INTERNATIONAL STANDARD

# ISO 3743-1

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# Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Engineering methods for small movable sources in reverberant fields

## Part 1: Comparison method for a hard-walled test room

*Acoustique — Détermination des niveaux de puissance et d'énergie acoustiques émis par les sources de bruit à partir de la pression acoustique — Méthodes d'expertise en champ réverbéré applicables aux petites sources transportables*

*Partie 1: Méthode par comparaison en salle d'essai à parois dures*

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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 3743-1 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

This second edition cancels and replaces the first edition (ISO 3743-1:1994), which has been technically revised.

ISO 3743 consists of the following parts, under the general title *Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Engineering methods for small movable sources in reverberant fields*:

— *Part 1: Comparison method for a hard-walled test room*

— *Part 2: Methods for special reverberation test rooms*

# Introduction

This part of ISO 3743 is an element of the series ISO 3740[1] to ISO 3747[7], 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[1]. ISO 3740[1] to ISO 3747[7] 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 method given in this part of ISO 3743 is based on a comparison of the sound pressure levels in octave frequency bands of a noise source under test with those of a calibrated reference sound source; A-weighted sound power levels or sound energy levels may be calculated from the octave-band levels. The method is applied in a hard-walled test room with prescribed acoustical characteristics, where it can be used for small items of portable equipment. Such a room allows either the sound power levels or the sound energy levels of the noise source under test to be determined, depending on the character of the noise emitted by the source. However, this kind of test room is not suitable for larger pieces of stationary equipment which, due to their manner of operation or installation, cannot readily be moved. The application of the method for use where the equipment or machinery is found *in situ* is described in ISO 3747[7].

The methods specified in this part of ISO 3743 permit the determination of the sound power level and the sound energy level in frequency bands and/or with frequency A-weighting applied.

This part of ISO 3743 describes a method of accuracy grade 2 (engineering grade) as defined in ISO 12001. For applications where greater accuracy is required, reference can be made to ISO 3741[2] or an appropriate part of ISO 9614[15][17]. If the relevant criteria for the measurement environment specified in this part of ISO 3743 are not met, it might be possible to refer to another standard from this series, or to an appropriate part of ISO 9614[15][17].

# Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Engineering methods for small movable sources in reverberant fields

## Part 1: Comparison method for a hard-walled test room

## 1 Scope

### 1.1 General

This part of ISO 3743 specifies methods for determining the sound power level or sound energy level of a noise source by comparing measured sound pressure levels emitted by this source (machinery or equipment) mounted in a hard-walled test room, the characteristics of which are specified, with those from a calibrated reference sound source. 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 octave, is calculated using those measurements. The sound power level or sound energy level with A-weighting applied is calculated using the octave-band levels.

### 1.2 Types of noise and noise sources

The method specified in this part of ISO 3743 is 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 may be a device, machine, component or sub-assembly. The maximum size of the source depends upon the size of the room used for the acoustical measurements (see 4.2).

### 1.3 Test environment

The test environment that is applicable for measurements made in accordance with this part of ISO 3743 is a hard-walled test room with prescribed acoustical characteristics.

### 1.4 Measurement uncertainty

Information is given on the uncertainty of the sound power levels and sound energy levels determined in accordance with this part of ISO 3743, for measurements made in frequency octave bands and for A-weighted frequency calculations performed on them. The uncertainty conforms to ISO 12001:1996, accuracy grade 2 (engineering 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 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 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[19], 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

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

where the reference value, $p_0$, is 20 µPa

[ISO/TR 25417:2007[18], 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[19], 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

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

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[18], 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

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

where the reference value, $E_0$, is (20 µPa)$^2$ s = $4 \times 10^{-10}$ 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[18]).

**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**
**comparison method**
method by which the sound power level or sound energy level of a noise source under test is determined from a comparison of the sound pressure levels produced by the source under test with those of a reference sound source of known sound power output, when both sources are operated in the same environment

**3.7**
**hard-walled test room**
room in which the acoustical reflectivity of all room surfaces (including the floor and ceiling) is high over the frequency range of interest

**3.8**
**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

**3.9**
**sound absorption coefficient**
$\alpha$
at a given frequency and for specified conditions, the relative fraction of sound power incident upon a surface which is not reflected

**3.10**
**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.

**3.11**
**frequency range of interest**
for general purposes, the frequency range of octave bands with nominal mid-band frequencies from 125 Hz to 8 000 Hz

NOTE For special purposes, the frequency range can be reduced, provided that the test environment, reference sound source, and instrument specifications are satisfactory for use over the modified frequency range. The frequency range can be extended downwards as far as the 63 Hz octave band, but cannot be extended upwards beyond the 8 000 Hz band. Any reduced or extended frequency range is clearly indicated as such in the report.

**3.12**
**reference box**
hypothetical right parallelepiped terminating on the floor of the test room on which the noise source under test is located, that just encloses the source including all the significant sound radiating components and any test table on which the source is mounted

NOTE If required, the smallest possible test table can be used for compatibility with emission sound pressure measurements at bystander positions in accordance with the ISO 11200 to ISO 11204 series.

**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 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, and that in the case of A-weighting is denoted $K_{1A}$.

**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[19], 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 should be indicated by appropriate subscripts; e.g. $L_{WA}$ denotes the A-weighted sound power level.

NOTE 2 This definition is technically in accordance with ISO 80000-8:2007[19], 8-23.

[ISO/TR 25417:2007[18], 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 $t_2$)

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

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[18], 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 should be indicated by appropriate subscripts; e.g. $L_{J\text{A}}$ denotes the A-weighted sound energy level.

[ISO/TR 25417:2007[18], 2.11]

# 4 Test room and size of noise source under test

## 4.1 Reference box

In order to assist in specification of the size of the test room, the reference box shall first be delineated. The reference box is a hypothetical surface defined by the smallest right parallelepiped that just encloses the noise source under test. 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, and the reference box shall be extended appropriately. When defining the dimensions of the reference box, elements protruding from the source which are not significant radiators of sound may be disregarded.

## 4.2 Volume of test room and size of noise source under test

The volume of the test room shall be at least 40 $m^3$, and at least 40 times the volume of the reference box.

In rooms with volumes between 40 $m^3$ and 100 $m^3$, the largest dimension of the reference box shall not exceed 1,0 m. In rooms with volumes greater than 100 $m^3$, the largest dimension of the reference box shall not exceed 2,0 m.

## 4.3 Acoustical properties of test room

A hard-walled room shall be used. This means that the sound absorption coefficient of any portion of any boundary surface shall not exceed 0,20 at all frequencies within the frequency range of interest. Most ordinary, unfurnished rooms without special acoustical treatment (e.g. acoustical ceilings and/or absorptive wall coverings) comply with this requirement. Table 1 gives guidelines.

**Table 1 — Acceptable and unacceptable rooms**

| Acceptable rooms | Unacceptable rooms |
|---|---|
| Nearly empty rooms with smooth hard walls and ceiling made of concrete, brick, plaster or tile | Rooms with upholstered furniture, machinery or industrial rooms with a small amount of sound absorptive material on ceiling or walls (e.g. partially absorptive ceiling) |
| Partly empty rooms, rooms with smooth hard walls | Rooms with some sound absorptive materials on both ceiling and walls |
| Rooms without upholstered furniture, right cuboid machinery rooms or industrial rooms, no sound absorptive materials on surfaces | Rooms with large amounts of sound absorptive materials on either ceiling or walls |
| Irregularly shaped rooms without upholstered furniture, irregularly shaped machinery rooms or industrial rooms, no sound absorptive materials on surfaces | |

## 4.4 Criterion for acoustic adequacy of test room

The suitability of a test room can differ from one noise source under test to another. The requirements for the room are most critical when a highly directional sound source is to be evaluated. When testing the general suitability of a test room, the procedure described hereafter shall be followed.

A highly directional, broad-band sound source, having a directivity index (see ISO 3744[4] or ISO 3745[5]) of at least 5 dB at all frequencies of interest above 500 Hz, is located in the test room as given in 6.3, so that the strongest component of sound energy is within 45° of the horizontal plane and is reflected at least once from a boundary with a minimum of loss before reaching any of the microphone positions. Microphone positions are chosen in accordance with 7.3 and the mean background noise corrected octave band time-averaged sound pressure level, $\overline{L_{p1}}$ , is determined [see Equation (14) omitting RSS terms, i.e.

$$L_{W(\mathrm{RSS})} \equiv \overline{L'_{p(\mathrm{RSS})}} \equiv K_{1(\mathrm{RSS})} \equiv 0$$

and substituting $\overline{L_{p1}}$ for $L_W$]. The sound source is then turned 45° to 135° in compliance with the requirement of 6.3 and the corresponding octave-band time-averaged sound pressure level, $\overline{L_{p2}}$ , is determined. This procedure is repeated twice more to determine $\overline{L_{p3}}$ and $\overline{L_{p4}}$ . The fourth position shall be within 45° to 90° of the first position. This whole procedure is then repeated four more times with the sound source turned upwards so that the strongest component of sound energy is within 45° of the vertical, and four more mean octave band time-averaged sound pressure levels are determined. The test room is considered to be suitable for the purposes of this part of ISO 3743 if the maximum difference between the octave band sound pressure levels of any two source positions for the frequency bands with mid-band frequencies between 125 Hz and 8 000 Hz does not exceed the standard deviations of reproducibility of Table 3.

NOTE As an alternative to the highly directional sound source, a sound source of the same type as the noise source to be tested can be used. However, if this alternative procedure is used, the suitability of the room can be taken as proven only for testing this type of noise source.

### 4.5 Criterion for background noise

The mean octave-band time-averaged sound pressure level of the background noise measured and averaged over the microphone positions or traverses (see 8.1.2), shall be at least 6 dB, and preferably more than 15 dB, below the corresponding mean uncorrected octave-band sound pressure levels (time averaged or single event) from the noise source under test (see 8.1.2 and 8.2.2) and from the reference sound source.

NOTE If it is necessary to make measurements where the difference between the sound pressure levels of the background noise and the sources is less than 6 dB, ISO 9614-1[15] or ISO 9614-2[16] can be used.

### 4.6 Ambient temperature and humidity

The ambient temperature and relative humidity in the test room shall be monitored and maintained at as nearly constant values as practicable during measurements.

## 5 Instrumentation and measurement equipment

### 5.1 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 shall meet the requirements given in ISO 6926.

### 5.2 Calibration

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 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.

## 6 Definition, location, installation, and operation of noise source under test

### 6.1 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 noise 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 noise 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 part of ISO 3743 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.

### 6.2 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 test room. If this is impractical, care shall be taken to minimize any sound radiated into the test 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, and the reference box (see 4.1) shall be extended appropriately.

### 6.3 Noise source location

The noise source to be tested shall be installed in the test room at one or more locations (see the following) as if it was being installed for normal use. If there are no contrary requirements, the source shall be placed on the floor of the test room. If a table or stand is considered essential for normal operation, the source shall be placed at the centre of the table top, and the source and table shall be regarded as an integral whole for the purpose of the test. The minimum distance between any wall or the ceiling of the test room and the reference box shall be 1 m. The sides of the reference box shall not be parallel to the walls of the room. Consideration shall be given to the placement of the source in relation to the microphone positions used for measurements, see 7.3. This usually leads to the source being placed near the middle of a large test room so that microphones can be positioned around all four sides of the source. In a small test room, the source can be placed nearer to one end of the room so that a reverberant sound field where measurements are made can be established at the other end.

A preliminary aural examination of the noise emitted by the source shall be made to determine whether it is noticeably directional. If a source emits more sound energy in one direction than another, it shall be oriented in such a way that the strongest component of sound energy is reflected at least once from a boundary surface of the test room, with a minimum of loss, before reaching any of the microphone positions.

The aural examination shall also be used to detect whether the noise emitted by the source contains discrete tones or strong components in narrow bands of frequency. If this is the case, some preliminary measurements shall be made (see 7.4) to determine whether it is necessary to use two different source locations in the test room, or even to repeat the tests in another, different test room, still complying with the requirements of this part of ISO 3743.

## 6.4 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 on the source are both minimized. In this case, the mounting base should be rigid (i.e. having a sufficiently 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 item 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 the test, or suspended in such a way that no structure-borne sound is transmitted via any attachment that is not an integral part of the source itself. If a noise source under test requires a support for its operation during testing, the support structure shall be small and considered as part of the source itself. Sources normally mounted through a window, wall or ceiling shall be mounted through a wall or ceiling of the test room.

## 6.5 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.

# 7 Measurement procedure

## 7.1 General

For determination of either the sound power level of a noise source emitting stationary noise or the sound energy level of a source which emits bursts of noise, two sets of measurements of sound pressure levels shall be made in the test room, first with the noise source under test operating and then with the reference sound source operating. The specifications given in a noise test code, if one exists, shall be followed, but in the absence of a noise test code the procedures described hereafter shall be followed for the test(s).

## 7.2 Location of noise source under test and reference sound source

For the first set of measurements, the noise source under test shall be located in accordance with 6.3.

For the second set of measurements, the reference sound source shall be placed on the floor of the test room in the same position as that occupied by the noise source under test during the first set of measurements.

The noise source under test shall remain in the test room when measurements are being made with the reference sound source, if its sound absorptivity (when not in operation) affects the sound pressure levels of the latter.

## 7.3 Microphone positions

A minimum of three microphone positions shall be used. The same microphone positions (and orientations) shall be used for measurements with the noise source under test and the reference sound source. If there are audible discrete tones in the sound emitted by the noise source under test, the procedure given in 7.4 shall be followed.

If practicable, all microphone positions shall be in the reverberant sound field. This requires that the minimum distance, $d_{\text{min}}$, in metres, between the sound source and the nearest microphone position be not less than $0{,}3V^{1/3}$, where $V$ is the volume, in cubic metres, of the test room.

No microphone position shall be closer than 0,5 m to the ceiling or any wall of the test room. The microphone positions shall be at least a distance of $\lambda/2$ from one another, where $\lambda$ is the wavelength of sound at the mid-band frequency of the lowest octave band in the frequency range of interest.

If the room is large enough, and the conditions for both $d_{\text{min}}$ and the minimum distance to the ceiling and walls are fulfilled, the number of microphone positions shall be five: one on each side of and one directly above the reference box.

NOTE The use of a moving microphone traversing a path in the test room at constant speed is often more convenient than the use of a number of microphones at fixed positions. The path can be a line, an arc, a circle or some other geometric figure, provided the plane of the path is at least 10° out of parallel with any room surface. Such a sweeping arrangement with a single microphone can be used if the rules for multiple, fixed microphones are complied with. The minimum path length of the sweep is 5 m.

## 7.4 Preliminary measurements for sources emitting audible discrete tones or narrow bands of noise

In order to make the preliminary measurements, to which reference is made in 6.3, to determine the number of source locations to be used, a minimum of six fixed microphone positions complying with the requirements given in 7.3 shall be employed. The standard deviation, $s_M$, of the preliminary sound pressure levels from the noise source under test, $L'_{pi(\text{pre})}$, shall then be calculated as follows:

$$s_M = \left[N_{M(\text{pre})} - 1\right]^{-1/2} \left\{ \sum_{i=1}^{N_{M(\text{pre})}} \left[L'_{pi(\text{pre})} - \overline{L'_{p(\text{pre})}}\right]^2 \right\}^{1/2} \tag{7}$$

where

$N_{M(\text{pre})}$ is the initial number of microphone positions;

$L'_{pi(\text{pre})}$ is the measured (uncorrected) time-averaged sound pressure level at the $i$th microphone position, from the preliminary measurements with the noise source under test in operation, in decibels;

$$\overline{L'_{p(\text{pre})}} = \left[ \frac{1}{N_{M(\text{pre})}} \sum_{i=1}^{N_{M(\text{pre})}} L'_{pi(\text{pre})} \right] \tag{8}$$

Depending on the value of $s_M$ for each frequency band of interest, the number of locations of the noise source in the test room, $N_S$, to be used in the sound power level or sound energy level determinations, shall be as given in Table 2.

**Table 2 — Required number of source locations**

| **Standard deviation**, $s_M$, dB | **Number of source locations** $N_S$ |
|---|---|
| $s_M \leqslant 2,5$ | 1 |
| $2,5 < s_M \leqslant 4,0$ | 2 in the same room |
| $s_M > 4,0$ | 2 in the same room, plus 2 more in another test room with different dimensions, still complying with 4.4 |

## 7.5 Measurement of sound pressure levels for a noise source which emits continuous noise

Time-averaged sound pressure levels from the noise source under test for each octave band in the frequency range of interest, $L'_{pi(\text{ST})}$, shall be obtained at each microphone position, $i$ ($i$ = 1, 2 … $n$), or with the moving microphone, and from the reference sound source, $L'_{pi(\text{RSS})}$. A suitable averaging time for the reference sound source is 30 s. If the sound output from the noise source under test is as stable as that of the reference sound source, then a similar averaging time is satisfactory, but if it is less stable or undergoes periodic cycles, a longer averaging time including one or more complete cycles is required. In the case of a moving microphone, the averaging time shall include at least one full traverse of the microphone path.

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 octave band, $L_{pi(\text{B})}$, shall be obtained at each microphone position or with the traversing microphone, over the same measurement time interval as that used for the noise source under test.

### 7.6 Measurement of sound pressure levels for a noise source which emits bursts of noise

Single event time-integrated sound pressure levels from the noise source under test for each octave band within the frequency range of interest, $L'_{Ei(\mathrm{ST})}$, shall be obtained at each microphone position or traverse, $i$ ($i$ = 1, 2 … $n$), either for one single sound event at a time (in which case the process shall be repeated $N$ times, where $N$ is at least five) or from several successive ($N$) sound events (where again $N$ is a minimum of five). The measurement time 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. The time-averaged sound pressure levels from the reference sound source, $L'_{pi(\mathrm{RSS})}$, shall also be measured, with an averaging time of 30 s. A moving microphone shall not be used to measure non-repetitive impulsive noise.

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

## 8 Determination of sound power levels and sound energy levels

### 8.1 Determination of sound power level

#### 8.1.1 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 (7.4), the measured time-averaged sound pressure level in each octave band over the frequency range of interest and for each of the $i$ microphone positions or microphone traverses, and averaged over $j$ source positions, $L'_{pi(\mathrm{ST})}$, shall be calculated using Equation (9):

$$L'_{pi(\mathrm{ST})} = 10 \lg \left\{ \frac{1}{N_\mathrm{S}} \sum_{j=1}^{N_\mathrm{S}} 10^{0,1\left[L'_{pi(\mathrm{ST})}\right]_j} \right\} \mathrm{dB} \qquad (9)$$

where

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

$N_\mathrm{S}$ is the number of source positions.

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

The mean time-averaged sound pressure level in the test room with the noise source under test in operation, and for each octave band, $\overline{L'_{p(\mathrm{ST})}}$, shall be calculated using Equation (10):

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

where

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

$N_\mathrm{M}$ is the number of microphone positions or individual microphone traverses.

The mean time-averaged sound pressure level in the test room, for the reference sound source, and for each octave band, $\overline{L'_{p(\mathrm{RSS})}}$, shall be calculated using Equation (11):

$$\overline{L'_{p(\mathrm{RSS})}} = 10 \lg \left[ \frac{1}{N_\mathrm{M}} \sum_{i=1}^{N_\mathrm{M}} 10^{0,1 L'_{pi(\mathrm{RSS})}} \right] \mathrm{dB} \tag{11}$$

where

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

$N_\mathrm{M}$ is the number of microphone positions or individual microphone traverses.

The mean time-averaged sound pressure level of the background noise in the test room, for each octave band, $\overline{L_{p(\mathrm{B})}}$, shall be calculated using Equation (12):

$$\overline{L_{p(\mathrm{B})}} = 10 \lg \left[ \frac{1}{N_\mathrm{M}} \sum_{i=1}^{N_\mathrm{M}} 10^{0,1 L_{pi(\mathrm{B})}} \right] \mathrm{dB} \tag{12}$$

where

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

$N_\mathrm{M}$ is the number of microphone positions or individual microphone traverses.

NOTE When a traverse over a single microphone path is used, $\overline{L'_{p(\mathrm{ST})}}$, $\overline{L'_{p(\mathrm{RSS})}}$ and $\overline{L_{p(\mathrm{B})}}$ are given directly by the time- and space-averaged levels obtained over that path.

### 8.1.3 Corrections for background noise

The background noise correction, $K_1$, shall be calculated using Equation (13):

$$K_1 = -10 \lg \left( 1 - 10^{-0,1 \Delta L_p} \right) \mathrm{dB} \tag{13}$$

where

$$\Delta L_p = \overline{L'_{p(\mathrm{ST})}} - \overline{L_{p(\mathrm{B})}}$$

in which

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

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

If 6dB $\leqslant \Delta L_p \leqslant$ 15dB, corrections shall be calculated in accordance with Equation (13) and corrections shall be applied.

If $\Delta L_p >$ 15dB, $K_1$ is assumed to be zero, and no correction for background noise shall be applied.

If $\Delta L_p$ < 6dB for one or more octave bands, the accuracy of the result(s) may be reduced and the value of $K_1$ to be applied in the case of these bands is 1,3 dB (the value for $\Delta L_p$ = 6dB). The result may, however, be reported and may be useful for determining an upper boundary to the sound power level of the noise source under test. If such data are reported, 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 and the background noise requirements of this part of ISO 3743 have not been fulfilled.

NOTE Refer to 4.5 for the criterion for background noise and to determine whether the measurements meet the requirements of this part of ISO 3743.

### 8.1.4 Calculation of sound power level

The sound power level of the noise source under test in each octave band, $L_W$, shall be calculated using Equation (14):

$$L_W = L_{W(\mathrm{RSS})} - \overline{L'_{p(\mathrm{RSS})}} + \overline{L'_{p(\mathrm{ST})}} + K_{1(\mathrm{RSS})} - K_1 \quad (14)$$

where

$L_{W(\mathrm{RSS})}$ is the calibrated octave band sound power level of the reference sound source, in decibels;

$K_{1(\mathrm{RSS})}$ is the background noise correction for the reference sound source, in decibels, calculated using Equation (13) with the substitution of $\overline{L'_{p(\mathrm{RSS})}}$ for $\overline{L'_{p(\mathrm{ST})}}$;

$K_1$ is the background noise correction, in decibels.

Reduced atmospheric pressure creates a bias in the sound power level. At altitudes greater than 500 m, sound power levels, $L_{W\mathrm{ref,atm}}$, corresponding to the reference static pressure 101,325 kPa and reference atmospheric temperature 23,0 °C shall be calculated in accordance with Annex A.

## 8.2 Determination of sound energy level

### 8.2.1 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 $N_\mathrm{e}$ single event time-integrated sound pressure levels have been measured one at a time at the $i$th microphone position or microphone traverse and for the $j$th source position, the mean measured single event time-integrated sound pressure level in each octave band at that position, $\left[L'_{Ei(\mathrm{ST})}\right]_j$ shall be calculated using Equation (15):

$$\left[L'_{Ei(\mathrm{ST})}\right]_j = 10 \lg \left\{ \frac{1}{N_\mathrm{e}} \sum_{q=1}^{N_\mathrm{e}} 10^{0,1\left[L'_{Ei,q(\mathrm{ST})}\right]_j} \right\} \mathrm{dB} \quad (15)$$

where

$\left[L'_{Ei,q(\mathrm{ST})}\right]_j$ is the measured (uncorrected) octave band single event time-integrated sound pressure level at the $i$th microphone position or for the $i$th microphone traverse, for the $j$th source position and for the $q$th event ($q$ = 1, 2 ... $N_\mathrm{e}$) of the noise source under test in operation, in decibels;

$N_\mathrm{e}$ is the number of measurements of single sound emission events.

If one single event time-integrated sound pressure level has been measured at the $i$th microphone position or traverse, and for the $j$th source position encompassing $N_e$ sound emission events, the mean measured single event time-integrated sound pressure level in each octave band at that position for one event, $\left[L'_{Ei(\text{ST})}\right]_j$ shall be calculated using Equation (16):

$$\left[L'_{Ei(\text{ST})}\right]_j = \left[L'_{Ei,N_e(\text{ST})}\right]_j - 10 \lg N_e \text{ dB} \quad (16)$$

where

$\left[L'_{Ei,N_e(\text{ST})}\right]_j$ is the measured (uncorrected) octave band single event time-integrated sound pressure level at the $i$th microphone position or for the $i$th microphone traverse, for the $j$th 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 (7.4) the mean measured single event time-integrated sound pressure level in each octave band over the frequency range of interest, for each of the $i$ microphone positions or traverses, and averaged over $j$ source positions, $L'_{Ei(\text{ST})}$, shall be calculated using Equation (17):

$$L'_{Ei(\text{ST})} = 10 \lg \left\{ \frac{1}{N_S} \sum_{j=1}^{N_S} 10^{0,1\left[L'_{Ei(\text{ST})}\right]_j} \right\} \text{ dB} \quad (17)$$

where

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

$N_S$ is the number of source positions.

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

The mean uncorrected single event time-integrated sound pressure level in the test room with the noise source under test in operation, and for each octave band, $\overline{L'_{E(\text{ST})}}$, shall be calculated using Equation (18):

$$\overline{L'_{E(\text{ST})}} = 10 \lg \left[ \frac{1}{N_M} \sum_{i=1}^{N_M} 10^{0,1 L'_{Ei(\text{ST})}} \right] \text{ dB} \quad (18)$$

where

$L'_{Ei(\text{ST})}$ is the mean measured (uncorrected) octave band single event time-integrated sound pressure level at the $i$th microphone position or for the $i$th 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 uncorrected time-averaged sound pressure level in the test room, for the reference sound source and for each octave band, $\overline{L'_{p(\text{RSS})}}$, shall again be calculated from Equation (11).

### 8.2.3 Corrections for background noise

The background noise correction, $K_1$, in each octave band shall be calculated in a similar manner to that of 8.1.3, using instead the difference between the mean measured single event time-integrated sound pressure level and the background noise level:

$$K_1 = -10 \lg(1 - 10^{-0,1\Delta L_E}) \text{ dB} \tag{19}$$

where

$$\Delta L_E = \overline{L'_{E(\text{ST})}} - \overline{L_{p(\text{B})}}$$

in which

$\overline{L'_{E(\text{ST})}}$ is the mean octave band single event time-integrated sound pressure level with the noise source under test in operation, in decibels,

$\overline{L_{p(\text{B})}}$ is the mean octave band time-averaged sound pressure level of the background noise, 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 $L'_{Ei(\text{ST})}$ and background noise level $L_{pi(\text{B})}$.

### 8.2.4 Sound energy level

The sound energy level of the noise source under test in each octave band, $L_J$, shall be calculated using Equation (20):

$$L_J = L_{W(\text{RSS})} - \overline{L'_{p(\text{RSS})}} + \overline{L'_{E(\text{ST})}} + K_{1(\text{RSS})} - K_1 \tag{20}$$

Reduced atmospheric pressure creates a bias in the sound energy level. At altitudes greater than 500 m, sound energy levels, $L_{J\text{ref,atm}}$, corresponding to the reference static pressure 101,325 kPa and reference atmospheric temperature 23,0 °C shall be calculated in accordance with Annex A.

## 8.3 A-weighted sound power level and sound energy level

Calculation of the A-weighted sound power level or sound energy level of the noise source under test from the measurements made in octave bands, shall be performed using the procedure given in Annex B.

# 9 Measurement uncertainty

## 9.1 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 part of ISO 3743 are estimated by the total standard deviation, in decibels:

$$u(L_W) \approx u(L_J) \approx \sigma_{\text{TO}} \tag{21}$$

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, $\sigma_{R0}$, in decibels, and the standard deviation, $\sigma_{omc}$, in decibels, describing the uncertainty due to the instability of the operating and mounting conditions of the source under test in accordance with:

$$\sigma_{tot} = \sqrt{\sigma_{R0}^2 + \sigma_{omc}^2} \tag{22}$$

Equation (22) shows that variations of operating and mounting conditions expressed by $\sigma_{omc}$ should be taken into account before a measurement procedure with a certain grade of accuracy (characterized by $\sigma_{R0}$) is selected for a specific machine family (see 9.5 and C.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 $\sigma_{tot}$, the expanded uncertainty $U$, in decibels, shall be calculated from

$$U = k\,\sigma_{tot} \tag{23}$$

The expanded 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.

## 9.2 Determination of $\sigma_{omc}$

The standard deviation $\sigma_{omc}$ [see Equation (C.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 $\sigma_{omc}$, repeated sound pressure levels are measured either at the microphone position associated with the highest sound pressure level, $L'_{pi(ST)}$, or measured and averaged over all measurement positions, $\overline{L'_{p(ST)}}$. 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, $\sigma_{omc}$ is designated as $\sigma'_{omc}$. It is possible that a noise test code provides a value of $\sigma_{omc}$ 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 $\sigma_{omc}$ 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.

## 9.3 Determination of $\sigma_{R0}$

### 9.3.1 General

The standard deviation $\sigma_{R0}$ includes all uncertainty due to conditions and situations allowed by this part of ISO 3743 (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 $\sigma_{omc}$.

The values of $\sigma_{R0}$ given in Table 3 reflect current knowledge. They are typical upper bounds taking into consideration the great variety of machines and equipment covered by this part of ISO 3743. Machinery-specific values may be derived from round robin tests (see 9.3.2) or by using the mathematical modelling approach (see 9.3.3). They should be given in noise test codes specific to machinery families (see 9.2 and Annex C).

### 9.3.2 Round robin test

The round robin test for determining $\sigma_{R0}$ 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 $\sigma'_{tot}$ 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 $\sigma'_{tot}$ , in decibels, of all results obtained with a round robin test includes the standard deviation $\sigma'_{omc}$ and allows $\sigma'_{R0}$ to be determined by using

$$\sigma'_{R0} = \sqrt{\sigma'^{2}_{tot} - \sigma'^{2}_{omc}} \quad (24)$$

If $\sigma'_{R0}$ 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 part of ISO 3743 to this particular family and used as $\sigma_{R0}$. Whenever available, such a value should be given in the noise test code specific to the machine family concerned (together with $\sigma_{omc}$) 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 $\sigma_{R0}$.

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 $\sigma_{R0,DL}$, and this designation should also be used for tests on large machines being not movable in space.

Values for $\sigma_{R0,DL}$ can be expected to be lower than those given in Table 3.

The determination of $\sigma_{R0}$ using Equation (24) is imprecise if $\sigma_{tot}$ is only slightly higher than $\sigma_{omc}$. In this case, Equation (24) gives a small value of $\sigma_{R0}$ but with a low accuracy. To limit this inaccuracy, $\sigma_{omc}$ should not exceed $\sigma_{tot} / \sqrt{2}$ .

### 9.3.3 Modelling approach for $\sigma_{R0}$

Generally $\sigma_{R0}$, 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, $\sigma_{R0}$ can be described by the modeling approach presented in ISO/IEC Guide 98-3, as follows:

$$\sigma_{R0} \approx \sqrt{(c_1 u_1)^2 + (c_2 u_2)^2 + ..... + (c_n u_n)^2} \quad (25)$$

In Equation (25) the uncertainty components due to the instability of the sound emission of the source are not included. These components are covered by $\sigma_{omc}$. Annex C discusses each component of the uncertainty $\sigma_{R0}$ in accordance with existing knowledge.

NOTE If the uncertainty components in the modelling approach are correlated, Equation (25) does not apply. Furthermore, the modelling approach requires detailed knowledge to determine the individual terms in Equation (25).

By contrast, the estimation of $\sigma_{R0}$ based on a round robin test does not require assumptions about possible correlations between the individual terms of Equation (25). A round robin test is currently more realistic than determining possible correlations between the single terms of Equation (25) 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.

## 9.4 Typical upper bound values of $\sigma_{R0}$

Table 3 shows typical upper bound values of the standard deviation $\sigma_{R0}$ for accuracy grade 2 that may cover most of the applications of this part of ISO 3743 (References [21][22]). In special cases or if certain requirements of this part of ISO 3743 are not met for a machine family or if it is anticipated that actual values of $\sigma_{R0}$ for a given family of machines are smaller than those given in Table 3, a round robin test is recommended to obtain machine-specific values of $\sigma_{R0}$.

**Table 3 —Typical upper bound values of the standard deviation of reproducibility of the method, $\sigma_{R0}$, for A-weighted sound power levels and sound energy levels determined in accordance with this part of ISO 3743**

| Frequency bandwidth | Octave mid-band frequency<br>Hz | Standard deviation of reproducibility, $\sigma_{R0}$<br>dB |
|---|---|---|
| Octave | 125 | 3,0 |
| | 250 | 2,0 |
| | 400 to 5 000 | 1,5 |
| | 8 000 | 2,5 |
| A-weighted per Annex B | | 1,5[a] |

[a] Applicable to noise sources which emit sound with a relatively "flat" spectrum in the frequency range from 125 Hz to 8 000 Hz.

## 9.5 Total standard deviation $\sigma_{tot}$ and expanded uncertainty, $U$

The total standard deviation and the expanded uncertainty shall be determined using Equation (22) and Equation (23), respectively. For the purpose of this part of ISO 3743, a normal distribution is assumed. Thus a coverage factor of $k = 2$ shall be used corresponding to a coverage probability of 95 %. The coverage factor and coverage probability have to be reported together with the expanded uncertainty.

EXAMPLE Accuracy grade 2; $\sigma_{omc} = 2{,}0$ dB; coverage factor $k = 2$; measured $L_{WA} = 82$ dB. Machine-specific determinations of $\sigma_{R0}$ have not been undertaken thus the value is taken from Table 3 ($\sigma_{R0} = 1{,}5$ dB). Using Equations (23) and (22) it follows

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

Additional examples of calculated values for $\sigma_{tot}$ are given in C.3.

NOTE The expanded uncertainty as described in this part of ISO 3743 does not include the standard deviation of production which is used in ISO 4871[8] for the purpose of making a noise declaration for batches of machines.

# 10 Information to be recorded

## 10.1 General

The information listed in 10.2 to 10.5, when applicable, shall be compiled and recorded for all measurements made in accordance with this part of ISO 3743.

## 10.2 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 the noise source in the test room;

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

## 10.3 Test room

The following information shall be recorded:

a) a description of the test room, showing the nature of the building, the construction and any treatment of the walls, floor and ceiling, and a sketch showing the location of the noise source under test and any other contents of the room;

b) a description of the suitability of the room for the purpose of the test in accordance with 4.4 (giving the maximum differences between sound pressure levels using the directional sound source);

c) the air temperature in degrees Celsius, the relative humidity expressed as a percentage, and the static pressure, in kilopascals, near the noise source at the time of test.

## 10.4 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 and the reference sound source, and to verify the calibration of the instrumentation system, in accordance with 5.2;

c) the calibrated sound power levels of the reference sound source in the various positions used.

## 10.5 Acoustical data

The following information shall be recorded:

a) the dimensions of the reference box;

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

c) the locations used for the reference sound source.

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

d) remarks on the subjective impression of the noise emitted by the source under test from aural examinations (directivity, discrete tones or components in narrow bands of frequency, temporal characteristics, etc.);

e) the time-averaged or single event time-integrated sound pressure levels of the noise source under test measured at each microphone position or over the path of the moving microphone, in octave bands;

f) the sound pressure levels of the background noise measured at each microphone position or over the path of the moving microphone, in octave bands;

g) the sound power levels or sound energy levels in decibels, in octave bands and A-weighted (if appropriate), rounded to the nearest 0,1 dB, optionally including a graphical representation;

NOTE ISO 9296[13] requires that the declared A-weighted sound power levels, $L_{W\text{Ad}}$, of computers and business equipment are expressed in bels, using the identity 1 B = 10 dB.

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

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

## 11 Test report

Only those recorded data (see Clause 10) 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 part of ISO 3743. If the reported sound power levels or sound energy levels have been obtained in full conformity with the requirements of this part of ISO 3743, 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 part of ISO 3743, then the report may state that the measurements have been conducted “in conformity with the requirements of this part of ISO 3743, except for…” and the discrepancies shall be clearly identified. In this case, the term “full conformity” shall not be stated or implied.

# Annex A
(normative)

# Sound power level and sound energy level under reference meteorological conditions

The sound power level under reference meteorological conditions of static pressure 101,325 kPa and atmospheric temperature 23,0 °C, $L_{W\text{ref,atm}}$, shall be calculated using Equation (A.1):

$$L_{W\text{ref,atm}} = L_W + C_2 \tag{A.1}$$

where

$L_W$ is the sound power level, in decibels, under the meteorological conditions which occurred at the time and place of the test, from Equation (14);

$C_2$ 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 [24][25]):

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

in which

$p_s$ is the static pressure, in kilopascals, at the time and place of the test,

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

$\theta$ is the air temperature, in degrees Celsius, at the time and place of the test,

$\theta_1$ = 296 K.

The air temperature, $\theta$, may be estimated, and the atmospheric pressure, $p_s$, can be calculated using Equation (A.2):

$$p_s = p_{s,0} \left(1 - aH_a\right)^b \tag{A.2}$$

where

$H_a$ is the altitude, in metres, of the test site;

$a$ = 2,256 0 × $10^{-5}$ $m^{-1}$;

$b$ = 5,255 3.

The sound energy level under reference meteorological conditions of static pressure 101,325 kPa and atmospheric temperature 23,0 °C, $L_{J\text{ref,atm}}$, shall be calculated using Equation (A.3):

$$L_{J\text{ref,atm}} = L_J + C_2 \tag{A.3}$$

where

$L_J$ is the sound energy level, in decibels, under the meteorological conditions which occurred at the time and place of the test, from Equation (20);

$C_2$ see Equation (A.1).

If the sound power level or the sound energy level is calculated under reference meteorological conditions, this fact shall be stated in the test report.

# Annex B
(normative)

# Calculation of A-weighted sound power levels and A-weighted sound energy levels from octave band levels

## B.1 A-weighted sound power levels

The A-weighted sound power level, $L_{WA}$, shall be calculated from Equation (B.1):

$$L_{WA} = 10 \lg \sum_{k=k_{min}}^{k_{max}} 10^{0,1(L_{Wk}+C_k)} \text{ dB} \quad \text{(B.1)}$$

where

$L_{Wk}$ is the sound power level in the $k$th octave band, in decibels;

$k$, $C_k$ are given in Table B.1;

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

## B.2 A-weighted sound energy levels

The A-weighted sound energy level, $L_{JA}$, shall be calculated from Equation (B.2):

$$L_{JA} = 10 \lg \sum_{k=k_{min}}^{k_{max}} 10^{0,1(L_{Jk}+C_k)} \text{ dB} \quad \text{(B.2)}$$

where

$L_{Jk}$ is the sound energy level in the $k$th octave band, in decibels;

$k$, $C_k$ are given in Table B.1;

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

## B.3 Values of $k$ and $C_k$ for use in calculations

For calculations with octave-band data, values of $k$ and $C_k$ are given in Table B.1.

**Table B.1 — Values of $k$ and $C_k$ for mid-band frequencies of octave bands**

| $k$ | **Octave mid-band frequency**<br>Hz | $C_k$<br>dB |
|---|---|---|
| 1 | 63 | −26,2[a] |
| 2 | 125 | −16,1 |
| 3 | 250 | −8,6 |
| 4 | 500 | −3,2 |
| 5 | 1 000 | 0,0 |
| 6 | 2 000 | 1,2 |
| 7 | 4 000 | 1,0 |
| 8 | 8 000 | −1,1 |

[a] This value of $C_k$ is given for use only where the test room and instrumentation are satisfactory for use at the frequency concerned.

# Annex C
(informative)

# Guidelines on the development of information on measurement uncertainty

## C.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 part of ISO 3743.

This annex complements Clause 9.

## C.2 Considerations on the total standard deviation $\sigma_{\text{tot}}$

The measurement uncertainty used in this part of ISO 3743 is determined by the expanded uncertainty $U$, which is derived directly from the total standard deviation $\sigma_{\text{tot}}$ [see Equation (23)] with $\sigma_{\text{tot}}$ being the approximation of the relevant $u(L_W)$ as defined in ISO/IEC Guide 98-3.

This total standard deviation, $\sigma_{\text{tot}}$, results from the two components $\sigma_{R0}$ and $\sigma_{\text{omc}}$ [see Equation (22)], which are significantly different in nature.

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

The machinery specific standard deviation $\sigma_{\text{omc}}$ cannot be calculated and has to be determined by repeated measurements as described in C.3. Information on the standard deviation $\sigma_{R0}$ is given in C.4.

## C.3 Considerations on $\sigma_{\text{omc}}$

The standard deviation $\sigma_{\text{omc}}$, described in 9.2, is calculated by

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

where

$L_{p,j}$ is the sound pressure level measured at a prescribed position and corrected for background noise for the $j$th 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 (C.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 $\sigma_{\text{omc}}$ 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 $\sigma_{\text{omc}}$ 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, $\sigma_{\text{tot}}$, investigations on $\sigma_{\text{omc}}$ have a higher priority compared to those on the other uncertainty components leading to $\sigma_{R0}$ [see Equation (22)]. This is because $\sigma_{\text{omc}}$ may be significantly larger in practice than e.g. $\sigma_{R0}$ = 1,5 dB for accuracy grade 2 measurements as given in Table 3.

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

**Table C.1 — Examples of calculated total standard deviations $\sigma_{\text{tot}}$ for three different cases**

| Standard deviation of reproducibility of the method, $\sigma_{R0}$, dB | **Operating and mounting conditions** | | |
|---|---|---|---|
| | stable | unstable | very unstable |
| | **Standard deviation, $\sigma_{\text{omc}}$, dB** | | |
| | 0,5 | 2 | 4 |
| | **Total standard deviation, $\sigma_{\text{tot}}$, dB** | | |
| 0,5<br>(Accuracy grade 1) | 0,7 | 2,1 | 4,0 |
| 1,5<br>(Accuracy grade 2) | 1,6 | 2,5 | 4,3 |
| 3<br>(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 $\sigma_{\text{tot}}$, because the different grades of accuracy of this part of ISO 3743 are currently defined by the value of $\sigma_{R0}$ only.

## C.4 Considerations on $\sigma_{R0}$

### C.4.1 General

Upper bound values of $\sigma_{R0}$ are given in Table 3. Additionally in 9.3, the investigation of values of $\sigma_{R0}$ 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 (25) which requires more detailed information.

If certain uncertainty components are not relevant for specific applications or are difficult to investigate, delimited definitions of $\sigma_{R0}$ should be given by noise test codes both for round robin tests (see Note to 9.3.2) 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 part of ISO 3743 were not available at the time of publication. Nonetheless, the following information may give a rough outline of the relevant quantities without being definitive.

### C.4.2 Contributions to the uncertainty $\sigma_{R0}$

#### C.4.2.1 General

Preliminary estimations show that when corrected for meteorological conditions, the sound power level, $L_{W\text{ref,atm}}$, is a function of a number of parameters, indicated by Equation (C.2):

$$L_{W\text{ref,atm}} = \delta_{\text{method}} + \delta_{\text{omc}} + L_{W\text{(RSS)}} - \overline{L'_{p\text{(RSS)}}} + \overline{L'_{p\text{(ST)}}} + K_{1\text{(RSS)}} - K_1 + C_2 + \delta_{\text{slm(RSS)}} + \delta_{\text{omc(RSS)}} + \delta_{\text{mic(RSS)}} + \delta_{\theta\text{(RSS)}} + \delta_{H\text{(RSS)}} + \delta_{\text{A(RSS)}} + \delta_{\text{method(RSS)}} + \delta_{\text{slm}} + \delta_{\text{mic}} + \delta_{\theta} + \delta_H \quad \text{(C.2)}$$

where

$\delta_{\text{method}}$ 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;

$\delta_{\text{omc}}$ 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 $\sigma_{R0}$ [see Equation (22)];

$L_{W\text{(RSS)}}$ is the calibrated octave band sound power level of the reference sound source, in decibels;

$\overline{L'_{p\text{(RSS)}}}$ is the mean octave band time-averaged sound pressure level of the reference sound source, in decibels;

$\overline{L'_{p\text{(ST)}}}$ is the mean octave band time-averaged sound pressure level of the noise source under test, in decibels;

$K_{1(\mathrm{RSS})}$ is the background noise correction for the reference sound source, in decibels;

$K_1$ is the background noise correction, 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 [24][25]):

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

$\delta_{\mathrm{slm}}$ is an input quantity to allow for any uncertainty in the measuring instrumentation, in decibels;

$\delta_{\mathrm{mic}}$ is an input quantity to allow for any uncertainty due to the finite number of microphone and source positions, in decibels;

$\delta_\theta$ is an input quantity to allow for any uncertainty due to fluctuations in air temperature in the reverberation test room, in decibels;

$\delta_H$ is an input quantity to allow for any uncertainty due to fluctuations in the relative humidity in the reverberation test room, in decibels;

$\delta_{\mathrm{slm(RSS)}}$ to $\delta_{\mathrm{method(RSS)}}$ are the above input quantities evaluated for the reference sound source.

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

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

NOTE 3 The quantities included in Equation (C.2) to allow for uncertainties are those thought to be applicable at the state of knowledge current at the time of publication of this part of ISO 3743, 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 $\sigma_{\mathrm{omc}}$ whereas $\sigma_{R0}$ includes the rest of the uncertainty components.

Table C.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 $\sigma_{R0}$ assumes that the individual uncertainty contributions are not correlated.

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

Explanation and numerical example for the uncertainty parameters in Table C.2 are given in C.4.2.2 to C.4.2.9. Formulae to calculate uncertainties are given with examples to show the expected range of measurement uncertainties.

**Table C.2 — Uncertainty budget for determinations of $\sigma_{R0}$ for sound power level and sound energy level, valid for frequencies from 500 Hz to 4 kHz, or for A-weighted measurements of a source with a relatively flat frequency spectrum**

| Quantity | | Estimate[a] dB | Standard uncertainty[a], $u_i$ | Probability distribution | Sensitivity coefficient[a], $c_i$ |
|---|---|---|---|---|---|
| $\delta_{\text{method}}$ | method | 0 | 0,3 dB | Normal | 1 |
| $\overline{L'_{p(\text{ST})}}$ | mean time-averaged sound pressure level | $\overline{L'_{p(\text{ST})}}$ | $s_{L'_{p(\text{ST})}}\Big\|_{\text{rep}}$ | Normal | $1 + \dfrac{1}{10^{0,1\Delta L_p} - 1}$ |
| $K_1$ | background noise correction | $K_1$ | $s_{L_{p(\text{B})}}$ | Normal | $\dfrac{1}{10^{0,1\Delta L_p} - 1}$ |
| $C_2$ | radiation impedance correction | $C_2$ | 0,2 dB | Triangular | 1 |
| $\delta_{\text{slm}}$ | sound level meter | 0 | 0,5 dB | Normal | 0,5 |
| $\delta_{\text{mic}}$ | sampling | 0 | $\dfrac{u_{(L'_{pi(\text{ST})})_j}}{\sqrt{N_{\text{M}}N_{\text{S}}}}$ | Normal | 0,5 |
| $\delta_\theta$ | temperature | 0 | $\Delta\theta/\sqrt{3}$ | Rectangular | $\dfrac{6,5}{273+\theta} + \dfrac{-0,57 + 0,25\lg(2,6f)}{1 + 0,0011H + 0,007\theta}$ |
| $\delta_H$ | 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.

### C.4.2.2 Measurement method, $\delta_{\text{method}}$

The uncertainty due to the measurement method applied, $u_{\text{method}}$, includes the derivation of results and associated uncertainties. Assuming known 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, $\sigma_{R0}$. An example of this latter case is the implementation of standards by inexperienced users.

Assuming the full modelling approach as implemented in this example is complete and correct, for frequencies above 100 Hz, the assumed value of this parameter is $u_{\text{method}}$ = 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 $u_{\text{method}}$ = 3 dB below 100 Hz.

Uncertainties related to the method directly affect results, so that $c_{\text{method}}$ = 1. In this example, for A-weighted measurements, the uncertainty contribution, $u_{\text{method}}\, c_{\text{method}}$, is typically 0,3 dB.

### C.4.2.3 Sound pressure level repeatability, $\overline{L'_{p(\text{ST})}}$

The uncertainty due to the repeatability, $u_{L'_{p(\text{ST})}}$, of measurements of the sound pressure level, $\overline{L'_{p(\text{ST})}}$, is the closeness of agreement between results of successive measurements carried out under the same conditions; it may be obtained from the standard deviation of repeatability, $s_{L'_{p(\text{ST})}}\Big|_{\text{rep}}$, using six measurements of the decibel sound pressure levels at a single microphone position (without correction for background noise).

These measurements are made under repeatability conditions, which are defined as: same measurement procedure; same observer; same measuring instrument; same location; and repetition over a short period of time. Although not specified in ISO/IEC Guide 98-3, it is common to dismantle then set up instrumentation and equipment between trials.

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

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

This may be further simplified to

$$c_{L'_{p(\mathrm{ST})}} = 1 + c_{K_1}$$

Measurement repeatability can be strongly influenced by averaging time. Using the same extreme scenario as for $c_{K_1}$ results in $c_{L'_{p(\mathrm{ST})}}$ = 1,3. If the averaging time does not cover a sufficient number of machinery cycles, the total uncertainty may be unacceptably large for an engineering grade standard. This component of uncertainty can often be made negligible with a sufficiently long averaging time consisting of an integer number of work cycles. Reduction of background noise can reduce the sensitivity coefficient and hence total uncertainty by up to a factor of 2. Reproducibility uncertainties are typically small, in this example the total uncertainty contribution is assumed to be 0,4 dB for both the reference sound source and the noise source under test.

#### C.4.2.4 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, $s_{L_{p(\mathrm{B})}}$, of the decibel values from repeated measurements of background noise at a single microphone position.

The sensitivity coefficient, $c_{K_1}$, due to the background noise $\overline{L_{p(\mathrm{B})}}$ is obtained from the derivative of $L_{W\mathrm{ref,atm}}$ with respect to $\overline{L_{p(\mathrm{B})}}$. Using Equations (13) and (14), the parameters in $L_{W\mathrm{ref,atm}}$ that are related to the source measurement are given by $\overline{L'_{p(\mathrm{ST})}} + 10\ \lg\left(1 - 10^{-0,1\Delta L_p}\right)\mathrm{dB}$, where $\Delta L_p = \overline{L'_{p(\mathrm{ST})}} - \overline{L_{p(\mathrm{B})}}$. 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 $\Delta L_p \leqslant 10\,\mathrm{dB}$ this may be further simplified to $\left|c_{K_1}\right| \approx 3,6/\Delta L_p - 0,24$. In an extreme scenario, high background noise levels with a standard deviation of 3 dB are assumed. The worst case, $\overline{L'_p} - \overline{L_{p(\mathrm{B})}}$ is 6 dB, (the minimum allowable at mid frequencies in 8.1). This results in a sensitivity coefficient of $c_{K_1}$ = 0,3 and a total contribution to uncertainty of 1,0 dB. Typically this contribution is closer to 0,4 dB due to better control of the background noise. Lowering 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). The uncertainty, $u_{K_1}$, is typically halved each time the averaging time is increased by a factor of four. In large rooms the reverberant field strength is stronger near noise sources, and background noise can be reduced by measuring closer to the source under test.

### C.4.2.5 Radiation impedance correction, $C_2$

The uncertainty, $u_{C_2}$ , in determining the meteorological correction, $C_2$ , (see Annex A), if applied, takes the value 0,1 dB.

For altitudes less than 500 m, no meteorological correction is required. At 120 m altitude and 23 °C the correction is zero and at 500 m altitude the correction is 0,4 dB. Assuming a triangular distribution for this uncertainty, the standard deviation is $s_{C_2} = 0{,}4/\sqrt{6} = 0{,}2\,\text{dB}$ .

The sensitivity coefficient for changes in meteorological conditions is denoted $c_{C_2}$ . Meteorological conditions have a direct effect on the measurement result, $c_{C_2}$ = 1. Assuming the altitude is less than 500 m and the meteorological correction is not applied, the standard deviation is 0,2 dB with corresponding uncertainty contribution of 0,2 dB. A lower uncertainty contribution can be obtained by measuring in a different location, or by applying the meteorological correction. Meteorological corrections for a reference sound source are provided by the manufacturer and this correction term $C_2$ is not required so that this uncertainty contribution for a reference sound source is $u_{C_2\text{(RSS)}}\, c_{C_2\text{(RSS)}}$ = 0 dB.

### C.4.2.6 Sound level meter, $\delta_{\text{slm}}$

The uncertainty in the measuring instrumentation is denoted $u_{\text{slm}}$. For a class 1 instrument, the value of this parameter is $u_{\text{slm}}$ = 0,5 dB.

The sensitivity coefficient for the sound level meter has the value 0,5. 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. The sensitivity coefficient is reduced so that the combined uncertainty is less than $u_{\text{slm}}$. Setting $c_{\text{slm}}$ = 0,5 results in an uncertainty contribution of 0,3 dB for both the reference sound source and noise source under test. Additional details regarding parameters affecting the uncertainty of sound level meters can be found in IEC 61672-1.

### C.4.2.7 Sampling, $\delta_{\text{mic}}$

The uncertainty due to a finite number of microphone and source positions, $u_{\text{mic}}$, is given by

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

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

The sensitivity coefficient for sampling, $c_{\text{mic}}$ takes the value 0,5. 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. The sensitivity coefficient is reduced so that the combined uncertainty is less than $u_{\text{mic}}$. Using three microphone positions and the extreme values from Table 2; i.e. a standard deviation of 2,5 dB and 1 source position, then $u_{\text{mic}}$ = 1,4 dB, and the total uncertainty contribution, $u_{\text{mic}}\, c_{\text{mic}}$ = 0,7 dB. A more typical value would be 0,4 dB for the source total uncertainty contribution and 0,2 dB for the contribution from the reference sound source. The uncertainty contribution can be reduced by increasing the reverberation time, adding diffusors, or increasing the number of source and microphone positions. Additional details regarding parameters affecting the uncertainty due to sampling can be found in ISO 3741[2].

### C.4.2.8 Temperature, $\delta_\theta$

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

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

The sensitivity coefficient due to the temperature, $c_\theta$, is obtained from a rough curve fit to the derivative of $L_W$ with respect to temperature. The equation for $L_W$ was obtained from ISO 3741[2] with the $C_1$ term omitted. Estimates of air absorption in the room were obtained from ISO 9613-1[14]. The pressure absorbed with each wall reflection was estimated from the absorption per metre in air, $\alpha_{\text{dBm}}$, and the Sabine estimate (4V/S) of the mean free path (approximately 3,3 m for 70 < V < 200 m$^3$)

$$c_\theta = \frac{6{,}5}{273+\theta} + 17{,}4\frac{V}{S}\left[1+\frac{1}{\alpha_{\text{room}}+4(V/S)\alpha_{\text{dBm}}}\right]\frac{\partial\alpha_{\text{dBm}}}{\partial\theta} \approx \frac{6{,}5}{273+\theta} + \frac{-0{,}57+0{,}25\,\lg(2{,}6f)}{1+0{,}001\ 1H+0{,}007\theta}$$

where

$H$ is the relative humidity expressed as a percentage;

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

For both the reference sound source and the noise source under test, the highest values for this parameter occur at 10 kHz in a dry room at low temperature. A typical worst case would occur when the source under test changes the room temperature by, say, 10 °C, so that $u_\theta$ = 2,9 °C. Assuming most of the sound produced by the source is below 1 kHz, at 20 °C and 10 % $H$ the sensitivity coefficient is approximately 0,3 so that $u_\theta c_\theta$ = 1 dB. Better control of temperature, allowing the room to come to temperature equilibrium before testing the reference sound source, 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. Recommended temperature and humidity ranges given in ISO 3741[2] are ±1 °C and ±3 % $H$ below 20 °C when below 30 % $H$, to a maximum of ±5 °C and ±10 % $H$ above 20 °C when above 30 % $H$. Assuming the room has attained an equilibrium temperature, the typical total uncertainty would be close to 0,2 dB.

### C.4.2.9 Humidity, $\delta_H$

The uncertainty due to changes in relative humidity, $u_H$, 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 $L_W$ with respect to relative humidity in a similar manner to that used for $c_\theta$.

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

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

For both the reference sound source and the noise source under test, the highest value for this parameter occurs at 10 kHz in a dry room. Assuming most of the sound produced by the source is below 1 kHz, if $H$ = 10 % the sensitivity coefficient is approximately 0,3. If the tolerance on relative humidity is ±5 %, then $u_H c_H$ = 1 dB. Better control of humidity, allowing the room to come to equilibrium before testing, or shorter measurement times can reduce this uncertainty. Higher humidity is typically associated with a lower sensitivity coefficient per degree change in temperature. The recommended humidity ranges given in ISO 3741[2] are ±3 %, if $H \leqslant$ 30 %, to a maximum of ±10 %, if $H >$ 30 % $H$. Assuming the room humidity is stable, typically the total uncertainty contribution would be 0,2 dB.

#### C.4.2.10 Typical value for $\sigma_{R0}$

Using the typical values from above, $\sigma_{R0(\mathrm{ST})}$ for the sound source alone is given by

$$\begin{aligned}\sigma_{R0(\mathrm{ST})} &= \sqrt{\sum_i (u_i\, c_i)^2} \\ &= \sqrt{0{,}3^2 + 0{,}4^2 + 0{,}4^2 + 0{,}2^2 + 0{,}3^2 + 0{,}4^2 + 0{,}2^2 + 0{,}2^2} \\ &= 0{,}9\,\mathrm{dB}\end{aligned}$$

Considering only the reference sound source, 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 $\sigma_{\mathrm{omc(RSS)}} = 0{,}5\,\mathrm{dB}$. The total combined contribution uncertainty for the reference sound source alone is

$$\begin{aligned}u\left[L_{W(\mathrm{RSS})}\right] &= \sqrt{\sum_i (u_i\, c_i)^2 + [\sigma_{\mathrm{omc(RSS)}}]^2} \\ &= \sqrt{\left(0{,}3^2 + 0{,}4^2 + 0{,}4^2 + 0^2 + 0{,}3^2 + 0{,}2^2 + 0{,}2^2 + 0{,}2^2\right) + 0{,}5^2} \\ &= 0{,}9\,\mathrm{dB}\end{aligned}$$

In this scenario, the total $\sigma_{R0}$ is

$$\sigma_{R0} = \sqrt{u\left[L_{W(\mathrm{RSS})}\right]^2 + \sigma_{R0(\mathrm{ST})}^2} = 1{,}3\ \mathrm{dB}$$

## C.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, $u(L_{W\,\mathrm{ref,atm}})$, in decibels, is given by Equation (C.3):

$$u(L_{W\,\mathrm{ref,atm}}) \approx \sigma_{\mathrm{tot}} = \sqrt{\sigma_{R0}^2 + \sigma_{\mathrm{omc}}^2} = \sqrt{\sum_i (c_i\, u_i)^2 + \sigma_{\mathrm{omc}}^2}\ \mathrm{dB} \tag{C.3}$$

## C.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 of the combined standard uncertainty of determinations of sound power levels, $u(L_{W\,\mathrm{ref,atm}})$. A value may then be selected for the coverage factor, $k$, and the product, $k\,\sigma_{\mathrm{tot}}$ yields an estimate of the expanded 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 uncertainty.

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