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Acoustics — Determination of occupational noise exposure — Engineering method

Acoustique — Détermination de l'exposition au bruit en milieu de travail — Méthode d'expertise

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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 9612 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

This second edition cancels and replaces the first edition (ISO 9612:1997), which has been technically revised.

Introduction

This International Standard provides a stepwise approach to the determination of occupational noise exposure from noise level measurements. The procedure contains the following major steps: work analysis, selection of measurement strategy, measurements, error handling and uncertainty evaluations, calculations, and presentation of results. This International Standard specifies three different measurement strategies: task-based measurement; job-based measurement; and full-day measurement. This International Standard gives guidance on selecting an appropriate measurement strategy for a particular work situation and purpose of investigation. This International Standard also provides an informative spreadsheet to allow calculation of measurement results and uncertainties. ISO is not responsible for errors that may arise or occur with the use of this spreadsheet.

This International Standard recognizes the use of hand-held sound level meters as well as personal sound exposure meters. The methods specified optimize the effort required for obtaining a given accuracy.

Acoustics — Determination of occupational noise exposure — Engineering method

1 Scope

This International Standard specifies an engineering method for measuring workers' exposure to noise in a working environment and calculating the noise exposure level. This International Standard deals with A-weighted levels but is applicable also to C-weighted levels. Three different strategies for measurement are specified. The method is useful where a determination of noise exposure to engineering grade is required, e.g. for detailed noise exposure studies or epidemiological studies of hearing damage or other adverse effects.

The measuring process requires observation and analysis of the noise exposure conditions so that the quality of the measurements can be controlled. This International Standard provides methods for estimating the uncertainty of the results.

This International Standard is not intended for assessment of masking of oral communication or assessment of infrasound, ultrasound and non-auditory effects of noise. It does not apply to the measurement of the noise exposure of the ear when hearing protectors are worn.

Results of the measurements performed in accordance with this International Standard can provide useful information when defining priorities for noise control measures.

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 1999, *Acoustics — Determination of occupational noise exposure and estimation of noise-induced hearing impairment*

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

IEC 60942:2003, *Electroacoustics — Sound calibrators*

IEC 61252, *Electroacoustics — Specifications for personal sound exposure meters*

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
A-weighted time-averaged sound pressure level
$L_{p,\text{A},T}$
A-weighted equivalent continuous sound pressure level
$L_{p,\text{A,eq}T}$
ten times the logarithm to the base 10 of the ratio of the time average of the square of the A-weighted sound pressure, p_A, 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

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

where the reference value, p_0, is 20 µPa

NOTE Adapted from ISO/TR 25417:2007 [9].

3.2
A-weighted noise exposure level normalized to an 8 h working day
daily noise exposure level
$L_\text{EX,8h}$
⟨occupational noise⟩ level, in decibels, given by the equation:

$$L_\text{EX,8h} = L_{p,\text{A,eq}T_\text{e}} + 10\,\text{lg}\left[\frac{T_\text{e}}{T_0}\right]\ \text{dB} \qquad (2)$$

where

- $L_{p,\text{A,eq}T_\text{e}}$ is the A-weighted equivalent continuous sound pressure level for T_e;
- T_e is the effective duration, in hours, of the working day;
- T_0 is the reference duration, $T_0 = 8$ h

NOTE 1 If the effective duration of the working day, T_e, is equal to 8 h, then $L_\text{EX,8h}$ equals $L_{p,\text{A,eq,8h}}$.

NOTE 2 If the average or normalized exposure over a number of days is desired, Equation (3) can be used:

$$\overline{L}_\text{EX,8h} = 10\,\text{lg}\left[\frac{1}{X}\sum_{x=1}^{X} 10^{0,1 \times L_{\text{EX,8h},x}}\right]\ \text{dB} \qquad (3)$$

The value of X is chosen according to the purpose of the averaging process. For example, $X = 5$ leads to a daily noise exposure level normalized to a nominal week of five 8 h working days.

NOTE 3 This definition differs from that given in ISO/TR 25417:2007 [9].

3.3
nominal day
working day over which it is chosen to determine the noise exposure

NOTE 1 The nominal day is determined from the work analysis and depends on the purpose of the measurements. For example, it may be a typical day representing the work performed over several days or the day with the highest noise exposure. See also 7.3.

NOTE 2 The noise exposure level is normally calculated on a daily basis, but there may be circumstances where the use of weekly or longer periods of noise exposure is considered appropriate.

3.4
C-weighted peak sound pressure level

$L_{p,\text{Cpeak}}$

ten times the logarithm to the base 10 of the ratio of the square of the C-weighted peak sound pressure, p_{Cpeak}, to the square of a reference value, p_0, expressed in decibels

$$L_{p,\text{Cpeak}} = 10 \lg \frac{p_{\text{Cpeak}}^2}{p_0^2} \text{ dB} \tag{4}$$

where the reference value, p_0, is 20 μPa.

3.5
task

⟨occupational noise⟩ distinct part of a worker's occupational activity

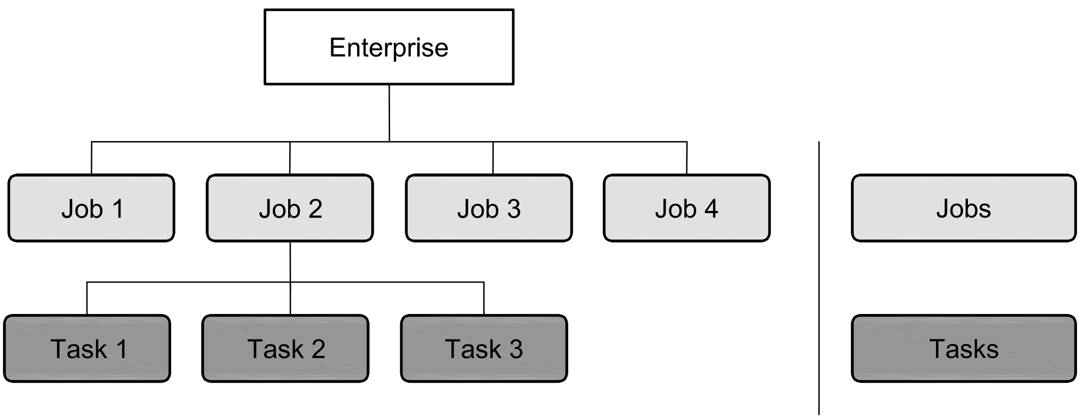
Figure 1 illustrates the hierarchy of jobs and tasks.

3.6
job

⟨occupational noise⟩ overall occupational activity that is carried out by a worker, consisting of all the tasks performed by the worker during the entire working day or shift

NOTE A worker often has a job title that describes his or her job, sometimes complemented with an additional description to ensure clear identification, e.g. “welder - process line A”.

Figure 1 illustrates the hierarchy of jobs and tasks.



Key

Job 1 scaffolders
Job 2 welders
Job 3 painters
Job 4 store keepers

Task 1 planning
Task 2 grinding
Task 3 welding

Figure 1 — An example illustrating the hierarchy of jobs and tasks

4 Symbols

c_i	sensitivity coefficient related to each input quantity	—
c_1	sensitivity coefficient associated with job noise level sampling	—
$c_{1a,m}$	sensitivity coefficient associated with noise level sampling of task m	—
$c_{1b,m}$	sensitivity coefficient associated with estimation of duration of task m	dB h^{-1}
c_2	sensitivity coefficient associated with measurement instrumentation	—
c_3	sensitivity coefficient associated with microphone position	—
i	task sample number	—
I	the total number of task samples	—
j	number of observations of task duration	—
J	total number of observations of task duration	—
k	coverage factor related to a confidence interval	—
K_N	denominator as given in C.3.3, Note 2	—
$L_{EX,8h}$	A-weighted noise exposure level normalized to a nominal 8 h working day	dB
$\overline{L}_{EX,8h}$	A-weighted noise exposure level normalized to a nominal 8 h working day averaged over a number of days	dB
$L_{EX,8h,m}$	A-weighted noise exposure level of task m contributing to the daily noise exposure level	dB
$L^*_{p,A,eqT,m}$	estimate of the true A-weighted equivalent continuous sound pressure level for task m	dB
$L_{p,A,T} = L_{p,A,eqT}$	A-weighted equivalent continuous sound pressure level over a period T	dB
$L_{p,A,eqT,m}$	A-weighted equivalent continuous sound pressure level for task m	dB
$\overline{L}_{p,A,eqT,m}$	arithmetic average of a number of samples of the A-weighted equivalent continuous sound pressure levels for task m	dB
$L_{p,A,eqT,n}$	A-weighted equivalent continuous sound pressure level of job sample n	dB
L_{p,A,eqT_e}	A-weighted equivalent continuous sound pressure level for the effective duration of the working day	dB
$L_{p,Cpeak}$	C-weighted peak sound pressure level	dB
m	task number	—
M	total number of tasks	—
n	job sample number	—
N	total number of job samples	—
n_G	number of workers in a homogenous exposure group	—
p_0	reference value; $p_0 = 2 \times 10^{-5}$ Pa	Pa
p_A	A-weighted sound pressure	Pa
p_{Cpeak}	C-weighted peak sound pressure	Pa
Q_2	correction for measurement instrumentation	dB
Q_3	correction for microphone position	dB
t	duration of measurement as described in Figure 2	h
T	time period over which an average is taken	h
T_0	reference duration; $T_0 = 8$ h	h

T_e	effective duration of the working day	h
T_m	duration of task m	h
$T_{m,j}$	duration of sample j of task m	h
T_n	duration of job sample n	h
U	expanded uncertainty	dB
u	combined standard uncertainty	dB
u_i	standard uncertainty of each input quantity	dB
u_1	standard uncertainty of the energy average of a number of measurements of A-weighted equivalent continuous sound pressure level	dB
u_1^*	estimated standard uncertainty of a number of measurements of A-weighted equivalent continuous sound pressure level	dB
$u_{1a,m}$	standard uncertainty due to noise level sampling of task m	dB
$u_{1b,m}$	standard uncertainty due to the estimation of duration of task m	h
u_2	standard uncertainty due to the instrumentation	dB
$u_{2,m}$	standard uncertainty due to the instrumentation in the task method	dB
u_3	standard uncertainty due to microphone position	dB
x	day number	—
X	total number of days	—

5 Instrumentation

5.1 Sound level meters and personal sound exposure meters

Measurements can be made by using either integrating-averaging sound level meters or personal sound exposure meters.

Sound level meters, including the microphone and associated cables, shall meet the requirements for IEC 61672-1:2002, class 1 or class 2 instrumentation. Class 1 instrumentation is preferred and should be used when measuring at very low temperatures or when the noise is dominated by high frequencies (see also Note 3).

Personal sound exposure meters, including the microphone and cable, shall meet the requirements specified in IEC 61252. Personal sound exposure meters fulfilling the requirements of IEC 61672-1:2002, class 1, are recommended and should be used when measuring at very low temperatures or when the noise is dominated by high frequencies (see also Notes 2 and 4).

NOTE 1 Most sound level meters that meet the requirements of IEC 60651:2001 [10] 1) and IEC 60804:2000 [11] 1) also meet the acoustic requirements of IEC 61672-1:2002.

NOTE 2 "Personal sound exposure meter" is often referred to as "noise dose meter" or "noise dosimeter" (North America).

NOTE 3 For IEC 61672-1:2002, class 1 instruments, the specified tolerance limits are applied for the temperature range from −10 °C to +50 °C. For instrumentation in accordance with IEC 61672-1:2002, class 2, and for personal sound exposure meters in accordance with IEC 61252, the influence of variations in the air temperature on the measured signal level is specified over the range from 0 °C to +40 °C. In order to maintain accuracy when performing measurements outside this temperature range, it can be necessary to use an instrument for which the manufacturer specifies compliance

1) Superseded.

for a wider temperature range. Alternatively, a sound level meter in accordance with IEC 61672-1:2002, class 1, may be selected. In cold conditions, the measuring instrument may be kept warm, e.g. under clothing, such that only the microphone is exposed to low temperatures.

NOTE 4 The choice of the instrumentation influences the uncertainty of the measurements.

NOTE 5 For personal sound exposure meters, IEC 61252 allows wide tolerances in the frequency characteristics above 4 000 Hz, which can lead to incorrect measurement of high frequency sound such as that from air nozzles. In order to reduce the uncertainty when measuring noise dominated by high frequencies, it may be necessary to use a measuring instrument for which the manufacturer specifies high frequency characteristics within a narrower tolerance range. Alternatively, a sound level meter specified in accordance with IEC 61672-1:2002, class 1, may be selected.

Personal sound exposure meters can have a cut-off level at around 70 dB. It should be checked whether this influences the measurement result.

5.2 Calibrator

The calibrator shall meet the requirements specified in IEC 60942:2003, class 1.

5.3 Periodic verification

The calibration of the sound calibrator and the compliance of the instrumentation system with the requirements of IEC 61672-1, IEC 61252 and other relevant standards 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 and the compliance of the instrumentation system with the requirements of IEC 61672-1 be verified at intervals not exceeding 2 years.

The date for the last periodic verification and the name of the laboratory that performed it shall be recorded and given in the measurement report.

6 Methodology — Chronological steps

6.1 Step 1: Work analysis

The work analysis shall provide sufficient information about the work and the workers under consideration so that an appropriate measurement strategy can be selected and measurements can be planned. Work analysis shall be carried out in accordance with Clause 7.

6.2 Step 2: Selection of the measurement strategy

A measurement strategy shall be selected from task-based measurement, job-based measurement or full-day measurement as specified in Clause 8. More than one measurement strategy may be used, if relevant (see Clause B.6).

6.3 Step 3: Measurements

The basic measurement quantity shall be $L_{p,\mathrm{A,eq}T}$. In addition, $L_{p,\mathrm{Cpeak}}$ shall be measured, if relevant. The measurements shall follow the chosen strategy as specified in one of Clauses 9, 10 or 11 and comply with the requirements of Clause 12.

6.4 Step 4: Error handling and uncertainties

Sources of errors and uncertainties that may influence the result shall be evaluated in accordance with Clauses 13 and 14.

6.5 Step 5: Calculation and presentation of results and uncertainty

Calculate $L_{EX,8h}$ as specified for the selected strategy (see Clauses 9, 10, and 11) and the uncertainty as specified in Annex C. The results and uncertainties can be calculated by using the spreadsheet provided with this International Standard.

The results shall be presented as specified in Clause 15. Annexes D, E, and F provide practical examples for the task-based, job-based, and full-day measurements, respectively.

7 Work analysis

7.1 Introduction

Work analysis is required in all situations. It shall provide the information necessary to:

a) describe the activities of the enterprise and the jobs of the workers under consideration;

b) define homogeneous noise exposure groups (see 7.2), if relevant;

c) determine a nominal day or days for each worker or group;

d) identify tasks which make up the jobs, if relevant;

e) identify possible significant noise events;

f) choose the measurement strategy;

g) establish the measurement plan.

The work shall be analysed with emphasis put on production, process, organization, workers and activities.

The measurements may be performed by using the task-based, job-based or full-day strategy. Whichever strategy is used, it is essential to identify all events which are significant with regard to noise exposure and to make sure that the measurement plan takes them into account. See Annex A for an example of a checklist.

NOTE The order in which the items above are performed can depend on the complexity of the situation on site. The items are strongly connected, and the process can therefore be iterative in complex situations, i.e. increased knowledge about one of the items can result in a new description or redefinition of others.

7.2 Defining homogeneous noise exposure groups

Measurement efforts can be reduced by defining homogeneous noise exposure groups. These are groups of workers that are performing the same job and are expected to have similar noise exposures during the working day. If used, the homogeneous noise exposure group shall be clearly identified and can consist of one or more workers.

NOTE A **homogeneous noise exposure group** is also called **similar noise exposure group** US.

Homogeneous noise exposure groups can be defined in a number of ways. For example, it may be possible to define such groups according to job title, function, work area or profession. Alternatively, the groups can be defined by analysing the work according to production, process or work activity criteria.

In whichever way the groups are defined, they should be verified in consultation with the workers and supervisor, and ultimately by evaluating the measurement results, see 10.4.

7.3 Determination of a nominal day

A nominal day, including work periods and breaks, shall be determined in consultation with both workers and management. The work shall be studied in order to obtain an overview and understanding of all factors which can influence the noise exposure. See Annex A for more details.

Issues that shall be addressed are:

a) tasks (content and duration) and variation within tasks;

b) main noise sources and noisy work areas;

c) work pattern and any significant noise events, resulting in a change of the noise level;

d) number and duration of breaks, meetings, etc., and whether they should be regarded as a part of the nominal day.

Measurements shall be planned to ensure that all significant noise events are included. For each of the events, it shall be recorded when it occurred, its nature, duration and daily frequency. An example of a checklist to ensure that significant noise events are detected during the work analysis is given in Annex A.

In some cases, the work and consequently the noise exposure, varies from day to day so that there is no typical daily exposure, e.g. for workers who work in different locations or jobs each day. In these cases, the nominal day can be defined from work situations during several days, e.g. 1 week. See also Notes to 3.2 and 3.3.

Any indicators that characterize the work with respect to noise shall be identified, quantified, and reported. Examples of such indicators are: type of production in process; materials; quantities; thickness of workpiece; adjustment; speed; and number of workers involved.

If the purpose of measurements is to estimate the long-term risk of hearing impairment of workers, then the nominal day chosen shall be representative of the average exposure over the period under consideration, in accordance with ISO 1999.

8 Selection of measurement strategies

8.1 General

The selection of an appropriate measurement strategy is influenced by several factors such as the purpose of the measurements, complexity of the work situation, number of workers involved, effective duration of the working day, time available for measurement and analysis, and amount of detailed information required.

8.2 Measurement strategies

Three measurement strategies for the determination of workplace noise exposure are offered by this International Standard. These are:

a) task-based measurement: the work performed during the day is analysed and split up into a number of representative tasks, and for each task separate measurements of sound pressure level are taken (see Clause 9);

b) job-based measurement: a number of random samples of sound pressure level are taken during the performance of particular jobs (see Clause 10);

c) full-day measurement: sound pressure level is measured continuously over complete working days (see Clause 11).

Detailed guidance on the choice of the measurement strategy is given in Annex B.

9 Strategy 1 — Task-based measurement

9.1 Dividing the nominal day into tasks

For the workers or homogenous noise exposure groups under evaluation, the nominal day shall be divided into tasks. Each task shall be defined such that $L_{p,\mathrm{A,eq}T}$ is likely to be repeatable. Care shall be taken to ensure that all relevant noise contributions are included. Detailed information regarding the duration of tasks is particularly important for noise sources with high noise levels.

Identification of the noise sources and tasks that give the highest peak levels is important to obtain a correct determination of both $L_{p,\mathrm{A,eq}T}$ and $L_{p,\mathrm{Cpeak}}$.

9.2 Duration of tasks

The durations of the tasks, T_m, shall be determined. This can be done by:

a) interviewing the workers and the supervisor;

b) observing and measuring durations during noise measurements;

c) gathering information regarding operation of typical noise sources (e.g. work processes, machines, activities at the workplace and in its surroundings).

Optionally, the duration of a task can be regarded as a variable. To determine possible variations in duration, the task can be observed and the duration recorded, for instance, three times. Alternatively, multiple workers and supervisors may be asked to indicate the most reasonable duration range.

If J observations of the task duration $T_{m,j}$ are available, the arithmetic average value of task duration, $\overline{T}_m$, is given by Equation (5):

$$\overline{T}_m = \frac{1}{J}\sum_{j=1}^{J} T_{m,j} \tag{5}$$

The sum of individual durations of tasks, T_m, which make up the nominal day, shall correspond to the effective duration of the working day. The effective duration of the working day, T_e, is given by:

$$T_\mathrm{e} = \sum_{m=1}^{M} \overline{T}_m \tag{6}$$

where

$\overline{T}_m$ is the arithmetic average duration of task m;

m is the number of a task;

M is the total number of tasks.

NOTE Task-based measurements can, for instance, be combined with full-day measurements to verify that all relevant sources are included.

9.3 Measurement of $L_{p,\mathrm{A,eq}T,m}$ for tasks

For each task, the $L_{p,\mathrm{A,eq}T,m}$ representative of the noise exposure of the worker shall be measured in accordance with Clause 12. The measurements shall cover variations in noise level within each task in time, space and working conditions.

The measurement technician shall ensure that the work situation is representative. The worker under consideration shall be observed during the measurements whenever possible. If the operating or work conditions deviate from the normal situation, this shall be recorded and reported.

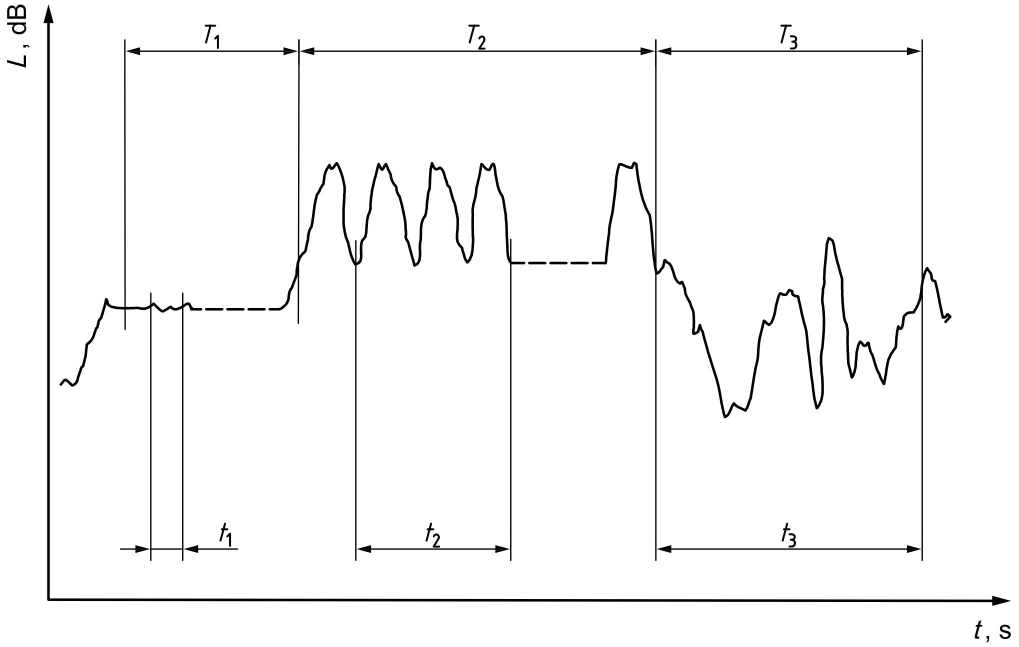
In cases when it is difficult for the measurement technician to follow the worker's activities without interfering with them, the activities during the measurements shall be registered by other means, e.g. by interviews or reviewing work records, and reported.

The duration of each measurement shall be long enough to represent the average equivalent continuous sound pressure level for the actual task. If the duration of the task is shorter than 5 min, the duration of each measurement shall be equal to the duration of the task. For longer tasks, the duration of each measurement shall at least be 5 min. The duration of each measurement may, however, be reduced if the level is found to be constant or repeatable, or if the noise from the task is considered to be a minor contributor to the total noise exposure, see Figure 2, Task 1.

If the noise during the task is cyclic, each measurement shall cover the duration of at least three well-defined cycles. If the duration of three cycles is shorter than 5 min, each measurement shall be at least 5 min. The duration of each measurement shall always correspond to the duration of a number of full cycles, see Figure 2, Task 2.

If the noise is randomly fluctuating during a task, the duration of each measurement shall be long enough to ensure that the measured $L_{p,\text{A},\text{eq}T,m}$ is representative of the whole of the task, see Figure 2, Task 3.

For each task, at least three measurements shall be made. To cover the real variation in noise level, it is recommended to measure at different times during the task or on different workers within a group.



Key

L	noise level as a function of time	t	time
T_1	duration of task 1	t_1	duration of measurement 1: nearly constant noise
T_2	duration of task 2	t_2	duration of measurement 2: cyclic fluctuating noise
T_3	duration of task 3	t_3	duration of measurement 3: randomly fluctuating noise

Figure 2 — An example of three periods with different noise situations and actual duration of each measurement

If the results of the three measurements of a task differ by 3 dB or more:

a) perform three or more additional measurements of the task; or

b) subdivide the task into further tasks, and repeat 9.2 and 9.3; or

c) repeat this subclause with a longer duration of each measurement.

NOTE Additional measurements do not reduce the range of measured values but can reduce the partial uncertainty.

Calculate the A-weighted equivalent continuous sound pressure level for task m from I separate measurements, $L_{p,\text{A,eq}T,mi}$, as follows:

$$L_{p,\text{A,eq}T,m} = 10 \lg \left(\frac{1}{I} \sum_{i=1}^{I} 10^{0,1 \times L_{p,\text{A,eq},T,mi}} \right) \text{dB} \tag{7}$$

where

$L_{p,\text{A,eq}T,mi}$ is the A-weighted equivalent continuous sound pressure level during a task of duration T_m;

i is the number of task sample m;

I is the total number of task samples m.

Calculate the uncertainty in accordance with Clause C.2.

9.4 Calculation of contribution from each task to daily noise exposure level

The calculation specified in this subclause is optional and may be performed if a value for the relative contribution of each task to the daily noise exposure level is required. Otherwise, proceed to 9.5.

The noise contribution from task m to the daily A-weighted noise exposure level, $L_{\text{EX,8h},m}$, can be calculated from:

$$L_{\text{EX,8h},m} = L_{p,\text{A,eq}T,m} + 10 \lg \left(\frac{\overline{T}_m}{T_0} \right) \text{dB} \tag{8}$$

where

$L_{p,\text{A,eq}T,m}$ is the A-weighted equivalent continuous sound pressure level for task m as given by Equation (7);

$\overline{T}_m$ is the arithmetic average duration of task m as given by Equation (5);

T_0 is the reference duration, $T_0 = 8$ h.

9.5 Determination of daily noise exposure level

Calculate the daily A-weighted noise exposure level, $L_{\text{EX,8h}}$, from Equation (9) or from Equation (10).

Equation (9) allows the calculation of daily A-weighted noise exposure level from the $L_{p,\text{A,eq}T,m}$ and the duration of each of the tasks. It uses the level calculated from Equation (7) and the duration in accordance with 9.2.

$$L_{\text{EX,8h}} = 10 \lg \left(\sum_{m=1}^{M} \frac{\overline{T}_m}{T_0} 10^{0,1 \times L_{p,\text{A,eq}T,m}} \right) \text{dB} \qquad (9)$$

where

$L_{p,\text{A,eq}T,m}$ is the A-weighted equivalent continuous sound pressure level for task m as given by Equation (7);

$\overline{T}_m$ is the arithmetic average duration of task m as given by Equation (5);

T_0 is the reference duration, $T_0 = 8$ h;

m is the task number;

M is the total number of tasks m contributing to the daily noise exposure level.

Equation (10) allows the calculation of the A-weighted noise exposure level from the noise contribution of each of the tasks. It may be used if the relative contribution from each task m has been calculated in accordance with 9.4 using Equation (8):

$$L_{\text{EX,8h}} = 10 \lg \left(\sum_{m=1}^{M} 10^{0,1 \times L_{\text{EX,8h},m}} \right) \text{dB} \qquad (10)$$

where

$L_{\text{EX,8h},m}$ is the A-weighted noise exposure level of task m contributing to the daily noise exposure level;

m is the task number;

M is the total number of tasks contributing to the daily noise exposure level.

10 Strategy 2 — Job-based measurement

10.1 General

The principle of this measurement strategy is that random samples of noise exposure are taken by measuring $L_{p,\text{A,eq}T}$ during the performance of jobs identified during the work analysis.

10.2 Measurement plan — Number, duration and distribution of measurements

The measurement plan shall be established as follows. From the jobs identified, homogeneous noise exposure groups shall be established (see also 7.2). For each homogeneous noise exposure group:

a) determine from Table 1 the minimum cumulative duration of measurement for the number of workers, n_G, of the homogeneous exposure group;

b) select a sample duration and number of samples, at least five, such that the cumulative duration meets or exceeds the minimum duration determined in the step above;

c) plan to take samples which are distributed randomly among the members of the group and across the duration of the working day.

NOTE Results of the work analysis, professional judgement, and practicability may guide the choice of a few samples to ensure that specific noise events are included. Increasing the number of samples reduces the uncertainty.

Table 1 — Specifications for the total minimum duration of measurement to be applied to a homogenous exposure group of size n_G

Number of workers in the homogenous exposure group n_G	Minimum cumulative duration of measurement to be distributed over the homogenous exposure group
$n_G \leqslant 5$	5 h
$5 < n_G \leqslant 15$	5 h + (n_G − 5) × 0,5 h
$15 < n_G \leqslant 40$	10 h + (n_G − 15) × 0,25 h
$n_G > 40$	17 h or split the group

EXAMPLE A measurement plan was to be made for a homogeneous exposure group of six workers. The measurement plan was as follows:

1) the minimum cumulative measurement duration of samples was determined to be 5,5 h (in accordance with Table 1);
2) the number of samples was chosen to be 10, which resulted in a duration of 33 min each;
3) three workers were randomly chosen among the six workers;
4) the first sample was chosen to start right at the beginning of the working day and the last one to include the end of the working day because work analysis had shown that these periods have a significant contribution to noise exposure;
5) the eight other samples were spread randomly over the rest of the working day.

10.3 Measurements

Measurements shall be carried out in accordance with Clause 12.

10.4 Determination of daily noise exposure levels for workers in a homogenous exposure group

Calculate the A-weighted equivalent continuous sound pressure level, $L_{p,\mathrm{A,eq}T_\mathrm{e}}$, for the effective duration of the working day, T_e, from Equation (11):

$$L_{p,\mathrm{A,eq}T_\mathrm{e}} = 10\ \mathrm{lg}\left(\frac{1}{N}\sum_{n=1}^{N}10^{0,1\times L_{p,\mathrm{A,eq}T,n}}\right)\ \mathrm{dB} \qquad (11)$$

where

$L_{p,\mathrm{A,eq}T,n}$ is the A-weighted equivalent continuous sound pressure level of sample n;

n is the job sample number;

N is the total number of job samples.

Calculate the daily A-weighted noise exposure level, $L_{\mathrm{EX,8h}}$, of the workers in a given homogenous exposure group from Equation (12):

$$L_{\mathrm{EX,8h}} = L_{p,\mathrm{A,eq}T_\mathrm{e}} + 10\ \mathrm{lg}\left(\frac{T_\mathrm{e}}{T_0}\right)\ \mathrm{dB} \qquad (12)$$

where

$L_{p,\text{A,eq}T_\text{e}}$ is the A-weighted equivalent continuous sound pressure level for the effective duration of the working day;

T_e is the effective duration of the working day;

T_0 is the reference duration, $T_0 = 8$ h.

Calculate the uncertainty in accordance with Clause C.3.

If the uncertainty contribution $c_1 u_1$ due to sampling (as obtained from Table C.4) is greater than 3,5 dB, modifications to the homogeneous exposure group should be made or the number of measurements should be increased to reduce the uncertainty.

11 Strategy 3 — Full-day measurement

11.1 General

Full-day measurement shall cover all work-related noise contributions and quiet periods during the working day. It is practical to perform these long-duration measurements by using personal sound exposure meters or similar instrumentation.

When using this measurement strategy, it shall be ensured that the chosen days are representative for what is defined as the relevant work situation.

For practical reasons, it may not be possible to measure over the entire working day. In these cases, measurements should be made over as large a part of the day as possible, covering all significant periods of noise exposure.

NOTE Since this measurement strategy collects all contributions, it also has the highest risk of including false contributions (see Clause 13). This risk can be reduced by carefully observing the worker during measurements, by taking spot measurements and/or by asking the worker at the end of the shift about the tasks he/she performed or the locations he/she worked at.

11.2 Observing work activities and monitoring measurements

Workers should be observed during the measurements. If this is not possible, the validity of the measurements should be checked by one or more of the following actions:

a) interviewing supervisors and workers;

b) taking spot measurements to verify the levels measured using personal sound exposure meters;

c) assessing the exposure of selected workers using the task-based measurements as specified in Clause 9;

d) an examination, by the worker and the measurement technician, of the personal sound exposure meter log (time history) at the end of the shift, in order to identify the different tasks and events. For this reason, the use of logging personal sound exposure meters is highly recommended.

11.3 Measurements

Measurements shall be carried out in accordance with Clause 12. Initially, three full-day measurements of $L_{p,\text{A,eq}T}$ representing the sound exposure of the workers shall be taken.

If the results of the three measurements differ by less than 3 dB, calculate the A-weighted equivalent continuous sound pressure level during the nominal day as the energy average of the three measurements. For calculation, see Equation (11).

If the results of the three measurements differ by 3 dB or more, take at least two additional full-day measurements, and calculate the A-weighted equivalent continuous sound pressure level during the nominal day as the energy average of all measurements.

11.4 Determination of daily noise exposure level

Calculate the daily A-weighted noise exposure level, $L_{\text{EX,8h}}$, from Equation (13):

$$L_{\text{EX,8h}} = L_{p,\text{A,eq}T_\text{e}} + 10\,\lg\left(\frac{T_\text{e}}{T_0}\right)\ \text{dB} \tag{13}$$

where

$L_{p,\text{A,eq}T_\text{e}}$ is the A-weighted equivalent continuous sound pressure level derived in accordance with 11.3;

T_e is the effective duration of the working day;

T_0 is the reference duration, $T_0 = 8$ h.

Calculate the uncertainty in accordance with Clause C.4.

12 Measurements

12.1 Selection of instrumentation

Measurements shall be performed using the following types of instrumentation (see also 5.1):

a) personal sound exposure meter worn by the worker whose noise exposure is being determined;

b) integrating-averaging sound level meter placed in discrete positions, or held in the hand whilst following a mobile worker.

Personal sound exposure meters may be used for measurements in all types of work situations. It is the preferred method when making long duration measurements for a mobile worker engaged in complex or unpredictable tasks or carrying out a large number of discrete tasks.

For measurements of single or multiple tasks at fixed workstations, hand-held or fixed sound level meters may be used.

12.2 Field calibration

Field calibration includes an acoustic calibration check of the entire measuring system, including the microphone, and is a distinct survey procedure separate from laboratory calibration. A field calibration shall consist of applying a sound calibrator meeting the requirements of IEC 60942:2003, class 1, to each microphone and recording the measured level at one or more frequencies within the frequency range of interest. Field calibration shall be carried out in a quiet location.

Before each series of measurements and at the start of each daily series of measurements, a field calibration with appropriate adjustment shall be performed. At the end of each series of measurements and at the end of each daily series of measurements, a field calibration without adjustment shall be performed. If the reading at any frequency at the end of a series of measurements differs from the reading of that frequency at the beginning of the series by more than 0,5 dB, the results of the series of measurements shall be discarded.

12.3 Instrument worn by the worker

The microphone shall be mounted on the top of the shoulder at a distance of at least 0,1 m from the entrance of the external ear canal at the side of the most exposed ear and should be approximately 0,04 m above the shoulder. The microphone and the cable shall be fastened in such a way that mechanical influence or covering by clothing do not lead to false results.

Care shall be taken not to disturb the work performance and especially not to introduce safety risks. Similarly, care shall be taken to avoid false contributions. See also 13.2.

NOTE 1 When using measuring instruments worn by the worker or in other cases when the microphone is placed very close to a worker's body, the measurement result is affected by screening effects and reflections by the body. This is especially valid for high-frequency noise and small noise sources at a short distance from the ear. In such cases, the measurements should be performed with microphones placed at both sides of the head in order to establish the exposure of the most exposed ear.

NOTE 2 The advantage of using personal sound exposure meters is that the workers being monitored do not have to be followed closely and several workers can be tested simultaneously.

The worker being monitored shall be informed of the purpose of the measurement. Workers shall be advised not to remove the measuring instrument during the entire measurement period and to perform their work normally.

The personal sound exposure meter shall be reset and started according to the manufacturer's instructions. This shall be done after the calibration has been performed, the measuring instrument has been attached and the microphone has been installed in place to ensure that no extraneous noises are introduced while fitting the personal sound exposure meter. The starting time of the measurement shall be noted. When the measurements are finished, the instrumentation shall be stopped according to the manufacturer's instructions before the removal of instrumentation and microphone. The time when the measurement was stopped shall be noted.

Any high peak sound levels recorded by the instrument which were not validated by observation shall be investigated and commented on in the report.

12.4 Integrating-averaging sound level meter

The measured levels shall be representative of the noise level at the worker's ear. If the sound field is uniform, precise measurement position is less critical.

Measurements should be made with the microphone positioned at the locations of the worker's head during normal performance of the job or task. Preferably, the microphone shall be placed at the centre plane of the worker's head, on a line with the eyes, with its axis parallel to the worker's vision, and without the worker present. Various relevant space positions of the worker's head shall be taken into account. The average sound pressure level at the workstation may also be found by moving the sound level meter around (by sweeping) in the area of interest. The sweep may be performed by moving the microphone at constant speed along a path shaped like the infinity sign: ∞.

In cases where the worker has to be present at his/her workstation, the microphone shall be placed or held at a distance between 0,1 m and 0,4 m from the entrance of the external ear canal and at the side of the most exposed ear.

If the worker's activity or the workstation configuration makes it impossible to keep the distance within 0,4 m, the use of an instrument worn by the worker is recommended.

If the worker's location is very close to the noise sources, the sound field should be carefully investigated and the microphone position and direction chosen shall be precisely stated in the test report.

If the head position at a workstation is not well defined, the following microphone heights may be used (see ISO 11200 [2], ISO 11201 [3], ISO 11202 [4], ISO 11203 [5] and ISO 11205 [6]):

a) Standing worker: 1,55 m ± 0,075 m above the ground on which the worker is standing;

b) Seated worker: 0,80 m ± 0,05 m above the middle of the seat plane with the seat set at or as near as possible to the midpoint of its horizontal and vertical adjustment.

Even if the worker is working at a fixed workstation, measurements with a fixed microphone position can give an over- or underestimation of the real exposure in cases where the worker moves about the machine. In these cases, a personal sound exposure meter should be used.

Close to the sound source, even small changes of the microphone position can result in significant variations of the sound pressure level. If tones are clearly audible at the workstation, standing sound waves can occur. To determine the local variation of the sound pressure level, the microphone should be moved through the relevant area of occupation close to the source. The variations of the sound pressure level observed during the movement of the microphone are treated as time-varying levels and averaged accordingly. If a scan is used for investigating the variations in an area, the noise level as a function of time, $L(t)$, should be measured with a suitable time resolution. Noise data for the uncertainty evaluations can then be obtained by splitting the whole measurement into three or preferably six periods with the same duration, and using the level for each of these in the calculations. Supplementary measurements with an instrument fixed to the worker in accordance with 12.3 reduce the uncertainty associated with the noise exposure from this source.

Special measurement procedures are required for the measurement of noise exposure underneath earphones (e.g. for secretaries, telephonists, pilots, air traffic controllers) or underneath helmets (e.g. pilot and motorcycle helmets). For noise sources close to the ear, measurements in the ear canal may be performed in accordance with ISO 11904-1 [7] or ISO 11904-2 [8].

13 Sources of uncertainty

13.1 General

Some sources of uncertainty need specific consideration in order to reduce their influence as far as possible. Uncertainties can be caused both by errors and by natural variation in the work situation.

The main sources of uncertainty in the result are:

a) variations in the daily work, operating conditions, uncertainty in sampling, etc.;

b) instrumentation and calibration;

c) microphone position;

d) false contributions, for instance from wind, airflows or impact on the microphone and the microphone rubbing on clothing;

e) lacking or faulty work analysis;

f) contributions from non-typical noise sources, speech, music (radio), alarm signals and non-typical behaviour.

Item a) depends on the complexity of the work situation. These variations are expected to be the highest for a mobile worker among non-constant noise sources. Item b) depends on where the microphone is fixed and what class of instrumentation and calibrator is used. Items c), d), and e) should be reduced by good practice as specified in this International Standard. Regarding item f), such possible sources of uncertainty shall be identified during work analysis and it shall be decided whether they are to be included or not.

The relevant noise contributions shall be identified during the work analysis and the measurements. If significant contribution from sources of error is detected, the measurements shall be rejected or corrected.

The measured noise exposure level and the associated uncertainty in the result depend on the measurement method used. A personal sound exposure meter can include contributions from speech, radios, etc. which can increase the measured noise exposure level. The use of a hand-held sound level meter ensures that such sources are excluded, e.g. by pausing the measurement. Measurements at fixed positions can lead to an underestimation of the worker's noise exposure due to the difficulty in handling noise contributions from sound sources close to the ear, such as hand-held tools.

13.2 Mechanical impacts on microphone

Errors due to mechanical impacts on the microphone shall be avoided by ensuring that the microphone or the windscreen is not being touched or hit by anything. This effect can be more difficult to observe when using a personal sound exposure meter. Many measuring instruments record high sound pressure levels if the microphone and/or the connecting devices are touched, rubbed or otherwise come into contact with other objects.

The measurements shall be checked for such uncertainty by comparing the detailed measurement result (log) where available, with observations during the measurements (e.g. notes in a handwritten log). If unexplained peak levels occur, the influence on the result shall be investigated, and the measurement shall be repeated if the result is significantly affected. In cases where non-logging instruments are used and unexplained high peak levels occur in the final result, the measurement shall be repeated.

13.3 Wind and airflows

Measurements in airflows with high flow velocity, e.g. wind, shall be avoided. If this is not possible, care shall be taken to minimize the flow-induced noise. If possible, the contribution of flow noise should be investigated by measurements made in similar work situations without airflows. If not, the airflow-induced noise can be assessed by measuring in places without the occupational noise but with similar flow.

Airflow-induced noise shall be reduced by using a windscreen on the microphone. For personal sound exposure meters, the size of the windscreen is usually limited. By using a hand-held sound level meter with a larger windscreen, the potential effect of airflow-induced noise can be controlled.

Hand-held sound level meters should be equipped with windscreens of a minimum 60 mm diameter to reduce the effect of airflow or wind.

NOTE Contributions from wind and airflows depend on the wind speed and the size of the windscreen. A-weighted sound pressure levels around 80 dB are usually not significantly influenced by airflow speeds up to 10 m/s, provided the windscreen is of 60 mm diameter or more.

13.4 Relevance of sound contributions

Care shall be taken in defining the sounds that are relevant for the noise exposure. Noise from sources such as radios, speech, and alarm signals shall be considered as relevant if work analysis has shown that they are part of the normal work condition. However, if the person who carries out the measurement has good reasons for considering such a contribution as being irrelevant, he/she may exclude it from the measured data, provided that this is reported.

If non-typical behaviour is observed at the workplace during measurements, an evaluation of possible influences on the measurement result shall be done. If the influence is regarded as significant, new measurements shall be performed.

14 Calculation of measurement uncertainties and presentation of the final results

The uncertainties associated with measuring occupational noise exposure shall be determined in accordance with Annex C.

The final result shall be given as both the measured value and the value of the uncertainty.

The expanded measurement uncertainty, together with the corresponding coverage factor, shall be stated for a one-sided confidence interval of 95 %.

15 Information to be reported

The report of noise exposure measurements carried out in accordance with this International Standard shall provide the following information:

a) general information:

   1) name of the client (company, department, etc.) of the investigation,

   2) identification of the worker(s) or group(s) of workers (such as name or worker number) whose exposure has been determined,

   3) name of the person(s) and company or institution who carried out measurements and calculations,

   4) purpose of the determination,

   5) reference to this International Standard and the strategy that has been applied;

b) work analysis:

   1) description of the work activities investigated,

   2) size and composition of homogeneous noise exposure groups, where relevant,

   3) description of the day(s) investigated, including the tasks comprising the nominal day when the task-based measurements have been made,

   4) measurement strategy/strategies employed, together with a reference to the statistical approach used;

c) instrumentation:

   1) identification and class of instrumentation used (manufacturer, model, serial number),

   2) configuration of the system, e.g. windscreen, extension cable, etc.,

   3) calibration traceability (date and result of the most recent verification of the components of the measuring system),

   4) documentation of calibration checks performed before and after each measurement;

d) measurements:

   1) identification of worker(s) whose noise exposure was measured,

   2) date and time of measurements,

   3) instrumentation used for each measurement (if various instruments are used),

   4) description of work undertaken by the worker during the course of the measurements, including duration of work activity and, if relevant, duration of cyclic events contained within the work activity,

5) report of any deviations from the normal work conditions or normal work behaviour during the course of the measurements,

6) production indicators related to the work being undertaken, where relevant,

7) description of the sources of noise contributing to the noise exposure,

8) description of any irrelevant sounds included in or deleted from the measured results,

9) description of any events observed which may have influenced the measurements (e.g. airflows, impacts on the microphone, impulsive noise),

10) relevant information on meteorological conditions (e.g. wind, rain, temperature),

11) position and orientation of microphone(s),

12) number of measurements at each position,

13) duration of each measurement,

14) duration of each task in the nominal day, and the associated uncertainty, when using the task-based approach,

15) results of each measurement, to include at least the $L_{p,\mathrm{A,eq}T}$ and, optionally, the highest $L_{p,\mathrm{Cpeak}}$ values;

e) results and conclusions:

1) A-weighted equivalent continuous sound pressure level $L_{p,\mathrm{A,eq}T}$ and, optionally, C-weighted peak sound pressure level $L_{p,\mathrm{Cpeak}}$ for each task/job,

2) when using the task-based measurement, the values of $L_{\mathrm{EX,8h},m}$ for each task, if relevant,

3) A-weighted noise exposure level $L_{\mathrm{EX,8h}}$ for the nominal day(s), and the highest C-weighted peak sound pressure level $L_{p,\mathrm{Cpeak}}$ if measured during all tasks, rounded to one decimal place,

4) uncertainty associated with $L_{\mathrm{EX,8h}}$ and $L_{p,\mathrm{Cpeak}}$, if available, for the nominal day(s), rounded to one decimal place (noise exposure and the measurement uncertainty shall be reported as separate values).

Annex A
(informative)

Example of a checklist to ensure that significant noise events are detected during the work analysis

	Yes	No
Are any of these situations encountered?		
• use of compressed air jets	❒	❒
• compressed air releases	❒	❒
• hammering	❒	❒
• intense impacts	❒	❒
• occasional use of very noisy machines and tools	❒	❒
• noisy vehicles passing by	❒	❒
Are there very noisy operations during particular phases?		
• at the beginning of shift	❒	❒
• at the end of shift	❒	❒
• during adjustment, supply phases	❒	❒
• during start-up and shut-down activities or production	❒	❒
• during cleaning phases	❒	❒
• other	❒	❒
Are there very noisy activities at neighbouring workstations?	❒	❒
• type: ____		
• exposed workstations: ______________________________		

See also 7.3.

Annex B
(informative)

Guide to the selection of measurement strategy

B.1 General

This annex provides details of basic measurement strategies and guidance on selecting the one most appropriate (see Clause 8).

B.2 Strategy 1 — Task-based measurement

This strategy focuses on the tasks producing significant noise exposure and on minimizing the measurement duration required for a specified uncertainty. Task-based measurement is most useful when the work can be split into well-defined tasks with clearly definable noise conditions during which measurements can be made. Care should, however, be taken to ensure that all relevant noise contributions are included in the measurement period, which requires knowledge of any short-duration high-exposure acoustical events during the working day.

The strategy is based on a detailed work analysis in order to understand all tasks. Further, it requires a continuous validation of the measurements. This allows a smaller number of measurements to be made of the tasks producing little variation in noise level.

Task-based measurements provide information on the contributions from the different tasks to the daily noise exposure. This is advantageous if the purpose of the measurements is to determine priorities for a noise control programme. It also opens the possibility of calculating the noise exposure for working days different from the measurement day as regards the distribution and durations of tasks. It can reduce the measurement effort compared to the other methods.

The use of this strategy gives significant time savings of measurement when large groups of workers are doing similar activities in similar acoustical environments. The measurements can also be more easily controlled.

If the work situation is complex, the work analysis can be time-consuming.

B.3 Strategy 2 — Job-based measurement

Job-based measurements are most useful when typical work patterns and tasks are hard to describe or when it is not desirable or practical to perform a detailed work analysis. It is not recommended to use this method if a job consists of a small number of very noisy tasks.

Job-based measurements can result in a reduced effort required for work analysis. Care should be taken in defining the jobs to ensure that the noise exposure of any worker within a given job is representative. This strategy can be time-consuming due to the time required for the measurements, but produces a smaller uncertainty in the result obtained.

As with task-based measurement, care should be taken to ensure that major noise contributions are included in the measuring period. Job-based measurements do not necessarily provide any information on the relative contribution of different tasks within a job to the daily noise exposure, since they do not take into account tasks being carried out within the defined job.

If the work situation is simple, this strategy can require a longer measurement duration than the task-based strategy.

B.4 Differences and similarities between task-based and job-based measurement

B.4.1 General. These two strategies are not mutually exclusive. Task-based and job-based measurements are both based on sampling of noise levels. A given work situation can, in many cases, be handled using one strategy or the other with the same quality of result.

The main differences between these strategies are described in B.4.2 to B.4.4.

B.4.2 Different homogeneous noise exposure groups. For job-based measurements, the homogeneous noise exposure groups can have a different content than for task-based measurements. As a job is a group of tasks performed by one worker, job-based measurement does not require a detailed breaking down of the work activity into tasks. Establishing homogeneous noise exposure groups is therefore less time-consuming than in the case of task-based measurements. Task-based measurements also require a better knowledge of the work situation than the other strategies, so that all tasks that contribute to the noise level are clarified along with their respective durations.

B.4.3 Different measurement plans. For job-based measurements, the measurement plan is normally easier to implement than for task-based measurements because there is no need to isolate each task that has to be measured during the working day.

B.4.4 Different durations of measurements. Job-based measurement requires longer measurement periods than task-based measurement.

B.5 Strategy 3 — Full-day measurement

Full-day measurement is, like job-based measurement, most useful when typical work patterns and tasks are hard to describe. However, it requires even less effort in analysing the work. On the other hand, if the work situation is simple, this strategy can require a longer measurement duration than any of the others.

Full-day measurement is recommended when the noise exposure pattern of workers is unknown, unpredictable or complex. It is also possible to use this strategy for any pattern of noise exposure, especially where it is not necessary or desirable to perform a detailed work analysis.

Full-day measurement can also be useful to verify that all the major contributions are included. For such checking purposes, the daily noise exposure level can be determined directly without any additional calculations.

By using a logging instrument, information about the fluctuations in noise level during the working day can be obtained, and it may be possible to determine the contributions from different tasks. It also gives the possibility to remove irrelevant sound contributions from the measurement results. Use of a logging instrument is therefore highly recommended when performing full-day measurements.

Measurements of long duration are most likely to be performed with a personal sound exposure meter or similar instrumentation that is worn by the worker whose noise exposure is being measured. In these cases, there is a high likelihood that measurements contain some artefacts that are not related to the typical noise exposure of the worker, e.g. impacts on the microphone (accidental or deliberate), or deliberate interference, such as shouting by work colleagues or attempts to work in a deliberately noisy manner. For these reasons, it is highly recommended that the measurements be directly observed by the measurement technician, or that some other equally effective means of identifying and accounting for these artefacts be used. Measurements that are unobserved are highly prone to such measurement artefacts, in which case the best approach may be to perform measurements over a number of days in order for the "novelty" of the measurement process to diminish.

B.6 Using more than one measurement strategy

There are occasions when it is necessary or desirable to use more than one measurement strategy. For instance, if the nominal day tends to be complex, the calculated noise exposure from task-based measurements can be checked by performing full-day measurements of selected workers.

There can be situations during full-day or task-based measurements where some tasks are not performed, although they are a part of the nominal day. In those cases, additional measurements of those tasks are necessary.

As a further example, some workers may work in different patterns during a day. This may require the use of job-based measurement for work in the morning, and task-based measurement for work in the afternoon.

B.7 Selection of measurement strategy for different work patterns

Table B.1 provides guidance to the selection of the basic measurement strategy depending on the work pattern.

Table B.1 — Selection of basic measurement strategy

Type or pattern of work	Measurement strategy		
	Strategy 1 Task-based measurement	**Strategy 2 Job-based measurement**	**Strategy 3 Full-day measurement**
Fixed workstation — Simple or single task	✓*	—	—
Fixed workstation — Complex or multiple tasks	✓*	✓	✓
Mobile worker — Predictable pattern — Small number of tasks	✓*	✓	✓
Mobile worker — Predictable work — Large number of tasks or complex work pattern	✓	✓	✓*
Mobile worker — Unpredictable work pattern	—	✓	✓*
Fixed or mobile worker — Multiple tasks with unspecified duration of tasks	—	✓*	✓
Fixed or mobile worker — No tasks assigned	—	✓*	✓
✓ Strategy can be used.			
* Recommended strategy.			

Annex C
(normative)

Evaluation of measurement uncertainties

C.1 General

This annex specifies the procedure for determining the expanded uncertainty of the A-weighted noise exposure level normalized to an 8 h working day, $L_{EX,8h}$ or, alternatively, of the measured value of the A-weighted equivalent continuous sound pressure level, $L_{p,A,eqT}$.

The procedure is in compliance with ISO/IEC Guide 98-3. The uncertainties can be calculated by using the spreadsheet provided with this International Standard.

Strict fulfilment of the requirements of this International Standard, in particular those relating to the avoidance of faulty contributions to the measured noise exposure level (see Clause 13), ensures that no systematic errors due to such faulty contributions are present in the final result.

Sources of uncertainty considered in this annex are indicated in Table C.1.

The uncertainty due to the selection of measurement day(s) is not included in Table C.1, as in many cases this can only be determined by extensive measurements over longer periods. However, strict fulfilment of the requirements of this International Standard, in particular regarding work analysis, keeps this uncertainty under control.

Table C.1 — Sources of uncertainty considered in determining the expanded uncertainty of A-weighted equivalent continuous sound pressure levels or noise exposure levels normalized to an 8 h working day

Source of uncertainty	Application	Subscript [a]	Clause
Sampling of task noise levels	Task-based measurement	1a	C.2
Estimation of task durations	Task-based measurement	1b	C.2
Sampling of job noise levels	Job-based measurement	1	C.3
Instrumentation	All strategies	2	C.5
Microphone location	All strategies	3	C.6

NOTE Table C.1 covers uncertainties listed against items a), b), and c) in 13.1. When the measurements are performed in accordance with this International Standard, it is assumed that the uncertainty due to errors listed in 13.1 d), e), and f) is reduced to be insignificant and/or included in the noise level sampling.

[a] Used in symbols for partial uncertainties and sensitivity coefficients.

In cases where there is evidence that a source of uncertainty not considered in this annex is playing a major role, its contribution can be included in the calculation of the combined standard uncertainty by adding lines to Table C.2 or Table C.3.

NOTE 1 The uncertainty for C-weighted peak sound pressure levels cannot be given due to insufficient background data. In most cases, the uncertainty for the peak sound pressure level can be expected to be greater than the uncertainty for the A-weighted equivalent continuous sound pressure level.

The contributions to the combined standard uncertainty, u, associated with the value of the noise exposure level depends on the standard uncertainty, u_i, of each input quantity and the related sensitivity coefficients, c_i.

The sensitivity coefficients are measures of how the noise exposure level is affected by changes in the values of the respective input quantities. Mathematically, they are equal to the partial derivatives of the functional relationship [see Equations (C.2) or (C.8) and ISO/IEC Guide 98-3] with respect to the relevant input quantity. The contributions of the respective input quantities are given by the products of the standard uncertainties and their associated sensitivity coefficients. The combined standard uncertainty, u, is obtained from the individual uncertainty contributions, $c_i u_i$, using Equation (C.1)

$$u^2 = \sum c_i^2 u_i^2 \quad \text{(C.1)}$$

The expanded uncertainty, U, is given by $U = ku$, where k is a coverage factor that is a function of the confidence interval. For the purpose of this International Standard, one-sided confidence interval of 95 % is considered, which results in $k = 1{,}65$. This means that 95 % of the values are below the upper limit, $[L_{\text{EX,8h}} + U]$.

This International Standard allows the use of statistical approaches for calculating the uncertainty other than the methods specified in this annex, e.g. methods based on scientific assessment (expert knowledge about uncertainties) or Monte Carlo simulations. If such methods are used, they shall be in full compliance with ISO/IEC Guide 98-3. It shall also be demonstrated that they do not underestimate the uncertainty. The method used shall be indicated in the test report.

NOTE 2 An explanation of the statistical background of the methods given in this annex is given in Reference [14].

C.2 Determination of the expanded uncertainty for task-based measurement

C.2.1 Functional relationship for task-based measurement

The general expression for the determination of the A-weighted noise exposure level, $L_{\text{EX,8h}}$, using task-based measurement is:

$$L_{\text{EX,8h}} = 10 \lg \left[\sum_{m=1}^{M} \frac{\overline{T}_m}{T_0} 10^{0{,}1 \times L^*_{p,\text{A,eq}T,m}} \right] \text{dB} \quad \text{(C.2)}$$

where

$\overline{T}_m$ is the arithmetic average duration of task m;

T_0 is the reference duration, $T_0 = 8$ h;

m is the task number;

M is the total number of tasks;

$L^*_{p,\text{A,eq}T,m}$ is the estimate of the true A-weighted equivalent continuous sound pressure level for task m, $L_{p,\text{A,eq}T,m}$ [see Equation (7)];

$$L^*_{p,\text{A,eq}T,m} = L_{p,\text{A,eq}T,m} + Q_2 + Q_3$$

in which

Q_2 is the correction for the measuring instrumentation used for the determination of the A-weighted continuous sound pressure level,

Q_3 is the correction for the microphone position used for the determination of the A-weighted equivalent continuous sound pressure level.

NOTE As the estimates of both Q_2 and Q_3 are approximately 0, $L^*_{p,\text{A,eq}T,m} \approx L_{p,\text{A,eq}T,m}$. Under these conditions, Equation (C.2) is identical to Equation (9).

C.2.2 Calculation of the combined standard uncertainty, u, and the expanded uncertainty, U

Considering that quantities involved are not correlated, the combined standard uncertainty for the A-weighted noise exposure level $L_{\text{EX,8h}}$, $u\left(L_{\text{EX,8h}}\right)$ shall, in accordance with ISO/IEC Guide 98-3, be calculated from the numerical values of uncertainty contributions, $c_j u_j$, as follows:

$$u^2(L_{\text{EX,8h}}) = \left(\sum_{m=1}^{M} \left[c_{1\text{a},m}^2 \left(u_{1\text{a},m}^2 + u_{2,m}^2 + u_3^2 \right) + \left(c_{1\text{b},m} u_{1\text{b},m} \right)^2 \right] \right) \quad \text{(C.3)}$$

where

$u_{1\text{a},m}$	is the standard uncertainty due to noise level sampling of task m, see C.2.3;
$u_{1\text{b},m}$	is the standard uncertainty due to the estimation of duration of task m, see C.2.3;
$u_{2,m}$	is the standard uncertainty due to the instrumentation used for task m;
u_3	is the standard uncertainty due to microphone position;
$c_{1\text{a},m}$ and $c_{1\text{b},m}$	are the corresponding sensitivity coefficients for task m;
m	is the task number;
M	is the total number of tasks.

The expanded uncertainty is $U = 1{,}65 \times u$.

NOTE 1 Due to the linear relation between the measured noise level and the estimate for the noise level, the sensitivity coefficients for instrumentation, $c_{2,m}$, microphone location, $c_{3,m}$, and noise level sampling, $c_{1\text{a},m}$, have the same values, i.e. $c_{2,m} = c_{3,m} = c_{1\text{a},m}$. The coefficients $c_{2,m}$ and $c_{3,m}$ are therefore replaced by $c_{1\text{a},m}$ in Equation (C.3).

NOTE 2 Equation (C.3) is strictly valid for the case where M A-weighted equivalent continuous sound pressure levels are determined using different instrumentation for each measurement. Nevertheless, since the main uncertainty contributions of instrumentation, such as influences of level linearity, frequency response of the microphone, angle of sound incidence and spectral weighting, are different in different sound field positions for the same instrumentation, it is assumed that Equation (C.3) is appropriate.

The corresponding uncertainty budget is shown in Table C.2.

Table C.2 — Uncertainty budget for determining noise exposure levels for task-based measurement

Quantity	Estimate	Standard uncertainty u_i	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $c_i u_i$ dB
$L_{p,\text{A,eq}T,m}$	Energy average of measured $L_{p,\text{A,eq}T,m}$ for task m	$u_{1\text{a},m}$ for each task, to be determined using Eq. (C.6)	Normal	$c_{1\text{a},m}$ for each task, to be determined using Eq. (C.4)	$c_{1\text{a},m}u_{1\text{a},m}$ 1 value per task
T_m	Estimated value of duration T_m for task m	$u_{1\text{b},m}$ for each task, to be determined using Eq. (C.7)	Normal	$c_{1\text{b},m}$ for each task, to be determined using Eq. (C.5)	$c_{1\text{b},m}u_{1\text{b},m}$ 1 value per task
Q_2	0	$u_{2,m}$ as given by Table C.5	Normal	$c_{2,m} = c_{1\text{a},m}$	$c_{1\text{a},m}u_{2,m}$
Q_3 [a]	0	u_3 as given in C.6	Normal	$c_{3,m} = c_{1\text{a},m}$	$c_{1\text{a},m}u_3$

[a] It is expected that Q_3 will be in the range from −1,0 dB to 0,5 dB. For simplicity, the arithmetic average estimate of Q_3 is taken equal to zero. The standard uncertainty related to microphone positions, u_3, is assumed to cover this extra uncertainty.

C.2.3 Contributions to measurement uncertainty and the uncertainty budget

For task-based measurement, the sensitivity coefficients are as follows:

$$c_{1\text{a},m} = \frac{\partial L_{\text{EX,8h}}}{\partial L^*_{p,\text{A,eq}T,m}} = \frac{T_m}{T_0} 10^{0,1 \times \left(L^*_{p,\text{A,eq}T,m} - L_{\text{EX,8h}}\right)} \tag{C.4}$$

$$c_{1\text{b},m} = \frac{\partial L_{\text{EX,8h}}}{\partial T_m} = 4,34 \times \frac{c_{1\text{a},m}}{T_m} \tag{C.5}$$

The standard uncertainty, $u_{1\text{a},m}$, in noise level due to sampling for task m is given by:

$$u_{1\text{a},m} = \sqrt{\frac{1}{I(I-1)}\left[\sum_{i=1}^{I}\left(L_{p,\text{A,eq}T,mi} - \bar{L}_{p,\text{A,eq}T,m}\right)^2\right]} \tag{C.6}$$

where

$\bar{L}_{p,\text{A,eq}T,m}$ is the arithmetic average of I measured A-weighted equivalent continuous sound pressure levels for task m, i.e. $\bar{L}_{p,\text{A,eq}T,m} = \frac{1}{I}\sum_{i=1}^{I} L_{p,\text{A,eq}T,mi}$;

i is the number of task sample;

I is the total number of task samples.

The standard uncertainty, $u_{1b,m}$, due to duration of task m can be calculated from the measured durations from independent measurements as follows:

$$u_{1b,m} = \sqrt{\frac{1}{J(J-1)}\left[\sum_{j=1}^{J}\left(T_{m,j} - T_m\right)^2\right]} \tag{C.7}$$

where J is the total number of observations of task duration.

NOTE If a time range has come out of the work analysis, an estimate is $u_{1b,m} = 0{,}5 \times (T_{max} - T_{min})$.

C.3 Determination of the expanded uncertainty for job-based measurement

C.3.1 Functional relationship for job-based measurement

The general expression for determination of the daily A-weighted noise exposure level, $L_{EX,8h}$, using job-based measurement is as follows:

$$L_{EX,8h} = 10 \lg \frac{T_e}{T_0}\left[\frac{1}{N}\sum_{n=1}^{N} 10^{0{,}1 \times L^*_{p,A,eqT,n}}\right] \text{dB} \tag{C.8}$$

where

T_e	is the effective duration of the working day;
T_0	is the reference duration, $T_0 = 8$ h;
n	is the number of job sample;
N	is the total number of job samples;
$L^*_{p,A,eqT,n}$	is the estimate of the true A-weighted equivalent continuous sound pressure level for the job sample n, $L_{p,A,eqT,n}$

$$L^*_{p,A,eqT,n} = L_{p,A,eqT,n} + Q_2 + Q_3$$

in which

Q_2	is the correction for the measurement instrumentation used for determination of the A-weighted equivalent continuous sound pressure level,
Q_3	is the correction for the microphone position used for determination of the A-weighted equivalent continuous sound pressure level.

NOTE As the estimates of both Q_2 and Q_3 are approximately 0, $L^*_{p,A,eqT,n} \approx L_{p,A,eqT,n}$. Under these conditions, Equation (C.8) gives the same result as Equations (11) and (12).

C.3.2 Calculation of the combined standard uncertainty, u, and the expanded uncertainty, U

The combined standard uncertainty for the A-weighted noise exposure level $L_{EX,8h}$, $u(L_{EX,8h})$, shall, in accordance with ISO/IEC Guide 98-3, be calculated from the numerical values of all uncertainty contributions, $c_i u_i$, taken from Table C.3 as follows:

$$u^2\left(L_{EX,8h}\right) = c_1^2 u_1^2 + c_2^2(u_2^2 + u_3^2) \tag{C.9}$$

The expanded uncertainty is $U = 1{,}65 \times u$.

NOTE Equation (C.9) is strictly valid for the case where N A-weighted equivalent continuous sound pressure levels are determined using different instrumentation for each measurement. Nevertheless, since the main uncertainty contributions of instrumentation, such as the influences of level linearity, the frequency response of the microphone, the angle of sound incidence and the spectral weighting, are different in different sound field positions for the same instrumentation, it is assumed that Equation (C.9) is appropriate.

C.3.3 Contributions to measurement uncertainty and the uncertainty budget

For job-based measurement:

— The uncertainty contribution, $c_1 u_1$, of job noise level sampling is given in Table C.4 as a function of the number, N, of job noise level samples and the standard uncertainty, u_1, of measured values $L_{p,\text{A,eq}T,n}$;

— The sensitivity coefficients, c_2 and c_3, for the uncertainty due to the instrumentation and that due to imperfect selection of measurement position, respectively, are as follows:

$$c_2 = 1 \tag{C.10}$$

$$c_3 = 1 \tag{C.11}$$

Table C.3 — Uncertainty budget for determination of noise exposure levels for job-based measurement

Quantity	Estimate	Standard uncertainty u_i	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $c_i u_i$ dB
$L_{p,\text{A,eq}T}$	$L_{p,\text{A,eq}T}$ energy average of the measured $L_{p,\text{A,eq}T,n}$	u_1 to be determined using Eq. (C.12)	Normal	c_1	$c_1 u_1$ as given by Table C.4
Q_2	0	u_2 as given by Table C.5	Normal	$c_2 = 1$	u_2
Q_3 [a]	0	u_3 as given in C.6	Normal	$c_3 = 1$	u_3

[a] It is expected that Q_3 will be in the range from −1,0 dB to 0,5 dB. For simplicity, the arithmetic average estimate of Q_3 is taken equal to zero. The standard uncertainty related to microphone positions, u_3, is assumed to cover this extra uncertainty.

The uncertainty contribution, $c_1 u_1$, of job noise level sampling is obtained directly from the energy average of the measured values of the job noise level samples, $L_{p,\text{A,eq}T,n}$, and the standard uncertainty, u_1, of these values using Table C.4.

The standard uncertainty, u_1, is given by Equation (C.12):

$$u_1^2 = \sqrt{\frac{1}{(N-1)}\left[\sum_{n=1}^{N}\left(L_{p,\text{A,eq}T,n} - \overline{L}_{p,\text{A,eq}T}\right)^2\right]} \tag{C.12}$$

where

$L_{p,\text{A,eq}T,n}$ is the A-weighted equivalent continuous sound pressure level for job noise level sample n;

$\overline{L}_{p,\text{A,eq}T}$ is the arithmetic average of N job samples of the A-weighted continuous equivalent sound pressure level, i.e. $\overline{L}_{p,\text{A,eq}T} = \frac{1}{N}\sum_{n=1}^{N} L_{p,\text{A,eq}T,n}$;

N is the total number of job samples.

NOTE Equation (C.12) is used to calculate u_1, the entry value of Table C.4. The resulting u_1 is denoted here as **standard uncertainty** to maintain similar terminology for all u_1 terms, but usually it is denoted **standard deviation**.

Table C.4 — Uncertainty contribution, c_1u_1, of job and full-day noise level sampling, in decibels, applicable to a set of N measured values, $L_{p,\text{A,eq}T,n}$, of standard uncertainty u_1

N	**Uncertainty contribution c_1u_1 of measured values $L_{p,\text{A,eq}T,n}$** dB											
	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	5,5	6
3	0,6	1,6	3,1	**5,2**	**8,0**	**11,5**	**15,7**	**20,6**	**26,1**	**32,2**	**39,0**	**46,5**
4	0,4	0,9	1,6	2,5	**3,6**	**5,0**	**6,7**	**8,6**	**10,9**	**13,4**	**16,1**	**19,2**
5	0,3	0,7	1,2	1,7	2,4	3,3	**4,4**	**5,6**	**6,9**	**8,5**	**10,2**	**12,1**
6	0,3	0,6	0,9	1,4	1,9	2,6	3,3	**4,2**	**5,2**	**6,3**	**7,6**	**8,9**
7	0,2	0,5	0,8	1,2	1,6	2,2	2,8	3,5	**4,3**	**5,1**	**6,1**	**7,2**
8	0,2	0,5	0,7	1,1	1,4	1,9	2,4	3,0	**3,6**	**4,4**	**5,2**	**6,1**
9	0,2	0,4	0,7	1,0	1,3	1,7	2,1	2,6	3,2	**3,9**	**4,6**	**5,4**
10	0,2	0,4	0,6	0,9	1,2	1,5	1,9	2,4	2,9	3,5	**4,1**	**4,8**
12	0,2	0,3	0,5	0,8	1,0	1,3	1,7	2,0	2,5	2,9	3,5	**4,0**
14	0,1	0,3	0,5	0,7	0,9	1,2	1,5	1,8	2,2	2,6	3,0	3,5
16	0,1	0,3	0,5	0,6	0,8	1,1	1,3	1,6	2,0	2,3	2,7	3,2
18	0,1	0,3	0,4	0,6	0,8	1,0	1,2	1,5	1,8	2,1	2,5	2,9
20	0,1	0,3	0,4	0,5	0,7	0,9	1,1	1,4	1,7	2,0	2,3	2,6
25	0,1	0,2	0,3	0,5	0,6	0,8	1,0	1,2	1,4	1,7	2,0	2,3
30	0,1	0,2	0,3	0,4	0,6	0,7	0,9	1,1	1,3	1,5	1,7	2,0

When c_1u_1 as obtained from Table C.4 is greater than 3,5 dB (values indicated in **bold** in Table C.4), it is recommended that the measurement plan be revised or changed to reduce u_1 (see 10.4).

NOTE 1 The values for $N = 3$ and $N = 4$ are given only for use with full-day measurements (see Clause C.4).

NOTE 2 In field situations where there is a need to evaluate whether more measurements are necessary, a simpler estimation of u_1 can be made. The estimated standard uncertainty, u_1^*, can be calculated by using the following equation:

$$u_1^* = \frac{L_{p,\text{A,eq}T,n(\text{max})} - L_{p,\text{A,eq}T,n(\text{min})}}{K_N}$$

where

$K_N = 2{,}2$ if $N < 6$

$K_N = 2{,}5$ if $N \in [6, 15]$

$K_N = 3{,}0$ if $N \in [16, 30]$

C.4 Uncertainty calculation for the full-day measurement

The procedure for calculation of uncertainty for full-day measurement is the same as for the job method. Thus, the uncertainty for full-day measurement is found from the uncertainty budget in Table C.3 and by using Equation (C.9) with $c_1 u_1$ from Table C.4, and u_2 and u_3 from Clauses C.5 and C.6.

C.5 Standard uncertainty, u_2, for the instrumentation used

The standard uncertainty, u_2 (or $u_{2,m}$ for the task m), of instrumentation is given in Table C.5.

Table C.5 — Standard uncertainty, u_2, of instrumentation

Type of instrumentation	Standard uncertainty u_2 (or $u_{2,m}$) dB
Sound level meter as specified in IEC 61672-1:2002, class 1	0,7
Personal sound exposure meter as specified in IEC 61252	1,5
Sound level meter as specified in IEC 61672-1:2002, class 2	1,5

NOTE 1 The standard uncertainty listed in Table C.5 is only valid for $L_{p,\text{A,eq}T}$. The uncertainty for $L_{p,\text{Cpeak}}$ can be considerably higher.

NOTE 2 The standard uncertainties, u_2 (or $u_{2,m}$), given in Table C.5 are based on empirical data. Experience shows that these standard uncertainty values of instrumentation are representative for most relevant situations.

The uncertainty of instrumentation in use depends on the characteristics of the noise exposure and the environmental conditions. These values cannot be derived directly from the tolerance limits given in instrument standards IEC 61672-1 and IEC 61252, which include the expanded uncertainties of the test laboratory. If the uncertainty of instrumentation in use was based on the tolerance limits given in the instrument standards, then rather large combined uncertainties would be calculated.

C.6 Standard uncertainty, u_3, due to measurement position

The standard uncertainty, u_3, due to measurement position is 1,0 dB.

NOTE The given value for standard uncertainty is based on empirical data. For cases when the microphone is worn by the worker and when the microphone is placed close to the worker's body, the uncertainty is due to screening effects and reflections from the body. For cases when measurements are performed with the worker absent, the uncertainty is due to the microphone position(s) not being fully representative of the true position(s) of the worker's head. See also 12.3 and 12.4 with regard to microphone position.

Annex D
(informative)

An example showing calculation of daily noise exposure level using task-based measurements

D.1 Step 1: Work analysis

In this example, the noise exposure level for welders working in a mechanical workshop is determined by using task-based measurements. The working day consists of the following sequence of tasks:

a) work planning (quiet);

b) two periods of cutting, grinding and welding of steel plates;

c) lunch (in this case, the lunch is regarded as part of the working day);

d) work planning (quiet);

e) two periods of cutting, grinding and welding of steel plates.

All welders perform the same work and therefore they can be regarded as one homogenous noise exposure group.

According to information from the supervisor, the work can be split into three separate tasks: welding, cutting and grinding, and quiet operations (breaks and planning).

The welders say that they spend between 1 h and 2 h a day on cutting and grinding, and between 4 h and 6 h on a day on welding. The rest of the day is spent on planning and breaks. The uncertainty is estimated to be 0,5 h for cutting and grinding and 1 h for welding.

Based on this information, the nominal day is defined in Table D.1.

Table D.1 — Welder's nominal day

Task	Duration h
Work planning, breaks (quiet)	1,5
Cutting and grinding	1,5
Welding	5,0
Total	8,0
NOTE The time spent on each task is calculated using the average of the range of values given by the welder and his or her supervisor.	

D.2 Step 2: Selection of strategy

Since the number of tasks is limited and well-defined, the situation is suitable for performing task-based measurements.

D.3 Step 3: Measurements

The noise contribution from work planning and breaks is of no importance to the overall noise exposure level. It is therefore sufficient to make some simple noise measurements with a sound level meter, just to ensure that the sound pressure level in these working periods (task) has negligible influence. In this example, $L_{p,\text{A,eq}T} = 70$ dB is set as a conservative estimate for such periods, provided that the check shows that the levels are at or below this level.

Since the noise contribution from both grinding and welding is highly dependent on the location of the worker's ears in relation to the noisy tool, it was decided to measure during these tasks using a personal sound exposure meter.

The measurement period should cover at least three work cycles. Observations have shown that the measurement duration for noise from grinding should be at least 7 min. Similarly, the measurement duration for noise from welding should be at least 4 min. However, in accordance with 9.3, the measurement duration should be at least 5 min. Hence, the measurement duration for welding is set to 5 min.

Since the range of measured values exceeds 3 dB, three additional measurements are made for each task. However, since the noise from quiet activities is negligible, only some brief samples of noise level are made during these tasks.

The first measurements resulted in the following values:

Noise level during planning and breaks	$L_{p,\text{A,eq}T,11} < 70$ dB		
Noise levels from welding	$L_{p,\text{A,eq}T,21} = 80{,}1$ dB	$L_{p,\text{A,eq}T,22} = 82{,}2$ dB	$L_{p,\text{A,eq}T,23} = 79{,}6$ dB
Noise levels from cutting and grinding	$L_{p,\text{A,eq}T,31} = 86{,}5$ dB	$L_{p,\text{A,eq}T,32} = 92{,}4$ dB	$L_{p,\text{A,eq}T,33} = 89{,}3$ dB

Since the difference between the measured noise levels from cutting and grinding exceeds 3 dB, at least three additional measurements are performed giving the following results:

Additional noise levels from cutting and grinding	$L_{p,\text{A,eq}T,34} = 93{,}2$ dB	$L_{p,\text{A,eq}T,35} = 87{,}8$ dB	$L_{p,\text{A,eq}T,36} = 86{,}2$ dB

D.4 Step 4: Error handling

In this example, observations during the measurements showed that there were no significant risks of making measurement errors.

D.5 Step 5: Calculation and presentation of the results including uncertainty

D.5.1 Calculation of daily A-weighted noise exposure level

The noise level from each task is calculated using Equation (7). The noise level from welding is then as follows:

$$L_{p,\text{A,eq}T,2} = 10\ \lg\left[\frac{1}{3}\times\left(10^{0,1\times 80,1}+10^{0,1\times 82,2}+10^{0,1\times 79,6}\right)\right]\ \text{dB} = 80{,}8\ \text{dB}$$

Similarly, the noise level from cutting and grinding was found to be 90,1 dB.

The noise level during planning and breaks was initially defined to be 70 dB.

The contribution to the daily A-weighted noise exposure level is calculated for each activity according to Equation (8).The contributions from the tasks to the daily noise exposure are then:

a) planning and breaks —

$$L_{\text{EX,8h,1}} = 70\ \text{dB} + 10\ \lg\left(\frac{1{,}5}{8}\right)\ \text{dB} = 62{,}7\ \text{dB}$$

b) welding —

$$L_{\text{EX,8h,2}} = 80{,}8\ \text{dB} + 10\ \lg\left(\frac{5}{8}\right)\ \text{dB} = 78{,}8\ \text{dB}$$

c) cutting and grinding —

$$L_{\text{EX,8h,3}} = 90{,}1\ \text{dB} + 10\ \lg\left(\frac{1{,}5}{8}\right)\ \text{dB} = 82{,}8\ \text{dB}$$

The daily A-weighted noise exposure level can now be calculated from Equation (10):

$$L_{\text{EX,8h}} = 10\ \lg\left(10^{0{,}1\times 62{,}7} + 10^{0{,}1\times 78{,}8} + 10^{0{,}1\times 82{,}8}\right)\ \text{dB} = 84{,}3\ \text{dB}$$

D.5.2 Calculation of uncertainty

The standard uncertainty, $u_{\text{1a,2}}$, due to sampling of welding noise levels is calculated from Equation (C.6).

$$u_{\text{1a,2}} = \sqrt{\frac{1}{2\times 3}\left[(-0{,}5)^2 + (1{,}6)^2 + (-1{,}0)^2\right]}\ \text{dB} = 0{,}8\ \text{dB}$$

Similarly, the standard uncertainty due to the noise level sampling from cutting and grinding is found to be $u_{\text{1a,3}} = 1{,}2$ dB. The standard uncertainty due to planning and breaks can be set to 0 dB since these tasks do not contribute to the combined standard uncertainty, u.

A personal sound exposure meter as specified in IEC 61252 has been used. Therefore, according to Table C.5, the standard uncertainty due to instrumentation is $u_{2,m} = 1{,}5$ dB.

In accordance with Clause C.6, the standard uncertainty due to the microphone position is $u_3 = 1{,}0$ dB.

The sensitivity coefficients for uncertainty due to noise level sampling, instrumentation, and measurement position are calculated from Equation (C.4).

For planning and breaks, with $L_{p,\text{A,eq}T,11} \leqslant 70$ dB, the sensitivity coefficient is:

$$c_{\text{1a,1}} \leqslant \frac{1{,}5}{8} \times 10^{(70{,}0 - 84{,}3)/10} = 0{,}007 \approx 0{,}0$$

For welding, the sensitivity coefficient is:

$$c_{\text{1a,2}} = \frac{5}{8} \times 10^{(80{,}8 - 84{,}3)/10} = 0{,}28$$

For cutting and grinding, the sensitivity coefficient is:

$$c_{1a,3} = 0{,}71$$

a) When the uncertainty in duration is excluded, the combined standard uncertainty is found from Equation (C.3), omitting the last part in the brackets.

$$u^2(L_{EX,8h}) = 0{,}28^2 \times \left(0{,}8^2 + 1{,}5^2 + 1{,}0^2\right) + 0{,}71^2 \times \left(1{,}2^2 + 1{,}5^2 + 1{,}0^2\right) = 2{,}67$$

In accordance with C.2.2, the expanded uncertainty, $U(L_{EX,8h})$, is

$$U(L_{EX,8h}) = 1{,}65 \times u = 1{,}65 \times \sqrt{2{,}67} = 2{,}7 \text{ dB}$$

b) When the uncertainty in duration is included, the standard uncertainty, $u_{1b,2}$, due to duration of task is given by Equation (C.7). For welding, the standard uncertainty, in hours, due to duration is:

$$u_{1b,2} = \sqrt{\frac{1}{2}\left[1^2 + 1^2\right]} = 1{,}0$$

The sensitivity coefficient related to the uncertainty due to duration is calculated by using Equation (C.5). For welding, this sensitivity coefficient, in decibels times reciprocal hours, is:

$$c_{1b,2} = 4{,}34 \times \frac{0{,}28}{5} = 0{,}24$$

The standard uncertainty due to the duration of cutting and grinding is $u_{1b,3} = 0{,}5$ h.

The sensitivity coefficient, in decibels times reciprocal hours, for cutting and grinding is:

$$c_{1b,3} = 2{,}1$$

The combined standard uncertainty, $u(L_{EX,8h})$, can now be calculated using Equation (C.3):

$$u^2(L_{EX,8h}) = 0{,}28^2 \times \left(0{,}8^2 + 1{,}5^2 + 1{,}0^2\right) + 0{,}71^2 \times \left(1{,}2^2 + 1{,}5^2 + 1{,}0^2\right) + \left(0{,}24 \times 1{,}0\right)^2 + \left(2{,}1 \times 0{,}5\right)^2 = 3{,}83$$

In accordance with C.2.2, the expanded uncertainty, $U(L_{EX,8h})$, is:

$$U(L_{EX,8h}) = 1{,}65 \times u = 1{,}65 \times \sqrt{3{,}83} \text{ dB} = 3{,}2 \text{ dB}$$

D.5.3 Conclusions

The welders are subject to a daily A-weighted noise exposure level of 84,3 dB, with an associated expanded uncertainty for a one-sided coverage probability of 95 % ($k = 1{,}65$) of 2,7 dB, if the uncertainty in duration is omitted or 3,2 dB if this uncertainty is included.

Annex E
(informative)

An example showing calculation of daily noise exposure level using job-based measurements

E.1 General

In this example, the noise exposure level for production line workers is determined from job-based measurements. Several automated production lines with no major technical differences operate in the plant.

E.2 Step 1: Work analysis

Production line workers perform the same work: running and controlling a production line and intervening in the case of a production incident. Their work includes many tasks (e.g. material supply, production control, product removal, adjustments). However, no distinctions have been found possible between the tasks during the work analysis for the following reasons: the noise exposure conditions of the workers are similar from task to task and the daily duration of each task cannot be determined from work descriptions. The workers make up a homogeneous noise exposure group numbering 18. The effective duration of the working day for this homogeneous noise exposure group is 7,5 h.

E.3 Step 2: Selection of strategy

From the work analysis for this homogeneous noise exposure group of 18 workers, it is neither practical nor desirable to perform a detailed task analysis. Therefore, job-based measurements are selected.

E.4 Step 3: Measurements

The choice of a measurement plan is guided by the following specifications:

— the total minimum duration of the measurements is given in Table 1: for a group of size 18, it amounts to 10,75 h;

— a minimum of five noise level samples of the same duration is required.

From this, it is decided to take six measurements and to set the measurement duration to 2 h.

The distribution of the six measurements among the workers in this homogeneous noise exposure group and over the working duration is made knowing that:

a) two personal sound exposure meters are available;

b) working periods for the group are 05:00 to 13:00 and 13:00 to 21:00.

Six workers are selected at random from the 18 members of the homogeneous noise exposure group. The selected distribution of the measurements is as follows:

Day 1: Morning team, 2 workers; measurement periods: 10:00 to 12:00 and 10:30 to 12:30;

Day 2: Morning team, 2 different workers; measurement periods: 08:00 to 10:00 and 08:30 to 10:30;

Day 2: Afternoon team, 2 different workers; measurement periods: 14:00 to 16:00 and 18:00 to 20:00.

The six measurements result in the following values of $L_{p,\text{A,eq}T,n}$:

88,1 dB 86,1 dB 89,7 dB 86,5 dB 91,1 dB 86,7 dB

The highest C-weighted peak sound pressure level measured is 137 dB.

E.5 Step 4: Error handling

No potential sources of errors are found.

E.6 Step 5: Calculation and presentation of the results and uncertainty

E.6.1 Calculation of daily A-weighted noise exposure level and uncertainty

The energy average of measured values, $L_{p,\text{A,eq}T_\text{e}}$, is calculated from Equation (11) as follows:

$$L_{p,\text{A,eq}T_\text{e}} = 10 \lg\left(\frac{1}{N}\sum_{n=1}^{N} 10^{0,1\times L_{p,\text{A,eq}T,n}}\right) \text{dB} = 88,4 \text{ dB}$$

The standard uncertainty of measured values is

$u_1 = 2,0$ dB

See Equation (C.12).

The uncertainty contribution due to job noise level sampling (value taken from Table C.4 for $N = 6$ and $u_1 = 2,0$ dB):

$c_1 u_1 = 1,4$ dB

Sensitivity coefficients are

$c_2 = c_3 = 1$

The standard uncertainty, u_2, due to instrumentation is taken from Table C.5 (the instrument used was a personal sound exposure meter):

$u_2 = 1,5$ dB

The standard uncertainty due to the microphone position (from Clause C.6) is:

$u_3 = 1,0$ dB

The combined standard uncertainty, u, of the result is derived from Equation (C.9):

$$u^2\left(L_{\text{EX,8h}}\right) = 1{,}4^2 + 1{,}5^2 + 1{,}0^2 = 5{,}21$$

$$u\left(L_{\text{EX,8h}}\right) = 2{,}3 \text{ dB}$$

The expanded uncertainty, $U(L_{\text{EX,8h}})$, is found to be (see C.3.2):

$$U\left(L_{\text{EX,8h}}\right) = 1{,}65 \times u = 3{,}8 \text{ dB}$$

E.6.2 Final result

For an effective duration of the working day $T_\text{e} = 7{,}5$ h and for an average noise level $L_{p,\text{A,eq}T} = 88{,}4$ dB, the daily A-weighted noise exposure level of this homogenous noise exposure group is calculated from Equation (13):

$$L_{\text{EX,8h}} = L_{p,\text{A,eq}T_\text{e}} + 10 \lg\left(\frac{T_\text{e}}{T_0}\right) \text{ dB} = 88{,}1 \text{ dB}$$

The expanded uncertainty, $U(L_{\text{EX,8h}})$, is

$$U(L_{\text{EX,8h}}) = 3{,}8 \text{ dB.}$$

E.6.3 Conclusions

The 18 members of the homogeneous noise exposure group receive a daily A-weighted noise exposure level of 88,1 dB, with an associated expanded uncertainty for a one-sided coverage probability of 95 % ($k = 1{,}65$) of 3,8 dB.

Annex F
(informative)

Sample calculation of daily noise exposure level using full-day measurements

F.1 General

This annex gives an example of the use of the full-day measurement strategy specified in Clause 11 in the determination of daily noise exposure level.

The example shows the application of the strategy to the task of determining the noise exposure of forklift truck drivers working in a company engaged in the manufacture and storage of wire rope.

F.2 Step 1: Work analysis

The work of the forklift truck workers involves transportation of raw materials and finished product within and between the production, storage and despatch areas of the workplace. The work of the drivers can vary depending upon the instructions of their supervisor. Trucks can be driven over a variety of surfaces while unloaded, partially loaded or fully loaded. Drivers spend a large part of the day within the truck cab, but are required to leave the cabs periodically in order to assist with loading and unloading, to discuss work with colleagues and supervisors, etc. The trucks are fitted with audible reversing alarms, the use of which is mandatory.

There are three forklift truck drivers. They work a 10 h shift, which includes three breaks of 20 min, 45 min and 20 min respectively. The two shorter breaks are taken at any convenient location within the workplace at a time to suit the driver. The longer break is taken at a fixed time in the staff canteen. The effective duration of the working day is therefore 9,25 h.

A description of the work activities was compiled by observation and confirmed by discussions with the drivers and their supervisors. The three forklift truck drivers were considered to form a homogeneous exposure group (see 7.2).

F.3 Step 2: Selection of strategy

Because the work patterns were relatively complex and unpredictable, the full-day measurement strategy was found to be most appropriate.

F.4 Step 3: Measurements

F.4.1 Measurement plan

Initially, a full-day measurement was performed on each of the drivers.

Properly calibrated personal sound exposure meters were fitted to each of the drivers at the start of the work shift. The drivers were informed as to the operation of the measuring instrument and were asked to work normally, to refrain from touching or interfering with the microphone or the measuring instrument, to try to avoid any inadvertent contact with the microphone, and to try to avoid unnecessary talking or shouting during the work shift.

The personal sound exposure meters were left undisturbed during the two shorter breaks. In this case, the noise exposure during the lunch break was considered to be irrelevant, and the personal sound exposure meters were put into “pause” mode by the measurement technician.

The personal sound exposure meters were removed at the end of the work shift and appropriate calibration procedures were performed.

Due to the need to allow time at the beginning and end of the work shifts for setting up and removing instrumentation and instructing the drivers, the measurement duration was slightly less than the duration of the full work shift. However, the measurements were of sufficient duration to cover all significant periods of noise exposure.

Following the initial three full-day measurements, it was found that the three results differed by more than 3 dB. Therefore, three additional full-day measurements were performed, using the same techniques described above. This gave a total of six full-day measurements.

F.4.2 Observing work activities and monitoring measurements

In order to evaluate any sources of uncertainty that may influence the results, the measurement technician periodically observed each of the drivers during the course of the measurements and made appropriate notes of their activities.

Furthermore, at the end of the work shift, the personal sound exposure meters were removed, and the technician interviewed each of the drivers to establish whether the working day was representative and to discover whether any non-typical tasks were carried out or whether any incident which would affect the measurements occurred.

F.5 Step 4: Error handling

No potential sources of error were found.

F.6 Step 5: Calculation and presentation of results and uncertainty

F.6.1 Measurement results

The results from the six measurements are shown in Table F.1.

Table F.1 — Measurement results

Driver/Day	Equivalent continuous sound pressure level $L_{p,\mathrm{A,eq}T,n}$ dB	Measurement duration t
1/1	88,0	8 h 15 min
2/1	91,9	8 h 10 min
3/1	87,6	8 h 15 min
1/2	90,4	8 h 00 min
2/2	89,0	8 h 05 min
3/2	88,4	8 h 10 min

F.6.2 Calculation of daily A-weighted noise exposure level

The daily A-weighted noise exposure level of the homogeneous exposure group of forklift truck drivers is derived from the energy average of the six measured values of $L_{p,\mathrm{A,eq}T,n}$, using Equation (11).

Using the values in Table F.1, the result is $L_{p,\mathrm{A,eq}T_\mathrm{e}}$ = 89,5 dB.

The daily A-weighted noise exposure level, $L_{\mathrm{EX,8h}}$, is derived from Equation (13). The effective duration of the working day, T_e = 9,25 h and the reference duration is 8 h.

Hence

$$L_{\mathrm{EX,8h}} = 89{,}5\ \mathrm{dB} + 10\ \lg\left(\frac{9{,}25}{8}\right)\ \mathrm{dB} = 90{,}1\ \mathrm{dB}$$

F.6.3 Calculation of uncertainty

For the full-day measurement strategy, the expanded uncertainty, U, is determined by following the procedures specified in Clause C.3.

The standard uncertainty of the energy averaged $L_{p,\mathrm{A,eq}T}$ value, u_1, is derived from Equation (C.12), i.e.

$$u_1 = \sqrt{\frac{1}{5}\left[\left(-1{,}2\right)^2 + 2{,}7^2 + \left(-1{,}6\right)^2 + 1{,}2^2 + \left(-0{,}2\right)^2 + \left(-0{,}8\right)^2\right]}\ \mathrm{dB} = 1{,}65\ \mathrm{dB}$$

The uncertainty contribution, c_1u_1, from Table C.4 for N = 6 and u_1 = 1,65 dB is c_1u_1 = 1,0 dB.

The standard uncertainty due to instrumentation, $u_{2,m}$, is taken from Table C.5, where, since the instrument used was a personal sound exposure meter:

$$u_2 = 1{,}5\ \mathrm{dB}$$

The standard uncertainty due to microphone position, u_3, is taken from C.6:

$$u_3 = 1{,}0\ \mathrm{dB}$$

The sensitivity coefficients, c_2 and c_3, are derived from Table C.3:

$$c_2 = c_3 = 1$$

The combined standard uncertainty, $u(L_{\mathrm{EX,8h}})$, of the result is derived from Equation (C.9):

$$u^2(L_{\mathrm{EX,8h}}) = \left(1{,}0^2 + 1{,}5^2 + 1{,}0^2\right) = 4{,}25$$

Hence, the combined standard uncertainty, $u(L_{\mathrm{EX,8h}})$ = 2,06 dB.

The expanded uncertainty, $U(L_{\mathrm{EX,8h}})$, is:

$$U(L_{\mathrm{EX,8h}}) = 1{,}65 \times u = 3{,}4\ \mathrm{dB}$$

F.6.4 Conclusions

The three forklift truck drivers are subject to a daily A-weighted noise exposure level of 90,1 dB, with the associated expanded uncertainty for a one-sided coverage probability of 95 % (k = 1,65) of 3,4 dB.

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