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Acoustics — Guidelines for the measurement and assessment of exposure to noise in a working environment

Acoustique — Guide pour le mesurage et l'évaluation de l'exposition au bruit en milieu de travail

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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.

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.

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

Annexes A to E of this International Standard are for information only.

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Introduction

The uniform measurement, analysis and evaluation of noise at the workplace is important in order to assess the potential effects of noise on the health, well-being, safety and working efficiency of the worker. Although standards exist specifying the noise measurements at the operator positions and in the environment of specific equipment and other standards describing the effects of noise on specific human functions, the present International Standard provides general guidance for what type of measurements at which positions are required for evaluation of the noise with respect to its effects on the worker in order to monitor compliance with established documents and in order to indicate the need for reducing noise by abatement measures.

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Acoustics — Guidelines for the measurement and assessment of exposure to noise in a working environment

1 Scope

This International Standard describes the determination of the acoustical quantities, especially the type and locations of sound pressure level measurements to be conducted, the time sampling and frequency analysis required and the special characteristics of the noise to be considered. The purpose is to allow an assessment of the noise in the working environment with respect to its various effects on the worker as a result of daily habitual exposure. This International Standard is intended to be used by appropriate authorities responsible for specifying and monitoring compliance with noise limits at the workplace and for deciding on the need for hearing conservation programmes and noise reduction measures. It does not by itself specify or recommend acceptable noise limits. The standard does not specify statistical sampling procedures to characterize the noise exposure of groups, although references to such procedures are included in the bibliography. The applications of the measurement results are described with respect to the effects of noise on hearing, interference with communication and other effects of noise. Special requirements for the description of infrasound and ultrasound exposure are included. Applications of the Standard to evaluate effects of the noise on health, working efficiency, well-being and the audibility of warning signals are summarized in Annex A. Annex B gives examples of equivalent continuous A-weighted sound pressure level calculations. Annex C discusses calculation of the rating level including tone and impulsive adjustment. Annex D specifies classes of accuracy for noise measurements. All the annexes are informative.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 266:1975, *Acoustics - Preferred frequencies for measurements*[1]

ISO 532:1975, *Acoustics - Method for calculating loudness level*

ISO 1996-1:1982, *Acoustics - Description and measurement of environmental noise - Part 1: Basic quantities and procedures*

ISO 1999:1990, *Acoustics - Determination of occupational noise exposure and estimation of noise-induced hearing impairment*

ISO/TR 3352:1974, *Acoustics - Assessment of noise with respect to its effect on the intelligibility of speech*

ISO 3891:1978, *Acoustics - Procedure for describing aircraft noise heard on the ground*

ISO 4869-1:1990, *Acoustics - Hearing protectors - Part 1: Subjective method for the measurement of sound attenuation*

ISO 4869-2:1994, *Acoustics - Hearing protectors - Part 2: Estimation of effective A-weighted sound pressure levels when hearing protectors are worn*

ISO/TR 4870:1991, *Acoustics - The construction and calibration of speech intelligibility tests*

ISO 7196:1995, *Acoustics - Frequency weighting characteristic for infrasound measurements*

ISO 7731:1986, *Acoustics - Danger signals for work places - Auditory danger signals*

ISO 9921-1:1995, *Ergonomic assessment of speech communication - Part 1: Speech interference level and communication distances for persons with normal hearing capacity in direct communication (SIL method)*

IEC 651:1979, *Electroacoustics - Sound level meters*[1]
Amendment 1:1993

IEC 804:1985, *Electroacoustics - Integrating-averaging sound level meters*[1]
Amendment 1:1989. Amendment 2:1993

IEC 942:1988, *Electroacoustics - Sound calibrators*[1]

IEC 1252:1993, *Electroacoustics - Specifications for personal sound exposure meters*

IEC 1260:1995, *Electroacoustics - Octave-band and fractional-octave-band filters*

3 Quantities and definitions

The following quantities are used in this International Standard. Instead of repeating the definitions of the quantities, reference is made to the relevant International Standards where the definitions are given.

[1]Under revision

Quantity	Symbol	Defined in
sound pressure level	L_p	ISO 1999
peak sound pressure level: level of the peak sound pressure	L_{peak}	IEC 651
A-weighted sound pressure level	L_{pA}	ISO 1999
C-weighted peak sound pressure level	L_{Cpeak}	IEC 651
equivalent continuous A-weighted sound pressure level over the duration T	$L_{Aeq,T}$	ISO 1999 ISO 9921-1 IEC 804
percentile level	$L_{AN,T}$	ISO 1996-1
octave-band sound pressure level		ISO 532
one-third-octave-band sound pressure level		ISO 532
time interval of 8 hours	T_0	
normalizing time interval: that time interval to which an equivalent continuous A-weighted sound pressure level is referred	T_N	
time interval of the daily duration of workers effective exposure to noise	T_e	
A-weighted sound exposure over duration T	$E_{A,T}$	ISO 1999
noise exposure level	$L_{EX,T}$	ISO 1999
noise-induced permanent threshold shift	NIPTS	ISO 1999
impulsive noise		ISO 12001
rating level	L_{Ar}	ISO 1996-1
speech interference level	SIL	ISO 9921-1 ISO/TR 3352
loudness level	L_N	ISO 226
perceived noise level	L_{PN}	ISO 3891

4 Measurements of noise in the working environment

4.1 General

This clause describes the procedure for measuring the sound pressure level at the work station. This procedure includes the use of instrumentation (4.2) and microphone location, measurement time interval and the determination of several noise quantities especially the equivalent continuous A-weighted sound pressure level (4.3.4), the normalized equivalent continuous A-weighted sound pressure level (4.3.5), the daily noise exposure (4.3.6) and rating level (4.3.10 and Annex C). A method to determine the equivalent continuous A-weighted sound pressure level and its uncertainty by sampling technique is presented in Annex D.1. For the purpose of determining compliance with prescribed noise limits and assessment of the uncertainty of measurement (Annex D.2), for comparing the result to a limit (Annex D.3) and for contents of the measurement report (Annex D.4), guidance is provided in annexes.

4.2 Instrumentation

4.2.1 Sound level meter

Sound level meters shall comply at least with the requirements for a type 2 instrument given in IEC 651. Type 1 sound level meters are preferred.

Personal sound exposure meters shall comply with IEC 1252. To indicate if the instrument is being overloaded by the peak sound pressure, instruments incorporating an overload indication are preferred.

Integrating-averaging sound level meters shall comply at least with the requirements for a type 2 instrument given in IEC 804.

4.2.2 Octave and one-third octave-band filters

Octave and one-third octave band filters shall comply with the requirements given in IEC 1260. The nominal centre frequencies of the frequency bands shall correspond to those of ISO 266.

4.2.3 Auxiliary measuring devices

A level recorder used for registration of the level shall comply with the relevant clauses of IEC 651, e.g. the requirements on time weighting.

A statistical analyzer for the measurement of the percentile level shall comply with the time weighting F of IEC 651. The level intervals for the classification shall be chosen in relation to the overall range of noise levels but they shall not exceed 5 dB.

Tape recorders or other devices to store noise signals shall be such that the overall measuring equipment at least complies with the specifications for a type 2 instrument in IEC 651 and IEC 804.

Sound calibrators used for calibrating and checking the sound measuring equipment shall comply with class 2 specifications or better as given in IEC 942.

4.2.4 Calibration and checking

A recalibration for compliance with IEC 651, IEC 804 or IEC 1252 shall be performed regularly. It is recommended that the time intervals for the recalibration do not exceed three years.

A field check shall be made by the user at least before and after each series of measurements. Electrical check of amplifiers, recorders and indicators shall be made as well as an acoustic check of the whole system including the microphone (e.g., by applying a sound calibrator). The acoustical check should be made on site wherever possible. The precision of measurement should be determined (see Annex D).

4.3 Measurements

4.3.1 General

The preferred basic measurement quantities are the equivalent continuous A-weighted sound pressure level ($L_{Aeq,T}$) and the A-weighted sound exposure ($E_{A,T}$) during a stated time interval, T.

Depending on the type of noise and the type of effect to be evaluated, additional measurement quantities such as the maximum instantaneous sound pressure level unweigthed L_{peak}, A-weighted L_{Apeak}, C-weighted L_{Cpeak} or other quantities, may be measured.

In some cases, measurement of octave or one-third-octave-band levels of audible, infra - or ultrasound may be indicated. If communication capability is required speech interference level (SIL), signal to noise ratio (S/N) or other measures may be needed.

Depending on the purpose, the measurement may be made at fixed location(s) or on person(s) during work. For high accuracy the on-person method (microphone following the exposed person) may be preferred.

The exposure to noise at the working place comprises the noises produced there and the noises arriving from other sources in the environment.

If some time intervals are excluded from the measurement, e.g. for assessments with respect to some effects such as annoyance or well-being, this must be stated in the test report. Possible exclusions are time intervals with:

- sounds produced at the specific working place by the person at this place speaking to other persons;
- noises consisting of communication signals addressed to the specific working place (e.g. telephone, public address system).

The measurement shall provide quantitative description of the characteristic potential exposure to noise at the working place. Characteristic potential exposure to noise is given, if the number of occurrences, the type and origin of the noises at the working station are typical for the working place on a long-term basis. To support this statement, suitable information may be collected or a sufficient number of independent measurements (samples) be performed.

If the exposure to noise is determined for a well-defined working location, the measurement is performed at this specific location. If the person occupies more than one working place, the equivalent continuous A-weighted sound pressure level or the A-weighted sound exposure may be determined either separately for the different working locations or for the person occupying these working locations, each for one period of time allowing determination of this person's cumulative exposure during the workshift.

4.3.2 Microphone locations and measurement positions

Preferably the microphone location shall be the position of the head of the person occupying the working place under consideration without the person present.

In other cases, when the person has to be in this working place, the microphone should be located, when practicable, approximately 0,10 m from the entrance of the external canal of the ear receiving the higher value of the equivalent continuous A-weighted sound pressure level. The microphone of sound exposure meters and sound level meters worn on a person shall be mounted on the helmet or on the shoulder or collar at a distance approximately between 0,1 m to 0,3 m from the entrance of the external canal of the ear.

NOTES

1 To support the microphone, a helmet or frame may be used.

2 A shoulder location should be used for the microphone, when convenient.

If the measuring instrument or parts of it are worn on the worker, care shall be taken not to disturb the performance of the person and especially not to introduce safety risks. Similarly, care should be taken to avoid misuse of the instrument during measurements.

If the head position at a working location is not well defined or otherwise stated by the appropriate authorities, the following microphone heights shall be used (see ISO 11201):

for standing persons	1,55 m ± 0,075 m above the ground on which the person is standing;
for seated persons	0,91 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.

For measurement positions at a specific location the reference direction of the microphone shall be in accordance with the manufacturer's instruction. (If possible, the microphone should point in the direction of sight of the person occupying this working place).

If the worker's locations are very close to the noise sources, the microphone location and direction shall be precisely stated in the test report.

NOTES

3 Near the sound source even small changes of the microphone location may result in variations of the sound pressure level. If tones are clearly audible at the working place (see Annex B), standing sound waves may occur. To determine the local variations of the sound pressure level, the microphone should be moved over a range of 0,10 m to 0,50 m. The variations of the sound level observed during the movement of the microphone are treated as time varying levels and averaged accordingly.

4 If the microphone must be located very close to a person's body, appropriate (sometimes elaborative) adjustments must be made by comparing results obtained with and without the person present. This applies particularly for noises with strong components at high frequencies and for small sources at a short distance. Normally values measured with the person present are higher than those without a person present.

5 Care must be taken when using a personal sound level meter with the microphone not located near the ear.

6 Special measurement procedures are required for the measurement of noise exposure under earphones (e.g. for secretaries, telephonists, pilots, aircontrollers) or under helmets (e.g. flying and motorcycle helmets); these methods are not described in this International Standard.

To reduce the measurement time in areas with a large number of working places the following procedure may be used:

Zones of working places with equal exposure to sound are defined and the measurement is performed at a sample of typical working places. The average of the measurement results at these locations is taken as representative for all working places of that zone. Such a grouping is only permissible if the levels $L_{Aeq,T}$ determined at different places differ by not more than 5 dB. In addition, compliance with noise limits shall be checked at all working places in case of doubt. For some work areas, it may be more appropriate to define zones in terms of equal levels, $L_{Aeq,T}$.

Working places with equal noise exposure may be:

- working places with workers with equal activity;
- working places where the noise exposure is essentially determined by noise sources at a large distance from the working places (e.g. more than 5 m to 20 m in factory halls).

NOTE 7 - At a distance from the noise source (about 5 m to 20 m) the level decreases by about 2 dB to 4 dB per doubling of the distance from the sound source in normal factory halls with low sound absorption.

In factory halls with high sound absorption the level decrease per doubling of the distance may amount to about 4 dB to 6 dB.

4.3.3 Measurement time

4.3.3.1 The normalizing/reference time interval, T_N, is that time interval representing the duration of one workshift (conventionally 8 hours (T_o)), over which a continuous A-weighted sound pressure level is determined.

The measurement time interval, T, is that time interval over which the squared A-weighted sound pressure is integrated and averaged.

NOTE 8 - The time and day of the measurement and the duration of measurement should be reported.

The measurement time intervals shall be chosen so that all significant variations of noise levels at the working place are measured and included. Further, the choice of the measurement time intervals shall be such that the measurement result is consistent with repetition.

During the measurement time interval, sound which is characteristic of the specific working place must exist (see 4.3.1). Two procedures may be used to acquire the characteristic noise exposure:

$T = T_N$: If the measurement time interval is extended over the normalizing/reference time interval, the total exposure to noise of the workshift to be rated may be determined directly.

$T < T_N$: If a measurement time interval is less than the normalizing/reference time interval, the characteristic noise exposure being measured may be selected by experience.

4.3.3.2 If the measurement is extended over a shorter time interval only ($T < T_N$), the measurement time interval or the sample must be chosen such that the noise exposure is determined which is characteristic of the working place and is representative for the normalizing time interval. It may be possible by questionnaire/collection of information regarding the typical noise sources (e.g. working processes, machines, activities at the working place and in its environment) to determine their time fraction of the workshift and contributed average level for each part time interval (see Annex B).

The measurement time interval depends on the type of noise exposure. It may be subdivided into part time intervals within which the exposure to noise is of the same type, e.g. corresponding to the different activities at the working place or in its environment.

The selected measurement duration shall depend on fluctuations of the noise. It shall be sufficiently long for the resulting noise exposure level to be representative of the activities performed by the employee. The duration shall be either the entire length of an activity, a portion thereof, or several repetitions of the activity, as required to stabilize the readings of the sound exposure level or the equivalent continuous A-weighted sound pressure level within 0,5 dB.

The minimum duration shall be 15 s. If the noise shows a pronounced periodicity, the minimum duration should be at least one cycle; otherwise a multiple of complete cycles shall be used.

The sampling procedure may be extended to several workshifts and averaged (see Annex D).

4.3.4 Determination of equivalent continuous A-weighted sound pressure level

The preferred method of measurement is to use an integrating-averaging sound level meter to measure the equivalent continuous A-weighted sound pressure level, $L_{\mathrm{Aeq},T}$, during the stated time interval.

If a sound level meter is used, and if the noise is such that the fluctuations in level are small (see the note), the arithmetic average of the indicated reading of the meter (or recorder) is approximately equal to the equivalent continuous A-weighted sound pressure level.

NOTE 9 - The noise may be deemed to have small fluctuations if the total meter excursion lies within a range of 5 dB with time weighting S.

If the measurement time interval T is subdivided into smaller intervals T_i, the equivalent continuous A-weighted sound pressure level is calculated by using the formula:

$$L_{\mathrm{Aeq},T} = 10 \lg \left(\frac{1}{T} \sum_{i=1}^{m} T_i \cdot 10^{L_{\mathrm{Aeq},Ti}/10} \right) \quad \mathrm{dB}$$

where:

$L_{\mathrm{Aeq},Ti}$ is the equivalent continuous A-weighted sound pressure level occurring over the time interval T_i;

T is equal to $\sum_{i=1}^{m} T_i$;

m is the total number of sub-intervals of time.

4.3.5 Normalization of equivalent continuous A-weighted sound pressure level to a nominal 8 h working day

In order to compare noise exposures from workdays of different durations it is desirable, for many purposes, to normalize daily occupational noise exposure of shorter or longer duration, T_e, to a nominal 8 hour work day. In this International Standard, the time interval over the 8 hour period is called T_0. The normalized daily noise exposure level is obtained by using the formula:

$$L_{EX,8h} = L_{Aeq,T_e} + 10 \lg \frac{T_e}{T_0} \text{ dB}$$

NOTE 10 - A noise exposure level normalized to a nominal 8 h working day, in decibels, may also be calculated from the daily A-weighted sound exposure, $E_{A,Te}$, in pascal squared seconds ($Pa^2 \cdot s$), using the following formula:

$$L_{EX,8h} = 10 \lg \frac{E_{A,T_e}}{1,15 \times 10^{-5} \text{ Pa}^2 \text{ s}} \text{ dB}$$

Some selected values of $E_{A,Te}$ with their corresponding values of noise exposure levels normalized to a nominal 8 h working day are given for illustration in table 1.

Table 1 - Daily A-weighted sound exposure, $E_{A,Te}$ and corresponding values of noise exposure levels normalized to a nominal 8 h working day.

$E_{A,Te}$ in $Pa^2 \cdot s \times 10^3$	$L_{EX,8h}$ in dB
0,364	75
0,458	76
0,576	77
0,726	78
0,913	79
1,15	80
1,45	81
1,82	82
2,29	83
2,89	84
3,64	85
4,58	86
5,76	87
7,26	88
9,13	89
11,5	90
14,5	91
18,2	92
22,9	93
28,9	94
36,4	95
45,8	96
57,6	97
72,6	98
91,3	99
115,0	100

4.3.6 Determination of the A-weighted sound exposure, $E_{A,Te}$

The preferred method is to use a personal sound exposure meter or an integrating-averaging sound level meter. $E_{A,Te}$ is related to $L_{Aeq,Te}$ by the formula:

$$E_{A,Te} = p_0^2 \cdot T_e \times 10^{L_{Aeq,Te}/10}$$

where p_o = 2 x 10^{-5} Pa and T_e is in seconds.

If the measurement time T_e is subdivided into smaller intervals T_{ei} for which the values $E_{A,Tei}$ are measured, $E_{A,Te}$ is calculated by using the formula:

$$E_{A,Te} = \sum_i E_{A,T_{ei}}$$

4.3.7 Determination of the normalized daily noise exposure level over a number of days

If the exposures averaged over n days are desired, for example, if nominal normalized noise exposure levels for weekly exposures are considered, the average value of $L_{EX,8h}$, over the whole period may be determined from the values of $(L_{EX,8h})_i$ for each day, using the following formula:

$$L_{EX,8h} = 10 \lg \left(\frac{1}{n} \sum_{i=1}^{n} 10^{0,1 L_{EX,8h}}\right) \text{ dB}$$

NOTE 11 - When averaging over periods longer than a week, it is suggested that the maximum and minimum daily levels also be provided.

4.3.8 Normalization of equivalent continuous A-weighted sound pressure level to a nominal 40 h working week

If normalized weekly exposure levels are considered, the average value $L_{EX,8h}$ in dB, over the whole week may be determined. Using the formula in 4.3.7, this results in:

$$L_{EX,w} = 10 \lg \left(\frac{1}{5} \sum_{i=1}^{n} 10^{0,1 (L_{EX,8h})_i}\right) \text{ dB}$$

where

$L_{EX,w}$ is the weekly average of the daily values of $L_{EX,8h}$

n is the number of working days over the week (may be different from 5).

4.3.9 Sound exposure of groups

It is sometimes appropriate to calculate sound exposure of groups. By doing so, not all individuals need to be sampled to obtain reliable results. Procedures for statistical sampling of noise exposure measurements of groups are included in the bibliography (Annex E).

4.3.10 Rating level

A rating level (see ISO 1996-1) is being used in some countries to characterize the overall effect of noise in the working environment. For such applications where it is considered essential to give extra weight to the tonal and/or impulsive character of the noise, the equivalent continuous A-weighted sound pressure level can be modified by adjustments for the tonal and/or impulsive character and normalized to a nominal 8 h working day. The level so adjusted and normalized is presented with guidelines for tone and impulse adjustment in Annex C.

4.4 Frequency analysis

If information on the frequency spectrum of the noise at the worker's position is required, e.g. to plan sound barriers or sound absorption, a frequency analysis may be performed using octave or one-third octave-band filters (see 4.2.2).

Depending on the purpose of the frequency analysis the measurement time shall be chosen appropriately, e.g., time interval at which the highest $L_{\mathrm{Aeq},T}$ value occurs, time interval of specific operating conditions, time interval with the noise containing prominent tones.

To prevent erroneous results of a frequency analysis, averaging over a number of repeated, independent measurements is recommended.

4.5 Infrasound, ultrasound

If infrasound (of less than 20 Hz) constitutes an essential part of the noise at the worker's position it is recommended to perform additional measurements using third octave-band filters or a band-filter with the characteristics specified in ISO 7196.

If ultrasound (above 16 kHz) or high frequency audible sound constitutes an essential part of the noise at the worker's position, measurements shall be performed with one-third octave-band filters or narrow-band filters with the centre frequencies covering the frequency range of interest, but at least for the centre frequencies from 16 000 Hz to 40 000 Hz. The sound level meter or integrating sound level meter used shall be a type 1 instrument in accordance with IEC 651 and have a known frequency response above 12 000 Hz.

The measurement time intervals shall be chosen such that results represent the long term average situation. At least information about the approximate levels in the infrasound and ultrasound frequency range shall be provided.

4.6 Special features of the noise

Where appropriate, special features of the noise that cannot be derived from the measurements specified above shall be described in the test report and be supported or completed by results of additional measurements, e.g., oscillograms, sonograms, percentile levels, level recordings, L_{peak}-values, L_{Aimax} values, duration of noise bursts, sharpness, etc.

Examples of special features:

Origin of the noise:
- the machine to which the worker is related;
- other machines in the same shop;
- outside the shop (traffic, aircraft, ...);
- people talking;
- forklift or other trucks.

Type of noise:
- machinery noise;
- speech, intelligible or unintelligible;
- music;
- animal sound;

- telephone bells ringing;
- traffic noise;
- sirens or hooters indicating shift and break time.

Characteristics of the noise:

- steady;
- non steady;
- impulsive;
- isolated impulses;
- sudden bursts of noise;
- rhythmic/cyclic;
- broad band;
- narrow band;
- tonal, low or high frequency;
- shriek;
- sharpness;
- high information content.

5. Application of measurement results

5.1 General

Measurements described in clause 4 may be applied to assess or rate various effects of occupational sound on human beings as described below.

The particular sound measurements and sound measurement locations required depend on the application of the measurement results and the particular potential effect that is being assessed. If the measurements are to be compared to specified guidelines or limit levels the overall accuracy desired will usually increase the closer the measured levels are to the limit values. The overall accuracy depends on the measurement precision and sampling technique (see Annex D). This clause describes the application of the measurements to evaluate the various effects of the noise with respect to its effects on the worker.

A summary table is given in 5.5.

5.2 Effects on, and protection of, hearing

Quantities used to assess or rate the effects of sound on hearing are:

- the noise exposure level normalized to a nominal eight hour working day, $L_{EX,8h}$;
- the A-weighted sound exposure over a duration T, usually eight hours, $E_{A,T}$;
- the 8 h rating level with tone adjustment $K_1 = 0$, explained in Annex C;
- the peak sound pressure level, L_{peak};
- the C-weighted peak sound pressure level L_{Cpeak}.

These quantities may be derived from measurements with integrating sound level meters or personal sound exposure meters as described in clause 4. They are used for the determination of occupational exposure to noise (ISO 1999), for estimation of the potential noise-induced hearing impairment (ISO 1999) and for risk evaluation (occupational noise regulations).

In addition, the maximum value of the sound pressure level and its duration may be required for risk evaluation (occupational noise regulations). Associated requirements for A- and C-weighted sound pressure levels respectively are used for hearing protector evaluation (ISO 4869-2), and frequency analysis of the noise is required for engineering noise control and hearing conservation programmes.

Hearing loss can be either temporary or permanent. ISO 1999 is concerned with noise-induced permanent threshold shift (NIPTS), an irreversible (sensorineural) loss of hearing that is caused by prolonged noise exposure. NIPTS is the hearing loss attributable to noise exposure alone in the absence of other causes. The permanent thresholds of hearing of a noise-exposed population depend upon the hearing threshold levels associated with age and upon NIPTS. There is a considerable variation in human sensitivity with respect to NIPTS as well as with respect to age-related threshold shifts. The hazardous nature of a noisy environment may therefore be described in terms of "damage risk". This is expressed as the increase in the percentage of the people exposed to the noise in that environment with a hearing threshold level exceeding a given fence relative to that value of a population not exposed to noise, but otherwise equivalent to the noise-exposed population. For impulsive noise with peak instantaneous sound pressure levels exceeding 140 dB, the damage risk estimates of ISO 1999 have not been confirmed by statistical data and should not be applied.

Based on the noise measurements according to clause 4, appropriate authorities may evaluate the risk of noise-induced hearing impairment from the occupational exposure and decide on the requirement of a hearing conservation programme including monitoring audiometry, the wearing of appropriate hearing protectors, or engineering or administrative reduction of the individual's or the group's noise exposure.

5.3 Effects on speech communication

A number of acoustic indices have been developed to indicate the degree of interference of noise with speech perception. These include the following:

- percentile level ($L_{AN,T}$). This is the sound pressure level exceeded on the average N % of the time, T.

- speech interference level (SIL). This is an average of the octave-band sound pressure levels at 500, 1 000, 2 000 and 4 000 Hz (ISO 9921-1, ISO/TR 3352). It is an approximate method for assessing the interfering effects of noise on speech.

- articulation index (AI). This is the most reliable prediction method and takes into account the fact that some frequencies are more effective in masking speech than others. The frequency range from 250 Hz to 7 000 Hz is divided into twenty bands. The difference between the speech and noise level in each of these bands is calculated and the resulting numbers combined to give a single index.

A-weighted sound pressure level, L_{pA}, and equivalent A-weighted sound pressure level, $L_{Aeq,T}$, over an appropriate time are also convenient indices of speech interference, and are sometimes used (ISO 9921-1).

ISO/TR 4870 also addresses methods of assessing the intelligibility of speech.

5.4 Effects of infrasound and ultrasound

One-third-octave-band analysis or narrow band spectral analysis are recommended for the assessment of the effects of ultrasound, up to 40 kHz. For airborne ultrasound the critical organ will generally be the ear; protection measures are thus modelled on procedures established for the audible frequency range. Effects of solid or liquid borne ultrasound are beyond the scope of this International Standard.

Infrasound of sufficiently high intensity can result in various auditory sensations and has been reported by some to affect the personal well-being. Ill effects of a permanent nature have not been attributed to occupational exposure. For the standardized description of infrasound in the range of 1 Hz to 20 Hz, a frequency weighting characteristic has been specified in ISO 7196, which is to be used for evaluating auditory perceptions and non-specific reactions.

Sometimes problems arise with noise with prominent low frequency components being still audible but attributed to infrasound.

NOTE 12 - As the G-weighting is restricted to the infrasonic range, it does not reflect the impact of such noise.

5.5 Summary

The following table provides a reference to applications of measurement results using ISO International Standards evaluating the various effects of noise on the worker as described in 5.1 to 5.4. Other effects are discussed in Annex A.

Table 2 - Application of measurement results to ISO standards

Application	ISO Standard		Acoustical quantity (measured or calculated)
	Number	Title	
Effects on hearing			
Determination of occupational sound exposure, the estimation of noise-induced hearing impairment and for risk evaluation (occupational noise regulations).	1999	Acoustics - Determination of occupational noise exposure and estimation of noise-induced hearing impairment	$L_{Aeq,T}$ L_{peak} $L_{p,max}$ $L_{EX,8h}$
Determination of the sound attenuation of hearing protectors at the threshold of audibility by a subjective method.	4869-1	Acoustics - Hearing protectors - Part 1: Subjective method for the measurement of sound attenuation	L_{pA} L_{pC}
	4869-2	Acoustics - Hearing protectors - Part 2: Estimation of effective A-weighted sound pressure levels when hearing protectors are worn	L_{pA}

Application	ISO Standard Number	Title	Acoustical quantity (measured or calculated)
Effects on communication and safety	9921	Ergonomic ass. etc.	L_{Aeq}, L_{pA}
Assessment of noise with respect to its effect on the intelligibility of speech	TR 3352	Acoustics - Assessment of noise with respect to its effect on the intelligibility of speech	$L_{AN,T}$ SIL AI
	TR 4870	Acoustics - The construction and calibration of speech intelligibility tests	L_{Aeq}
Standardization of auditory danger signals in work places	7731	Danger signals for work places - Auditory danger signals	L_{Aeq}
Annoyance, comfort, morale			
Calculation of loudness level (this may be used for rating devices).	532	Acoustics - Method for calculating loudness level	$L_{p,octave}$ $L_{p,1/3\text{-}octave}$
Description and measurement of environmental noise. To be used with appropriate criteria to rate the noise level in a community to assess their response.	1996-1	Acoustics - Description and measurement of environmental noise - Part 1: Basic quantities and procedures	$L_{Aeq,T}$
Measurement and description of aircraft noise on the ground	3891	Acoustics - Procedure for describing aircraft noise heard on the ground	L_{Aeq}, L_{PN}
Description of infrasound with respect to its effects on humans	7196	Acoustics - Frequency weighting characteristic for infrasound measurements	

ANNEX A
(informative)

OTHER EFFECTS OF NOISE

A.1 Scope

Other effects of noise are at this time less amenable to standardization, but those for which the methods given in this International Standard may be used, are summarized in this annex.

A.2 Extra-auditory health effects

The equivalent continuous A-weighted sound pressure level, $L_{\text{Aeq},T}$, is usually used as a first approach in the assessment of stress. However, the information content and variations in noise levels can strongly affect physiological responses.

The relationship between noise and stress is still unclear. In experimental studies, noise has been shown to produce an increase in adrenocorticotrophic hormone (ACTH) release and an elevation of corticosteroid levels; effects on the systemic circulation including constriction of blood vessels and hypertension; and effects on the autonomic nervous system such as eye dilation, tachycardia and increased skin conductance. All of these effects are normal physiological responses. If and to what extent and at what levels, however, these temporary stress effects after long-term habitual exposure can result in, or contribute to, permanent health changes, such as increased blood pressure and hypertension, is still unclear and more studies are required in this area.

A.3 Noise effects on safety

It is known that noise interference with speech and hearing in occupational situations may lead to accidents due to misunderstanding, non understanding, inability to hear warning shouts, approaching vehicles, falling objects etc. Communication while wearing hearing protectors requires special attention and there is a need for some means of assessing and describing the perception of auditory cues when hearing protectors are worn. The hearing ability of the listener also affects the level at which speech may be understood in noise. Other special cases requiring careful attention to communication of speech signals include classrooms and conference rooms.

A number of International Standards are being developed on the noise emitted by emergency vehicles, warning signals and alarms. An example of this is ISO 7731. These standards specify temporal pattern, frequency and noise level, consequently requiring detailed frequency analysis.

A.4 Effects on working efficiency

A frequently used descriptor is the equivalent continuous A-weighted sound pressure level, $L_{\text{Aeq},T}$, over an appropriate time interval T.

The effects of noise on working efficiency are dependent not only upon the quality of the noise but also upon other variables such as task and individual. It is clear that when a task depends upon auditory cues, masking of these cues by noise will interfere with the performance of the task. The hearing handicapped also require additional signal level of the auditory cues. An assessment of working efficiency must be based on individual experience and studies of particular environments.

Noise can act as a distracting stimulus, and may also affect the psycho-physiological state of the individual. Impulsive sounds may produce disruptive effects as the result of startle responses. Noise can change the alertness of an individual and can increase or decrease efficiency. Performance of tasks involving monotonous activity is not always degraded by noise. Mental activities involving vigilance, information gathering and analytical processes appear to be particularly sensitive to noise. The specific effects depend very much on the type of noise, its duration and the occupation.

There are no International Standards on this subject at present.

A.5 Annoyance/comfort/morale

Noise annoyance may be defined as a feeling of displeasure evoked by a noise. The effect of noise on annoyance, comfort and morale depends upon the physical, psychological or economic circumstances, and there are considerable differences in individual reactions to the same noise.

A number of acoustic indices have been developed to assess the relationship between exposure to noise and annoyance, among them loudness in sones or loudness level in phones, calculated from octave and one-third octave band analysis (ISO 532), and the perceived noise level, L_{PN}, calculated from one-third octave band analysis (ISO 3891, used mainly in aircraft noise assessment). The noise rating number, NR, calculated from octave-band analysis is one of many indices developed for rating the noise level in a community in order to assess their response. Other indices such as the number of specific events are also useful to characterize the environment.

Whatever acoustic scale is used to assess annoyance, it must be recognized that reactions will vary greatly due to psychosocial differences. For example, noise produced by people is generally more annoying than mechanically produced noise. Nevertheless, for both noises the equivalent continuous A-weighted sound pressure level over an appropriate period is a useful quantity for assessing annoyance, well-being and morale.

It should be noted that noise is not always perceived as detrimental. Music at work may increase morale, low level masking noise in an office may provide more privacy and reduce interference from other noises (see A.4).

ANNEX B
(informative)

EXAMPLE OF THE CALCULATION OF THE EQUIVALENT CONTINUOUS A-WEIGHTED SOUND PRESSURE LEVEL USING THE FORMULA IN 4.3.4

At a working place (mounting place) the foreman and the persons concerned estimated the different activities and their sub-intervals of time T_i. During each sub-interval of time the equivalent continous A-weighted sound pressure level $L_{\text{Aeq},Ti}$ of the characteristic noise was determined. For the four activities below, the noise exposure was determined by the noise from the adjacent work places.

Activities	T_i in min	$L_{\text{Aeq},Ti}$ in dB	$10 \lg \frac{T_i}{T} 10^{L_{\text{Aeq},Ti}/10}$ in dB
1: cutting holes	5	107	87,2
2: sawing tubes (circular saw)	285	91	88,7
3: tightening screws (electrical screwdriver)	70	98	89,6
4: marking and preparation	120	89	83

From the formula in 4.3.4, $L_{\text{Aeq,8h}}$ is calculated with

$$T = \Sigma T_i = 8\text{h}: \quad L_{\text{Aeq,8h}} = 94 \text{ dB}$$

ANNEX C
(informative)

DETERMINATION OF THE RATING LEVEL

C.1 FORMULAE FOR THE CALCULATION OF THE RATING LEVEL

The rating level for each reference time interval is calculated from the following formula:

$$(L_{\mathrm{Ar},Tr})_i = (L_{\mathrm{Aeq},Tr})_i + K_{\mathrm{T}i} + K_{\mathrm{I}i}$$

where:

T_r is the duration of the reference time interval (see C.5);

$(L_{\mathrm{Aeq},Tr})_i$ is the equivalent continuous A-weighted sound pressure level over the specified reference time interval; sample i;

$K_{\mathrm{T}i}$ is a tone adjustment applicable to the reference time interval (see C.2);

$K_{\mathrm{I}i}$ is an impulsive adjustment applicable to the ith reference time interval (see C.3).

NOTE 13 - For the purpose of this annex the reference time interval is identical with the normalizing time interval defined in 4.2.3.

If the tone or impulse characteristics are present for only a part of a reference time interval the values K_T and K_I may be adjusted in proportion to the duration or by applying the following formula:

$$(L_{\mathrm{Ar},Tr})_i = 10 \lg \frac{1}{T_r} \sum_{j=1}^{N} T_j \times 10^{((L_{\mathrm{Aeq},Tr})_j + K_j)/10} \quad \mathrm{dB}$$

where:

$(L_{\mathrm{Ar},\mathrm{Tr}})_i$ is the rating level of reference time interval i;

T_r is the duration of a reference time interval;

T_j is a sub-interval of time (see C.5);

$(L_{\mathrm{Aeq},Tr})_j$ is the equivalent continuous A-weighted sound pressure level over the time interval T_j;

K_j $= K_{\mathrm{T}j} + K_{\mathrm{I}j}$ is the sum of tone and impulse adjustment for the time interval T_j.

The result is rounded to the nearest decibel.

C.2 TONE ADJUSTMENT, K_T

If tonal components are essential characteristics of the noise within a specified time interval, an adjustment is applied for that time interval to the measured equivalent continuous A-weighted sound pressure level when calculating the rating level L_{Ar}. The value of this adjustment must be stated. Unfortunately there does not exist a simple procedure for the objective measurement of a tone adjustment K_T.

NOTE 14 - In some practical cases a prominent tone component may be detected in one-third-octave spectra if the level of a one-third-octave band exceeds the level of the adjacent bands by 5 dB or more, but generally a narrow-band frequency analysis will be required for detailed analysis of the occurrence of one or more audible tones in a noise signal.

If tonal components are clearly audible and their presence can be detected by a one-third-octave analysis the adjustment may be 5 dB to 6 dB. If the component(s) are just detectable by the observer and/or demonstrated by a narrow-band analysis a 2 dB to 3 dB adjustment may be appropriate.

C.3 IMPULSE ADJUSTMENT, K_I

If impulsiveness is an essential characteristic of the noise within a specified time interval, an adjustment is applied for this time interval to the measured equivalent continuous A-weighted sound pressure level when calculating the rating level L_{Ar}. Its value must be stated.

One method of describing the impulsiveness of the noise within a specified measurement time interval is to measure the difference between $L_{AIeq,T}$, i.e. the AI-weighted sound pressure level averaged over the time interval T, and $L_{Aeq,T}$. The sound pressure levels $L_{AIeq,T}$ and $L_{Aeq,T}$ (measured with the time-weightings I and S or F) shall be determined simultaneously.

The difference may be used as impulse adjustment: $K_I = L_{AIeq,T} - L_{Aeq,T}$.

This definition of K_I has the advantage that the measurement quantity $L_{AIeq,T}$ automatically includes the impulse adjustment into the result of the measurement. In this case the explicit statement of the impulse adjustment K_I is not required.

For noise with $K_I \leq 2$ dB the impulse adjustment can be neglected. If K_I is not determined as described above, an impulse adjustment of 3 dB or 6 dB is frequently used, depending on the prominence of the impulsiveness in the noise.

The character of the noise may also be illustrated by determination of the peak level and the number of the peaks within the specified time interval.

C.4 LONG TERM AVERAGE RATING LEVEL

If the noise exposure at a given workplace varies from day to day by more than the uncertainty related to the required class of accuracy (Annex D), the characteristic noise exposure is given by the long term average rating level:

$$L_{Ar,LT} = 10 \lg \left(\frac{1}{N} \sum_{i=1}^{N} 10^{(L_{Ar,Ti})_i/10} \right) \quad \text{dB}$$

where:

$(L_{\mathrm{Ar},T\mathrm{r}})_i$	is the rating level in the time interval number i;
T_i	is the duration of time interval i
N	is the number of reference time intervals of duration T_r.

The long term time interval must be so chosen that long term variations in the noise exposure are covered. It will frequently be of the order of magnitude of one week.

C.5 8 h RATING LEVEL, $L_{\mathrm{Ar,8h}}$

The 8 h rating level is calculated by using the method described in C.1 to C.4 with T_r = 8 h. This method applies also to those situations where $\Sigma T_j \neq T_\mathrm{r}$.

If the exposure to noise varies from day to day and if it is desired to use an average over N days, for example if an average over the weekly exposure is considered, the average 8 h rating level is calculated by using the formula:

$$(L_{\mathrm{Ar,8h}})_{\mathrm{av}} = 10 \lg \left(\frac{1}{N} \sum_{i=1}^{N} 10^{(L_{\mathrm{Ar,8h}})_i/10} \right) \ \mathrm{dB}$$

where:

$(L_{\mathrm{Ar,8h}})_i$	is the 8 h rating level of day i;
N	is the total number of days.

ANNEX D
(informative)

CLASSES OF ACCURACY FOR NOISE MEASUREMENTS

D.1 ASSESSMENT OF THE EQUIVALENT CONTINUOUS A-WEIGHTED SOUND PRESSURE LEVEL $L_{Aeq,T}$ BY SAMPLING TECHNIQUE

D.1.1 Principle

A number of uncorrelated values, $L_{Aeq,Ti}$, called here L_i, are collected during the observation period T. The estimation of $L_{Aeq,T}$ and of associated confidence limits are given below.

D.1.2 Estimation of $L_{Aeq,T}$

If n is the number of the independent samples, $L_{Aeq,T}$ is approximated by the relation:

$$L_{Aeq,T} = 10 \lg \frac{1}{n} \sum_{i=1}^{n} 10^{0,1 L_i} \text{ dB} = \bar{L} + 0,115\ s^2$$

where $\bar{L} = \frac{1}{n} \sum_{i=1}^{n} L_i$ is the arithmetic mean, in decibels, and

$$s = \sqrt{\frac{\sum_{i=1}^{n} (L_i - \bar{L})^2}{n-1}}$$ is the standard deviation, in decibels.

D.1.3 Estimation of the confidence limits

The confidence limits associated to the estimation of $L_{Aeq,T}$ are given by the relation:

$$CL = \pm \sqrt{\frac{s^2}{n} + \frac{0,026 \cdot s^4}{n-1}} \cdot t_{n-1}$$

where t_{n-1} is the Student factor for (n-1) degrees of freedom and for a chosen probability α and s is the standard deviation, in decibels

Table D.1 presents the confidence limits for a 90 % confidence interval.

Table D.1 - 90 % confidence limits, according to the number *n* of samples and the standard deviation *s* of their levels

	s											
n	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	5,5	6
5	0,5	1,0	1,5	2,0	2,6	3,3	3,9	4,7	5,5	6,4	7,4	8,4
6	0,4	0,8	1,3	1,7	2,2	2,8	3,4	4,0	4,7	5,5	6,3	7,2
7	0,4	0,7	1,1	1,6	2,0	2,5	3,0	3,6	4,2	4,9	5,6	6,4
8	0,3	0,7	1,0	1,5	1,8	2,3	2,7	3,3	3,8	4,4	5,1	5,8
9	0,3	0,6	1,0	1,3	1,7	2,1	2,5	3,0	3,5	4,1	4,7	5,3
10	0,3	0,6	0,9	1,2	1,6	2,0	2,4	2,8	3,3	3,8	4,4	5,0
12	0,3	0,5	0,8	1,1	1,4	1,7	2,1	2,5	2,9	3,4	3,9	4,4
14	0,2	0,5	0,7	1,0	1,3	1,6	1,9	2,3	2,7	3,1	3,5	4,0
16	0,2	0,4	0,7	0,9	1,2	1,5	1,8	2,1	2,5	2,9	3,3	3,7
18	0,2	0,4	0,6	0,9	1,1	1,4	1,7	2,0	2,3	2,7	3,1	3,5
20	0,2	0,4	0,6	0,8	1,0	1,3	1,6	1,9	2,2	2,5	2,9	3,3
25	0,2	0,3	0,5	0,7	0,9	1,1	1,4	1,6	1,9	2,2	2,5	2,9
30	0,2	0,3	0,5	0,7	0,8	1,0	1,3	1,5	1,7	2,0	2,3	2,6

D.2 PRECISION OF MEASUREMENTS

The total uncertainty of the measurement (ε) takes into consideration the uncertainty due to the instrumentation (u_i) and this due to the procedure used.

D.2.1 Uncertainty due to the instrumentation: u_i

This uncertainty (90 % confidence level) is estimated in table D.2, according to the type of the instrumentation used.

Table D2: Uncertainty u_i due to the instrumentation

1 Sound level meter according to IEC 651	Type 1	Type 2	Type 3
2 Integrating sound level meter according to IEC 804	Type 1	Type 2	Type 3
3 Calibrator IEC 942	Type 0	Type 1	Type 2
4 Uncertainty u_i	negligible	1 dB	1,5 dB

NOTES:

15 - This uncertainty is estimated for conventional workshop noises having a wideband frequency spectrum limited to 8 kHz and whose direction of incidence is known.

16 - If Type 1 sound level meter is used, the uncertainty can be considered as negligible.

D.2.2 Uncertainty due to sampling (if used): u_s

The uncertainty due to the sampling (u_s) is given as the 90 % confidence limits given in table D.1 or using the formula in D.1.3 with α = 0,1.

D.2.3 Total uncertainty of the measurement: ε

- If the measurement is extended over the total time interval T, the total uncertainty ε shall be considered equal to u_i given in table D.2.

- If sampling is used, the total uncertainty ε shall be considered as the root sum square on u_i and u_s:

$$\epsilon = \sqrt{u_i^2 + u_s^2}$$

- If no sampling is used but if the measurement does not cover the total time interval T (e.g.: measurements made during specific time intervals containing typical noise), the total uncertainty ε is given in table D.3 according to the class of the instrumentation used.

Table D.3: Total uncertainty ε, if no sampling is used, nor measurement during the total period T

1 Sound level meter according to IEC 651	Type 1	Type 2	Type 3
2 Integrating sound level meter according to IEC 804	Type 1	Type 2	Type 3
3 Calibrator IEC 942	Type 0	Type 1	Type 2
4 Uncertainty	1,5 dB	3 dB	8 dB

According to the total uncertainty ε, three measurement precision classes are defined, presented in table D.4.

Table D.4: Measurement precision classes

Total Uncertainty ε in decibels	$\varepsilon \leq 1,5$	$1,5 < \varepsilon \leq 3$	$3 < \varepsilon \leq 8$
Measurement precision class	1	2	3
Designation	Reference measurement	Engineering measurement	Survey measurement