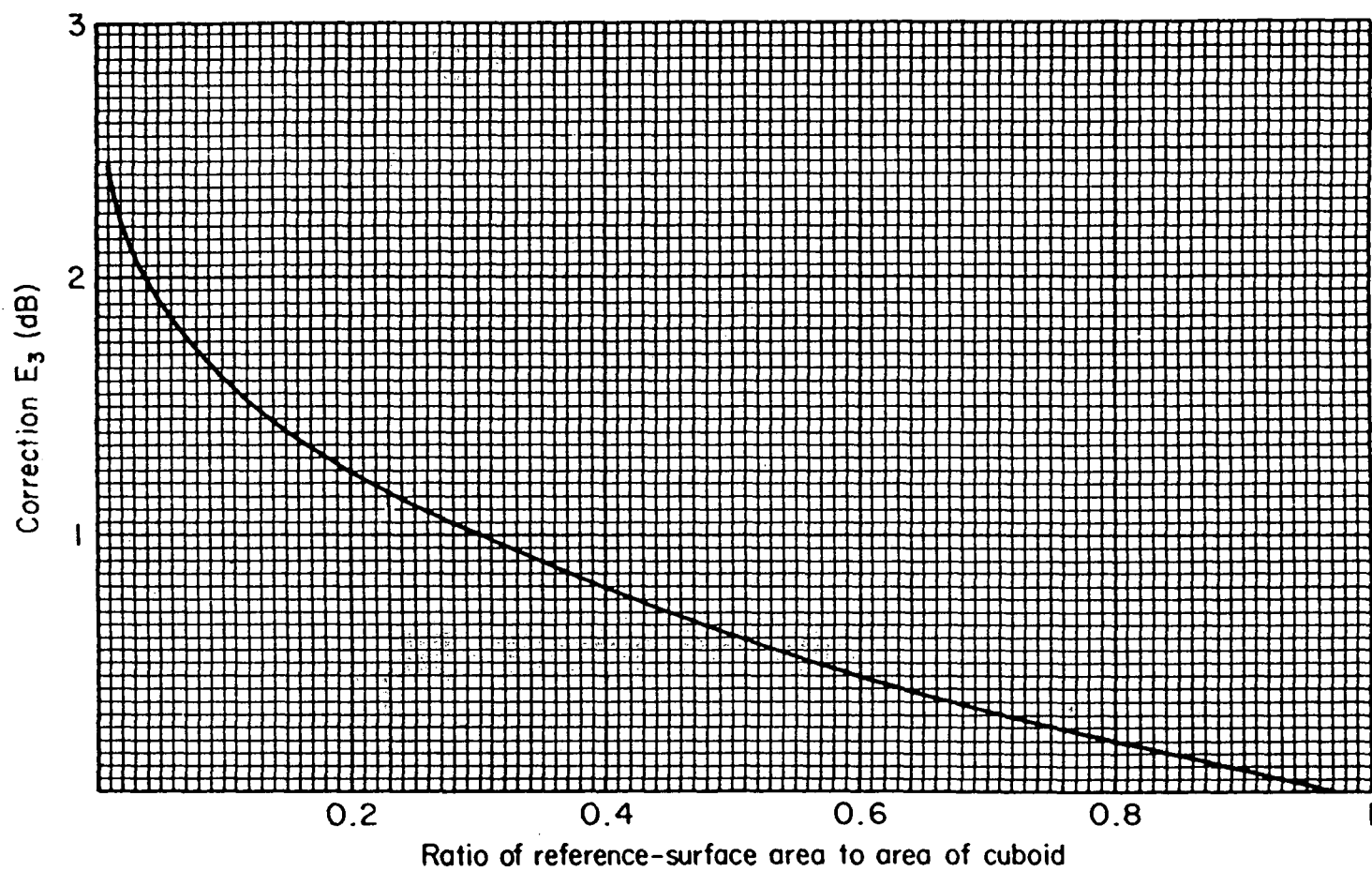


Fig. 7. Correction E_3 for a conformal surface from a cuboid.

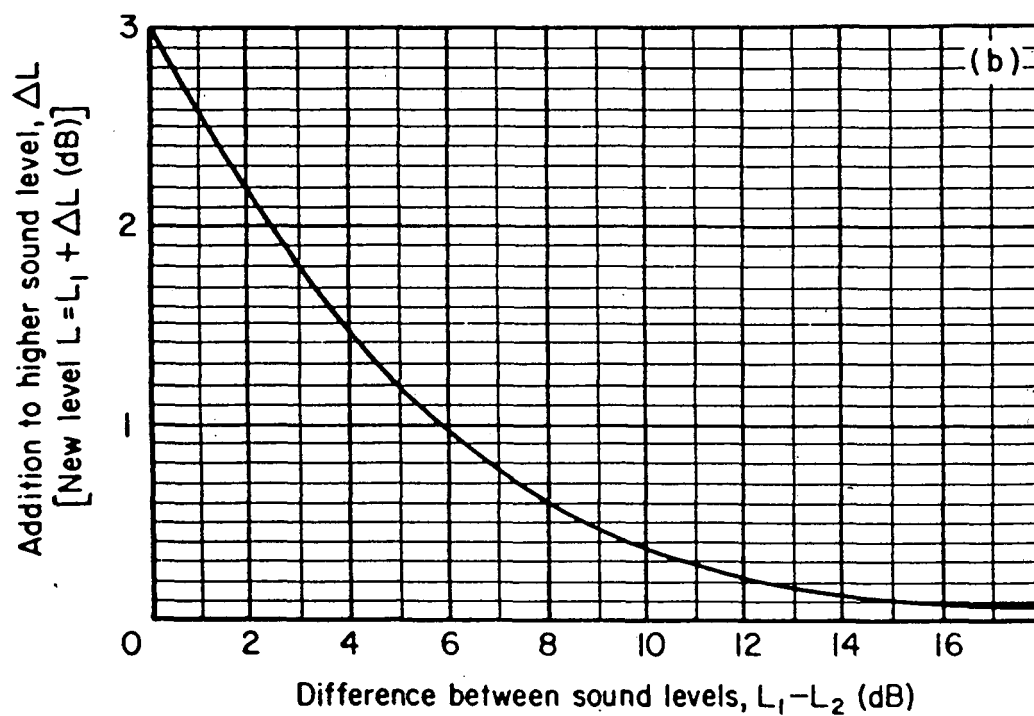
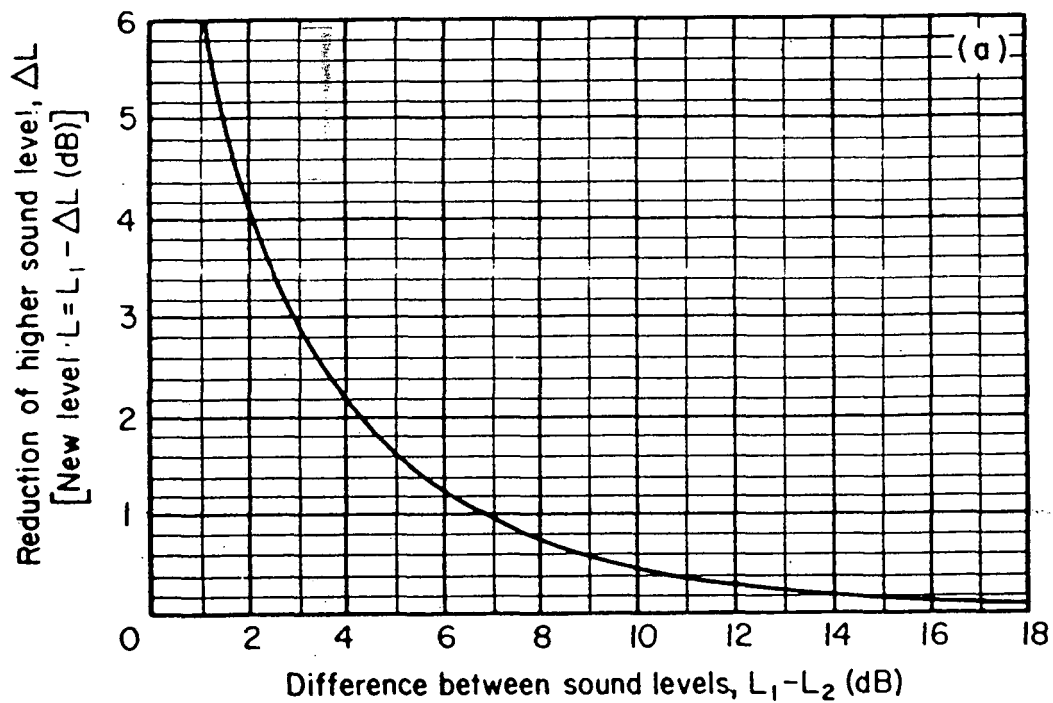


Fig. 8. Addition and subtraction of sound levels. (a) Subtraction of sound levels. (b) Addition of sound levels.

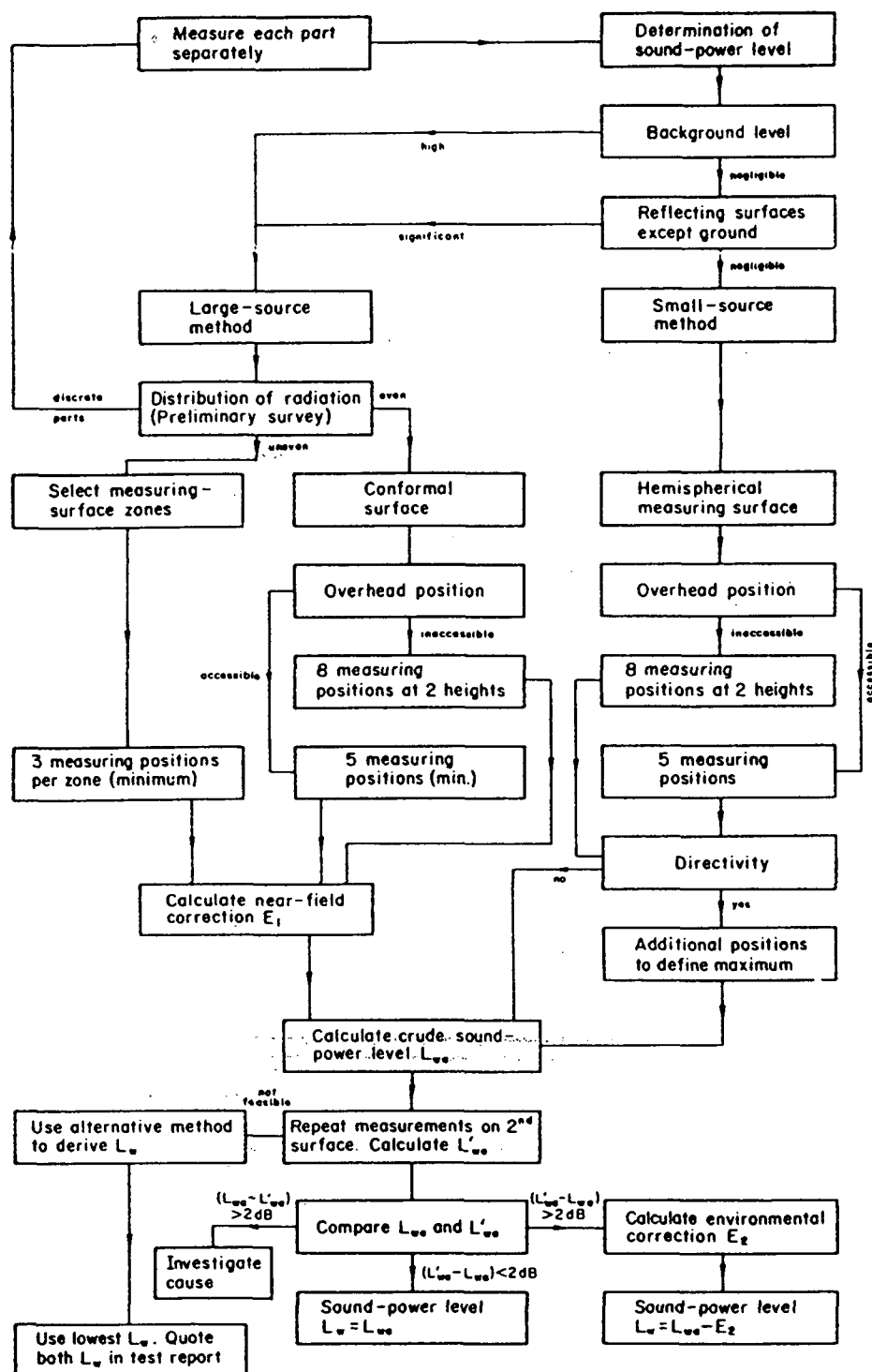


Fig. 9. Flow chart for determination of sound-power level.

APPENDIX A

Correction for a reverberant test environment based on the calculation of the room constant

When a machine is located in an enclosed space, reverberation effects should be taken into account when determining sound-power levels. Section 2.4.1.5 described the two-surface method to correct for reverberation. This appendix describes an alternative method, whereby it is required to estimate the sound absorbing properties of the space in which the machine is located. It is recommended that the correction should be calculated before taking measurements, as corrections can be applied only within a limited range from the machine, depending on "room" properties.

The room constant, R , of the space in which the machine is located shall, for the purpose of this specification be calculated as:

$$R = S \bar{\alpha} / (1 - \bar{\alpha})$$

Where,

$$\bar{\alpha} = (\alpha_1 S_1 + \alpha_2 S_2 + \dots + \alpha_i S_i + \dots + \alpha_n S_n) / (S_1 + S_2 + \dots + S_i + \dots + S_n)$$

α_i is the sound-absorption coefficient of surface S_i

S_i is area of a surface with constant acoustic properties.

The summation should also include surfaces other than walls, such as sound-absorbing pads suspended from ceilings etc. Openings in the walls and ceiling of the room shall also be taken into account, by assuming their sound-absorption coefficient to be unity.

The sound-absorption properties will usually be frequency dependent and the room constant will have to be calculated for each octave band separately.

The environmental correction factor E_2 depends on the ratio of the room constant and the surface area of the measuring surface:

$$E_2 = 10 \log (1 + 4S/R)$$

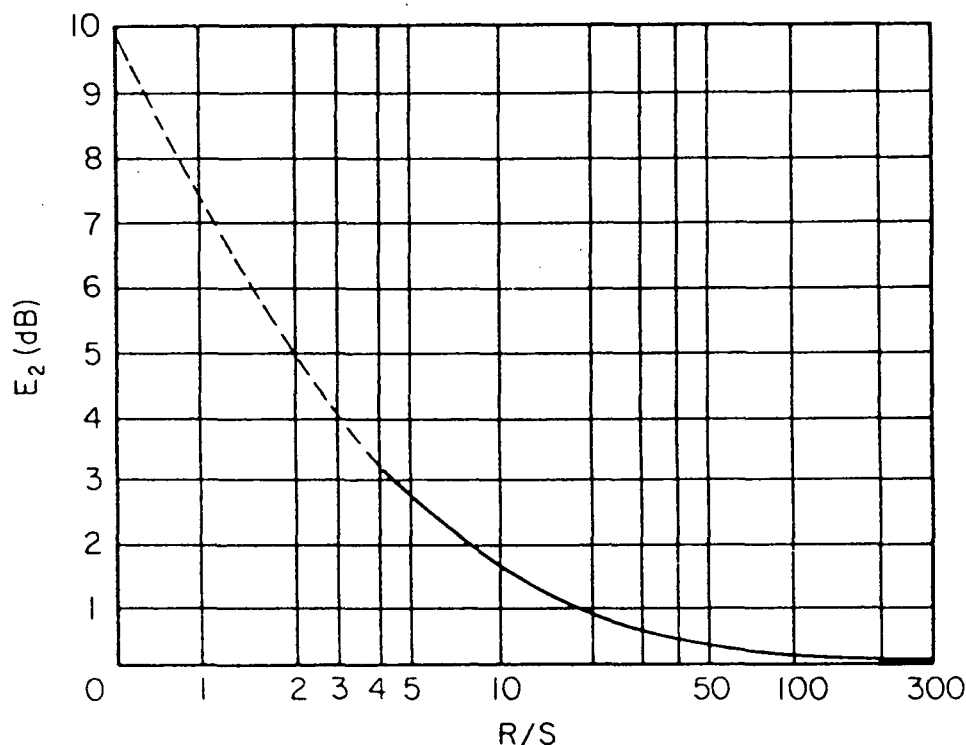


Fig. A1. Determination of correction E_2 for reverberant environment.

The value of E_2 can be read from Fig. A.1 and the corrected sound-power level is determined from:

$$L_w = L_{wa} - E_2$$

Where,

L_{wa} is the crude sound-power level calculated on the assumption of no reverberation.

For values of E_2 larger than 3 the measurement surface is in the reverberant field and the present procedure cannot be applied. If E_2 is larger than 3dB for some or all octave bands the measurement surface should be chosen closer to the machine or sound-absorbing material should be added (temporarily) in the test space to reduce reverberations.

If it is not practicable to increase the absorption of the test room and closer measuring positions are still in the reverberant sound field, it is possible to obtain an approximate estimate of sound-power level from the equation.

$$L_w = L_p - 10 \log (4/R)$$

Where $\bar{L}_p$ is the mean of sound-pressure level measurements made at least 1 m from the source or any reflecting surfaces. At least 5 measuring positions should be used, spaced around the source as in the small or large-source methods.

It should be noted that the precision of this determination depends on the correct assessment of the various absorption coefficients used to derive R . This will not normally be high where measurements are made in factories or machine rooms. The dimensions of the room should be roughly equal and the derivation of R becomes increasingly unreliable when one dimension exceeds the others by a factor of about 3. In this case the room constant must be determined by more sophisticated methods which are outside the scope of this specification and specialist advice should be sought.

APPENDIX B

The Use of a Sound-Level Meter for making Vibration Measurements

Some commercial sound-level meters can be fitted with accelerometers and be used for making vibration measurements. The transducer normally measures vibratory acceleration but, by using an integrator in the input to the sound-level meter, it is possible to measure vibratory velocity or displacement. For the purpose of this Specification the vibratory velocity is the parameter of interest and this appendix summarises the method of measuring this with a sound-level meter. It assumes throughout that an integrator set to velocity is used in conjunction with the accelerometer. However it should be noted that if the integrator has a low output signal an accelerometer preamplifier may be necessary to avoid signal-to-noise ratio problems. The equipment manufacturer should therefore be consulted.

B1 The Radiation Efficiency of a Randomly Vibrating Plate

The sound power radiated from a randomly vibrating plate is related to the surface average of the root-mean-square vibratory velocity through the radiation efficiency (or radiation ratio), σ . The value of σ depends on the mechanism causing the vibrations; three conditions may be distinguished and are described below. It is not within the scope of this specification to prescribe rules for determining the radiation efficiency in the situation described in (b) and (c) so sound-power levels derived from such vibration measurements should be recorded with a note that they may be higher than the true sound-power level.

(a) Excitation by Air-borne Sound Waves

In this case the radiation efficiency is nearly equal to unity and in the equation for determining sound-power level,

$$L_w = L_v + 10 \log S/s_0 + 10 \log \sigma$$

the final term $10 \log \sigma$ equals zero.

This equation is therefore applicable to cases such as furnace walls, pipes and ducting where the vibrations are excited by an internal sound field. However, for plates fixed at the edges, the value of σ reduces increasingly below unity as the frequency reduces below the critical frequency. This effect is particularly marked with large undamped plates (due to the plate resonances), and the assumption that σ is unity is most reliable for small damped plates or plates which are subdivided by ribbing. Similarly, for pipes, the value of σ reduces increasingly below unity as the frequency reduces below the critical frequency. In these cases the calculated sound-power level will therefore be an overestimate of the true sound-power level and a note should be made in the Test Report.

(b) Excitation by a Distant Vibrator

In this case the vibrations in the plate will be due to free bending waves and the radiation efficiency depends upon frequency; below the critical frequency of the plate the radiation frequency will be considerably less than unity; above the critical frequency it will tend towards unity as the frequency increases.

This case could arise with forced draught ducting in the neighbourhood of the fan where the vibrations are excited by mechanical vibration of the fan or its driver.

(c) Excitation by a Point or Line Source in the Plate

Here again, the radiation efficiency depends on frequency - whether it is above or below the critical frequency of the plate; it also depends on the distance from the source.

This case could arise with noise radiated by vibrations in a wall excited by the supports of a noisy pipe, or from a floor on which a machine is standing.

B2 Calibration and Measurements

The meter may be provided with a separate scale for measuring the vibratory velocity directly and it can be calibrated using a vibration exciter table or, if this is not available, with reference to

an internal voltage. Alternatively, a decibel scale may be used in the meter and the velocity level may be measured. The meter can then be calibrated acoustically with a pistonphone or similar device, but a correction to the meter reading must be made to allow for the sensitivity of the accelerometer.

These two methods are described below.

B2.1 The Measurement of Vibratory Velocity

B2.1.1 Calibration

Most sound-level meters have an internal reference voltage against which the meter can be calibrated and, for measurements in the field, this is often the only means of calibration. The method for doing this will depend on the design of the meter and the manufacturer's instructions must be followed; in principle it involves adjusting the sensitivity correction of the meter to match the voltage sensitivity of the accelerometer (normally quoted in mV/g).

It is good practice however to check the calibration of the meter by means of a vibration exciter table and, where possible, this should be done before and after a series of measurements.

Such a table provides a quoted value of peak acceleration at a particular frequency and this must therefore be converted to the equivalent velocity level.

Example

Frequency of table,	f	$= 79.6 \text{ Hz}$
$\omega = 2 \pi f$		$= 500 \text{ rad/s}$
Peak acceleration		$= 1g (= 9.81 \text{ m/s}^2)$
RMS acceleration	a	$= 9.81 / \sqrt{2}$
RMS velocity $= a/\omega$		$= 9.81 / (500 \sqrt{2})$
	v	$= 0.014 \text{ m/s}$
Velocity level	L_v	$= 20 \log v/v_0$
		$= 109 \text{ dB}$

B2.1.2 Measurements

The method of mounting the accelerometer on the surface to be measured influences the frequency response of the accelerometer and gives an upper limit to the frequency range over which it can be used. Ideally, the accelerometer should be mounted on a steel stud to give the widest frequency range, but these are rarely available. The next best method is to attach it to the surface with an adhesive or wax, or with a magnet; but this may limit the region of flat response to below 5kHz, so it is important to ascertain the frequency characteristic for the particular mounting method. Readings should not be made above the upper limit of flat response.

The use of an integrator to convert acceleration to velocity introduces a frequency dependent characteristic into the response of the system, arising from the effect of integration, namely:-

$$v = a/\omega$$

This means that readings of acceleration must be adjusted for frequency in order to be used for velocity. However, this can usually be done by using the appropriate velocity scale in the meter and the above equation need only be used with meters which do not have alternative scales.

B2.2 The Measurement of Vibratory-Velocity Level

B2.2.1 Calibration

If the sound-level meter is only provided with a dB scale, or it is preferred to use this to measure velocity level, the meter may be calibrated acoustically using the microphone and a pistonphone or similar device. However, this sets the sensitivity correction to match the sensitivity of the microphone and the readings must be adjusted to match the sensitivity of the accelerometer. The following correction must be used:-

$$L_v = L_m + 20 \log ((s_p \cdot p_0) / (\omega_0 \cdot s_a \cdot v_0))$$

Where,

$$L_v = \text{velocity level} \quad (\text{dB})$$

$$L_m = \text{meter reading} \quad (\text{dB})$$

$$s_p = \text{microphone sensitivity} \quad (\text{mV} \cdot \text{m}^2 / \text{N})$$

$$p_0 = 2 \times 10^{-5} \quad (\text{N/m}^2)$$

$$\omega_0 = 2\pi f_0 \quad (\text{rad})$$

$$s_a = \text{accelerometer sensitivity} \quad (\text{mV} \cdot \text{s}^2 / \text{m})$$

$$v_0 = 5 \times 10^{-8} \quad (\text{m/s})$$

and f_0 is the virtual frequency of the integrator where the response curve for velocity intersects the response curve for acceleration.

Example

The following characteristics can be typical for a sound-level meter and accelerometer:-

$$s_p = 50 \quad (\text{mV} \cdot \text{m}^2 / \text{N})$$

$$f_0 = 4 \quad (\text{Hz})$$

$$\omega_0 = 25 \quad (\text{rad})$$

$$s_a = 60 \quad (\text{mV/g})$$

$$s_a = 6.12 \quad (\text{mV} \cdot \text{s}^2 / \text{m})$$

$$L_v = L_m + 20 \log ((50 \times 2 \times 10^{-5} \times 10^8) / (25 \times 6.12 \times 5))$$

$$L_v = L_m + 42 \quad (\text{dB})$$

B2.2.2 Measurements

The advantage of using the sound-level meter in this mode is that it can be conveniently changed from noise to vibration measurements by substituting the accelerometer and integrator for the microphone. No change of scale or adjustment of sensitivity correction is necessary. The same restrictions apply for frequency range according to the method of accelerometer mounting as discussed in B.2.1.2.

APPENDIX C

Contour Methods for determining the Sound-Power Levels of Complete Plants

The procedure described in this specification is based on considering each item of equipment in a plant individually and assessing its contribution to the noise level at a distant point, which means taking into account the particular attenuation between the source and the point. For a noise source in the middle of the plant this involves the attenuation within the plant itself, and the ground-effects curves of Figs.F2 and F3 include an allowance for this. However, it is not always possible to determine the sound-power levels of individual noise sources in existing plants where the equipment is close together and it may be necessary to determine the sound-power level of the plant as a whole, treating it as a single source. But the sound-power level determined in this way is not equivalent to the sum of the sound-power levels of the individual sources because it includes the effect of attenuation within the plant; it may therefore be expected to be lower. If it is used in conjunction with the attenuation curves of this specification there will be a double allowance for in-plant attenuation and the results will be less reliable. Incomplete evidence so far available indicates that this effect is likely to be small and no specific deduction is recommended.

The determination of the sound-power level of a complete plant does not constitute a formal part of the specification. Nevertheless there are many instances where it is the only course available and its use may be a valuable adjunct to the procedures described in this specification, provided that its limitations are appreciated, so a brief description is given here. The method is only suitable for outdoor use.

C1 Contour Measurement at Ground Level

The most common procedure for complete plants is to make measurements of the sound-pressure levels at various points on a closed contour around the plant, using a hand-held sound-level meter. Measurements should then be made at a minimum of 8 positions around the plant and the preferred shape of the contour is a circle, but other shapes may be used provided there are no reversals of curvature. The measuring positions should be evenly spaced around the contour and where the difference in sound level between neighbouring positions exceeds 6dB(A) the number of positions should be increased. A preliminary survey of the sound field around the plant is therefore necessary, using the sound-level meter set to dB(A) and the subjective judgement of the ears. Measuring positions should be eliminated where there is interference from neighbouring plants. In some instances significant lengths of the contour may have to be eliminated and this will affect the reliability of the determination. The mean radius of the contour should be approximately 1.5 times the mean radius of the plant to minimise the directional effects of individual equipment items. Where this is not practicable, because of neighbouring plants, the number of measuring positions should be increased.

The mean sound-pressure level in each octave band is calculated according to 3.1.3 and is used to derive the sound-power levels from the equation in 3.2.1. In this case, however, the area of the measuring surface, S , is taken to be twice the ground area enclosed by the contour.

A correction should be applied for the geometric near-field error derived from the table in 3.2.2.3. The appropriate value for Q is given by:

$$Q = r_p^2 / r_m^2$$

where,

r_p is the mean radius of the plant

r_m is the mean radius of the contour.

C2 Measurements on an enveloping Surface

A disadvantage of the method described above is that it only measures the sound energy radiated at a small angle from the ground and no account is taken of energy radiated at larger angles, although this may contribute to the noise levels at distant positions. It is preferable to make measurements over an enveloping surface as in the small and large-source procedures described in 2.4. This means including overhead microphone positions on an imaginary spherical or box-like surface by using a pole or a crane. The actual area of the measuring surface so defined is then to be used to calculate the sound-power level.

For a large plant it may not be practicable to use overhead positions but it may still be possible to make measurements at two or more heights around the periphery and these will give a better estimate of the sound-power level of the plant than those made according to C.1.

APPENDIX D

Model Formats for specifying Noise Limits

D1 Noise Limits for Complete Plant

D1.1 Application

The noise limits specified in D1.5 refer to the complete plant. Limits for individual items of equipment shall be derived from them such that the total of the equipment noise does not exceed the various limits for the plant.

The limits for work areas, specified under code G, refer to any position at or beyond 1 m from the surface of any equipment; the other limits refer to the whole of the relevant areas. After the plant has been commissioned a noise survey will be made in these areas to check that the limits have been met.

*However, an exception is made for the neighbourhood-area noise levels, which will be assessed by calculation using the procedures of OCMA Noise Procedure Specification NWG-1. It is required that Figure of the specification shall be used for ground-effects attenuation.

*To meet the requirements for neighbourhood-noise levels the total noise emission for the plant is quoted as sound-power levels and these shall be calculated from the sum of the sound-power levels for individual items of equipment derived from the procedures of OCMA Noise Procedure Specification NWG-1.

(* Delete as necessary)

D1.2 Overriding Limits

The absolute limit specified against code AL1 shall not be exceeded by a sound-pressure level as measured with an instrument set to "fast" response at any time or at any place not less than 1 m from the surface of equipment which is accessible to personnel. The limit specified against code AL2 shall not be exceeded at accessible positions near infrequent sources such as emergency vents. These positions shall be agreed with the Principal.

D1.3 Limits for Broad-band Noise

The sound-pressure level limits specified against code G apply to general work areas within the plant; the other limits apply to the areas listed in D1.5 Table 4. Where separate limits are specified for particular times of the day or for special plant operations these are also given in D1.5 Table 4.

D1.4 Modifications for Narrow-band or Impulsive Noise

When there is equipment within the plant under contract which contains an annoying characteristic such as narrow-band or impulsive components, its noise emission shall be reduced. For impulsive noise the reduction shall be in the overall noise emission; for narrow-band noise the reduction shall apply to the octave bands containing the characteristic.

*In any area, the contribution of noise from the equipment emitting narrow-band noise shall be reduced below the broad-band noise level from the other equipment in the contract by the amount specified against codes AR1 or AR2, as indicated in the relevant reduction code for the area. The broad-band noise level to which the reductions refer is the actual noise in the area as calculated or measured. The corresponding reductions for equipment emitting impulsive noise are specified against codes BR1 or BR2, as indicated in the relevant reduction code for the area. The Contractor shall be responsible for assessing how the reductions shall be referred to the noise limits for the individual items of equipment emitting the characteristic noise.

*In any area the contribution of noise from the equipment emitting narrow-band noise shall be reduced below the total broad-band noise level in the area by the amount specified against codes AR1 and AR2, as indicated in the relevant reduction code for the area. The total noise to which the reductions refer is the sum of the actual noise from the equipment in the contract as calculated.

ted or measured, and the noise levels, SPL1, SPL2, etc., specified by the Principal for the area. The corresponding reductions for equipment emitting impulsive noise are specified against codes BR1 or BR2, as indicated in the relevant reduction codes for the area. The Contractor shall be responsible for assessing the total noise in the area and how the reductions shall be referred to the noise limits for the individual items of equipment emitting the characteristic noise.

*In any area, the contribution of noise from the equipment emitting narrow-band noise shall be reduced below the broad-band limit for the area by the amount specified against codes AR1 or AR2, as indicated in the relevant reduction code for the area. The contribution from any equipment emitting impulsive noise shall be reduced below the broad-band limit by the amount specified against codes BR1 or BR2, as indicated in the relevant reduction code for the area.

(* Delete as necessary)

(Note: The three options refer respectively to paragraphs (a), (b) and (c) of 4.2. Appendix E gives appropriate reductions for narrow-band noise when masking noise is present.)

D1.5 TABULATION OF NOISE LIMITS FOR COMPLETE PLANT

Project Identification												
Table 1. <u>Overriding Limits</u>												
Absolute Limit, AL1:												
Special Limit, AL2: Locations:												
Octave-band centre frequency (Hz)	dB(A)	31.5	63	125	250	500	1k	2k	4k	8k		
Table 2. <u>Limits for Broad-Band Noise</u>												
The following limits shall not be exceeded in the areas and for the times designated in Table 2												
Limit Type	Limit Code	Sound-pressure Level (dB re 2×10^{-5} N/m ²)										Relevant Reduction Codes
General Work Area	G											
Speech and Work Interference	S1											
	S2											
Neighbourhood Area*	N1											
	N2											
Accommodation	A1											
	A2											
Plant Sound-power Level (dB re 10^{-12} W)												
Neighbourhood Area*	NP1											
	NP2											
Table 3. <u>Modifications for Narrow-Band and Impulsive Characteristics</u>												
Characteristic	Reduction Code	Reduction (dB)										Comment
Narrow-Band Noise	AR1											
	AR2											
Impulsive Noise	BR1											
	BR2											
Existing Noise Levels*	Code	Sound-pressure Level (dB re 2×10^{-5} N/m ²)										
Area:	SPL1											
Area:	SPL2											
Table 4. <u>Application of Noise Limits</u>												
Limit Time	Limit Code	Area	Day/time	Special Operations								
Speech and Work Interference	S1											
	S2											
Neighbourhood Area**	N1/NP1											
	N2/NP2											
Accommodation	A1											
	A2											

(* Delete as necessary)

(** For N1/N2 give map reference)

D2 Equipment Noise Limits

Project:

Equipment item no. and title:

Order no:

D2.1 Application of Noise Limits

The equipment noise limits listed in D2.3 Table 1 and Table 2 have been selected so that the total plant noise generated shall not exceed the Principal's requirements. These limits are specific to the items listed in this order.

The general limits in D2.3 Table 1 have been selected to meet the general work-area limit in which the equipment operates. They shall not be exceeded at any position around the equipment at a distance of 1 m or greater from the equipment surface. Special limits may be required at certain defined locations. The limits in D2.3 Table 2 have been selected to meet the neighbourhood-area limits for the plant as a whole and the equipment must comply with the most restrictive of these two criteria.

These noise limits shall be modified when the equipment emits annoying characteristics such as narrow-band or impulsive noise. The modifications for narrow-band noise shall apply only to the octave band or bands in which the characteristics occur. They vary according to whether the requirements derive from work-area noise or from neighbourhood noise and the equipment must comply with the most restrictive of the two criteria. For work-area noise the modifications for noise characteristics take the form of reductions in the sound-pressure level limits of D2.3 Table 1 by the amounts given in D2.3 Table 3. For neighbourhood noise the modifications take the form of maximum sound-power levels in the relevant octave bands and these apply to all items of equipment in the plant. Where the equipment in this order emits characteristic noise it shall meet the lower of the sound-power levels in D2.3 Table 2 or Table 4 in the relevant octave band.

* If the equipment emits fluctuating or intermittent noise, the maximum level shall meet the specified limits.

* If the equipment emits fluctuating or intermittent noise a level 3dB below the maximum shall meet the specified limits.

* If the equipment emits slowly fluctuating or intermittent noise the equivalent continuous sound level, L_{eq} , over the most noisy 8 hours shall meet the specified limits. The maximum level shall not be more than 10dB higher than these limits.

(* The Contractor should delete the options not required for the particular equipment.)

D2.2 Requirements

The Vendor shall provide information on the noise emitted by his standard equipment and the equipment as modified to meet this specification. Measurements shall be made in accordance with the Oil Companies Materials Association Specification NWG-1. Alternatively, equivalent national or international test procedures may be used by agreement with the Principal.

All modifications to standard equipment necessary to meet the requirements of this specification shall be stated. Such modifications shall not conflict with the requirements of other specifications for the equipment.

The operating conditions to which these noise limits refer shall be agreed with the Principal.

Where large equipment has to be treated as a number of noise-emitting components, separate noise limits may be specified for each. The Vendor shall then provide information on these separate components obtained in accordance with the large-source procedure of Specification NWG-1.

D2.3 NOISE LIMITS

Octave-band centre frequency (Hz)	dB(A)	31.5	63	125	250	500	1k	2k	4k	8k
-----------------------------------	-------	------	----	-----	-----	-----	----	----	----	----

Table 1. Sound-pressure level limits (dB re 2×10^{-5} N/m²)

General Limits										
Special Limits										

Location of special limits:

Table 2. Sound-power level limits (dB re 10^{-12} W)

Equipment component										
1.										
2.										
3.										

Table 3. Reductions to sound-pressure level limits for narrow-band or impulsive noise

Characteristic	Reduction (dB)									
Narrow-band noise										
Impulsive noise										

Table 4. Modified sound-power level limits where narrow-band or impulsive noise is present (dB re 10^{-12} W)

Equipment component										
1.										
2.										
3.										

D2.4 Information to be provided by the Vendor

The Vendor shall provide the following information with his tender. The noise levels quoted shall relate to the equipment in its normal operating condition and any other design or expected mode of operation.

- The maximum and average sound-pressure levels at 1 m from the equipment surface (in dB(A) and octave bands) for typical standard equipment and the equipment with noise control. The position of the maximum shall be defined.
- The sound-power levels of typical standard equipment and the equipment with noise control (in octave bands).

- (c) Details of how the information in (a) and (b) have been derived (whether by direct measurement on similar equipment or by extrapolation from other equipment of different size). These shall include full information on the noise test; for example, all readings taken and any corrections applied, the measurement positions (with dimensioned sketch), the test environment, and the operating conditions of the equipment. The basis for any extrapolation shall be given.
- (d) Any characteristic noise components such as narrow-band or impulsive noise and the octave bands in which the narrow-band noise occurs (a narrow-band component would be noticeable to the ear as a distinguishable pitch and would represent a dominant feature of the total noise).
- (e) His recommendations for the noise control of standard equipment to meet the Principal's noise limits (where it is impractical to redesign the equipment). The noise-control measures shall not conflict with the requirements of other specifications for the equipment.
- (f) Details of noise-reduction features included in the supply.
- (g) The guaranteed sound-pressure and sound-power levels of the equipment including any noise-reduction features included in the Vendor's supply. These levels shall apply to the equipment as installed by the Principal in accordance with any special provisions specified by the Vendor.

Table 5. Tabulated Data to be provided by the Vendor

Octave-band centre frequency (Hz)	dB(A)	31.5	63	125	250	500	1k	2k	4k	8k
-----------------------------------	-------	------	----	-----	-----	-----	----	----	----	----

Sound-pressure levels at 1 m (dB re 2×10^{-6} N/m²)

Average										
Maximum										
At specified position										

Position of maximum:

Component	Sound-power levels (dB re 10^{-12} W)									
1.										
2.										
3.										

Octave bands in which narrow-band noise is present:

Method of test:

(Attach separate sheet showing individual measurements and dimensioned sketch)

Operating conditions:

Directivity Index and direction:

(Note: The Directivity Index shall be quoted as sound-pressure level for small sources and sound-power level for large sources as defined by OCMA Specification NWG-1.)

APPENDIX E

Narrow-Band Noise

E1 General

A pure tone is audible against broad-band masking noise only if the level of the pure tone exceeds the spectrum level of the masking noise by more than a certain critical amount. The term spectrum level means the level of the 1 Hz bandwidth spectrum, and the term pure tone means a sound with a bandwidth of not more than 1 Hz.

The audible threshold of a pure tone against white noise (noise of constant spectrum level) varies with the frequency of the pure tone and the level of the masking noise. For the purposes of this specification, the audible threshold is taken to be as shown in Fig. E1. In practice, narrow-band noise is seldom of 1 Hz bandwidth or less and masking noise is never of constant spectrum level. The effective masking noise is contained within a limited bandwidth, termed the critical bandwidth, centred on the pure-tone frequency. This means that broad-band noise outside the critical bandwidth is ineffective in masking the narrow-band noise.

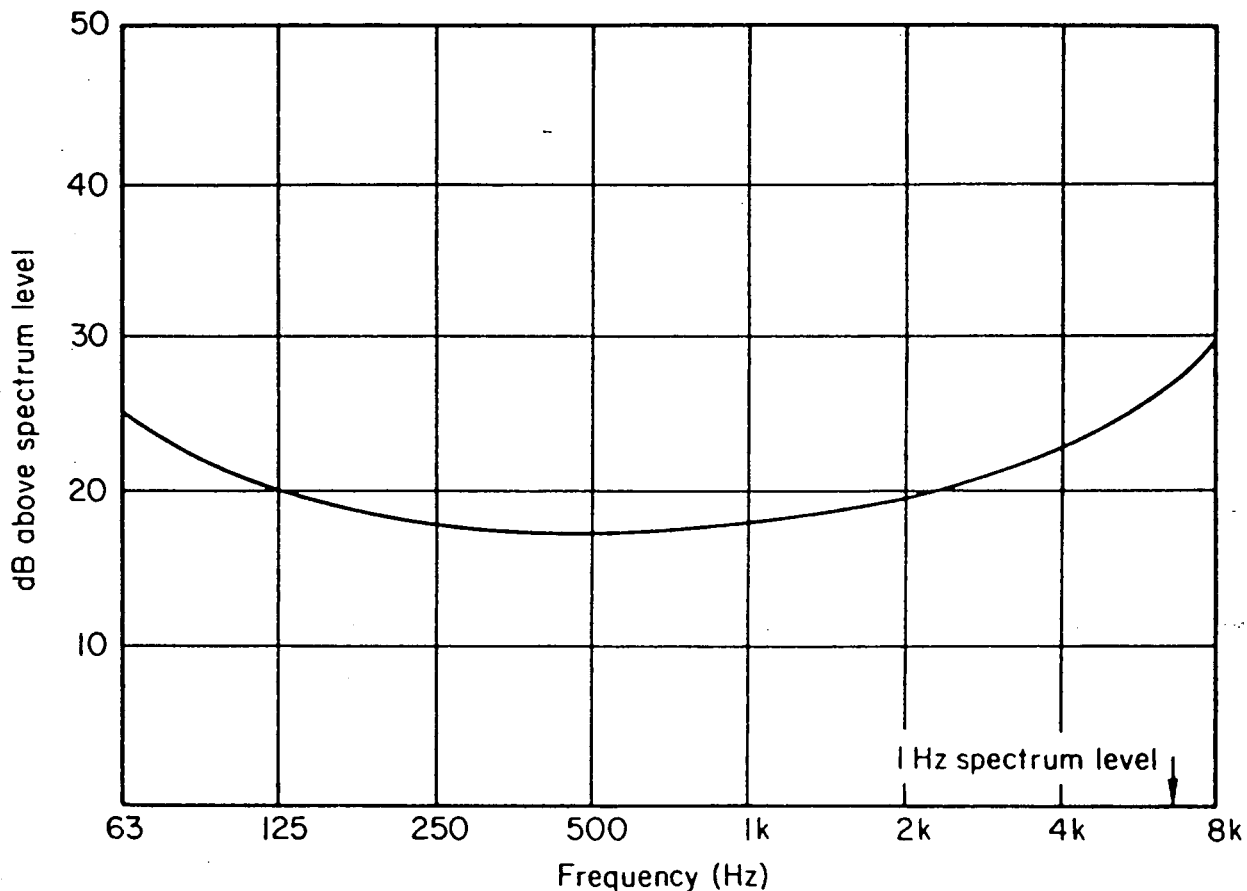


Fig. E1. Threshold of audibility of pure tone above 1 Hz spectrum of broad-band noise (based on Hawkins & Stephens).

E2 Application

For the purposes of this specification there are two possible approaches.

- (a) A simplified approach using octave-band levels only.
- (b) A detailed approach using narrow-band analysis.

E2.1 Octave-Band Level Method

This method is applicable where:

- (a) Octave-band sound-pressure levels can be measured around the source emitting the narrow-band noise, or can be calculated from sound-power level data.
- (b) Octave-band sound-pressure levels of the masking noise from other sources can be measured or calculated.
- (c) The octave band containing the narrow-band noise can be identified from the octave-band spectrum (with the additional aid of the ear).

These conditions apply to many situations in which this specification is used.

Three simplifying assumptions are made:

- (a) That the narrow-band noise is a pure tone and that source-noise spectrum level in the octave band containing the narrow-band noise is negligible.
- (b) That the masking noise is of constant spectrum level in the octave band containing the narrow-band noise.
- (c) That the octave band is not less than the critical bandwidth.

The narrow-band noise will not be audible if its octave-band level lies below the octave-band level of the masking noise by an amount equal to or greater than the value given in the following table:

Octave-band centre frequency (Hz)	63	125	250	500	1k	2k	4k	8k
Difference*	0	0	5	8	11	12	11	8

*Difference = (octave-band level of masking noise) – (octave-band level of narrow-band noise).

If a source contains prominent narrow-band noise, the level of the octave bands containing narrow bands is likely to be higher than those of the neighbouring octave bands. If a narrow-band noise occurs at the cross-over between two octave bands, these two adjacent bands are likely to be elevated. In this case the narrow-band noise shall be considered as existing in each band.

There may be separate narrow-band elements in adjacent or other octave bands. If these can be identified by octave-band analysis and the ear, they shall be treated separately by this method.

E2.2 Narrow-band Analysis Method

If it is not practicable to employ the method of E2.1, or if the Principal requires it, narrow-band analysis shall be used. The bandwidth employed shall be not more than 1% or 10Hz, whichever is less.

Narrow-band noise shall be deemed to be present if the analyser trace of the total noise (narrow-band plus masking) shows a peak which exceeds the mean spectrum level by more than the amounts shown in Fig. E1. The maximum level of the peak shall be taken and the relative octave-band shall be that containing the narrow-band. If the peak is flat topped and wider than the bandwidth of the analyser the spectrum level of the top may be taken. The spectrum level of the masking noise is taken as the level of that part of the total noise spectrum either side of the peak in an octave-band centred on the peak frequency (that is from $0.707f$ to $1.414f$).

E2.3 No External Masking Noise

If there is no masking noise available other than the noise from the source in question, and if it is necessary to employ an objective means of determining the presence of narrow-band noise (as defined in 1.4.2) the method of E2.2 shall be employed.

APPENDIX F

The Calculation of Neighbourhood Noise

F1 The sound-pressure level at a point in the neighbourhood is calculated from the equation.

$$L_p = L_w + D - K$$

where,

$$K = K_1 + K_2$$

K_1 is the combined effect of geometrical attenuation and atmospheric absorption (see F1.1).

K_2 is the ground-effects attenuation (see F1.2).

F1.1 Air Absorption

The absorption of sound in air depends on the air temperature and relative humidity; it is also frequency dependent. For coastal climates with relatively little variation in temperature and humidity it suffices to take average values. Unless otherwise specified by the Principal, air absorption shall be taken into account by reading the factor K_1 from Fig. F1 (which shows the combined effect of geometrical and atmospheric attenuation).

(Note: The value of air absorption in Fig. F1 is equal to $5 \text{ r.f. } 10^{-6} \text{ dB}$, where f is the octave-band centre frequency.)

F1.2 Ground Effects

Usually, sound that reaches the observer has travelled close to the ground; the observer may receive sound along two different paths, one direct and one with a reflection from the ground. The extent to which the ground modifies the sound field at the observer depends on the source and observer height and the properties of the ground surface in between. The ground effect can be allowed for by using a correction factor K_2 , to be read from Figs. F2 or F3 as specified by the Principal.

It must be noted that the ground effects of Figs. F2 and F3 include the in-plant screening of a typical arrangement of process area and tanks but not the attenuation of significant discrete barriers. The ground-effects attenuation should be determined from Fig. F2 when there is flat or rising ground between the source and the point and a fairly clear line of sight. Fig. F3 should be used when there is screening by other plant, buildings, tanks, etc., so that there is no clear line of sight.

The ground-effects attenuation shall be taken as zero across open water.

F1.3 Screens

If acoustic screening is to be used, the calculation of the screening effect must be agreed with the Principal because screens can modify the ground-effects attenuation.

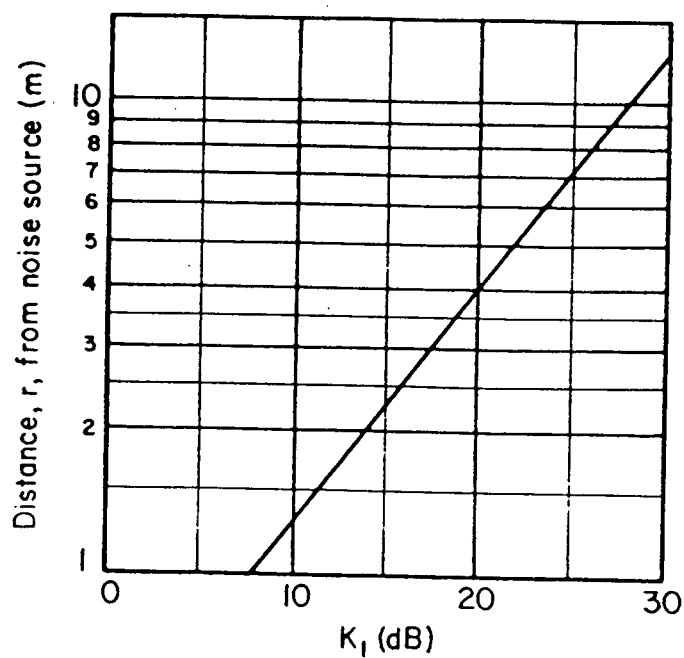
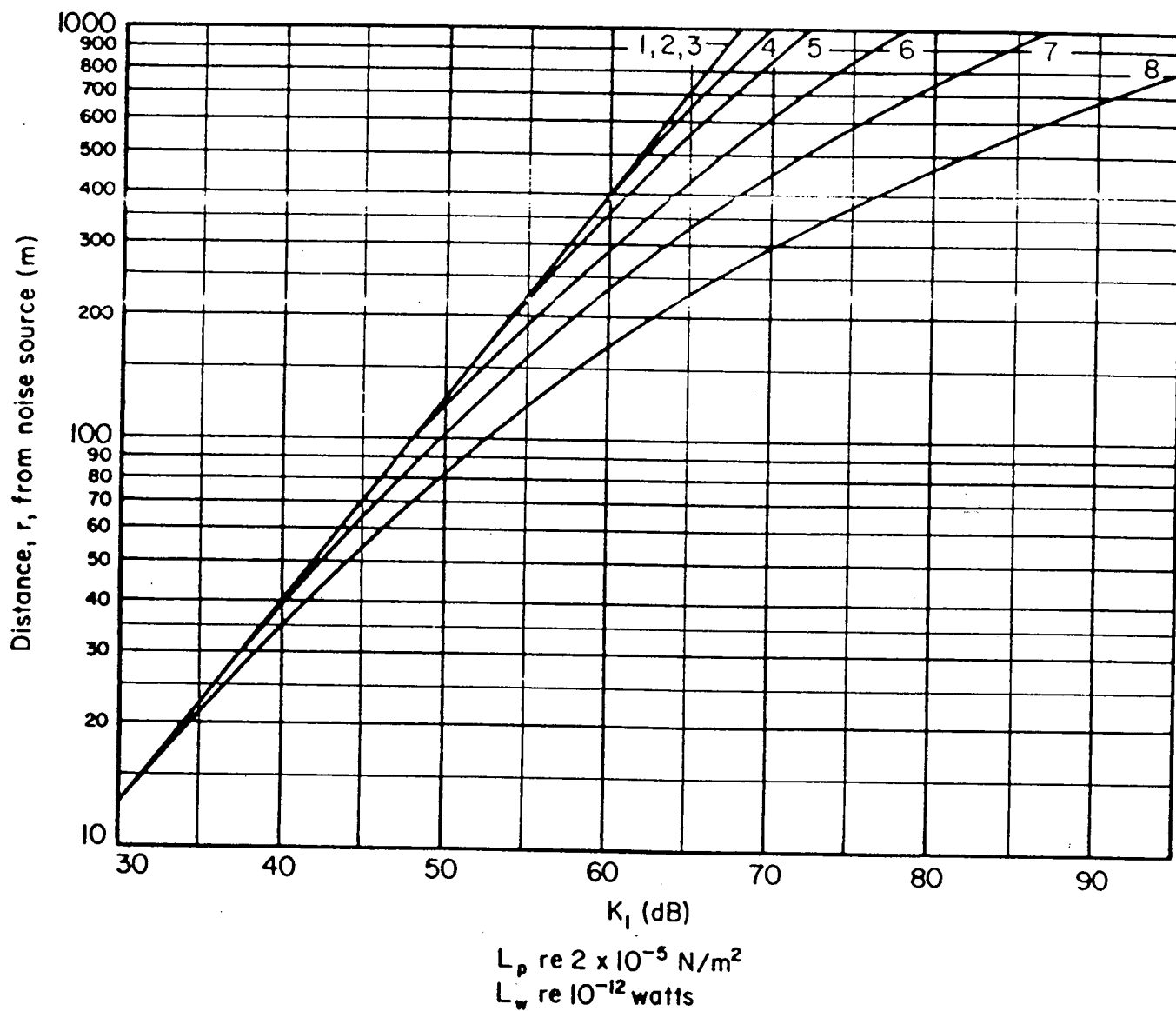


Fig. F1. Attenuation factor, K_1 (dB). 1, 63 Hz band; 2, 125 Hz band; 3, 250 Hz band; 4, 500 Hz band; 5, 1000 Hz band; 6, 2000 Hz band; 7, 4000 Hz band; 8, 8000 Hz band.

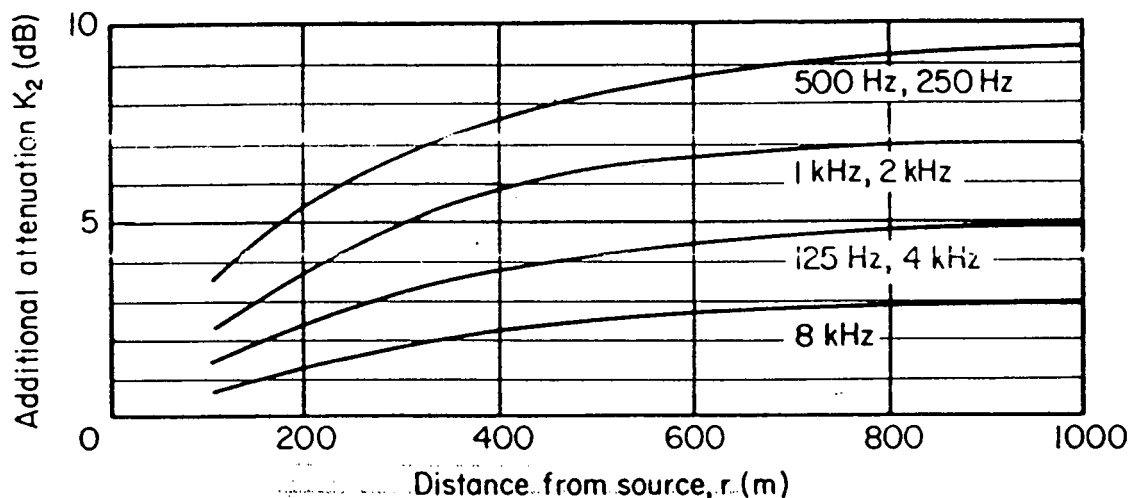


Fig. F2. Ground effects: minimal screening. r , distance from source to community (m); h , elevation of source above grade (m). If $h/r < 1/100$ use full value of K_2 . If $h/r > 1/100$ reduce value of K_2 towards zero at $h/r = 3/100$ in proportion to increase in h/r (e.g. at $h/r = 2/100$ use half value) subject to further limit that $K_2 = 0$ if $h > 15$ m.

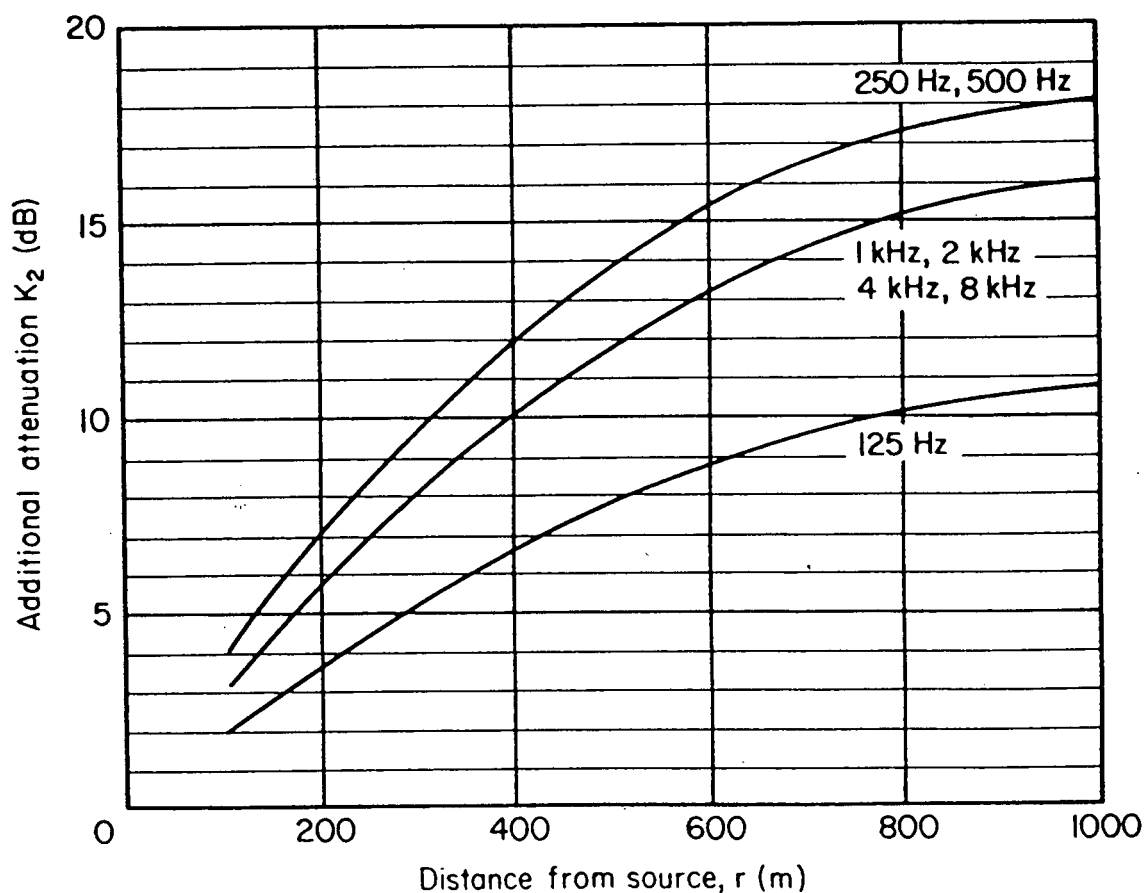


Fig. F3. Ground effects: significant screening. r , distance from source to community (m); h , elevation of source above grade (m). If $h/r < 1/100$ use full value of K_2 . If $h/r > 1/100$ reduce value of K_2 towards zero at $h/r = 3/100$ in proportion to increase in h/r (e.g. at $h/r = 2/100$ use half value) subject to further limit that $K_2 = 0$ if $h > 15$ m.

APPENDIX G

The Directivity Index for Large Sources

If the variation in sound level over the measuring surface of a large source is 6dB(A) or more, the measuring surface must be divided into two or more zones and their sound-power levels calculated separately. The total sound-power level of the source is then calculated from the sum of the individual levels (see 2.4.2.4). To determine the directivity index, these zones must be split up or grouped into five zones approximating to the faces of a cuboid and their individual sound-power levels examined.

(Note: The sound-power level, L_{wn} , of any part of a zone divided into N parts is calculated from the sound-power level, L_w , of the zone using the equation: $L_{wn} = L_w - 10 \log N$)

If one of the vertical faces has a sound-power level 6dB or more than that of any other face, directivity indices shall be allocated to the various faces according to Fig. G1, where face 1 contains the

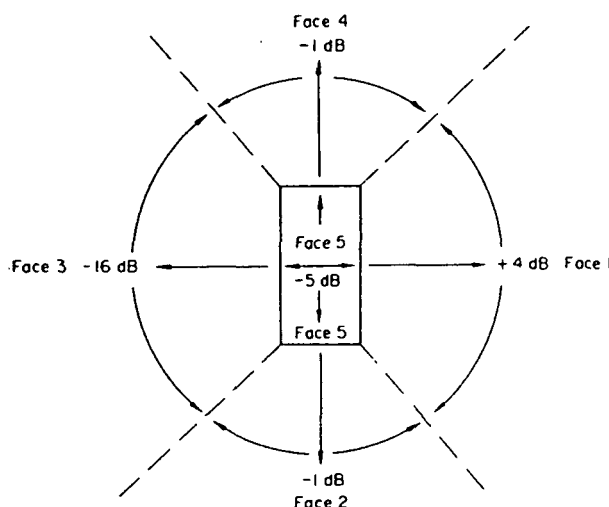


Fig. G1. Plan of large source showing directivity indices associated with sound-power level of Face 1. Notes: (1) Face 5 has a horizontal directivity index of -5dB in all directions. (2) Directivity index of source normal to Face 1:

$$D_1 = 10 \log [\text{antilog} (L_{w1} + 4)/10 + \text{antilog} (L_{w2} - 1)/10 + \text{antilog} (L_{w3} - 16)/10 + \text{antilog} (L_{w4} - 1)/10 + \text{antilog} (L_{w5} - 5)/10] - L_w$$

maximum sound-power level. The directivity index of the source in the direction normal to face 1 is given by:

$$D_1 = 10 \log (\text{antilog} (L_{w1} + 4) / 10 + \text{antilog} (L_{w2} - 1) / 10 + \text{antilog} (L_{w4} - 1) / 10 + \text{antilog} (L_{w3} - 16) / 10 + \text{antilog} (L_{w5} - 5) / 10) - L_w$$

where,

L_{wn} is the sound-power level of face n

L_w is the total sound-power level of the source

The directivity indices for other directions can be derived from analogous equations; the indices for faces 1 to 4 shall be used for the appropriate directions for all calculations of neighbourhood noise. They may be used for work areas at distances at least twice that of the source dimension, D_0 ; for lesser distances the procedure of 3.3.1.5 may be used. No account is taken of vertical directivity from large sources because its effect is frequently reduced by wind effects and temperature inversions.

Notes

1. The directivity index of each face is regarded as acting over a right angle centred on the normal to the face. The sound energy is therefore radiated into a quarter of a hemisphere and a correction of 6dB is included in the index so that calculations based on a hemisphere may be used.

2. The directivity indices in Fig. G1 contain screening terms obtained from VDI 2714.
3. Each directivity index contains an allowance for the diffracted sound energy from the other faces.
4. If the source has been treated as consisting of several discrete radiating parts (2.4.2.5) they shall be grouped to derive the appropriate sound-power levels for the faces of a cuboid.
5. This method is applicable to a large source consisting of a number of small sources surrounded by a high screen, provided that the screen height is greater than its length. If it is not, the source should also be treated as a screened source and the results from the two methods compared. Cases of doubt should be referred to the Principal for approval.

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- 145 : 87 90/10 Copper Nickel Alloy Piping for Offshore Applications—Specification: Flanges Composite and Solid
- 146 : 87 90/10 Copper Nickel Alloy Piping for Offshore Applications—Specification: Fittings
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(*Incorporating Amendments Nos 1 to 3*)
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143	Recommendations for Tube End Welding: Tubular Heat Transfer Equipment Part 1— Ferrous Materials
147	Recommendations for the Design and Construction of Refrigerated Liquefied Gas Storage Tanks
151	Liquid Ring Vacuum Pumps and Compressors
153 : 96	EEMUA Supplement to ASME B31.3—1996 Edition, Process Piping
154	Guidance to Owners on Demolition of Vertical Cylindrical Steel Storage Tanks
159 : 94	Users' Guide to the Maintenance and Inspection of Above-ground Vertical Cylindrical Steel Storage Tanks
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164	Seal-less Centrifugal Pumps: Class 1
167	EEMUA Specification for Quality Levels for Carbon Steel Valve Castings
168	A Guide to the Pressure Testing of In-Service Pressurised Equipment
169	Specification for High Frequency Electric Welded (HFEW) Pipe
170	Specification for Production Testing of Valves—Part 1 Ball Valves (<i>Incorporating Amendments No 1</i>)
171	Specification for Production Testing of Valves—Part 2 Plug Valves
172	Specification for Production Testing of Valves—Part 3 Gate Valves
173	Specification for Production Testing of Valves—Part 4 Butterfly and Globe Valves
179 : 96	A Working Guide for Carbon Steel Equipment in Wet H ₂ S Service (Developed largely from Oil Refinery experience)
180 : 96	Guide for Designers and Users on Frangible Roof Joints for Fixed Roof Storage Tanks
182	Specification for Integral Block and Bleed Valve Manifolds for Direct Connection to Pipework (<i>Incorporating Amendment No 1</i>)
183 : 99	Guide for the Prevention of Bottom Leakage from Vertical, Cylindrical, Steel Storage Tanks
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190 : 00	Guide for the Design, Construction and Use of Mounded Horizontal Cylindrical Bulk Storage Vessels for Pressurised LPG at Ambient Temperatures

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- 195 : 99 Compendium of EEMUA Information Sheets on Topics Related to Pressure-Containing Equipment (*Incorporating Amendment No 1*)

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Amendments Where amendments have been issued, these are listed in bracketed italics after the title of the publication. It is intended that amendments be placed on the website www.eemua.co.uk/publications/amendments.

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- 132 : 88 Specification for Three-phase Cage Induction Motors (*Amdt No 1, Mar 02*)
- 133 : 88 Specification for Underground Armoured Cable Protected against Solvent Penetration and Corrosive Attack
- 181 : 95 A Guide to Risk Based Assessments of In-situ Large Ex 'e' and Ex 'N' Machines
- 186 : 97 A Practitioner's Handbook—Electrical Installation, Inspection and Maintenance in Potentially Explosive Atmospheres (*Updated & reprinted 2002*)
- 198* Electromagnetic Compatibility A User Guide to Installations and Standards

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- 143 : 85 Recommendations for Tube End Welding: Tubular Heat Transfer Equipment, Part 1 — Ferrous Materials (*No subsequent parts issued*)
- 151 : 87 Liquid Ring Vacuum Pumps and Compressors
- 153 : 96 EEMUA Supplement to ASME B31.3 —1996 Edition, Process Piping (*Amdts Dec 2000 & Feb 02*)
- 164 : 93 Seal-less Centrifugal Pumps: Class 1
- 167 : 91 Specification for Quality Levels for Carbon Steel Valve Castings
- 168 : 91 A Guide to the Pressure Testing of In-Service Pressurised Equipment
- 169 : 93 Specification for High Frequency Electric Welded Line Pipe (*Obsolescent*)
- 170 : 91 Specification for Production Testing of Valves—Part 1 Ball Valves (*Reprinted 2001 incorporating Amdt No 1 Apr 96 & other minor changes*)
- 171 : 94 Specification for Production Testing of Valves—Part 2 Plug Valves (*Errata & Amdt No 1 Apr 96*)
- 172 : 95 Specification for Production Testing of Valves — Part 3 Gate Valves (*Amdt No 1 Jan 96*)
- 173 : 95 Specification for Production Testing of Valves — Part 4 Butterfly and Globe Valves
- 179 : 96 A Working Guide for Carbon Steel Equipment in Wet H₂S Service (Developed largely from Oil Refinery experience)
- 182 : 95 Specification for Integral Block and Bleed Valve Manifolds for Direct Connection to Pipework (Incorporating Information Sheet No 20: Application Guidelines) (*Reprinted incorporating Amdt No 1 Nov 98*)
- 184 : 96 Guide to the Isolation of Pressure Relieving Devices
- 185 : 96 Guide for Hot Tapping on Piping and other Equipment (*Reprinted 2000 incorporating Amdt No 1 Dec 97*)
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- 196 : 99 Valve Purchasers' Guide to the European Pressure Equipment Directive (*Reprinted 2002 incorporating Amdts 1–3, Nov 00, Feb 02 & Aug 02, respectively*)

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- 200 : 00 Guide to the Specification, Installation and Maintenance of Spring Supports for Piping
- 202 : 01 Guide to the Use of ISO 15649 and ANSI/ASME B31.3 for Piping in Europe in Compliance with the Pressure Equipment Directive (*Reprinted 2002 incorporating Amdt No 1 May 02*)

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