INTERNATIONAL STANDARD

ISO 3741

Fourth edition
2010-10-01

Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Precision methods for reverberation test rooms

Acoustique — Détermination des niveaux de puissance et des niveaux d'énergie acoustiques émis par les sources de bruit à partir de la pression acoustique — Méthodes de laboratoire en salles d'essais réverbérantes

Reference number
ISO 3741:2010(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 3741 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

This fourth edition cancels and replaces the third edition (ISO 3741:1999), which has been technically revised. It also incorporates the Technical Corrigendum ISO 3741:1999/Cor.1:2001.

Introduction

This International Standard is one of the series ISO 3740[2] to ISO 3747[8], which specify various methods for determining the sound power levels and sound energy levels of noise sources including machinery, equipment and their sub-assemblies. The selection of one of the methods from the series for use in a particular application depends on the purpose of the test to determine the sound power level or sound energy level and on the facilities available. General guidelines to assist in the selection are provided in ISO 3740[2]. ISO 3740[2] to ISO 3747[8] give only general principles regarding the operating and mounting conditions of the machinery or equipment for the purposes of the test. It is important that test codes be established for individual kinds of noise source, in order to give detailed requirements for mounting, loading, and operating conditions under which the sound power levels or sound energy levels are to be obtained.

The methods given in this International Standard require the source under test to be mounted in a reverberation test room having specified acoustical characteristics. The methods are then based on the premise that the sound power or sound energy of the source under test is directly proportional to the mean-square sound pressure averaged in space and time, and otherwise depends only on the acoustical and geometric properties of the room and on the physical constants of air.

For a source emitting sound in narrow bands of frequency or at discrete frequencies, a precise determination of the radiated sound power level or sound energy level in a reverberation test room requires greater effort than for a source emitting sound more evenly over a wide range of frequencies, because:

a) the space- and time-averaged sound pressure along a short microphone path, or as determined with an array of a small number of microphones, is not always a good estimate of the space- or time-averaged mean-square pressure throughout the room;

b) the sound power or sound energy radiated by the source is more strongly influenced by the normal modes of the room and by the position of the source within the room.

The increased measurement effort in the case of a source emitting narrow bands of sound or discrete tones consists of either the optimization and qualification of the test room or the use of a greater number of source locations and microphone positions (or increased path length for a moving microphone). The addition of low-frequency absorbers or the installation of rotating diffusers in the test room can help to reduce the measurement effort.

The methods specified in this International Standard permit the determination of the sound power level and the sound energy level in one-third-octave frequency bands, from which octave band data, A-weighted frequency data, and total unweighted sound can be computed.

This International Standard describes methods of accuracy grade 1 (precision grade) as defined in ISO 12001. The resulting sound power levels and sound energy levels include corrections to allow for any differences that might exist between the meteorological conditions under which the tests are conducted and reference meteorological conditions. For applications in reverberant environments where reduced accuracy is acceptable, reference can be made to ISO 3743-1[3], ISO 3743-2[4] or ISO 3747[8].

INTERNATIONAL STANDARD **ISO 3741:2010(E)**

Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Precision methods for reverberation test rooms

1 Scope

1.1 General

This International Standard specifies methods for determining the sound power level or sound energy level of a noise source from sound pressure levels measured in a reverberation test room. The sound power level (or, in the case of noise bursts or transient noise emission, the sound energy level) produced by the noise source, in frequency bands of width one-third-octave, is calculated using those measurements, including corrections to allow for any differences between the meteorological conditions at the time and place of the test and those corresponding to a reference characteristic impedance. Measurement and calculation procedures are given for both a direct method and a comparison method of determining the sound power level and the sound energy level.

In general, the frequency range of interest includes the one-third-octave bands with mid-band frequencies from 100 Hz to 10 000 Hz. Guidelines for the application of the specified methods over an extended frequency range in respect to lower frequencies are given in Annex E. This International Standard is not applicable to frequency ranges above the 10 000 Hz one-third-octave band.

NOTE For higher frequencies, the methods specified in ISO 9295 can be used.

1.2 Types of noise and noise sources

The methods specified in this International Standard are suitable for all types of noise (steady, non-steady, fluctuating, isolated bursts of sound energy, etc.) defined in ISO 12001.

The noise source under test can be a device, machine, component or sub-assembly. This International Standard is applicable to noise sources with a volume not greater than 2 % of the volume of the reverberation test room. For a source with a volume greater than 2 % of the volume of the test room, it is possible that the achievement of results as defined in ISO 12001:1996, accuracy grade 1 (precision grade) is not feasible.

NOTE In specific cases, the source volume can be increased to a maximum of 5 % of the room volume. In such cases, the relevant noise test code indicates the possible consequences on the measurement uncertainty.

1.3 Reverberation test room

The test rooms that are applicable for measurements made in accordance with this International Standard are reverberation test rooms meeting specified requirements (see Clause 5).

1.4 Measurement uncertainty

Information is given on the uncertainty of the sound power levels and sound energy levels determined in accordance with this International Standard, for measurements made in specific frequency bands and for the A-weighted sum of all frequency bands. The uncertainty conforms to ISO 12001:1996, accuracy grade 1 (precision grade).

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies

ISO 3382-2, *Acoustics — Measurement of room acoustic parameters — Part 2: Reverberation time in ordinary rooms*

ISO 5725 (all parts), *Accuracy (trueness and precision) of measurement methods and results*

ISO 6926, *Acoustics — Requirements for the performance and calibration of reference sound sources for the determination of sound power levels*

ISO 12001:1996, *Acoustics — Noise emitted by machinery and equipment — Rules for the drafting and presentation of a noise test code*

ISO/IEC Guide 98-3, *Uncertainty in measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

IEC 60942:2003, *Electroacoustics — Sound calibrators*

IEC 61183, *Electroacoustics — Random-incidence and diffuse-field calibration of sound level meters*

IEC 61260:1995, *Electroacoustics — Octave-band and fractional-octave-band filters*

IEC 61672-1:2002*, Electroacoustics — Sound level meters — Part 1: Specifications*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
sound pressure

p

difference between instantaneous pressure and static pressure

NOTE 1 Adapted from ISO 80000-8:2007[21], 8-9.2.

NOTE 2 Sound pressure is expressed in pascals.

3.2
sound pressure level

L_p

ten times the logarithm to the base 10 of the ratio of the square of the sound pressure, p, to the square of a reference value, p_0, expressed in decibels

$$L_p = 10 \lg \frac{p^2}{p_0^2} \text{ dB} \tag{1}$$

where the reference value, p_0, is 20 µPa

[ISO/TR 25417:2007[20], 2.2]

NOTE 1 If specific frequency and time weightings as specified in IEC 61672-1 and/or specific frequency bands are applied, this is indicated by appropriate subscripts; e.g. L_{pA} denotes the A-weighted sound pressure level.

NOTE 2 This definition is technically in accordance with ISO 80000-8:2007[21], 8-22.

3.3
time-averaged sound pressure level

$L_{p,T}$

ten times the logarithm to the base 10 of the ratio of the time average of the square of the sound pressure, p, during a stated time interval of duration, T (starting at t_1 and ending at t_2), to the square of a reference value, p_0, expressed in decibels

$$L_{p,T} = 10 \lg \left[\frac{\frac{1}{T}\int_{t_1}^{t_2} p^2(t)\mathrm{d}t}{p_0^2} \right] \mathrm{dB} \qquad (2)$$

where the reference value, p_0, is 20 µPa

NOTE 1 In general, the subscript "T" is omitted since time-averaged sound pressure levels are necessarily determined over a certain measurement time interval.

NOTE 2 Time-averaged sound pressure levels are often A-weighted, in which case they are denoted by $L_{p\mathrm{A},T}$, which is usually abbreviated to $L_{p\mathrm{A}}$.

NOTE 3 Adapted from ISO/TR 25417:2007[20], 2.3.

3.4
single event time-integrated sound pressure level

L_E

ten times the logarithm to the base 10 of the ratio of the integral of the square of the sound pressure, p, of an isolated single sound event (burst of sound or transient sound) over a stated time interval T (starting at t_1 and ending at t_2) to a reference value, E_0, expressed in decibels

$$L_{E,T} = 10 \lg \left[\frac{\int_{t_1}^{t_2} p^2(t)\mathrm{d}t}{E_0} \right] \mathrm{dB} \qquad (3)$$

where the reference value, E_0, is (20 µPa)^2 s = 4 × 10^{-10} Pa^2 s

NOTE 1 This quantity can be obtained by $L_{p,T} + 10 \lg \frac{T}{T_0}$ dB, where T_0 = 1 s.

NOTE 2 When used to measure sound immission, this quantity is usually called "sound exposure level" (see ISO/TR 25417:2007[20]).

3.5
measurement time interval

T

portion or a multiple of an operational period or operational cycle of the noise source under test for which the time-averaged sound pressure level is determined

NOTE Measurement time interval is expressed in seconds.

3.6
reverberation test room

test room meeting the requirements of this International Standard

3.7
reverberant sound field

that portion of the sound field in the test room over which the influence of sound received directly from the source is negligible

3.8
reverberation time

T_n

duration required for the space-averaged sound energy density in an enclosure to decrease $10^{-n/10}$ (i.e. by n dB) after the source emission has stopped

[ISO 80000-8:2007[21], 8-29]

NOTE 1 Reverberation time is expressed in seconds.

NOTE 2 The reverberation time is frequency dependent.

NOTE 3 For the purposes of this International Standard, $n = 60$, and the symbol used is T_{60}.

3.9
sound absorption coefficient

α

at a given frequency and for specified conditions, the relative fraction of sound power incident upon a surface which is not reflected

NOTE For the purposes of this International Standard, sound absorption coefficients are calculated in accordance with ISO 354[1].

3.10
equivalent sound absorption area

A

product of the area and sound absorption coefficient of a surface

NOTE Equivalent sound absorption area is expressed in square metres.

3.11
reference sound source

sound source meeting specified requirements

NOTE For the purposes of this International Standard, the requirements are those specified in ISO 6926:1999, Clause 5.

3.12
frequency range of interest

for general purposes, the frequency range of one-third-octave bands with nominal mid-band frequencies from 100 Hz to 10 000 Hz

NOTE For special purposes, the frequency range can be extended or reduced, provided that the test environment and instrumentation otherwise meet all requirements of this International Standard. The frequency range can be extended downwards as far as the 50 Hz one-third-octave band (see Annex E), but cannot be extended upwards beyond the 10 000 Hz band. Any reduced or extended frequency range is clearly indicated as such in the report.

3.13
background noise

noise from all sources other than the noise source under test

NOTE Background noise includes contributions from airborne sound, noise from structure-borne vibration, and electrical noise in the instrumentation.

3.14
background noise correction

K_1

correction applied to the measured sound pressure levels in the reverberation test room to account for the influence of background noise

NOTE 1 Background noise correction is expressed in decibels.

NOTE 2 The background noise correction is frequency dependent; the correction in the case of a frequency band is denoted K_{1f}, where f denotes the relevant mid-band frequency.

3.15
sound power

P

through a surface, product of the sound pressure, p, and the component of the particle velocity, u_n, at a point on the surface in the direction normal to the surface, integrated over that surface

[ISO 80000-8:2007[21], 8-16]

NOTE 1 Sound power is expressed in watts.

NOTE 2 The quantity relates to the rate per time at which airborne sound energy is radiated by a source.

3.16
sound power level

L_W

ten times the logarithm to the base 10 of the ratio of the sound power of a source, P, to a reference value, P_0, expressed in decibels

$$L_W = 10 \lg \frac{P}{P_0} \text{ dB} \tag{4}$$

where the reference value, P_0, is 1 pW

NOTE 1 If a specific frequency weighting as specified in IEC 61672-1 and/or specific frequency bands are applied, this is indicated by appropriate subscripts; e.g. $L_{W\mathrm{A}}$ denotes the A-weighted sound power level.

NOTE 2 This definition is technically in accordance with ISO 80000-8:2007[21], 8-23.

[ISO/TR 25417:2007[20], 2.9]

3.17
sound energy

J

integral of the sound power, P, over a stated time interval of duration T (starting at t_1 and ending at t_2)

$$J = \int_{t_1}^{t_2} P(t)\,\mathrm{d}t \tag{5}$$

NOTE 1 Sound energy is expressed in joules.

NOTE 2 The quantity is particularly relevant for non-stationary, intermittent sound events.

[ISO/TR 25417:2007[20], 2.10]

3.18
sound energy level

L_J

ten times the logarithm to the base 10 of the ratio of the sound energy, J, to a reference value, J_0, expressed in decibels

$$L_J = 10 \lg \frac{J}{J_0} \text{ dB} \tag{6}$$

where the reference value, J_0, is 1 pJ

NOTE If a specific frequency weighting as specified in IEC 61672-1 and/or specific frequency bands are applied, this is indicated by appropriate subscripts; e.g. $L_{J\mathrm{A}}$ denotes the A-weighted sound energy level.

[ISO/TR 25417:2007[20], 2.11]

4 Reference meteorological conditions

Reference meteorological conditions for the purpose of determining the sound power level and sound energy level are:

a) air temperature: 23,0 °C;

b) static pressure: 101,325 kPa;

c) relative humidity: 50 %.

5 Reverberation test room

5.1 General

The reverberation test room shall be large enough and have a low enough total sound absorption to provide an adequate reverberant sound field for all frequency bands within the frequency range of interest. Guidelines for the design of rooms suitable for use in determining sound power levels and sound energy levels in accordance with this International Standard are given in Annex A. Guidelines for the design of rotating diffusing vanes in the room are given in Annex B.

5.2 Volume and shape of test room

The recommended minimum volume of the room is given in Table 1. All test rooms should be qualified using Annex C. For test rooms with volumes less than the values shown in Table 1 for the frequency range of interest, or with a volume exceeding 300 m^3, the adequacy of the room for broadband measurements shall be demonstrated using the procedure specified in Annex C. A room qualification procedure for the measurement of discrete-frequency components is specified in Annex D, which also specifies a general room qualification procedure as an alternative to qualification of individual sources (using 8.4.2 or 8.5.2). Information is given in Annex E to assist in testing at frequencies below 100 Hz.

Table 1 — Recommended minimum volume of the reverberation test room as a function of the lowest frequency band of interest

Lowest one-third-octave band frequency of interest Hz	Minimum volume of the reverberation test room m^3
100	200
125	150
160	100
⩾200	70

5.3 Sound absorption of test room

The sound absorption of the test room primarily affects the minimum distance to be maintained between the noise source under test and the microphone positions. It also influences the sound radiation of the source and the frequency response characteristics of the test space. For these reasons, the sound absorption of the test room shall be neither too large nor extremely small (see Annex A).

Over the frequency range of interest, all room surfaces within one wavelength of the noise source under test shall be designed to be reflective with an absorption coefficient less than 0,06. If low-frequency panel absorbers are required as per Annex C and/or Annex D, these devices may be mounted within one wavelength (at the lowest frequency of interest) of the noise source under test, but not closer than 1,5 m. The remaining surfaces shall have absorptive properties such that the reverberation time, T_{60} (for measurement, see 8.7), in seconds, in each one-third-octave band below 6.3 kHz, without the source under test in place, is numerically greater than the ratio of V and S:

$$T_{60} > \frac{V}{S} \tag{7}$$

where

V is the volume, expressed in cubic metres, of the reverberation test room;

S is the total surface area, expressed in square metres, of the test room.

If the requirement for the reverberation time given by Inequality (6) is not met, the adequacy of the room for broadband measurements shall be established by the procedure specified in Annex C.

NOTE Above 5 kHz, much of the absorption in the room is due to air. Keeping the relative humidity above 50 % helps to avoid excessive air absorption.

5.4 Criteria for background noise

5.4.1 Relative criteria for background noise

5.4.1.1 General

The time-averaged sound pressure level of the background noise in each frequency band within the frequency range of interest, measured and averaged (see 9.1.3 and 9.2.3) over the microphone positions or traverses, shall be below the corresponding time-averaged sound pressure level of the noise source under test by at least:

a) 6 dB for one-third-octave bands of mid-band frequency 200 Hz and below and 6 300 Hz and above;

b) 10 dB for one-third-octave bands of mid-band frequency from 250 Hz to 5 000 Hz.

If these requirements are met, the background noise criteria of this International Standard are satisfied.

NOTE 1 The same criteria are applied to single event time-integrated sound pressure levels: the measurement time interval for the time average is the same as the measurement time interval associated with the single event.

NOTE 2 The noise associated with the microphone traversing mechanism, if one is used for the measurements, is considered to be part of the background noise. In such cases, the background noise is measured with the traversing mechanism operating.

5.4.1.2 Relative background noise criteria for frequency band measurements

The requirements of 5.4.1.1 may not be achievable in all frequency bands, even when the background noise levels in the test room are extremely low and well controlled. Therefore, any band within the frequency range of interest in which the A-weighted sound power level or sound energy level (see Annex F) of the noise source under test (after correcting for background noise in accordance with 9.1.2 or 9.2.2) is at least 15 dB below the highest A-weighted band sound power or sound energy level may be excluded from the frequency range of interest for the purposes of determining compliance with the above criterion for background noise.

5.4.1.3 Relative background noise criteria for A-weighted measurements

If the A-weighted sound power level or sound energy level is to be determined and reported, the following steps shall be followed to determine whether this quantity meets the background noise criteria of this International Standard:

a) the A-weighted sound power level or sound energy level is computed in accordance with the procedures in this International Standard using the data from every frequency band within the frequency range of interest;

b) the computation is repeated, but excluding those bands for which $\Delta L_p < 6$ dB for one-third-octave bands of mid-band frequency 200 Hz and below and 6 300 Hz and above, and for which $\Delta L_p < 10$ dB for one-third-octave bands of mid-band frequency from 250 Hz to 5 000 Hz.

If the difference between these two levels is less than 0,5 dB, the A-weighted sound power level or sound energy level determined from the data for all bands may be considered as conforming to the background noise criteria of this International Standard.

5.4.2 Absolute criteria for background noise

If it can be demonstrated that the background noise levels in the test room at the time of the measurements are less than or equal to those given in Table 2 for all bands within the frequency range of interest, the measurements can be taken as having met the background noise requirements of this International Standard, even if the 6 dB or 10 dB requirements are not met for all bands. It can be assumed that the source emits little or no measurable noise in these frequency bands, and that the data reported represent an upper bound to the sound power level or sound energy level in these bands.

In the case where some of the measured levels from the source under test are less than or equal to those given in Table 2, the frequency range of interest may be restricted to a contiguous range of frequencies that includes both the lowest and highest frequencies at which the sound pressure level from the noise source exceeds the corresponding value in Table 2. In such cases, the applicable frequency range of interest shall be reported.

5.4.3 Statement of non-conformity with background noise criteria

If neither the relative criteria of 5.4.1 nor the absolute criteria in 5.4.2 are met, the report shall clearly state that the background noise requirements of this International Standard have not been met, and shall identify the particular frequency bands that do not meet the criteria. Furthermore, the report shall not state or imply that the measurements have been made "in full conformity" with this International Standard.

Table 2 —Absolute maximum background noise levels in test room

One-third-octave mid-band frequency Hz	Maximum band sound pressure level dB
50	42
63	39
80	36
100	33
125	30
160	27
200	24
250	21
315	18
400	15
500	12
630	11
800	11
1 000	10
1 250	10
1 600	10
2 000	10
2 500	10
3 150	10
4 000	10
5 000	10
6 300	10
8 000	10
10 000	10

5.5 Atmospheric temperature, humidity and pressure

In the region where the microphones are located, the variations of atmospheric temperature and relative humidity shall be within the limits shown in Table 3.

Measurements of atmospheric pressure shall be made to within ±1,5 kPa.

The limits of Table 3 are generally sufficient. However, other temperature and humidity conditions may be specified in noise test codes for specific equipment types, especially if the operation of the equipment or noise emission levels depend on ambient conditions. In such cases, those conditions shall be applied.

Table 3 — Allowable limits in the variation of atmospheric temperature and relative humidity during measurements in the reverberation test room

Ranges of temperature θ °C	Ranges of relative humidity %		
	< 30 %	30 % to 50 %	> 50 %
	Allowable limits for temperature and relative humidity		
$-5 \leqslant \theta < 10$	± 1 °C, ± 3 %	± 1 °C, ± 5 %	± 3 °C, ± 10 %
$10 \leqslant \theta < 20$	± 1 °C, ± 3 %	± 3 °C, ± 5 %	± 3 °C, ± 10 %
$20 \leqslant \theta \leqslant 50$	± 2 °C, ± 3 %	± 5 °C, ± 5 %	± 5 °C, ± 10 %

6 Instrumentation and measurement equipment

6.1 General

The instrumentation system, including the microphones and cables, shall meet the requirements of IEC 61672-1:2002, class 1, and the filters shall meet the requirements of IEC 61260:1995, class 1. The reference sound source, if employed for the comparison method (see 8.1), shall meet the requirements given in ISO 6926.

6.2 Calibration

The microphones shall be calibrated for random incidence as specified in IEC 61183.

Before and after each series of measurements, a sound calibrator meeting the requirements of IEC 60942:2003, class 1 shall be applied to each microphone to verify the calibration of the entire measuring system at one or more frequencies within the frequency range of interest. Without any further adjustment, the difference between the readings made before and after each series of measurements shall be less than or equal to 0,5 dB. If this value is exceeded, the results of the series of measurements shall be discarded.

The calibration of the sound calibrator, the compliance of the instrumentation system with the requirements of IEC 61672-1, the compliance of the filter set with the requirements of IEC 61260, and, if used, the compliance of the reference sound source with the requirements of ISO 6926, shall be verified at intervals in a laboratory making calibrations traceable to appropriate standards.

Unless national regulations dictate otherwise, it is recommended that the sound calibrator should be calibrated at intervals not exceeding 1 year, the reference sound source should be calibrated at intervals not exceeding 2 years, the compliance of the instrumentation system with the requirements of IEC 61672-1 should be verified at intervals not exceeding 2 years, and the compliance of the filter set with the requirements of IEC 61260 should be verified at intervals not exceeding 2 years.

7 Definition, location, installation, and operation of noise source under test

7.1 General

It is important to decide which components, sub-assemblies, auxiliary equipment, power sources, etc., constitute integral parts of the noise source whose sound power level or sound energy level is to be determined. It is important also to define the manner in which the source is installed and operated for the test, since both these factors can have a significant influence on the sound power or sound energy emitted. This clause describes the approach to be adopted in setting up the source for testing and in defining the conditions, so as to achieve an arrangement which is reproducible and which can be related clearly to the results obtained.

This International Standard gives general specifications relating to noise source definition, installation and operation, but these are overridden by the instructions and specifications of a noise test code, if any exists, for the particular type of source under test.

7.2 Auxiliary equipment

Care shall be taken to ensure that any electrical conduits, piping or air ducts connected to the noise source under test do not radiate significant amounts of sound energy into the test environment.

If practicable, all auxiliary equipment necessary for the operation of the noise source under test that is not a part of it shall be located outside the reverberation test room. If this is impractical, care shall be taken to minimize any sound radiated into the room from such equipment. The noise source under test shall be taken to include all significant sources of sound emission, including auxiliary equipment which cannot either be removed or adequately quietened.

7.3 Noise source location

The noise source to be tested shall be installed in the reverberation test room at one or more locations relative to the boundary surfaces, as if it were in normal use. If a particular position is not otherwise specified, the source shall be placed on the floor at least 1,5 m from any wall of the room. If two or more source positions are necessary in accordance with 8.4.2.4 or Annex D, the distance between different positions shall be equal to or larger than the half wavelength of sound corresponding to the lowest mid-band frequency of measurement. In the case of a test room having a rectangular floor, the noise source under test shall be placed asymmetrically on the floor.

Tabletop equipment shall be placed on the floor of the reverberation test room, at least 1,5 m from any wall, unless a table or stand is considered essential for normal operation. In the latter case, the equipment shall be placed at the centre of the tabletop, and the source and table shall be regarded as an integral whole for the purpose of the test.

7.4 Installation and mounting conditions

In many cases, the sound power or sound energy emitted by a source is affected by the support or mounting conditions. Whenever a typical condition of mounting exists for the noise source under test, that condition shall be used or simulated, if feasible.

Mounting conditions specified or recommended by the manufacturer of the noise source under test shall be used unless otherwise specified in any relevant noise test code. If a typical mounting condition does not exist, or cannot be utilized for the test, or if there are several alternative possibilities, care shall be taken to ensure that the mounting arrangement does not induce a variability in the sound output of the source which is atypical. Precautions shall be taken to reduce any sound radiated from the structure on which the noise source is mounted.

Many small sound sources, although themselves poor radiators of low-frequency sound, can, as a result of the method of mounting, radiate more low-frequency sound when their vibrational energy is transmitted to surfaces large enough to be efficient radiators. In such cases, resilient mounting shall be interposed, if possible, between the noise source under test and the supporting structure, so that the transmission of vibration to the support and the reaction of the source are both minimized. In this case, the mounting base should be rigid (i.e. have a sufficient high mechanical impedance) to prevent it from vibrating excessively and radiating sound. However, resilient mounts shall be used only if the noise source under test is resiliently mounted in typical field installations.

Coupling conditions, e.g. between prime movers and driven machines, can exert considerable influence on the sound radiation of the noise source under test. It may be appropriate to use a flexible coupling, but similar considerations apply to these as to resilient mounts.

Noise sources that are hand held in normal usage shall either be held by hand for the purpose of test, or suspended in such a way that no structure-borne sound is transmitted via any attachment that does not belong to the noise source under test. If the noise source under test requires a support for its operation during testing, the support structure shall be small, considered to be a part of the noise source under test, and as described in the relevant noise test code, if any exist.

Base-mounted machinery and equipment intended exclusively for mounting in front of a wall shall be installed on an acoustically hard floor surface in front of an acoustically hard wall. Wall-mounted machinery and equipment shall be placed on an acoustically hard wall.

7.5 Operation of source during test

The sound power or sound energy emitted by a source can be affected by the load applied, the running speed, and the conditions under which it is operating. The source shall be tested, wherever possible, under conditions that are reproducible and representative of the noisiest operation in typical usage. The specifications given in a noise test code, if any exists, shall be followed, but in the absence of a noise test code one or more of the following modes of operation shall be selected for the test(s):

a) source under specified load and conditions;

b) source under full load [if different from a)];

c) source under no load (idling);

d) source at maximum operating speed under defined conditions;

e) source operating under conditions corresponding to maximum sound generation representative of normal use;

f) source with simulated loading, under defined conditions;

g) source undergoing a characteristic work cycle under defined conditions.

The source shall be stabilized in the desired operating condition, with any power source or transmission system running at a stable temperature, prior to the start of measurements for sound power level or sound energy level determination. The load, speed and operating conditions shall either be held constant during the test, or varied through a defined cycle in a controlled manner.

If the sound power or sound energy emission depends on secondary operating parameters, e.g. the type of material being processed or the design of cutting tool, those parameters shall be selected, as far as is practicable, that give the smallest variations and that are typical of normal use. If simulated loading conditions are used, they shall be chosen such that the sound power levels or sound energy levels of the source under test are representative of normal use.

The noise emission levels for certain equipment, e.g. electronic equipment with speed-controlled cooling fans or air-conditioning equipment containing compressors, may be greatly affected by the ambient temperature in the test room. If not otherwise specified, such as in an applicable test code, it is recommended that for such equipment the ambient temperature in the test room be set at a value typical of its operation, maintained to within ± 2 °C, and reported.

8 Measurements in the reverberation test room

8.1 General

Procedures are described for two alternative methods of determining sound power levels and sound energy levels:

a) the method using the equivalent sound absorption area of the reverberation test room, referred to as the direct method;

b) the method using a reference sound source of known sound power level, referred to as the comparison method.

Both methods are applicable over the range of one-third-octave bands with nominal mid-band frequencies from 100 Hz to 10 000 Hz, but for special purposes the range may be extended downwards in frequency as far as the one-third-octave of mid-band frequency 50 Hz (see 3.12), by following the guidelines given in Annex E.

8.2 Initial location of the noise source under test

For the direct method, the noise source under test shall be located in the reverberation test room at an initial position, selected in accordance with 7.3.

8.3 Microphone positions

For both the direct method and the comparison method, the numerical value of the minimum distance, d_{min}, in metres, between the noise source under test and the nearest microphone position, for each frequency band of interest, shall be not less than:

$$d_{\text{min}} = D_1 \sqrt{\frac{V}{T_{60}}} \tag{8}$$

where

D_1 = 0,08;

V is the volume, in cubic metres, of the reverberation test room;

T_{60} is the reverberation time, in seconds.

In order to minimize the near-field bias error and ensure that the measurement points are located in the reverberant part of the sound field, it is strongly recommended that the value of D_1 be 0,16 for frequencies below 5 000 Hz.

When using the comparison method, the minimum distance between the noise source under test and the nearest microphone position may also be calculated from Equation (9), in which case either Equation (8) or Equation (9) may be used to determine the minimum distance.

$$d_{\text{min}} = D_2 \times 10^{0{,}05\left(L_{W\text{r}} - L_{p\text{r}}\right)} \tag{9}$$

where

D_2 = 0,4;

$L_{W\text{r}}$ is the known sound power level of the reference sound source, in decibels;

$L_{p\text{r}}$ is the time-averaged sound pressure level when the reference sound source is operated in the reverberation test room, in decibels.

In order to minimize the near-field bias error and ensure that the measurement points are located in the reverberant part of the sound field, it is strongly recommended that the value of D_2 be 0,8 for frequencies below 5 000 Hz.

If the room and test set-up have been qualified in accordance with Annex D, the same number of microphones and the same microphone positions or continuous microphone traverse used for the qualification shall be used for the sound pressure measurements.

If the reverberation test room has not been qualified in accordance with Annex D, six discrete microphone positions shall be selected from which the standard deviations of sound pressure levels are to be estimated (see 8.4.2). The six microphones shall be more than 1,0 m distant from any of the surfaces of the room and more than d_{min} from the source. The minimum distance between the microphone positions shall correspond to half the wavelength of the lowest mid-band frequency of interest. For measurements other than those for estimating the standard deviations, a continuous microphone traverse may be used.

If a continuous microphone traverse is used, it shall meet the following requirements:

a) no point on the traverse shall be any closer than d_{min} from the source;

b) no point on the traverse shall be any closer than 1,0 m to any surface of the test room;

c) no point on the traverse shall, at any time, be closer than 0,5 m to any surface of a diffuser;

d) the microphone traverse should not lie in any plane within 10° of a room surface;

e) the microphone traversing path may be a straight line, or a circular arc, or a circle — the length of the path, l, shall be at least $l \geqslant 3\lambda$ or $l \geqslant 10{,}3$ m, whichever is smaller, where λ is the wavelength, in metres, of sound at the lowest mid-band frequency of interest.

In order to ensure that the measurement points are located in the reverberant part of the sound field, in smaller rooms, it is strongly recommended that the length of traverse be achieved by dividing it between two (or more) traverses, provided the minimum distance between their paths is more than 1 m or half the wavelength at the lowest mid-band frequency of interest, whichever is smaller.

This is the minimum length of the traverse; a greater length may be required either from 8.4.2.3 or from Annex D.

8.4 Measurement of sound pressure levels

8.4.1 General

For both the direct method and the comparison method, time-averaged sound pressure levels from the noise source under test for each one-third-octave band in the frequency range of interest, $L'_{pi(\text{ST})}$, shall be obtained at each microphone position, i, or over each microphone traverse (i = 1, 2 … n), over a suitable measurement time interval, for each mode of operation selected (see 7.5). If the test room has been qualified in accordance with Annex D, the same number of microphones and the same microphone positions or continuous microphone traverse used for the qualification shall be used for the sound pressure measurements. If the test room has not been qualified in accordance with Annex D, six discrete microphone positions shall be selected as described in 8.3 and these shall be regarded as initial positions for the purpose of further evaluation, see 8.4.2.

Where the source, or background, sound pressure levels at individual microphone positions vary with time, it may be necessary to increase the measurement time interval and the interval chosen shall be stated in the test report. For frequency bands centred on or below 160 Hz, the measurement time interval shall be at least 30 s. For frequency bands centred on or above 200 Hz, the measurement time interval shall be at least 10 s. If the rotating vane diffuser is used, the measurement time interval shall be an integral multiple of, or more than 10 times, the period of rotation. When using a traversing microphone, the measurement time interval shall include at least two full traverses.

In addition, either immediately before or immediately after the sound pressure levels from the noise source under test are measured, the time-averaged sound pressure levels of the background noise for each one-third-octave band in the frequency range of interest, $L_{pi(\text{B})}$, shall be obtained at each microphone position or over each microphone traverse, over the same measurement time interval as that used for the noise source under test.

8.4.2 Further evaluation in a test room that is not qualified for the measurement of discrete-frequency components (see Annex D)

8.4.2.1 General

For test rooms that have been qualified for the measurement of sources containing discrete frequency components in accordance with Annex D, the procedures specified in 8.4.2.2 to 8.4.2.5 are not required.

8.4.2.2 Determination of standard deviations from preliminary measurements

The standard deviation, s_M, of the sound pressure levels measured at six initial microphone positions in accordance with 8.4.1, for each one-third-octave band shall be determined from Equation (10):

$$s_\mathrm{M} = \sqrt{\sum_{i=1}^{N_\mathrm{M(pre)}} \frac{\left[L'_{pi\mathrm{(pre)}} - L'_{p\mathrm{m(pre)}}\right]^2}{N_\mathrm{M(pre)} - 1}} \tag{10}$$

where

$L'_{pi\mathrm{(pre)}}$ is the one-third-octave band time-averaged sound pressure level measured at the ith initial microphone position, with the noise source under test in operation, in decibels;

$L'_{p\mathrm{m(pre)}}$ is the arithmetic mean value of the one-third-octave band time-averaged sound pressure levels measured at the six initial microphone positions, with the noise source under test in operation, in decibels;

$N_\mathrm{M(pre)}$ = 6, the initial number of microphone positions.

8.4.2.3 Number of microphone positions to be used

If the standard deviation of the sound pressure levels, s_M, obtained from Equation (10) exceeds 1,5 dB for one or more one-third-octave bands, the noise source under test emits sound containing significant discrete frequency components. In this case, either the room and the test set-up shall be modified so that it can be qualified in accordance with Annex D or the number of microphone positions, N_M, required for determining the mean sound pressure level in accordance with 9.1.3, and subsequently for determining the sound power levels, shall be determined from Table 4.

Alternatively, when using a traversing microphone, the minimum length of the microphone traversing path shall be the smaller of:

$$\left.\begin{aligned} l &= \frac{\lambda}{2} N_\mathrm{M} \\ l &= 10{,}3 \end{aligned}\right\} \tag{11}$$

where

l is the length, in metres, of the microphone traversing path;

λ is the wavelength, in metres, of sound at the mid-band frequency of measurement;

N_M is the number of microphone positions determined from Table 4.

When a large number of microphone positions is required, the use of a microphone traverse is recommended.

In order to ensure that the measurement points are located in the reverberant part of the sound field, in smaller rooms, it is strongly recommended that the length of traverse be achieved by dividing it between two (or more) traverses, provided the minimum distance between their paths is more than 1 m or half the wavelength at the lowest mid-band frequency of interest, whichever is smaller.

Table 4 —Minimum number of microphone positions for the measurement of sound pressure levels

One-third-octave mid-band frequency Hz	**Standard deviation**, s_M dB		
	$s_M \leqslant 1,5$	$1,5 < s_M \leqslant 3$	$s_M > 3$
	Minimum value of N_M		
100, 125, 160	6	6	6
200, 250, 315		6	12
400, 500, 630		12	24
$\geqslant 800$		15	30

8.4.2.4 Evaluation of need for additional noise source positions

If the standard deviation of the sound pressure levels, s_M, determined in 8.4.2.2 exceeds 1,5 dB for one or more one-third-octave bands, the noise source under test emits sound containing significant discrete frequency components. In this case, either the room and the test set-up shall be modified so that it can be qualified in accordance with Annex D or the number of source positions, N_S, shall be determined from Equation (12) and Table 5:

$$N_S \geqslant K_S \left[\left(\frac{T_{60}}{V} \right) \left(\frac{1\,000}{f} \right)^2 + \frac{1}{N_M} \right] \tag{12}$$

where

K_S is obtained from Table 5 for the appropriate frequency band;

T_{60} is the numerical value of the reverberation time, in seconds, of the test room for the particular one-third-octave band;

V is the numerical value of the volume, in cubic metres, of the reverberation test room;

f is the numerical value of the mid-band frequency, in hertz, of the one-third-octave band;

N_M is the number of microphone positions for the measurement of sound pressure level, obtained from Table 4 for the appropriate frequency band.

The use of a rotating diffuser may reduce the need for additional source positions (see Annex B). The need for additional source positions can also be reduced by limiting the reverberation time to increase the modal overlap. For one-third-octave bands with mid-band frequencies below 1 000 Hz, it is recommended that the reverberation time, T_{60}, in seconds satisfies the following inequality

$$T_{60} < V \left(\frac{f}{1\,000} \right)^2$$

where

V is the numerical value of the volume, in cubic metres, of the reverberation test room;

f is the numerical value of the mid-band frequency, in hertz, of the particular one-third-octave band.

8.4.2.5 Measurements to be used for determining sound power levels

If fixed microphone positions are used, and the results of the evaluations in 8.4.2.3 and 8.4.2.4 show that no additional microphone positions or source positions are needed, then the measurements from 8.4.1 using the initial six discrete positions can be taken as final. If the evaluations of 8.4.2.3 show that additional microphone positions or traverses are needed, repeated sets of measurements shall be taken using the number of microphone positions or lengths of microphone traverse determined. If additional source positions are needed in accordance with 8.4.2.4, the same number of microphone positions or the same traverse lengths shall be used for each, i.e. the evaluation of 8.4.2.3 does not need to be repeated for each source position.

8.5 Measurement of single event time-integrated sound pressure levels

8.5.1 General

For both the direct method and the comparison method, single event time-integrated sound pressure levels from the noise source under test for each one-third-octave band in the frequency range of interest, $L'_{Ei(\mathrm{ST})}$, shall be obtained, at each microphone position, i (i = 1, 2 … N_M). Measurements shall include either one single sound event at a time (in which case the process shall be repeated N_e times, where N_e is at least five) or several successive (N_e) sound events (where again N_e is a minimum of five) for each mode of operation selected (see 7.5). If the test room has been qualified in accordance with Annex D, the same number of microphones and the same microphone positions used for the qualification shall be used for the sound pressure measurements. If the test room has not been qualified in accordance with Annex D, six discrete microphone positions shall be selected as described in 8.3 and these shall be regarded as initial positions for the purpose of further evaluation, see 8.5.2. A moving microphone shall not be used for measurements on a source emitting non-repetitive impulsive noise.

Table 5 —Minimum number of source locations and value, K_S, for the measurement of sound pressure levels

One-third-octave mid-band frequency Hz	**Standard deviation,** s_M dB		
	$s_\mathrm{M} \leqslant 1,5$	$1,5 < s_\mathrm{M} \leqslant 3$	$s_\mathrm{M} > 3$
	K_S		
100, 125, 160	—	2,5	5
200, 250, 315		5	10
400, 500, 630		10	20
⩾800		12,5	25
Minimum value of N_S	1	by Equation (12)	

The measurement time interval for the noise source under test shall be long enough to contain all that part of the noise of the event(s), including the decay, which make a significant contribution to the single event time-integrated sound pressure level.

In addition, either immediately before or immediately after the sound pressure levels from the noise source under test are measured, the time-averaged sound pressure levels of the background noise for each one-third-octave band in the frequency range of interest, $L_{pi(\mathrm{B})}$, shall be obtained at each microphone position, over a representative measurement time interval.

8.5.2 Further evaluation in a test room that is not qualified for the measurement of discrete-frequency components (see Annex D)

8.5.2.1 General

The need for additional microphone and noise source positions shall be evaluated following similar procedures to those of 8.4.2, using single event time-integrated sound pressure levels instead of time-averaged sound pressure levels.

8.5.2.2 Measurements to be used for determining sound energy levels

If the results of the evaluations in 8.5.2.1 show that no additional microphone positions or source positions are needed, then the measurements from 8.5.1 using the initial six microphone positions can be taken as final. If the evaluations of 8.5.2.1 show that additional microphone positions are needed, repeated sets of measurements shall be taken using the number of microphone positions determined. If additional source positions are needed in accordance with 8.5.2.1, the same number of microphone positions shall be used for each.

8.6 Measurement of sound pressure levels from the reference sound source for the comparison method

8.6.1 Location of the reference sound source

The position of the reference sound source shall be on the floor of the reverberation test room, and more than 1,5 m from the walls of the room. The noise source under test shall be located in the reverberation room during the measurements of the reference sound source. If the source under test is not easily moved, the reference sound source shall be installed as close as practical but at least 1,5 m from the source under test (see next paragraph). This single position for the reference sound source suffices, even when multiple positions are required for the noise source under test in accordance with 8.4.2 or 8.5.2.

The preferred location of the reference sound source corresponds to the location to be used for the noise source under test (or one of the locations, if multiple locations are required for the source under test).

8.6.2 Sound pressure levels from the reference sound source

The time-averaged sound pressure levels in each one-third-octave band over the frequency range of interest from the reference sound source shall be measured using the same discrete microphone positions or traverses as in 8.4.1 or 8.5.1 for the noise source under test. Measurement of the reference sound source shall be made at the same temperature, pressure, and humidity used for the measurement of the noise source under test within the limits specified in 5.5.

NOTE Requirements for the reference sound source are described in 6.2 and the evaluations of 8.4.2 need not be conducted for the reference sound source.

8.7 Measurement of reverberation time

The reverberation times of the test room, T_{60}, shall be measured in accordance with ISO 3382-2, except that only the first 10 dB or 15 dB decay, denoted respectively T_{10f} and T_{15f}, shall be used (ISO 80000-8[21]). Reverberation times shall be measured with the noise source under test in the test room if it is likely to affect the reverberation time significantly. For one-third-octave bands with mid-band frequencies from 6 300 Hz to 10 kHz, the same number of measurements of decays shall be used as for the band with a mid-band frequency of 5 000 Hz.

8.8 Measurement of meteorological conditions

The meteorological conditions (air temperature, static pressure, and relative humidity) around the noise source at the time of the test shall be measured. The accuracy and precision of the equipment shall be sufficient to allow determination of conformity with the requirements of 5.5.

9 Determination of sound power levels and sound energy levels

9.1 Determination of sound power levels

9.1.1 Calculation of measured time-averaged sound pressure levels for multiple source positions

If more than one position of the noise source under test has been used (8.4.2.4), the measured time-averaged sound pressure level in each one-third-octave band over the frequency range of interest and for each of the i microphone positions or microphone traverses, for the chosen mode of operation of the source under test and averaged over j source positions, $L'_{pi(\text{ST})}$, shall be calculated using Equation (13):

$$L'_{pi(\text{ST})} = 10 \lg \left\{ \frac{1}{N_\text{S}} \sum_{j=1}^{N_\text{S}} 10^{0{,}1\left[L'_{pi(\text{ST})}\right]_j} \right\} \text{dB} \tag{13}$$

where

$\left[L'_{pi(\text{ST})}\right]_j$ is the measured (uncorrected) one-third-octave band time-averaged sound pressure level at the ith microphone position or for the ith microphone traverse, and for the jth source position, with the noise source under test in operation (ST), in decibels;

N_S is the number of source positions.

9.1.2 Corrections for background noise

The background noise correction, K_{1i}, at the ith microphone position or for the ith microphone traverse in each one-third-octave band shall be calculated using Equation (14):

$$K_{1i} = -10 \lg\left(1 - 10^{-0{,}1\Delta L_{pi}}\right) \text{dB} \tag{14}$$

where

$$\Delta L_{pi} = L'_{pi(\text{ST})} - L_{pi(\text{B})}$$

in which

$L'_{pi(\text{ST})}$ is the measured (uncorrected) one-third-octave band time-averaged sound pressure level at the ith microphone position or for the ith microphone traverse, with the noise source under test in operation, in decibels,

$L_{pi(\text{B})}$ is the one-third-octave band time-averaged sound pressure level of the background noise (B) measured at the ith microphone position or for the ith microphone traverse, in decibels.

If $\Delta L_{pi} \geqslant 15$ dB, K_{1i} is assumed to be zero, and no correction for background noise shall be applied.

If 6 dB $\leqslant \Delta L_{pi} <$ 15 dB, for one-third-octave bands of mid-band frequency 200 Hz and below, and 6 300 Hz and above, K_{1i} shall be calculated in accordance with Equation (14).

If 10 dB $\leqslant \Delta L_{pi} <$ 15 dB, for one-third-octave bands of mid-band frequency 250 Hz to 5 000 Hz, K_{1i} shall be calculated in accordance with Equation (14).

If $\Delta L_{pi} <$ 6 dB for one or more one-third-octave bands of mid-band frequency 200 Hz and below and 6 300 Hz and above, K_{1i} shall be set to 1,26 dB (the value for ΔL_{pi} = 6 dB). If $\Delta L_{pi} <$ 10 dB for one or more one-third-octave bands of mid-band frequency 250 Hz to 5 000 Hz, K_{1i} shall be set to 0,46 dB (the value for ΔL_{pi} = 10 dB). In either case, it shall be clearly stated in the text of the report, as well as in graphs and tables of results, that the data in such bands represent upper bounds to the sound power level of the noise source under test.

If the modelling approach of Annex G is used for the measurement uncertainty due to background noise, it shall be evaluated with full correction in accordance with Equation (15), without restricting the level difference between source under test and background noise.

The measured time-averaged sound pressure levels shall each be corrected for the presence of background noise. The corrected one-third-octave band time-averaged sound pressure level at the ith microphone position or for the ith microphone traverse, with the noise source under test in operation, $L_{pi(\mathrm{ST})}$, in decibels, is given by

$$L_{pi(\mathrm{ST})} = L'_{pi(\mathrm{ST})} - K_{1i} \tag{15}$$

where

$L'_{pi(\mathrm{ST})}$ is the measured (uncorrected) one-third-octave band time-averaged sound pressure level at the ith microphone position or for the ith microphone traverse, with the noise source under test in operation, in decibels;

K_{1i} is the background noise correction, in decibels.

9.1.3 Calculation of mean time-averaged sound pressure levels in the test room

The mean background noise corrected one-third-octave band time-averaged sound pressure level in the test room with the noise source under test in operation, $\overline{L_{p(\mathrm{ST})}}$, shall be calculated using Equation (16):

$$\overline{L_{p(\mathrm{ST})}} = 10\lg\left[\frac{1}{N_\mathrm{M}}\sum_{i=1}^{N_\mathrm{M}} 10^{0,1 L_{pi(\mathrm{ST})}}\right]\ \mathrm{dB} \tag{16}$$

where

$L_{pi(\mathrm{ST})}$ is the corrected one-third-octave band time-averaged sound pressure level at the ith microphone position or for the ith microphone traverse, with the noise source under test in operation, in decibels;

N_M is the number of microphone positions or individual microphone traverses.

The mean background noise corrected one-third-octave band time-averaged sound pressure level of the reference sound source (RSS) in the test room, $\overline{L_{p(\mathrm{RSS})}}$, shall be calculated using Equation (17):

$$\overline{L_{p(\mathrm{RSS})}} = 10\lg\left[\frac{1}{N_\mathrm{M}}\sum_{i=1}^{N_\mathrm{M}} 10^{0,1 L_{pi(\mathrm{RSS})}}\right]\ \mathrm{dB} \tag{17}$$

where

$$L_{pi(\mathrm{RSS})} = L'_{pi(\mathrm{RSS})} - K_{1i(\mathrm{RSS})}$$

in which

$L'_{pi(\mathrm{RSS})}$ is the measured (uncorrected) one-third-octave band time-averaged sound pressure level of the reference sound source at the ith microphone position or for the ith microphone traverse, in decibels,

$K_{1i(\mathrm{RSS})}$ is the background noise correction for the reference sound source at the ith microphone position or for the ith microphone traverse, in decibels, calculated using Equation (14) with the substitution of $L'_{pi(\mathrm{RSS})}$ for $L'_{pi(\mathrm{ST})}$;

N_M is the number of microphone positions or individual microphone traverses.

To determine whether the background noise criteria of 5.4 have been met, the quantities given by Equations (18) and (19) are also required.

The mean uncorrected one-third-octave band time-averaged sound pressure level in the test room, with the noise source under test in operation, $\overline{L'_{p(\mathrm{ST})}}$, in decibels, is given by

$$\overline{L'_{p(\mathrm{ST})}} = 10 \lg \left[\frac{1}{N_\mathrm{M}} \sum_{i=1}^{N_\mathrm{M}} 10^{0,1 L'_{pi(\mathrm{ST})}} \right] \mathrm{dB} \tag{18}$$

where

$L'_{pi(\mathrm{ST})}$ is the measured (uncorrected) one-third-octave band time-averaged sound pressure level at the ith microphone position or for the ith microphone traverse, with the noise source under test in operation, in decibels;

N_M is the number of microphone positions or individual microphone traverses.

The mean one-third-octave band time-averaged sound pressure level of the background noise (B), $\overline{L_{p(\mathrm{B})}}$, in decibels, is given by

$$\overline{L_{p(\mathrm{B})}} = 10 \lg \left[\frac{1}{N_\mathrm{M}} \sum_{i=1}^{N_\mathrm{M}} 10^{0,1 L_{pi(\mathrm{B})}} \right] \mathrm{dB} \tag{19}$$

where

$L_{pi(\mathrm{B})}$ is the one-third-octave band time-averaged sound pressure level of the background noise measured at the ith microphone position or for the ith microphone traverse, in decibels;

N_M is the number of microphone positions or individual microphone traverses.

9.1.4 Calculation of sound power levels using the equivalent absorption area of the room (direct method)

The sound power level of the noise source under test in each one-third-octave band, L_W, under reference meteorological conditions, shall be calculated using Equation (20):

$$L_W = \overline{L_{p(\mathrm{ST})}} + \left\{ 10\,\lg\frac{A}{A_0}\,\mathrm{dB} + 4{,}34\frac{A}{S}\,\mathrm{dB} + 10\,\lg\left(1+\frac{S\,c}{8\,V\,f}\right)\mathrm{dB} + C_1 + C_2 - 6\,\mathrm{dB}\right\} \tag{20}$$

where

$\overline{L_{p(\mathrm{ST})}}$ is the mean corrected one-third-octave band time-averaged sound pressure level in the test room with the noise source under test in operation, in decibels;

A is the equivalent absorption area, in square metres, of the room

$$A = \frac{55{,}26}{c}\left(\frac{V}{T_{60}}\right)$$

in which T_{60} is the reverberation time, in seconds, of the reverberation test room at the mid-band frequency of the measurement(s);

A_0 = 1 m^2;

S is the total surface area, in square metres, of the reverberation test room;

c is the speed, in metres per second, of sound at the temperature, θ, in degrees Celsius, of the air in the reverberation test room at the time of test,

$$c = 20{,}05\sqrt{273 + \theta}$$

V is the volume, in cubic metres, of the reverberation test room;

f is the mid-band frequency, in hertz, of the measurement(s);

C_1 is the reference quantity correction, in decibels, to account for the different reference quantities used to calculate decibel sound pressure level and decibel sound power level, and is a function of the characteristic impedance of the air under the meteorological conditions at the time and place of the measurements:

$$C_1 = -10\,\lg\frac{p_\mathrm{s}}{p_{\mathrm{s},0}}\,\mathrm{dB} + 5\,\lg\left(\frac{273{,}15 + \theta}{\theta_0}\right)\mathrm{dB}$$

C_2 is the radiation impedance correction, in decibels, to change the actual sound power relevant for the meteorological conditions at the time and place of the measurement into the sound power under reference meteorological conditions, the value shall be obtained from the appropriate noise test code, but in the absence of a noise test code, the following equation is valid for a monopole source, and is a mean value for other sources (see References [23][31]):

$$C_2 = -10\,\lg\frac{p_\mathrm{s}}{p_{\mathrm{s},0}}\,\mathrm{dB} + 15\,\lg\left(\frac{273{,}15 + \theta}{\theta_1}\right)\mathrm{dB}$$

in which

p_s is the static pressure, in kilopascals, in the test room at the time of test,

$p_{\mathrm{s},\,0}$ is the reference static pressure, 101,325 kPa,

θ is the air temperature, in degrees Celsius, in the test room at the time of test,

θ_0 = 314 K,

θ_1 = 296 K.

NOTE The value given for θ_0 leads to a characteristic impedance of air of 400 Ns/m^3 at the reference static pressure 101,325 kPa (References [22][23]). This value is not related to any real environmental condition, it is a consequence of the decibel reference values used for sound pressure and for sound power.

$$\theta_0 = 273{,}15\ \mathrm{K} \times \left[\frac{331{,}45\ \mathrm{m/s} \times 1{,}292\,9\ \mathrm{kg/m^3} \times 1\ \mathrm{pW}}{(20\,\mathrm{\mu Pa})^2 \times 1\ \mathrm{m}^2} \right]^2 = 313{,}51\ \mathrm{K} \approx 314\ \mathrm{K}$$

9.1.5 Calculation of sound power levels using the reference sound source (comparison method)

The sound power level of the noise source under test in each one-third-octave band, L_W, under reference meteorological conditions, shall be calculated using Equation (21):

$$L_W = L_{W(\mathrm{RSS})} + \left(\overline{L_{p(\mathrm{ST})}} - \overline{L_{p(\mathrm{RSS})}} \right) + C_2 \tag{21}$$

where

$L_{W(\mathrm{RSS})}$ is the one-third-octave band sound power level of the reference sound source, determined in accordance with ISO 6926 and corrected to the meteorological conditions at the time of test, in decibels;

$\overline{L_{p(\mathrm{ST})}}$ is the mean corrected one-third-octave band time-averaged sound pressure level in the test room, from the noise source under test, in decibels;

$\overline{L_{p(\mathrm{RSS})}}$ is the mean background noise corrected one-third-octave band time-averaged sound pressure level in the test room, from the reference sound source, in decibels;

C_2 $= -10\ \lg \dfrac{p_\mathrm{s}}{p_{\mathrm{s},\,0}}\ \mathrm{dB} + 15\ \lg \left[\dfrac{273{,}15 + \theta}{\theta_1} \right]\ \mathrm{dB}$

9.2 Determination of sound energy levels

9.2.1 Calculation of the mean of the measured single event time-integrated sound pressure levels for multiple sound emission events and for multiple source positions

If N_e single event time-integrated sound pressure levels have been measured one at a time at the ith microphone position and for the jth source position, the mean measured single event time-integrated sound pressure level at that position, $\left[L'_{Ei(\mathrm{ST})} \right]_j$ shall be calculated using Equation (22):

$$\left[L'_{Ei(\mathrm{ST})} \right]_j = 10\ \lg \left\{ \frac{1}{N_\mathrm{e}} \sum_{q=1}^{N_\mathrm{e}} 10^{0{,}1 \left[L'_{Ei,q(\mathrm{ST})} \right]_j} \right\}\ \mathrm{dB} \tag{22}$$

where

$\left[L'_{Ei,q(\mathrm{ST})}\right]_j$ is the measured (uncorrected) one-third-octave band single event time-integrated sound pressure level at the ith microphone position, for the jth source position and for the qth event (q = 1, 2 ... N_e) of the noise source under test in operation, in decibels;

N_e is the number of measurements of single sound emission events.

If one single event time-integrated sound pressure level has been measured at the ith microphone position and for the jth source position encompassing N_e sound emission events, the mean measured single event time-integrated sound pressure level at that position for one event, $\left[L'_{Ei(\mathrm{ST})}\right]_j$ shall be calculated using Equation (23):

$$\left[L'_{Ei(\mathrm{ST})}\right]_j = \left[L'_{Ei,N_\mathrm{e}(\mathrm{ST})}\right]_j - 10 \lg N_\mathrm{e} \ \mathrm{dB} \tag{23}$$

where

$\left[L'_{Ei,N_\mathrm{e}(\mathrm{ST})}\right]_j$ is the measured (uncorrected) one-third-octave band single event time-integrated sound pressure level at the ith microphone position, for the jth source position and encompassing N_e successive sound emission events of the noise source under test in operation, in decibels;

N_e is the number of sound emission events encompassed by one measurement of single sound emission events.

If more than one position of the noise source under test has been used (8.4.2.4) the mean measured single event time-integrated sound pressure level in each one-third-octave band over the frequency range of interest, for each of the i microphone positions, for the chosen mode of operation of the noise source under test and averaged over j source positions, $L'_{Ei(\mathrm{ST})}$, shall be calculated using Equation (24):

$$L'_{Ei(\mathrm{ST})} = 10 \lg \left\{ \frac{1}{N_\mathrm{S}} \sum_{j=1}^{N_\mathrm{S}} 10^{0,1\left[L'_{Ei(\mathrm{ST})}\right]_j} \right\} \mathrm{dB} \tag{24}$$

where

$\left[L'_{Ei(\mathrm{ST})}\right]_j$ is the mean measured (uncorrected) one-third-octave band single event time-integrated sound pressure level at the ith microphone position and for the jth source position, with the noise source under test in operation, in decibels;

N_S is the number of source positions.

9.2.2 Corrections for background noise

The background noise correction, K_{1i}, in each one-third-octave band and for each fixed microphone position shall be calculated in a similar manner to that of 9.1.2, using instead the difference between the mean measured single event time-integrated sound pressure level and the background noise level:

$$K_{1i} = -10 \lg(1 - 10^{-0,1 \Delta L_{Ei}}) \ \mathrm{dB} \tag{25}$$

where

$$\Delta L_{Ei} = L'_{Ei(\mathrm{ST})} - L_{pi(\mathrm{B})}$$

in which

$L'_{Ei(\mathrm{ST})}$ is the mean measured (uncorrected) one-third-octave band single event time-integrated sound pressure level at the ith microphone position, with the noise source under test in operation, in decibels,

$L_{pi(\mathrm{B})}$ is the one-third-octave band time-averaged sound pressure level of the background noise measured at the ith microphone position, in decibels.

The integration time $T = t_2 - t_1$ and other measurement parameters shall be the same for the measurement of the single event time-integrated sound pressure level, $L'_{Ei(\mathrm{ST})}$, and background noise level, $L_{pi(\mathrm{B})}$.

The mean measured one-third-octave band single event time-integrated sound pressure level at the ith microphone position, with the noise source under test in operation, in decibels, shall be corrected for the presence of background noise as follows:

$$L_{Ei(\mathrm{ST})} = L'_{Ei(\mathrm{ST})} - K_{1i} \tag{26}$$

where

$L'_{Ei(\mathrm{ST})}$ is the mean measured (uncorrected) one-third-octave band single event time-integrated sound pressure level at the ith microphone position, with the noise source under test in operation, in decibels;

K_{1i} is the background noise correction, in decibels.

9.2.3 Calculation of mean single event time-integrated sound pressure levels in the test room

The mean corrected one-third-octave band single event time-integrated sound pressure level in the test room with the noise source under test in operation, $\overline{L_{E(\mathrm{ST})}}$, shall be calculated using Equation (27):

$$\overline{L_{E(\mathrm{ST})}} = 10 \lg \left[\frac{1}{N_\mathrm{M}} \sum_{i=1}^{N_\mathrm{M}} 10^{0,1 L_{Ei(\mathrm{ST})}} \right] \mathrm{dB} \tag{27}$$

where

$L_{Ei(\mathrm{ST})}$ is the mean corrected one-third-octave band single event time-integrated sound pressure level at the ith microphone position, with the noise source under test in operation, in decibels;

N_M is the number of microphone positions.

To determine whether the background noise criteria of 5.4 have been met, the quantities given by Equations (28) and (29) are also required.

The mean uncorrected one-third-octave band single event time-integrated sound pressure level in the test room, with the noise source under test in operation, $\overline{L'_{E(\mathrm{ST})}}$, in decibels, is given by

$$\overline{L'_{E(\mathrm{ST})}} = 10 \lg \left[\frac{1}{N_\mathrm{M}} \sum_{i=1}^{N_\mathrm{M}} 10^{0,1 L'_{Ei(\mathrm{ST})}} \right] \mathrm{dB} \tag{28}$$

where

$L'_{Ei(\mathrm{ST})}$ is the mean measured (uncorrected) one-third-octave band single event time-integrated sound pressure level at the ith microphone position, with the noise source under test in operation, in decibels;

N_M is the number of microphone positions.

The mean one-third-octave band time-averaged sound pressure level of the background noise, $\overline{L_{p(\mathrm{B})}}$, in decibels, is given by

$$\overline{L_{p(\mathrm{B})}} = 10\ \lg\left[\frac{1}{N_\mathrm{M}}\sum_{i=1}^{N_\mathrm{M}} 10^{0{,}1L_{pi(\mathrm{B})}}\right]\ \mathrm{dB} \tag{29}$$

where

$L_{pi(\mathrm{B})}$ is the one-third-octave band time-averaged sound pressure level of the background noise measured at the ith microphone position, in decibels;

N_M is the number of microphone positions.

9.2.4 Calculation of sound energy levels using the equivalent absorption area of the room (direct method)

The sound energy level of the noise source under test in each one-third-octave band, L_J, under reference meteorological conditions, shall be calculated (References [25][26]) using Equation (30) (see 9.1.4):

$$L_J = \overline{L_{E(\mathrm{ST})}} + \left[10\ \lg\frac{A}{A_0}\,\mathrm{dB} + 4{,}34\,\frac{A}{S}\,\mathrm{dB} + 10\ \lg\left(1+\frac{S\,c}{8V\,f}\right)\mathrm{dB} + C_1 + C_2 - 6\ \mathrm{dB}\right] \tag{30}$$

where $\overline{L_{E(\mathrm{ST})}}$ is the mean corrected one-third-octave band single event time-integrated sound pressure level in the test room with the noise source under test in operation, in decibels.

The explanations for all other variables are the same as for Equation (20).

9.2.5 Calculation of sound energy levels using the reference sound source (comparison method)

The sound energy level of the noise source under test in each one-third-octave band, L_J, under reference meteorological conditions, shall be calculated using Equation (31):

$$L_J = L_{W(\mathrm{RSS})} + \left(\overline{L_{E(\mathrm{ST})}} - \overline{L_{p(\mathrm{RSS})}}\right) + C_2 \tag{31}$$

where

$L_{W(\mathrm{RSS})}$ is the one-third-octave band sound power level of the reference sound source, determined in accordance with ISO 6926 under the same meteorological conditions as those at the time of test, in decibels;

$\overline{L_{E(\mathrm{ST})}}$ is the mean corrected one-third-octave band single event time-integrated sound pressure level in the test room, from the noise source under test, in decibels;

$\overline{L_{p(\mathrm{RSS})}}$ is the mean background noise corrected one-third-octave band time-averaged sound pressure level in the test room, from the reference sound source, in decibels;

C_2 is the radiation impedance correction, in decibels, to change the actual sound power relevant for the meteorological conditions at the time and place of the measurement into the sound power under reference meteorological conditions, the value shall be obtained from the appropriate noise test code, but in the absence of a noise test code, the following equation is valid for a monopole source, and is a mean value for other sources (see References [23][31]):

$$C_2 = -10 \lg \frac{p_s}{p_{s,0}} \text{ dB} + 15 \lg \left(\frac{273{,}15 + \theta}{\theta_1} \right) \text{ dB}$$

9.3 A-weighted sound power level and sound energy level

Where required, the A-weighted sound power level or sound energy level of the noise source under test shall be calculated using the procedure given in Annex F.

10 Measurement uncertainty

10.1 Methodology

The uncertainties of sound power levels, $u(L_W)$, in decibels, and sound energy levels, $u(L_J)$, in decibels, determined in accordance with this International Standard are estimated by the total standard deviation, in decibels:

$$u(L_W) \approx u(L_J) \approx \sigma_{\text{tot}} \qquad (32)$$

This total standard deviation is obtained using the modelling approach described in ISO/IEC Guide 98-3. This requires a mathematical model which in case of lack of knowledge can be replaced by results from measurements, including results from round robin tests.

In this context this standard deviation is expressed by the standard deviation of reproducibility of the method, σ_{R0}, in decibels, and the standard deviation, σ_{omc}, in decibels, describing the uncertainty due to the instability of the operating and mounting conditions of the source under test in accordance with:

$$\sigma_{\text{tot}} = \sqrt{\sigma_{R0}^2 + \sigma_{\text{omc}}^2} \qquad (33)$$

Equation (33) shows that variations of operating and mounting conditions expressed by σ_{omc} should be taken into account before a measurement procedure with a certain grade of accuracy (characterized by σ_{R0}) is selected for a specific machine family (see 10.5 and G.3).

NOTE If different measurement procedures offered by the ISO 3740 to ISO 3747 series are used, systematic numerical deviations (biases) may additionally occur.

Derived from σ_{tot}, the expanded measurement uncertainty, U, in decibels, shall be calculated from

$$U = k \, \sigma_{\text{tot}} \qquad (34)$$

The expanded measurement uncertainty depends on the degree of confidence that is desired. For a normal distribution of measured values, there is 95 % confidence that the true value lies within the range $(L_W - U)$ to $(L_W + U)$, [or $(L_J - U)$ to $(L_J + U)$]. This corresponds to a coverage factor of $k = 2$.

If the purpose of determining the sound power level is to compare the result with a limit value, it can be more appropriate to apply the coverage factor for a one-sided normal distribution. In that case, the coverage factor $k = 1{,}6$ corresponds to a 95 % confidence level.

10.2 Determination of σ_{omc}

The standard deviation σ_{omc} [see Equation (G.1)] which describes the uncertainty associated with the instability of the operating and mounting conditions for the particular source under test shall be taken into account when determining the measurement uncertainty. It can be determined separately from repeated measurements carried out on the same source at the same location by the same persons, using the same measuring instruments and the same measurement position(s). To determine σ_{omc}, repeated sound pressure levels are measured either at the microphone position associated with the highest sound pressure level, $L'_{pi(\mathrm{ST})}$, or measured and averaged over all measured positions, $\overline{L'_{p(\mathrm{ST})}}$. Measurements are then corrected for background noise. For each of these repeated measurements, the mounting of the machine and its operating conditions shall be readjusted. For the individual sound source under test, σ_{omc} is designated as σ'_{omc}. It is possible that a noise test code provides a value of σ_{omc} which is representative for the machine family concerned. This value should take into account all possible variations of operating and mounting conditions that are within the scope of the noise test code.

NOTE If the sound power has only a small variation with time and the measurement procedure is defined properly, a value of 0,5 dB for σ_{omc} can apply. In other cases, e.g. a large influence of the material flow into and out of the machine or material flow that varies in an unpredictable manner, a value of 2 dB is appropriate. However, in extreme cases such as strongly varying noise generated by the processed material (stone-breaking machines, metal-cutting machines and presses operating under load) a value of 4 dB results.

10.3 Determination of σ_{R0}

10.3.1 General

The standard deviation σ_{R0} includes all uncertainty due to conditions and situations allowed by this International Standard (different radiation characteristics of the source under test, different instrumentation, different implementations of the measurement procedure), except that due to instability of the sound power of the source under test. The latter is considered separately by σ_{omc}.

The values of σ_{R0} given in Table 6 reflect current knowledge. They are typical upper bounds taking into consideration the great variety of machines and equipment covered by this International Standard. Machinery-specific values may be derived from round robin tests (see 10.3.2) or by using the mathematical modelling approach (see 10.3.3). They should be given in noise test codes specific to machinery families (see 10.2 and Annex G).

10.3.2 Round robin test

The round robin test for determining σ_{R0} shall be carried out in accordance with ISO 5725, where the sound power level of the source under test is determined under reproducibility conditions, i.e. different persons carrying out measurements at different testing locations with different measuring instruments. Such a test provides the total standard deviation σ'_{tot} relevant for the individual sound source which has been used for the round robin test. Participating laboratories in round robin tests should cover all possible practical situations.

This total standard deviation σ'_{tot}, in decibels, of all results obtained with a round robin test includes the standard deviation σ'_{omc} and allows σ'_{R0} to be determined by using

$$\sigma'_{R0} = \sqrt{{\sigma'_{\mathrm{tot}}}^2 - \sigma'^2_{\mathrm{omc}}} \tag{35}$$

If σ'_{R0} values obtained from many different pieces of machinery belonging to the same family deviate within a small range only, their mean value can be regarded as typical for the application of this International Standard to this particular family and used as σ_{R0}. Whenever available, such a value should be given in the noise test code specific to the machine family concerned (together with σ_{omc}) and used in particular for the purpose of declaring noise emission values.

If no round robin test has been carried out, the existing knowledge about the noise emission from a particular family of machines may be used to estimate realistic values of σ_{R0}.

For certain applications, the effort involved in a round robin test can be reduced by omitting measurements for different locations, e.g. if machines under test are usually installed under conditions with a small background noise correction K_1 or if the noise emission of a machine is rechecked at the same location. Results of such delimited tests should be denoted by $\sigma_{R0,\,\mathrm{DL}}$, and this designation should also be used for tests on large machines being not movable in space.

Values for $\sigma_{R0,\ \mathrm{DL}}$ can be expected to be lower than those given in Table 6.

The determination of σ_{R0} using Equation (35) is imprecise if σ_{tot} is only slightly higher than σ_{omc}. In this case, Equation (35) gives a small value of σ_{R0}, but with a low accuracy. To limit this inaccuracy, σ_{omc} should not exceed $\sigma_{\mathrm{tot}} / \sqrt{2}$.

10.3.3 Modelling approach for σ_{R0}

Generally σ_{R0}, in decibels, is dependent upon several partial uncertainty components, $c_i\, u_i$, associated with the different measurement parameters such as uncertainties of instruments, environmental corrections, and microphone positions. If these contributions are assumed to be uncorrelated, σ_{R0} can be described by the modelling approach presented in ISO/IEC Guide 98-3, as follows:

$$\sigma_{R0} \approx \sqrt{(c_1 u_1)^2 + (c_2 u_2)^2 + \ldots.. + (c_n u_n)^2} \tag{36}$$

In Equation (36) the uncertainty components due to the instability of the sound emission of the source are not included. These components are covered by σ_{omc}. Annex G discusses each component of the uncertainty σ_{R0} in accordance with existing knowledge.

NOTE If the uncertainty components in the modelling approach are correlated, Equation (36) does not apply. Furthermore, the modelling approach requires detailed knowledge to determine the individual terms in Equation (36).

By contrast, the estimation of σ_{R0} based on a round robin test does not require assumptions about possible correlations between the individual terms of Equation (36). A round robin test is currently more realistic than determining possible correlations between the single terms of Equation (36) and their dependencies on all other influencing parameters using the modelling approach. However, round robin tests are not always possible and are often replaced by experience from earlier measurements.

10.4 Typical upper bound values of σ_{R0}

Table 6 shows typical upper bound values of the standard deviation σ_{R0} for accuracy grade 1 that may cover most of the applications of this International Standard (References [27][28]). In special cases or if certain requirements of this International Standard are not met for a machine family or if it is anticipated that actual values of σ_{R0} for a given family of machines are smaller than those given in Table 6, a round robin test is recommended to obtain machine-specific values of σ_{R0}.

Table 6 —Typical upper bound values of the standard deviation of reproducibility of the method, σ_{R0}, for A-weighted sound power levels and sound energy levels determined in accordance with this International Standard

Frequency bandwidth	One-third-octave mid-band frequency Hz	Standard deviation of reproducibility, σ_{R0} dB
One-third-octave	100[a] to 160	3,0
	200 to 315	2,0
	400 to 5 000	1,5
	6 300 to 10 000	3,0
A-weighted per Annex F		0,5[b]

[a] Guidelines for frequencies below 100 Hz are given in Annex E.

[b] Applicable to noise sources which emit sound with a relatively “flat” spectrum in the frequency range from 100 Hz to 10 000 Hz.

10.5 Total standard deviation σ_{tot} and expanded measurement uncertainty, U

The total standard deviation and the expanded measurement uncertainty shall be determined using Equation (33) and Equation (34), respectively.

EXAMPLE Accuracy grade 1; σ_{omc} = 2,0 dB; coverage factor k = 2; measured $L_{W\text{A}}$ = 82 dB. Machine-specific determinations of σ_{R0} have not been undertaken thus the value is taken from Table 6 (σ_{R0} = 0,5 dB). Using Equations (34) and (33) it follows

$$U = 2 \times \sqrt{0{,}5^2 + 2^2} \text{ dB} = 4{,}1 \text{ dB}$$

Additional examples of calculated values for σ_{tot} are given in G.3.

NOTE The expanded measurement uncertainty as described in this International Standard does not include the standard deviation of production which is used in ISO 4871[9] for the purpose of making a noise declaration for batches of machines.

11 Information to be recorded

11.1 General

The information listed in 11.2 to 11.5, when applicable, shall be compiled and recorded for all measurements made in accordance with this International Standard.

11.2 Noise source under test

The following information shall be recorded:

a) a description of the noise source under test (including the manufacturer, type, technical data, dimensions, serial number and year of manufacture);

b) a description of any treatment of auxiliary equipment for the purpose of the test;

c) the mode(s) of operation used for the test(s) and the relevant measurement time interval(s);

d) the installation and mounting conditions;

e) the location(s) of noise source in the test room;

f) the location(s) of the reference sound source in the test room.

11.3 Test environment

The following information shall be recorded:

a) a description of the test room, including the dimensions in metres, the surface treatment of the walls, ceiling and floor, and a sketch showing the location of the noise source under test and the room contents;

b) the air temperature in degrees Celsius, the relative humidity expressed as a percentage, and the static pressure, in kilopascals, in the room at the time of test.

11.4 Instrumentation

The following information shall be recorded:

a) the equipment used for the measurements, including the name, type, serial number and manufacturer;

b) the date and place of calibration; the methods used to calibrate the sound calibrator, verify the calibration of the instrumentation system and, if used, to calibrate the reference sound source, in accordance with 6.2.

11.5 Acoustical data

The following information shall be recorded:

a) the method (direct or comparison) used for the determination of sound power levels or sound energy levels;

b) the microphone positions or traverse used for the measurements (with a sketch if necessary) and a description of how the microphone is traversed;

For each mode of operation under which the noise source was tested:

c) all sound pressure levels, whether time averaged or single event time-integrated, measured in the reverberation test room from the noise source under test and for the background noise;

d) the mean time-averaged or single event time-integrated sound pressure levels in the reverberation test room from the noise source under test and the mean background noise levels;

e) the corrections, in decibels, to account for background noise, in each one-third-octave band and at each microphone position or over each microphone traverse;

f) the sound power levels or sound energy levels, in decibels, in one-third-octave bands and, if applicable, A-weighted, rounded to the nearest 0,1 dB; a graphical representation may optionally be recorded in addition;

NOTE ISO 9296[15] requires that the declared A-weighted sound power levels, $L_{W\mathrm{Ad}}$, of computers and business equipment are expressed in bels, using the identity 1 B = 10 dB.

g) the expanded measurement uncertainty of the results, in decibels, together with the associated coverage factor and coverage probability;

h) the date and time when the measurements were performed.

12 Test report

Only those recorded data (see Clause 11) which are required for the purpose of the measurements shall be reported. The report shall also contain any statements required to be reported by certain clauses in the main body of this International Standard. If the reported sound power levels or sound energy levels have been obtained in full conformity with the requirements of this International Standard, the report shall state this fact. If the levels have not been obtained in full conformity, the report shall not state or imply that they have been. If one or a small number of identifiable discrepancies exist between the reported levels and the requirements of this International Standard, then the report may state that the measurements have been conducted "in conformity with the requirements of this International Standard, except for…" and the discrepancies shall be clearly identified. In this case, the term "full conformity" shall not be stated or implied.

For example, if the volume of the source under test exceeds 2 % of the volume of the test room (see 1.2), the report shall clearly state that this requirement has not been met. Furthermore, the report shall not state or imply that the measurements have been made "in full conformity" with ISO 3741.

Annex A
(informative)

Guidelines for the design of reverberation test rooms

A.1 General

For accurate determination of the sound power level or sound energy level of a device, machine, component or sub-assembly, the reverberation test room should have:

a) adequate volume;

b) suitable shape and/or diffusing elements;

c) suitably small sound absorption over the frequency range of interest;

d) sufficiently low background noise levels.

A.2 Volume of reverberation test room

The requirements for reverberation test room volume are given in 5.2.

As shown in Table 1, a volume of 200 m^3 is required for general purpose measurements in which the 125 Hz octave band (or 100 Hz one-third-octave band) is the lowest band in the frequency range of interest.

NOTE In large rooms (i.e. those with volumes greater than 200 m^3) air absorption can cause an undesirable reduction in the uniformity of the reverberant sound field at frequencies above 3 000 Hz. Keeping the relative humidity above 50 % reduces air absorption.

A.3 Shape of reverberation test room

If the room is not a right cuboid, none of its surfaces should be parallel. If the room is a right cuboid, its proportions should be selected so that the ratio of any two dimensions does not equal or closely approximate an integer.

The proportions 1:2$^{1/3}$:4$^{1/3}$ are frequently used. Other room dimension ratios that have been found to be satisfactory for rooms having a volume near 200 m^3 are given in Table A.1.

Table A.1 — Recommended room dimension ratios for right cuboid rooms

l_y/l_x	l_z/l_x
0,83	0,47
0,83	0,65
0,79	0,63
0,68	0,42
0,70	0,59
NOTE The symbols l_x, l_y and l_z represent the room dimensions.	

A.4 Absorption of reverberation test room

The sound absorption coefficient of the surfaces of the reverberation test room should be small enough to ensure an adequate reverberant sound field.

The sound absorption coefficient should be large enough to minimise the effect of the room modes on the sound power produced by the source below a frequency, f, in hertz, given by:

$$f = \frac{2\ 000}{V^{1/3}}$$

where V is the numerical value of the room volume, expressed in cubic metres.

For frequencies below f, the average sound absorption coefficient, $\bar{\alpha}$, of all the surfaces of the reverberation test room should not exceed 0,16. For frequencies above f or equal to f, the average sound absorption coefficient should not exceed 0,06.

Annex B

(informative)

Guidelines for the design of rotating diffusing vanes

Rotating diffusers in a reverberation test room are useful for the following two reasons:

a) the diffuser reduces the spatial variance of the mean-square sound pressure in the room, which improves the accuracy of estimates of the space-averaged sound pressure level;

b) the diffuser distributes the sound power flow from the source throughout the room, which usually makes the sound power of the source less dependent on the room dimensions and on source position in the reverberation test room.

The effectiveness of rotating diffusers depends primarily on their size. The diffuser should, therefore, be as large as the room dimensions permit. The diffuser panels should not be of lightweight construction. A surface density of at least 5 kg/m^2 is recommended. The speed of rotation should be high enough so that sound pressures can be averaged over at least 10 complete revolutions of the diffuser to meet the requirements of 8.4.1.

The practical design problems associated with large, heavy panels rotating at high speed can best be overcome by designing the diffuser as a disk, cone or cylinder, and balancing the surface areas so that the centre of gravity is on the diffuser axis. A double conical diffuser 5 m in diameter has been operated successfully at 2,6 rad/s. Diffuser surfaces which are not parallel to any room surface appear to give best results.

Annex C
(normative)

Reverberation test room qualification procedure for the measurement of broad-band sound

C.1 Introduction

If the room volume is less than that specified in 5.2 or if the absorption of the test room is more than specified in 5.3, the procedure described in this annex shall be used to determine whether broad-band sounds can be measured with the reproducibility specified in Table 6. It provides a measure of the variability in the coupling between the sound source and the reverberant sound field as well as that in the space- and time-averaging procedure. The reproducibility of the broad-band sound measurements for each one-third-octave band is expressed in terms of the standard deviation of the measurements.

C.2 Instrumentation and equipment

The instrumentation and microphone traverse or array shall be the same as those used during the actual testing of a noise source. The test procedure given in this annex requires the use of a reference sound source having the characteristics specified in ISO 6926.

The instrumentation shall conform to the requirements laid down in Clause 6.

The microphone traverse or array shall conform to the requirements specified in 8.3.

C.3 Test procedure

Six or more reverberant sound field measurements shall be taken of the one-third-octave band time-averaged sound pressure levels in the room, each with the reference sound source placed at a different location within the room, under the following conditions.

a) The source location shall be selected within a floor area not closer than 1,5 m to a wall and not closer to the microphone than permitted by 8.3. The distance between any two source locations shall be greater than $\lambda/4$, where λ is the wavelength at the centre frequency of the lowest frequency band for which the room is to be qualified. No source location shall lie on a room centreline. The source locations shall be in the general vicinity of the location intended for the noise source being evaluated.

b) With the reference sound source at each of the above locations, measurements of the one-third-octave or octave band time-averaged sound pressure levels shall be recorded to at least the nearest 0,1 dB.

c) The microphone traverse or array, sound diffusers (if any), instrumentation, and observation time shall be identical to those used for carrying out actual tests with equipment in the source area being qualified.

C.4 Calculation

For each frequency band for which the test room is to be qualified, the standard deviation, s_S, shall be calculated using Equation (C.1):

$$s_\mathrm{S} = \sqrt{\sum_{i=1}^{N_\mathrm{S}} \frac{\left(L_{pi} - L_{p\mathrm{m}}\right)^2}{N_\mathrm{S} - 1}} \qquad \text{(C.1)}$$

where

L_{pi} is the band sound time-averaged pressure level obtained in accordance with the time- and space-averaging technique described in 9.1, in decibels;

$L_{p\mathrm{m}}$ is the arithmetic mean of the band time-averaged sound pressure levels, in decibels;

N_S is the number of source positions.

C.5 Qualification

For each frequency band, the reverberation test room is qualified for the measurement of broad-band sound if the calculated standard deviation does not exceed the limits given in Table C.1.

Table C.1 — Maximum allowable standard deviation of L_{pi}

One-third-octave mid-band frequency Hz	**Maximum allowable standard deviation**, s_S dB
100 to 160	1,5
200 to 630	1,0
800 to 2 500	0,5
3 150 to 10 000	1,0

Annex D
(normative)

Reverberation test room qualification procedure for the measurement of discrete-frequency components

D.1 Introduction

When the sound of equipment being tested contains significant discrete-frequency components, measurement problems arise because the spatial variance of the sound field and the space and frequency domain variances of the coupling of a sound source to the modes of a reverberation test room are much larger for discrete-frequency sound than for broad-band sound. Ways to deal with these problems when needed are specified in 8.4.2. An alternative to these procedures is to optimize the initial design of the room and the test set-up to meet the measurement reproducibility objectives of Clause 10 for any and all spectral compositions. Since it is not possible to predict quantitatively the acoustical performance of many of the design features used in such design optimizations, this annex provides an experimental qualification procedure for determining the combined effectiveness of all features of the test facility.

At low frequencies, the major problem tends to be the small number of room modes which can be excited at any given frequency. This deficiency can be improved by using a larger room, optimizing the room proportions (see A.3) and by introducing additional damping into the room to broaden the frequency response (modal bandwidth) of each mode (see A.4). It is possible, however, that the qualification criteria (see Table D.1) can be met at low frequencies only by using a large rotating diffuser of the type described in Annex B.

At high frequencies, the limiting factor is the number of microphone positions used. It is possible to use an array of discrete microphone positions provided an effective rotating diffuser is employed, but frequently it may be necessary to use a continuous spatial averaging scheme employing a long microphone traverse. Circular traverses provide more length in a given space than linear ones and are easier to automate.

Table D.1 — Maximum allowable sample standard deviations, s_f

One-third-octave mid-band frequency Hz	Maximum allowable standard deviation, s_f dB
100 to 160	3,0
200 to 315	2,0
400 to 630	1,5
800 to 2 500	1,0

D.2 General

The procedure specified in this annex provides an upper limit estimate of the uncertainty of measuring discrete frequency sounds in a given reverberation test room using a particular source location, or set of locations, and a given microphone array or path. If the standard deviations do not exceed the values given in Table D.1 over the frequency range of interest, the test facility [consisting of the room, the source location(s), the instrumentation, the diffuser (if any), and the microphone array or path] is satisfactory for testing any noise source whose spectrum contains significant discrete-frequency components. Thus, no additional evaluations (such as in 8.4.2) are then necessary for any particular noise source to be tested.

The qualification procedure makes use of the fact that a pure tone signal represents the worst case so that the standard deviations obtained with this procedure are greater than or equal to the standard deviations of reproducibility encountered in testing any realistic noise source.

D.3 Instrumentation and measurement equipment

In addition to the instrumentation and equipment specified in Clause 6, the following items are required for the room qualification test:

a) a loudspeaker of 200 mm diameter or less with an airtight back enclosure;

b) a signal generator, frequency synthesizer, or oscillator; a frequency counter or an analyser that can be used to determine frequency; an amplifier, and a voltmeter.

It may be necessary to try several models of loudspeaker in order to find one having a sufficiently smooth frequency response to meet the criteria of D.4.

The signal generator, frequency synthesizer or oscillator shall be capable of generating one or more sinusoidal signals at the frequencies and tolerances given in Table D.2, and shall be stable to within ± 0,1 Hz over the frequency range of interest, and shall have less than 0,1 % total harmonic distortion.

The frequency counter or frequency analyser shall be accurate to within ± 0,05 Hz over the frequency range of interest.

The power amplifier used to drive the loudspeaker shall have an output impedance that is compatible with the electrical impedance of the loudspeaker and shall have sufficient power handling capability (see D.4).

The voltmeter shall have sufficient precision to enable monitoring the voltage across the loudspeaker terminals to within ± 1,0 %, at all test frequencies shown in Table D.2.

D.4 Loudspeaker test

Locate the loudspeaker at any convenient place on the hard, reflecting floor of a hemi-anechoic facility, or on a reflecting surface located in a suitable quiet location outdoors that meets the requirements of ISO 3744[5], with the loudspeaker cone facing upwards. Place a microphone, which shall be of the same manufacturer and model as the microphones used in the reverberation test room facility, with its diaphragm horizontal at a distance of 10 mm to 20 mm coaxially above the plane of the rim of the loudspeaker. Using the same indicating device and frequency analyser as used in sound power determinations (see 6.1), measure and record the sound pressure levels at the test frequencies shown in Table D.2 to the nearest 0,5 dB.

It should be noted that the loudspeaker test uses a near-field measurement to obtain the frequency response of the loudspeaker. This is based on the fact that the near-field sound pressure level of a small monopole-type source is related to the sound power level in a manner which is essentially independent of frequency because the real part of the acoustic admittance seen by such a source is essentially independent of frequency.

The loudspeaker is suitable only if the sound pressure levels at adjacent frequencies do not differ by more than 1 dB.

D.5 Room test

Place the loudspeaker, with the cone facing away from the nearest room surface (including the floor), at the location(s) and height(s) corresponding to the source position(s) to be qualified. At least six discrete microphone positions meeting the location requirements of 8.3, or a continuous microphone traverse with a length of at least $l \geqslant 3\lambda$, where λ is the wavelength of sound at the lowest mid-band frequency of interest, shall be selected for the measurements. If a revolving or oscillating sound diffuser is used, the diffuser shall be in operation.

Determine the space- and time-averaged sound pressure level at the test frequencies listed in Table D.2. The loudspeaker input voltage shall be the same as for the loudspeaker test (see D.4).

NOTE If an array of fixed microphone positions is used, the array can either be scanned and the average sound pressure level obtained automatically (see 8.3) or the levels at the individual microphone positions can be determined and the average level obtained by computation.

Frequency variations shall not exceed ± 0,1 Hz during each set of measurements.

D.6 Computational procedure

Correct the room levels taken under D.5 to remove the influence of the near-field loudspeaker characteristic by subtracting, at each frequency, the loudspeaker level taken in D.4 to obtain the corrected sound pressure levels, $L_{p\mathrm{k}}$.

For each one-third-octave band, calculate the arithmetic mean, $L_{p\mathrm{m}}$, of the room sound pressure levels so corrected and compute the standard deviation, s_f, of the difference between the corrected room levels and the mean level:

$$s_f = \sqrt{\sum_{k=1}^{N_f} \frac{\left(L_{pk} - L_{p\mathrm{m}}\right)^2}{N_f - 1}} \tag{D.1}$$

where

L_{pk} is the time-averaged sound pressure level (corrected for loudspeaker response) produced in the test room by the loudspeaker source when excited at the kth test frequency, averaged over all microphone positions (and if appropriate, over all loudspeaker source locations), in decibels;

$L_{p\mathrm{m}}$ is the arithmetic mean of $L_{p\mathrm{k}}$ values, averaged over all N_f test frequencies in a given one-third-octave band, in decibels;

N_f is the number of test frequencies in a given one-third-octave band.

D.7 Qualification

For each particular one-third-octave band, the test facility [room, source location(s), instrumentation, rotating diffuser (if any), and microphone array or traverse] qualifies for the measurement of the sound power level or sound energy level produced by noise sources containing significant discrete-frequency components if the computed standard deviation does not exceed the limits given in Table D.1. If the room does not qualify with the initial choice for the number of microphone positions or length of microphone traverse, additional positions or a greater length of traverse may be used and the measurements repeated in an attempt to qualify the room for a single source position.

It is not necessary to qualify the test room at frequencies above the 2 500 Hz one-third-octave band.

If a continuous microphone traverse of length l is used, the qualification needs to be carried out only at frequencies below f_1 or f_2, whichever is larger.

$$f_1 = \frac{6\,000}{l}$$

$$f_2 = \frac{5\,000}{V^{1/3}}$$

where

l is the numerical value of the length, in metres, of the microphone traverse path;

V is the numerical value of the volume, in cubic metres, of the test room.

D.8 Multiple source locations

If the test room does not qualify with a single source position, or if multiple source positions are in any case used during actual testing, the qualification procedure (D.7) may be repeated using one or more additional loudspeaker positions. In this case, the sound pressure levels shall be averaged first over the individual source positions [in equivalence to Equation (13)], and then over the individual microphone positions or microphone traverses [in equivalence to Equation (16)]. The resulting average sound pressure level, for each frequency band, is then used in place of L_{pk} in Equation (D.1).

If the qualification is based on multiple loudspeaker locations, the same set of locations shall be used for the noise source under test. The sound pressure levels determined for the several microphone positions and source locations shall be averaged.

Table D.2 — Test frequencies for alternative qualification of reverberation test room for measuring sound power levels and sound energy levels of noise sources emitting significant discrete-frequency components

	Centre frequency of one-third-octave bands Hz														
	100	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**
	—	—	147	—	—	—	361	—	—	—	—	—	1 470	—	—
	—	113	148	—	226	—	364	—	—	—	—	1 130	1 480	—	2 260
	—	114	149	—	228	—	367	—	564	712	—	1 140	1 490	—	2 280
	90	115	150	180	230	285	370	450	570	720	900	1 150	1 500	1 800	2 300
	91	116	151	182	232	288	373	455	576	728	910	1 160	1 510	1 820	2 320
	92	117	152	184	234	291	376	460	582	736	920	1 170	1 520	1 840	2 340
	93	118	153	186	236	294	379	465	588	744	930	1 180	1 530	1 860	2 360
	94	119	154	188	238	297	382	470	594	752	940	1 190	1 540	1 880	2 380
	95	120	155	190	240	300	385	475	600	760	950	1 200	1 550	1 900	2 400
	96	121	156	192	242	303	388	480	606	768	960	1 210	1 560	1 920	2 420
	97	122	157	194	244	306	391	485	612	776	970	1 220	1 570	1 940	2 440
	98	123	158	196	246	309	394	490	618	784	980	1 230	1 580	1 960	2 460
	99	124	159	198	248	312	397	495	624	792	990	1 240	1 590	1 980	2 480
	100	125	160	200	250	315	400	500	630	800	1 000	1 250	1 600	2 000	2 500
	101	126	161	202	252	318	403	505	636	808	1 010	1 260	1 610	2 020	2 520
	102	127	162	204	254	321	406	510	642	816	1 020	1 270	1 620	2 040	2 540
	103	128	163	206	256	324	409	515	648	824	1 030	1 280	1 630	2 060	2 560
	104	129	164	208	258	327	412	520	654	832	1 040	1 290	1 640	2 080	2 580
	105	130	165	210	260	330	415	525	660	840	1 050	1 300	1 650	2 100	2 600
	106	131	166	212	262	333	418	530	666	848	1 060	1 310	1 660	2 120	2 620
	107	132	167	214	264	336	421	535	672	856	1 070	1 320	1 670	2 140	2 640
	108	133	168	216	266	339	424	540	678	864	1 080	1 330	1 680	2 160	2 660
	109	134	169	218	268	342	427	545	684	872	1 090	1 340	1 690	2 180	2 680
	110	135	170	220	270	345	430	550	690	880	1 100	1 350	1 700	2 200	2 700
	111	136	171	222	272	348	433	555	696	888	1 110	1 360	1 710	2 220	2 720
	—	137	172	—	274	—	436	560	702	—	—	1 370	1 720	—	2 740
	—	138	173	—	276	—	439	—	—	—	—	1 380	1 730	—	2 760
Increment, Hz	1	1	1	2	2	3	3	5	6	8	10	10	10	20	20
Tolerance of increment, Hz	±0,3	±0,3	±0,3	±0,5	±0,5	±1	±1	±1,5	±2	±3	±3	±5	±5	±5	±5
Number of test frequencies, N_f	22	26	27	22	26	22	27	23	24	23	22	26	27	22	26

Annex E
(informative)

Extension of frequency range to frequencies below 100 Hz

E.1 Additional frequency range

Measurements in accordance with this International Standard may be extended down in frequency to include the 50 Hz, 63 Hz, and 80 Hz frequency bands. Users of this International Standard may use either the direct method (see 9.1.4 and 9.2.4) or the comparison method (see 9.1.5 and 9.2.5) subject to the additional requirements and guidelines of this annex. If using the latter, the reference sound source shall include calibrated sound power levels for these bands in accordance with ISO 6926.

E.2 Supplement to Table 6

Table E.1 — Standard deviations of reproducibility and typical total standard deviations of sound power levels and sound energy levels below 100 Hz

One-third-octave mid-band frequency Hz	**Standard deviation of reproducibility**, σ_{R0} dB
50 to 80	3,9

For rooms of volume less than 200 m^3, the standard deviation of reproducibility may be higher. (See Table E.1.)

E.3 Supplement to Table 1 (Minimum volume of the reverberation test room as a function of the lowest frequency band of interest)

In general, the greater the volume of the reverberation room, the lower the variation in reproducibility of the sound power levels and sound energy levels at low frequencies. For the purpose of this annex, rooms with volumes greater than 200 m^3 are recommended.

E.4 Supplement to Table 4 (Minimum number of microphone positions for the measurement of sound pressure level) and Table 5 (Minimum number of source locations for the measurement of sound pressure level)

The same values as given for 125 Hz are applicable.

E.5 Supplement to Table C.1

The reverberation test room may be qualified for the measurement of broad-band sound following the procedures of Annex C using Table E.2.

Table E.2 — Maximum allowable standard deviation of L_{pi}

One-third-octave mid-band frequency Hz	Maximum allowable standard deviation, s_s dB
50 to 80	2,0

E.6 Supplement to Tables D.1 and D.2

The reverberation test room may be qualified for the measurement of discrete-frequency components following the procedures of Annex D using Table E.3 and E.4.

Table E.3 —Maximum allowable sample standard deviations, s_f

One-third-octave mid-band frequency Hz	Maximum allowable standard deviation, s_f dB
50 to 80	3,0

Table E.4 — Test frequencies for alternative qualification of reverberation test room for measuring sound power levels and sound energy levels of noise sources emitting significant discrete-frequency components

	Centre frequency of one-third-octave bands Hz		
	50	**63**	**80**
	—	—	—
	—	—	—
	—	56,4	71,2
	45,0	57,0	72,0
	45,5	57,6	72,8
	46,0	58,2	73,6
	46,5	58,8	74,4
	47,0	59,4	75,2
	47,5	60,0	76,0
	48,0	60,6	76,8
	48,5	61,2	77,6
	49,0	61,8	78,4
	49,5	62,4	79,2
	50,0	63,0	80,0
	50,5	63,6	80,8
	51,0	64,2	81,6
	51,5	64,8	82,4
	52,0	65,4	83,2
	52,5	66,0	84,0
	53,0	66,6	84,8
	53,5	67,2	85,6
	54,0	67,8	86,4
	54,5	68,4	87,2
	55,0	69,0	88,0
	55,5	69,6	88,8
	56,0	70,2	—
	—	—	—
Increment, Hz	0,5	0,6	0,8
Tolerance of increment, Hz	±0,2	±0,2	±0,3
Number of test frequencies, N_f	23	24	23

Annex F
(normative)

Calculation of octave band sound power levels and sound energy levels, A-weighted sound power levels and A-weighted sound energy levels from one-third-octave band levels

F.1 Sound power levels

F.1.1 Octave band levels

The sound power level in the ith octave band, L_{Wi}, where $1 \leqslant i \leqslant 8$ is an integer number identifying octave bands with mid-band frequencies in the range 63 Hz to 8 000 Hz, shall be calculated from Equation (F.1):

$$L_{Wi} = 10 \lg \sum_{k=3i-2}^{3i} 10^{0,1 L_{Wk}} \text{ dB} \tag{F.1}$$

where

L_{Wk} is the sound power level in the kth one-third-octave band, in decibels;

k is an integer number lying within the range $3i - 2$ to $3i$, and which identifies the three one-third-octave bands (see Table F.1) which make up the ith octave band.

F.1.2 A-weighted level

The A-weighted sound power level, L_{WA}, shall be calculated from Equation (F.2):

$$L_{W\text{A}} = 10 \lg \sum_{k=k_{\text{min}}}^{k_{\text{max}}} 10^{0,1(L_{Wk}+C_k)} \text{ dB} \tag{F.2}$$

where

L_{Wk} is the sound power level in the kth one-third-octave band, in decibels;

k, C_k are given in Table F.1;

k_{min}, k_{max} are the values of k corresponding, respectively, to the lowest and highest one-third-octave bands of measurement.

F.1.3 Unweighted level

The unweighted sound power level over the whole frequency range of interest, L_W, shall be calculated from Equation (F.3):

$$L_W = 10 \lg \sum_{k=k_{\text{min}}}^{k_{\text{max}}} 10^{0,1 L_{Wk}} \text{ dB} \tag{F.3}$$

where

L_{Wk} is the sound power level in the kth one-third-octave band, in decibels;

k_{min}, k_{max} are the values of k corresponding, respectively, to the lowest and highest one-third-octave bands of measurement.

F.2 Sound energy levels

F.2.1 Octave band levels

The sound energy level in the ith octave band, L_{Ji}, where $1 \leqslant i \leqslant 8$ is an integer identifying octave bands with mid-band frequencies in the range 63 Hz to 8 000 Hz, shall be calculated from Equation (F.4):

$$L_{Ji} = 10 \lg \sum_{k=3i-2}^{3i} 10^{0,1 L_{Jk}} \text{ dB} \tag{F.4}$$

where

L_{Jk} is the sound energy level in the kth one-third-octave band, in decibels;

k is an integer number lying within the range $3i - 2$ to $3i$, and which identifies the three one-third-octave bands (see Table F.1) which make up the ith octave band.

F.2.2 A-weighted level

The A-weighted sound energy level, $L_{J\text{A}}$, shall be calculated from Equation (F.5):

$$L_{J\text{A}} = 10 \lg \sum_{k=k_{\text{min}}}^{k_{\text{max}}} 10^{0,1(L_{Jk}+C_k)} \text{ dB} \tag{F.5}$$

where

L_{Jk} is the sound energy level in the kth one-third-octave band, in decibels;

k, C_k are given in Table F.1;

k_{min}, k_{max} are the values of k corresponding, respectively, to the lowest and highest one-third-octave bands of measurement.

F.2.3 Unweighted level

The unweighted sound energy level over the whole frequency range of interest, L_J, shall be calculated from Equation (F.6):

$$L_J = 10 \lg \sum_{k=k_{\text{min}}}^{k_{\text{max}}} 10^{0,1 L_{Jk}} \text{ dB} \tag{F.6}$$

where

L_{Jk} is the sound energy level in the kth one-third-octave band, in decibels;

k_{min}, k_{max} are the values of k corresponding, respectively, to the lowest and highest one-third-octave bands of measurement.

F.3 Values of k and C_k for use in calculations

For calculations with one-third-octave band data, values of k and C_k are given in Table F.1.

Table F.1 — Values of k and C_k for mid-band frequencies of one-third-octave bands

k	**One-third-octave mid-band frequency** Hz	C_k dB
1	50[a]	–30,2
2	63[a]	–26,2
3	80[a]	–22,5
4	100	–19,1
5	125	–16,1
6	160	–13,4
7	200	–10,9
8	250	–8,6
9	315	–6,6
10	400	–4,8
11	500	–3,2
12	630	–1,9
13	800	–0,8
14	1 000	0,0
15	1 250	0,6
16	1 600	1,0
17	2 000	1,2
18	2 500	1,3
19	3 150	1,2
20	4 000	1,0
21	5 000	0,5
22	6 300	–0,1
23	8 000	–1,1
24	10 000	–2,5

[a] The values of C_k for these three frequencies are given for use only in connection with Annex E.

Annex G
(informative)

Guidelines on the development of information on measurement uncertainty

G.1 General

The accepted format for the expression of uncertainties generally associated with methods of measurement is that given in ISO/IEC Guide 98-3. This format incorporates a budget of uncertainty components, in which all the various sources of uncertainty are identified and from which the combined total measurement uncertainty can be obtained.

To determine the noise emission of machines and equipment, it is advisable to split up its total uncertainty into two different groups of uncertainty components:

a) those that are intrinsic to the measurement procedure;

b) those that result from the instability of the sound emission of the machine.

Based on current knowledge, this annex provides additional explanations and information by which ISO/IEC Guide 98-3 could be applied in practice for this International Standard.

This annex complements Clause 10.

G.2 Considerations on the total standard deviation σ_{tot}

The measurement uncertainty used in this International Standard is determined by the expanded measurement uncertainty, U, which is derived directly from the total standard deviation σ_{tot} [see Equation (34)] with σ_{tot} being the approximation of the relevant $u(L_W)$ as defined in ISO/IEC Guide 98-3.

This total standard deviation, σ_{tot}, results from the two components, σ_{R0} and σ_{omc} [see Equation (33)], which are significantly different in nature.

Both quantities are assumed to be statistically independent and are determined separately.

The machinery specific standard deviation, σ_{omc}, cannot be calculated and has to be determined by repeated measurements as described in G.3. Information on the standard deviation, σ_{R0}, is given in G.4.

The largest sources of variability, other than those due to the source operating characteristics, possible deviations from the theoretical model (direct method) and errors in the calibration of the reference sound source (comparison method) in the test methods specified in this International Standard are associated with inadequate sampling of the sound field and with variations in the acoustic coupling from the noise source to the sound field (for different test rooms and for different positions within a test room). In any laboratory, it may be possible to reduce measurement uncertainty by one or more of the following procedures:

a) use of multiple source locations;

b) improvement of spatial sampling of the sound field by increasing the number of microphone positions or the length of the microphone traverse;

c) addition of low-frequency sound absorbers to improve modal overlap;

d) use of moving diffuser elements.

A large reverberation test room may be used to reduce variability at low frequencies, although the precision of high-frequency sound power level determinations may be degraded. Conversely, a small room may lead to reduced variability at high frequencies, but might increase it at low frequencies. Thus, if improved precision is needed, and if two reverberation test rooms are available, it may be desirable to carry out the low-frequency sound power level or sound energy level determinations in the larger room and high-frequency determinations in the smaller room.

G.3 Considerations on σ_{omc}

The standard deviation, σ_{omc}, described in 10.2, is calculated by

$$\sigma_{\text{omc}} = \sqrt{\frac{1}{N-1}\sum_{j=1}^{N}\left(L_{p,j} - L_{p\text{av}}\right)^2}\ \text{dB} \tag{G.1}$$

where

$L_{p,j}$ is the sound pressure level measured at a prescribed position and corrected for background noise for the jth repetition of the prescribed operating and mounting conditions;

$L_{p\text{av}}$ is its arithmetic mean level calculated for all these repetitions.

These measurements are carried out at the microphone position associated with the highest sound pressure level. When measurements are averaged over all measurement positions, $L_{p,j}$, and $L_{p\text{av}}$, are replaced in Equation (G.1), by $\overline{L_{p,j}}$, and $\overline{L_{p\text{av}}}$, respectively.

In general, the mounting and operating conditions to be used for noise emission measurements are prescribed by machinery specific noise test codes. Otherwise, these conditions shall be defined precisely and described in the test report.

Some recommendations for defining these conditions and consequences for the expected values of σ_{omc} are given in the following.

The test conditions shall represent normal usage and conform to manufacturers' and users' recommended practice. However, even in normal usage, slightly different modes of operation, variations in material flow, and other conditions varying between different phases of operation may occur. This uncertainty covers both the uncertainty due to variation in long-term operating conditions (e.g. from day to day) and fluctuations of noise emission measurements repeated immediately after readjusting mounting and operating conditions.

Machines that stand exclusively on soft springs or on heavy concrete floors do not normally exhibit any effect of mounting. However, there can be large discrepancies between measurements on heavy concrete floors and those made *in situ*. The uncertainty due to mounting can be highest for machinery that is connected to auxiliary equipment. Hand-held machines may also cause problems. This parameter should be investigated if movement of the machine or mounts causes changes in noise. If there is a range of possible mounting conditions to be included in a single declaration, then σ_{omc} is estimated from the standard deviation of the sound levels for these mounting conditions. If there is any known effect due to mounting, recommended mounting conditions should be documented in the relevant noise test code or manufacturers' recommended practice.

With respect to the main uncertainty quantity, σ_{tot}, investigations on σ_{omc} have a higher priority compared to those on the other uncertainty components leading to σ_{R0} [see Equation (33)]. This is because σ_{omc} may be significantly larger in practice than, for example, σ_{R0} = 0,5 dB for accuracy grade 1 measurements as given in Table 6.

If $\sigma_{\text{omc}} > \sigma_{R0}$, the application of measurement procedures with a high accuracy, i.e. a low value of σ_{R0} makes no sense economically because this is not going to result in a lower value of the total uncertainty.

Table G.1 — Examples of calculated total standard deviations σ_{tot} for three different cases

Standard deviation of reproducibility of the method, σ_{R0}, dB	**Operating and mounting conditions**		
	stable	unstable	very unstable
	Standard deviation, σ_{omc}, dB		
	0,5	2	4
	Total standard deviation, σ_{tot}, **dB**		
0,5 (Accuracy grade 1)	0,7	2,1	4,0
1,5 (Accuracy grade 2)	1,6	2,5	4,3
3 (Accuracy grade 3)	3,0	3,6	5,0

These examples show that it may be superfluous to extend the measuring effort to ensure a measurement of accuracy grade 1 if the uncertainty associated with the mounting and operating conditions is large.

Furthermore, situations where $\sigma_{\text{omc}} > \sigma_{R0}$ may create substantial misunderstandings with respect to the true relevant total standard deviation σ_{tot}, because the different grades of accuracy of this International Standard are currently defined by the value of σ_{R0} only.

G.4 Considerations on σ_{R0}

G.4.1 General

Upper bound values of σ_{R0} are given in Table 6. Additionally in 10.3, the investigation of values of σ_{R0} that are relevant to individual machines or machine families in order to achieve more realistic values is recommended. These investigations shall be carried out either by measurements under reproducibility conditions as defined in ISO 5725 or by calculations using the so-called modelling approach based on Equation (36) which requires more detailed information.

If certain uncertainty components are not relevant for specific applications or are difficult to investigate, delimited definitions of σ_{R0} should be given by noise test codes both for round robin tests (see Note to 10.3.2) and for the modelling approach analogously.

The budget approach, however, implies both statistically independent components c_i, u_i and especially the existence of equations which allow assessment of these uncertainty components by considering either measurement parameters and environmental conditions or a reasonably large body of practical experience. However, relevant well-founded data for this International Standard were not available at the time of publication. Nonetheless, the following information may give a rough outline of the relevant quantities without being definitive.

G.4.2 Contributions to the uncertainty σ_{R0}

G.4.2.1 General

Preliminary estimations show that when corrected for meteorological conditions, the sound power level, L_W, is a function of a number of parameters, indicated by the following equation, obtained with appropriate substitution in Equation (20):

$$L_W = \delta_{\text{method}} + \delta_{\text{omc}} + \overline{L'_{p(\text{ST})}} + 10\ \text{lg}\frac{A}{A_0}\ \text{dB} + 4{,}34\frac{A}{S}\text{dB} + 10\,\text{lg}\left(1+\frac{S\,c}{8\,V\,f}\right)\text{dB} - K_1 + C_1 + C_2 - 6\ \text{dB} + \delta_{\text{slm}} + \delta_H \tag{G.2}$$

where

δ_{method}	is an input quantity to allow for any uncertainty due to the measurement method applied including the derivation of results and associated uncertainties, in decibels;
δ_{omc}	is an input quantity to allow for any uncertainty due to operating and mounting conditions, in decibels — this quantity is not included in the calculation of σ_{R0} [see Equation (33)];
$\overline{L'_{p(\text{ST})}}$	is the mean one-third-octave band time-averaged sound pressure level of the noise source under test, in decibels (see 9.1.3);
A	is the equivalent absorption area, in square metres, of the room (see 3.10), $A = \frac{55{,}26}{c}\left(\frac{V}{T_{60}}\right)$ in which T_{60} is the reverberation time, in seconds, of the reverberation test room at the mid-band frequency of the measurement(s) (see 3.8);
A_0	= 1 m^2;
S	is the total surface area, in square metres, of the reverberation test room;
V	is the volume, in cubic metres, of the reverberation test room;
f	is the mid-band frequency, in hertz, of the measurement band;
c	is the speed, in metres per second, of sound at the temperature, θ, in degrees Celsius, of the air in the reverberation test room at the time of test $c = 20{,}05\sqrt{273 + \theta}$;
K_1	is the background noise correction, in decibels (see 9.1.2);
C_1	is the reference quantity correction, in decibels, to account for the different reference quantities used to calculate decibel sound pressure level and decibel sound power level, and is a function of the characteristic impedance of the air under the meteorological conditions at the time and place of the measurements: $C_1 = -10\ \text{lg}\frac{p_{\text{s}}}{p_{\text{s,}\,0}}\ \text{dB} + 5\ \text{lg}\left[\frac{273{,}15 + \theta}{\theta_0}\right]\ \text{dB}$

C_2 is the radiation impedance correction, in decibels, to change the actual sound power relevant for the meteorological conditions at the time and place of the measurement into the sound power under reference meteorological conditions, the value shall be obtained from the appropriate noise test code, but in the absence of a noise test code, the following equation is valid for a monopole source, and is a mean value for other sources (see References [23][31])

$$C_2 = -10 \lg \frac{p_\text{s}}{p_{\text{s},0}} \text{dB} + 15 \lg \left(\frac{273{,}15 + \theta}{\theta_1} \right) \text{dB}$$

in which

p_s is the static pressure, in kilopascals, in the test room at the time of test,

$p_{\text{s},0}$ is the reference static pressure, 101,325 kPa,

θ is the air temperature, in degrees Celsius, in the test room at the time of test,

θ_0 = 314 K (see 9.1.4),

θ_1 = 296 K;

δ_slm is an input quantity to allow for any uncertainty in the measuring instrumentation;

δ_H is an input quantity to allow for any uncertainty due to fluctuations in the relative humidity in the reverberation test room.

NOTE 1 A similar expression to that of Equation (G.2) applies to sound energy levels.

NOTE 2 Similar expressions to that of Equation (G.2) apply with respect to sound power levels determined in frequency bands and with A-weighting applied.

NOTE 3 The quantities included in Equation (G.2) to allow for uncertainties are those thought to be applicable at the state of knowledge current at the time of publication of this International Standard, but further research could reveal that there are others.

A probability distribution (normal, rectangular, Student's t, etc.) is associated with each of the input quantities. Its expectation (mean value) is the best estimate for the value of the input quantity and its standard deviation is a measure of the dispersion of values, termed uncertainty.

The uncertainty components related to mounting and operating conditions are already covered by σ_omc whereas σ_{R0} includes the rest of the uncertainty components.

Table G.2 provides some information about current expectations concerning the values for the components, c_i, u_i, that are necessary to calculate $\sigma_{R0} = \sqrt{\sum_i (c_i \, u_i)^2}$ dB.

The calculation of σ_{R0} assumes that the individual uncertainty contributions are not correlated.

The standard uncertainties from some contributions remain to be established by research.

Information needed from which to derive the overall uncertainty of the direct method is that illustrated in Table G.2 and in G.4.3, and the information relating to the comparison method is that illustrated in G.4.4.

G.4.3 Direct method

G.4.3.1 General

An explanation and numerical example for the uncertainty parameters in Table G.2 are given in G.4.3.2 to G.4.3.12. Formulae to calculate uncertainties are given with examples to show the expected range of measurement uncertainties.

Table G.2 — Uncertainty budget for determinations of σ_{R0} for sound power level and sound energy level using the direct method, valid for A-weighted measurements of a source with a relatively flat frequency spectrum

Quantity		Estimate dB	Standard uncertainty[a], u_i	Probability distribution	Sensitivity coefficient[a], c_i
δ_{method}	method	0	0,3	Normal	1
$\overline{L'_{p(\text{ST})}}$	mean time-averaged sound pressure level	$\overline{L'_{p(\text{ST})}}$	$\dfrac{u_{L'_{pi(\text{ST})j}}}{\sqrt{N_\text{M} N_\text{S}}}$	Normal	$1+\dfrac{1}{10^{0,1\Delta L_p}-1}$
K_1	background noise correction	K_1	$s_{L_{p(\text{B})}}$	Normal	$\dfrac{1}{10^{0,1\Delta L_p}-1}$
V/S	ratio of room volume to surface area	0	$u_{V/S}$	Normal	$\dfrac{240}{T_{60}\, c}-\dfrac{4,3\, c}{(V/S)(8\, f\, V/S+c)}$
V	room volume	0	u_V	Normal	$4,3/V$
T_{60}	reverberation time	0	$\sqrt{\dfrac{2,42\, T}{f}+\dfrac{s_T^2}{N_{\text{decay}}}}$	Normal	$\dfrac{-4,3}{T_{60}}-\dfrac{240\, V}{T_{60}^2\, S\, c}$
θ	temperature	0	$\Delta\theta/\sqrt{3}$	Rectangular	$\dfrac{8,7}{273+\theta}+\dfrac{-0,57+0,25\,\lg(2,6f)}{1+0,0011H+0,007\theta}$
p_s	static pressure	0	$\Delta p_\text{s}/\sqrt{3}$	Rectangular	$-8,7/p_\text{s}$
δ_{slm}	sound level meter	0	0,3	Normal	1
δ_H	relative humidity	0	$\Delta H/\sqrt{3}$	Rectangular	$\dfrac{-2,6\,+\,1,6\,\lg(0,7f)}{1\,+\,0,5H}$

[a] Quantities are described in the numerical example following this table.

G.4.3.2 Measurement method, δ_{method}

The uncertainty due to the measurement method applied, u_{method}, includes the derivation of results and associated uncertainties. Assuming know biases are accounted for, this uncertainty can only be derived from practical experience or round robin testing. This uncertainty approaches zero as the modelling approach becomes more sophisticated. If, however, there is a lack of knowledge or if it is difficult or impractical to model certain uncertainty components, this component of uncertainty could become the sole determinant of measurement reproducibility, σ_{R0}. An example of this latter case is the implementation of standards by inexperienced users.

For frequencies above 100 Hz, experience has shown that the approximate value of uncertainty due to the measurement method applied is u_{method} = 0,3 dB. Below 100 Hz, the wavelength reduces both the effective number of possible microphone positions and the number of room modes. This increases this parameter to u_{method} = 3 dB below 100 Hz.

The measurement method has a direct effect on the measurement result so the sensitivity coefficient, c_{method} = 1.

For measurements above 100 Hz, the uncertainty contribution is 0,3 dB.

G.4.3.3 Sound pressure level repeatability, $\overline{L'_{p(\text{ST})}}$

The uncertainty due to measurement repeatability, $u_{L'_{p(\text{ST})}}$, is the closeness of agreement between results of successive measurements; it may be obtained from the standard deviation of measured levels

$$u_{L'_{p(\text{ST})}} = \frac{u_{L'_{pi(\text{ST})j}}}{\sqrt{N_\text{M}\,N_\text{S}}} = \frac{1}{\sqrt{N_\text{M}\,N_\text{S}}}\sqrt{\sum_{j=1}^{N_\text{S}}\sum_{i=1}^{N_\text{M}}\frac{\left\{\left[L'_{pi(\text{ST})}\right]_j - L'_{p\text{m(ST)}}\right\}^2}{N_\text{M}\,N_\text{S} - 1}}$$

where $L'_{p\text{m(ST)}}$ is the arithmetic mean value of the uncorrected time-averaged sound pressure levels with the noise source under test in operation, in decibels.

The sensitivity coefficient, $c_{\overline{L'_{p(\text{ST})}}}$, is influenced by background noise levels. It is obtained from the derivative of L_W with respect to $\overline{L'_{p(\text{ST})}}$. Using a derivation similar to that for c_{K_1}, (below), the sensitivity coefficient due to repeatability is:

$$c_{L'_{p(\text{ST})}} = 1 + \frac{1}{10^{0,1\Delta L_p} - 1}$$

This may be further simplified to $c_{L'_{p(\text{ST})}} = 1 + c_{K_1}$. Using the same extreme scenario given below for c_{K_1} results in $c_{L'_{p(\text{ST})}} = 1{,}1$. If the requirements on the number of source and microphone positions in 8.4.2 are met, the worst case uncertainty contribution should be 1 dB or lower in single frequency bands. For the A-weighted value, the summation across multiple frequency bands tends to make an uncertainty contribution of 0,2 dB more typical. The uncertainty contribution can be reduced by increasing the reverberation time, reducing the variability of measurements in the room using diffusors, or increasing the number of source and microphone positions. Measurement repeatability can also be strongly influenced by averaging time. If the averaging time does not cover a sufficient number of machinery cycles, the total uncertainty may be unacceptably large for a precision grade standard. For extremely low noise sources, reduction of background noise can reduce the sensitivity coefficient and hence total uncertainty by up to a factor of 2. In this example, the uncertainty contribution is assumed to be 0,2 dB.

G.4.3.4 Background noise correction, K_1

The uncertainty, u_{K_1}, due to the background noise correction, K_1, can be obtained from the standard deviation, $s_{L_{p(\text{B})}}$, of the decibel values from of repeated measurements of background noise at a single microphone position.

The sensitivity coefficient, c_{K_1}, due to the background noise $\overline{L_{p(\text{B})}}$ is obtained from the derivative of L_W with respect to $\overline{L_{p(\text{B})}}$. Using Equations (14) and (15), $\overline{L_{p(\text{ST})}}$ is given by $\overline{L_{p(\text{ST})}} = \overline{L'_{p(\text{ST})}} + 10\lg\left(1 - 10^{-0,1\Delta L_p}\right)$ dB, where $\Delta L_p = \overline{L'_{p(\text{ST})}} - \overline{L_{p(\text{B})}}$. In this example, the sign of the sensitivity coefficient is unimportant, and reduces to:

$$\left|c_{K_1}\right| = \frac{1}{10^{0,1\Delta L_p} - 1}$$

For $\Delta L_p \leqslant 10$ dB this may be further simplified to $\left|c_{K_1}\right| \approx 3{,}6/\Delta L_p - 0{,}24$. In an extreme scenario, low noise sources are assumed with background noise standard deviation of 3 dB. The worst case $\overline{L'_{pA}} - \overline{L_{pA(B)}}$ is 10 dB (the minimum allowable at mid frequencies in 9.1.2). This results in a sensitivity coefficient of c_{K_1} = 0,11 and a total contribution to uncertainty of 0,3 dB. Typically this contribution is 0,03 dB due to better control of the background noise. Lowering the fluctuations in background noise can reduce this uncertainty component. Significant reductions in the sensitivity coefficient are obtained by reducing background noise by systematically tracking down and blocking and/or absorbing noise from unwanted sources (through proper grounding, lead wrapping, vibration isolation, adding mass, adding absorptive materials, etc., as appropriate). Furthermore, the uncertainty, u_{K1}, is typically halved each time the averaging time is increased by a factor of four.

G.4.3.5 Room volume to surface area ratio, V/S

The uncertainty, $u_{V/S}$, related to the estimate of the ratio of room volume to surface area is a ratio; the two measured quantities are correlated since the same dimensions are used to obtain both. For a right cuboid room, the uncertainty, Δl, in the measurement of each room dimension, l_x, l_y, l_z, should typically be less than 1 % of that dimension. The uncertainty in the resulting ratio, V/S, is then $u_{V/S} = 2\,\Delta l\,(V/S)^2 \sqrt{\left(l_x^{-4} + l_y^{-4} + l_z^{-4}\right)/3}$ (approximately 0,4 % of V/S).

The sensitivity coefficient, $c_{V/S}$, is obtained from the derivative of the sound power level, L_W, Equation (G.2) with respect to V/S:

$$c_{V/S} = \frac{240}{T_{60}\ c} - \frac{4{,}3\,c}{(V/S)(8\ f\ V/S + c)}$$

The sensitivity coefficient is largest at low frequencies. Assuming a small room with $V/S \approx 0{,}66$, and T_{60} = 1 s, at 200 Hz the sensitivity coefficient is −0,9, and with a 0,4 % uncertainty in V/S the associated total uncertainty is −0,003 dB The sensitivity coefficient increases to 0,7 at 8 kHz, and uncertainties at each frequency are correlated so that the A-weighted uncertainty depends on the spectral shape. A typical total uncertainty in the A-weighted value is 0,002 dB.

G.4.3.6 Room volume, V

The uncertainty related to the estimation of the room volume is u_V. For a right cuboid room, the uncertainty, Δl, in the measurement of each room dimension, l_x, l_y, l_z, should typically be less than 1 % of that dimension with a rectangular distribution, giving a standard deviation of $\Delta l/\sqrt{3}$. The room volume then has a standard uncertainty of $u_V = \Delta l\ V \sqrt{\left(l_x^{-2} + l_y^{-2} + l_z^{-2}\right)/3}$ (approximately 1 % of the room volume).

The sensitivity coefficient, c_V, is obtained by ignoring the V/S terms, which are accounted for separately, and taking the derivative of the remaining terms in L_W, Equation (G.2) with respect to V:

$$c_V = 4{,}3/V$$

Assuming 1 % uncertainty for the room volume, the combined uncertainty would be 0,04 dB. Extremely careful measurement is required in a non-right cuboid room to ensure this uncertainty remains low.

G.4.3.7 Reverberation time, T_{60}

The uncertainty in the determination of the reverberation time of the room, u_T, is obtained from the standard deviation, s_T, of decay measurements of the reverberation time, T_{60}, and the following formula which is loosely based on ISO 354:2003[1], Equation (10):

$$u_T = \sqrt{\frac{2{,}42\, T_{60}}{f} + \frac{s_T^2}{N_{\text{decays}}}}$$

where N_{decays} is the total number of reverberation time decay measurements, (typical $N_{\text{decays}} = 120$), and f is the one-third octave mid-band frequency.

The sensitivity coefficient, c_T, due to reverberation time is obtained from the derivative of L_W [Equation (20)] with respect to reverberation time. For terms containing A, the equivalent absorption area of the room, derivatives were taken with respect to reverberation time after substitution for A:

$$c_T = \frac{-4{,}3}{T_{60}} - \frac{240\, V}{T_{60}^2\, S\, c}$$

The worst case example assumes a source producing dominant noise at about 500 Hz. Using the minimum 1 s reverberation time from Equation (6) and assuming a standard deviation $s_T = 0{,}2$ s at 500 Hz, the sensitivity coefficient is –5 dB/s and the worst case uncertainty contribution $u_T\, c_T = 1$ dB. More typically the uncertainly contribution is $u_T\, c_T = 0{,}05$ dB due to typically longer T_{60}, and multiple frequency bands contributing to the A-weighted value. The uncertainty contribution can be reduced by increasing T_{60}, reducing the variability in measured decays, or increasing the number of measured decays.

G.4.3.8 Temperature, θ

The uncertainty due to changes in temperature, u_θ, in this example, assumes that the temperature in degrees Celsius, θ, falls within a range, $\pm \Delta\theta$, with a rectangular distribution:

$$u_\theta = \Delta\theta / \sqrt{3}$$

The sensitivity coefficient due to the temperature, c_θ, is obtained from a rough curve fit to the derivative of L_W [Equation (20)] with respect to temperature. The C_1 and C_2 terms were differentiated with respect to temperature. For terms containing A, the equivalent absorption area of the room, derivatives were taken with respect to a after substitution of $A = a\, S$. The required $\partial a / \partial \theta$ was estimated from ISO 9613-1[16]. The amplitude of the pressure absorbed with each wall reflection, a, was estimated from the room absorption, a_{room}, the absorption per metre in air, a_{dBm}, and the Sabine estimate (4 V/S) of the mean free path (approximately 3,3 m for 70 m^3 < V < 200 m^3)

$$c_\theta = \frac{8{,}7}{273+\theta} + 17{,}4 \frac{V}{S}\left[1 + \frac{1}{a_{\text{room}} + 4(V/S)a_{\text{dBm}}}\right]\frac{\partial a_{\text{dBm}}}{\partial \theta} \approx \frac{8{,}7}{273+\theta} + \frac{-0{,}57 + 0{,}25\,\lg(2{,}6\, f)}{1 + 0{,}0011 H + 0{,}007\,\theta}$$

where

H is the relative humidity, expressed as a percentage;

f is the highest frequency significantly affecting the A-weighted levels.

The restrictions in Table 3 limit the highest value for this uncertainty contribution, $u_\theta\, c_\theta$, to below 1,0 dB at 10 kHz. Assuming most of the sound produced by the source is below 1 kHz, a worst case value would be 0,5 dB using the humidity ranges from Table 3. This is close to the value given in the formulae above. Typically, the uncertainty can be kept below 0,05 dB for sources that do not affect the room air temperature.

Better control of temperature, allowing the room to come to temperature equilibrium, or shorter measurement times can reduce this uncertainty. Higher temperature and humidity are typically associated with a lower sensitivity coefficient per degree change in temperature.

G.4.3.9 Static pressure, p_s

The uncertainty due to changes in static pressure, u_{p_s}, in this example, assumes that the static pressure, p_s, falls within a range, $\Delta p_\mathrm{s} = \pm 4$kPa, with a rectangular distribution and is given by:

$$u_{p_\mathrm{s}} = \Delta p_\mathrm{s} / \sqrt{3}$$

The sensitivity coefficient due to the static pressure, c_{p_s}, is obtained from the derivative of L_W [Equation (20)] with respect to static pressure, p_s. The C_1 and C_2 terms were differentiated with respect to static pressure.

$$c_{p_\mathrm{s}} = \frac{-8{,}7}{p_\mathrm{s}}$$

The uncertainty contribution is usually small, $u_{p_\mathrm{s}} c_{p_\mathrm{s}} \approx 0{,}05$ dB; however, static pressure may affect u_omc, the uncertainty due to the reproducibility of the operating conditions.

G.4.3.10 Sound level meter, δ_slm

For sound power measurements the uncertainty in the measuring instrumentation, u_slm, for a class 1 instrument is $u_\mathrm{slm} = 0{,}3$ dB (Reference [29]). This figure is consistent with variations found by experience between national laboratories.

Uncertainties in the sound level meter directly affect measured levels, so that $c_\mathrm{slm} = 1$, and the uncertainty contribution is 0,3 dB. Additional details regarding parameters affecting the uncertainty of sound level meters can be found in IEC 61672-1. A lower sensitivity coefficient, c_slm, is possible using the comparison method, this also requires a separate accounting for the uncertainties due to the reference sound source.

G.4.3.11 Relative humidity, δ_H

The uncertainty due to changes in relative humidity, u_H, in this example assumes that the relative humidity, H, falls within a range, $\pm \Delta H$, with a rectangular distribution; it is given by

$$u_H = \Delta H / \sqrt{3}$$

The sensitivity coefficient due to the relative humidity, c_H, is obtained from a rough curve fit of the derivative of L_W [Equation (20)] with respect to relative humidity in a similar manner to that used for c_θ.

$$c_H = \frac{-2{,}6 + 1{,}6\,\lg(0{,}7\,f)}{1 + 0{,}5\,H} \qquad \text{if} \qquad H > 10\ \%$$

where f is the highest frequency significantly affecting the A-weighted levels.

The restrictions in Table 3 limit the highest value for this uncertainty contribution, $u_H\,c_H$, to below 1,0 dB at 10 kHz. Assuming most of the sound produced by the source is below 1 kHz, a worst case value would be 0,5 dB using the humidity ranges from Table 3. This is close to the value given in the preceding formulae. Typically this uncertainty can be kept below 0,05 dB. Better control of humidity, allowing the room to come to a humidity equilibrium, or shorter measurement times can reduce the uncertainty u_H. Higher humidity is associated with a lower sensitivity coefficient c_H.

G.4.3.12 Typical value for σ_{R0}

Using the typical values from above, σ_{R0}, based on Equation (G.2), is

$$\begin{aligned}\sigma_{R0} &= \sqrt{\sum_i (u_i\ c_i)^2} \\ &= \sqrt{0{,}3^2 + 0{,}2^2 + 0{,}03^2 + 0{,}002^2 + 0{,}04^2 + 0{,}05^2 + 0{,}05^2 + 0{,}05^2 + 0{,}3^2 + 0{,}05^2} \\ &= 0{,}5\ \text{dB}\end{aligned}$$

G.4.4 Comparison method

The uncertainty budget for the comparison method is obtained by the application of the uncertainty budget for the direct method to both the source under test $\sigma_{R0(\text{ST})}$ and the reference sound source $u(L_{W(\text{RSS})})$. The resulting uncertainties are added using the equation

$$\sigma_{R0} = \sqrt{u(L_{W(\text{RSS})})^2 + (\sigma_{R0(\text{ST})})^2}$$

Uncertainties for the source under test and the reference sound source are in many cases the same, leading to an approximate 40 % increase for each parameter relative to the direct method. The exceptions are: a) the comparison method does not use the reverberation time, T_{60}; b) some errors in sampling, $\delta_{\overline{L'_{p(\text{ST})}}}$, sound level meter, δ_{slm}, and method, δ_{method}, cancel each other out.

In the comparison method, the reverberation time, T_{60}, room volume, V, and room surface area, S, are not calculated, so the associated uncertainties are set to zero for both the source under test, and the reference sound source.

When the same microphone and source positions are used for the reference sound source and the source under test, some contributions to uncertainty effectively cancel. On the assumption that the uncertainty due to sampling is typically reduced by the comparison method the sensitivity coefficient can be halved $c_{L'_{p(\text{ST})}} = 0{,}5$ for both the source under test and the reference sound source. The worst case occurs for a source producing narrow band noise. Similar to the example for the direct method, if the requirements on the number of source and microphone positions in 8.4.2 are met, using $c_{L'_{p(\text{ST})}} = 0{,}5$, the worst case uncertainty contribution is 0,5 dB. The typical contribution is 0,1 dB.

When measurements with the same sound level meter are repeated over a short time span, systematic errors related to calibration, directional response, frequency weighting, temperature pressure and humidity can cancel. Since the uncertainty for the source under test and reference sound source are calculated separately and then added, the sensitivity coefficient requires reduction so that the combined uncertainty is less than u_{slm}. Setting c_{slm} = 0,5 results in an uncertainty contribution of 0,15 dB. Similarly, c_{method} = 0,5 may be used for the uncertainty due to the method and results in an uncertainty contribution of 0,15 dB.

For the source under test, the uncertainty contributions are the same as for the direct method with the exception of the terms for reverberation time, sampling, and sound level meter, as previously noted. In this worst case scenario, the contribution to uncertainty, $\sigma_{R0(\text{ST})}$, from the source under test is

$$\begin{aligned}\sigma_{R0(\text{ST})} &= \sqrt{\sum_i (u_i\ c_i)^2} \\ &= \sqrt{0{,}15^2 + 0{,}1^2 + 0{,}03^2 + 0^2 + 0^2 + 0^2 + 0{,}05^2 + 0{,}05^2 + 0{,}15^2 + 0{,}05^2} \\ &= 0{,}25\ \text{dB}\end{aligned}$$

For the reference sound source, the uncertainty contributions are similar to the source under test with the exception that there is an additional contribution due to the calibration, operating and mounting conditions of the reference sound source. Typically, after applying the manufacturer's recommended corrections, this uncertainty $\sigma_{\text{omc(RSS)}} = 0{,}5\ \text{dB}$. The uncertainty due to the number of microphone and source positions is assumed to be $u_{L'_{p(\text{ST})}}\ c_{L'_{p(\text{ST})}} = 0{,}03\ \text{dB}$. Even in a worst case situation, the sound power output of a reference sound source should significantly exceed the background noise, so that $u_{K_1}\ c_{K_1} \approx 0{,}0\ \text{dB}$. In this scenario, the contribution to uncertainty from the reference source, $u(L_{W(\text{RSS})})$ is

$$\begin{aligned} u\left[L_{W(\text{RSS})}\right] &= \sqrt{\sum_i \left(u_i\ c_i\right)^2 + [\sigma_{\text{omc(RSS)}}]^2} \\ &= \sqrt{\left(0{,}15^2 + 0{,}03^2 + 0{,}0^2 + 0^2 + 0^2 + 0^2 + 0{,}05^2 + 0{,}05^2 + 0{,}15^2 + 0{,}05^2\right) + 0{,}5^2} \\ &= 0{,}55\ \text{dB} \end{aligned}$$

In this scenario, the expected uncertainty due to the comparison method is

$$\sigma_{R0} = \sqrt{u[L_{W(\text{RSS})}]^2 + [\sigma_{R0(\text{ST})}]^2} = 0{,}61\ \text{dB}$$

As is apparent from this example, some uncertainty contributions are negligible compared to others and might be disregarded when establishing an uncertainty budget for a specific application. Efforts to reduce the combined uncertainty should always be focused on the most dominant contributions.

G.5 Combined standard uncertainty

In the case of negligible correlation between the input quantities, the combined standard uncertainty of the determination of the sound power level, $u(L_W)$ in decibels, is given by Equation (G.3):

$$u\left(L_W\right) \approx \sigma_{\text{tot}} = \sqrt{\sigma_{R0}^2 + \sigma_{\text{omc}}^2} = \sqrt{\sum_i \left(c_i\ u_i\right)^2 + \sigma_{\text{omc}}^2}\ \text{dB} \qquad \text{(G.3)}$$

G.6 Measurement uncertainty based on reproducibility data

In the absence of data for uncertainty contributions and possible correlations between input quantities, values for the standard deviation of reproducibility as given in Clause 9 may be used as an estimate for the combined standard uncertainty of determinations of sound power levels, $u(L_W)$. A value may then be selected for the coverage factor, k, and the product, $k\ \sigma_{\text{tot}}$, yields an estimate of the expanded measurement uncertainty, U, with the chosen coverage probability. By convention, a coverage probability of 95 % is usually chosen, and assuming a normal distribution the associated two-sided coverage factor is 2. To avoid misinterpretation, the coverage probability should be stated in test reports, together with the expanded measurement uncertainty.

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ICS 17.140.01

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