Measuring Occupational Noise

How to do noise surveys, calculate exposure to noise, and analyze and report the results

WORK SAFE BC

About WorkSafeBC

At WorkSafeBC, we're dedicated to promoting safe and healthy workplaces across B.C. We partner with workers and employers to save lives and prevent injury, disease, and disability. When work-related injuries or diseases occur, we provide compensation and support injured workers in their recovery, rehabilitation, and safe return to work. We also provide no-fault insurance and work diligently to sustain our workers' compensation system for today and future generations. We're honoured to serve the workers and employers in our province.

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We provide information and assistance with health and safety issues in the workplace.

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If you have questions about workplace health and safety or the Occupational Health and Safety Regulation, call during our office hours (8:05 a.m. to 4:30 p.m.) to speak to a WorkSafeBC officer.

If you're in the Lower Mainland, call 604.276.3100. Elsewhere in Canada, call toll-free at 1.888.621.7233 (621.SAFE).

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Foreword

This is the fourth edition of this publication, which was first printed in 1996. This edition combines two publications that were previously separate: *Occupational Noise Surveys* and *Basic Noise Calculations*.

This revision reflects the latest editions of international and national standards, including CSA Standard Z107.56-18, *Measurement of Noise Exposure* and CSA Standard Z1007-16, *Hearing Loss Prevention Program (HLPP) Management*. (CSA Group, formerly the Canadian Standards Association, is an organization that issues international industry standards.)

Health and safety resources

All employers — no matter how big or small — are responsible for the health and safety of their workers. To help support the health and safety needs of small and micro businesses, a wide range of information and resources are available on worksafebc.com, and through our partnership with Small Business BC.

Many of our resources are available to order in hard copy from the WorkSafeBC Store at worksafebcstore.com. In addition to books, you'll find DVDs, posters, and brochures. If you have any questions about placing an order online, please contact a customer service representative at 604.232.9704, or toll-free at 1.866.319.9704.

You can find a web book of this manual online at worksafebc.com/smallbusiness.

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Introduction

Requirements for professional noise surveyors

Professional noise surveyors must be familiar with the requirements in Part 7 of the Regulation and in CSA Standard Z107.56-18, *Measurement of Noise Exposure* (which is updated from time to time).

Sources close to the ear

This manual doesn't cover measurements of noise exposure from sources close to the ear, such as radios or headphones. If these exist in your workplace, the surveyor needs to understand the unique requirements of such measurements. For more information, see CSA Standard Z107.56-18.

Calculating noise exposure can be difficult if you are unfamiliar with decibels (dB) and logarithmic scales. Often the best way to get accurate noise measurements is to hire a professional to conduct an occupational noise-exposure survey. Currently, however, you don't need certification to conduct noise surveys in British Columbia. This can make it difficult for employers to know whether a professional they hire or a noise-survey report they purchase meets the requirements of the Occupational Health and Safety Regulation (specifically Part 7, "Noise, Vibration, Radiation and Temperature").

Who should read this manual?

This manual is for employers who want to conduct a noise survey on their own and employers who have decided they need to hire a professional noise surveyor but want to make sure the person they're hiring is qualified to do the work.

If you have some technical knowledge and familiarity with noise measurement, you may be able to do your own noise survey after reading this manual. If you decide you need a consultant's help, this manual gives you some background to discuss your needs and the services a competent professional should provide.

This manual may also be useful to WorkSafeBC officers and others who want a refresher on the noise-survey process and the formulas involved in noise calculations.

Why do a noise survey?

The main reasons to do an occupational noise survey are as follows:

- To evaluate the noise environment and identify workers who are exposed to noise levels that are harmful to their hearing
- To comply with the Regulation
- To help come up with solutions and strategies, which may include a hearing-loss prevention program (also called a hearing conservation program) and noise control
- To see how effective the noise-control methods are

Why are noise calculations necessary?

Employers must measure noise exposure if workers could be exposed to hazardous noise or if you already know that the worker could be exposed to noise levels greater than 82 dBA L_{ex}. (See the "Terms" section, pages 6–8, for a description of dBA and L_{ex}.) There are some exemptions; see section 7.4 of the Regulation.

Often, however, measurements alone aren't enough to make an accurate estimate of exposure for a full day, week, or month. You may need to combine your measurements with other data or make corrections to the results. (For example, there are different workshift lengths, and various artifacts can affect the measurement.)

You can do these calculations using basic arithmetic and by using the formulas, charts, and tables in Part 3 and the appendixes of this manual. When looking at noise measurements for a group of workers, you'll also need to calculate standard deviation. Scientific calculators, business calculators, or Excel spreadsheets are useful for this.

How is this manual organized?

Part 1: The basics defines basic terms and talks about initial (or "walk-through") noise surveys and formal surveys.

Part 2: Conducting the measurements shows you how to meet the requirements of the Regulation. It includes how to do an occupational noise survey, what noise measurements you need to take, and how to make sure they're accurate and valid.

Part 3: Noise calculations for analyzing noise exposure gives common examples of noise calculations that determine whether a worker's exposure is above the maximum limit (the criterion level). Some technical knowledge is useful to analyze the results of the noise surveys and to do the calculations.

Part 4: Reporting the results explains how to prepare a report once you've taken noise measurements.

The **appendixes** include both a graph and a table that can help you calculate noise exposure (specifically noise dose and L_{ex}).

This manual does not replace the Occupational Health and Safety Regulation

This manual explains the basic requirements for measuring and calculating workplace noise levels. You should also refer to the Regulation to be sure you're meeting your legal responsibilities for workplace health and safety. You can find a searchable version of the Regulation and its accompanying Guidelines at worksafebc.com/law-policy.

In this manual, the word *must* refers to a requirement that's specified in the Regulation. The word *should* refers to a recommended action that's not required by the Regulation but will improve workplace safety.

Part 1: The basics

Terms

Decibels and frequency weighting (dBA and dBC)

Sound pressure, which is perceived as loudness, is measured in decibels (dB). Noise-measuring instruments, including integrating sound level meters and noise dosimeters, detect sound pressure.

These instruments have electronic networks that can imitate the frequency response of the ear. The most commonly used network is the A-weighting network, which measures sound levels in dBA, also written as dB(A).

When measuring peak sound levels, the C-weighting network is used. Sound levels are expressed as dBC.

With occupational noise, we're more concerned with workers' noise exposure rather than just the noise levels in the workplace. Generally, the greater the noise exposure, the greater the risk of hearing loss.

We use special terms for noise exposure to reflect the hearing-loss hazard. You'll also find these terms in the Regulation:

- Daily energy-averaged sound level (or L_{ex}, in dBA)
- Peak sound level (in dBC)

5 dB exchange rate

WorkSafeBC doesn't use the 5 dB exchange rate, which is used almost exclusively in the United States. With this exchange rate, exposure time needs to be cut in half for each 5 dB increase. This exchange rate gives noise exposure results that are significantly lower than those resulting from the 3 dB exchange rate.

3 dB exchange rate

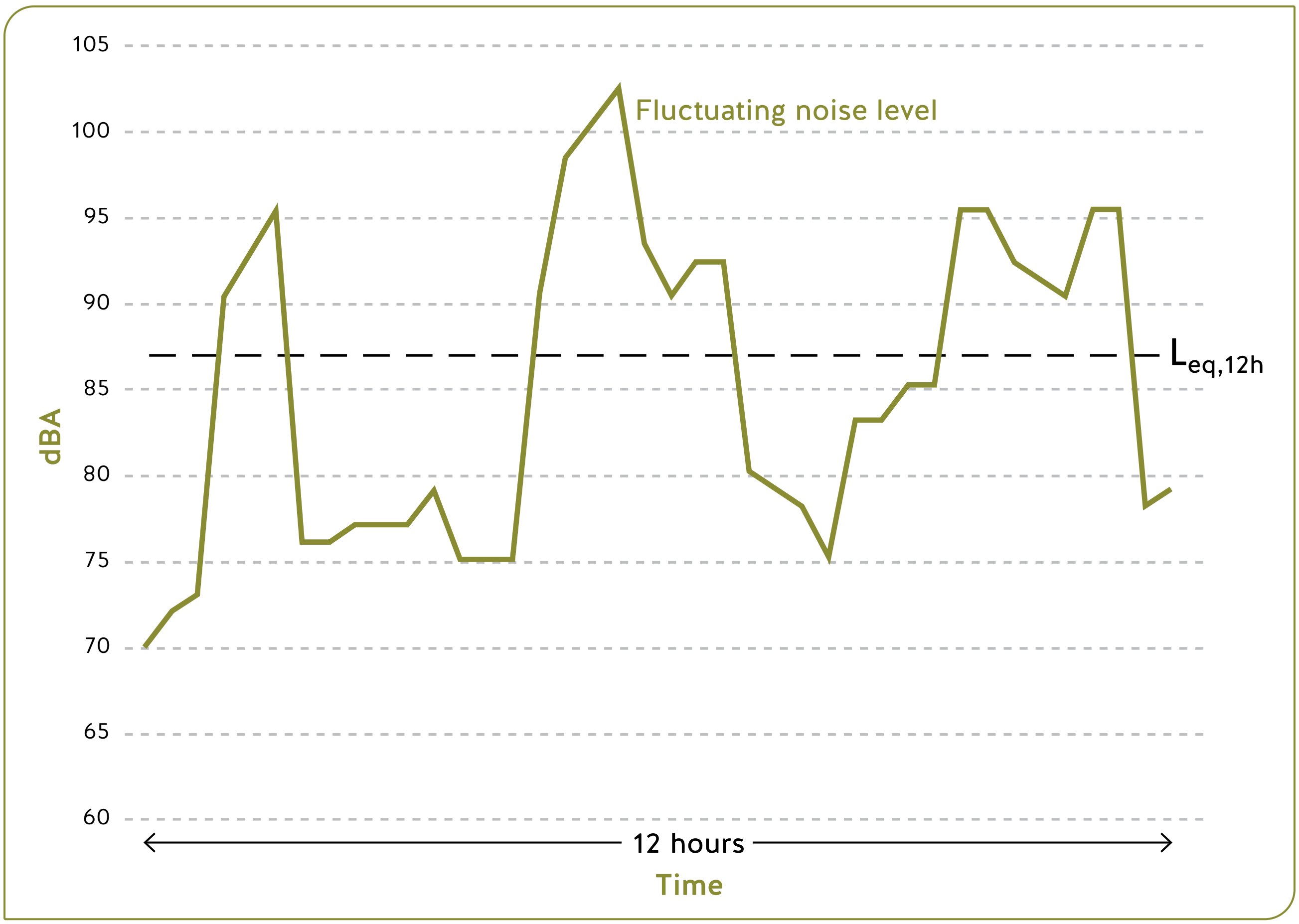
WorkSafeBC, along with most other provinces and countries in the world, uses the 3 dB exchange rate to determine allowable sound levels for exposures other than 8 hours a day. The 3 dB exchange rate is also known as the equal energy principle.

With this exchange rate, whenever a sound increases by 3 dB, we say that the intensity of the sound has doubled. You need to cut the exposure time in half to maintain an equivalent amount of noise exposure. For example, an exposure of 85 dBA for 8 hours is equal to 88 dBA for 4 hours. On the other hand, if a sound level decreases by 3 dB, you'd double the exposure time to get the same dose of noise energy.

Equivalent sound level ($L_{eq,t}$)

Because sound is often a complex and fluctuating signal (see the figure below), the sound level needs to be averaged over a certain amount of time. $L_{eq,t}$ is the average sound level over the duration of the measurement. The *eq* is for "equivalent," and *t* is the length of time over which the sound is measured. (*L_{eq}* is pronounced by saying the letters *L-E-Q*.) For example, 89 dBA $L_{eq,10s}$ is an average level of 89 dBA over a 10-second measurement. $L_{eq,24h}$ is the average level of a 24-hour measurement.

Example of $L_{eq,t}$ derived from fluctuating noise over a 12-hour period



Noise-exposure level (L_{ex})

Noise-exposure level is written as L_{ex}, which is pronounced by saying the three letters *L-E-X.* The *ex* is for "exposure."

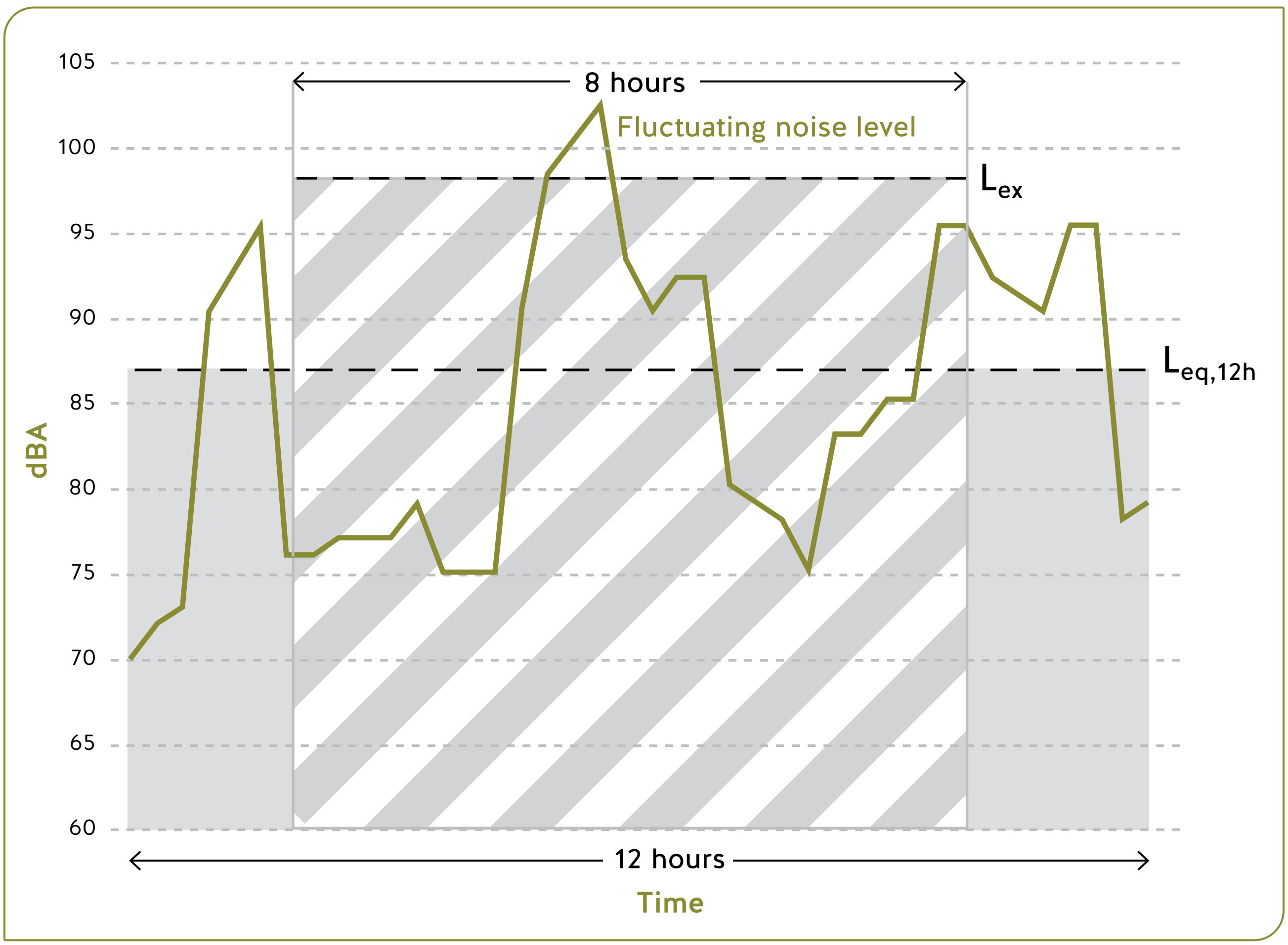
L_{ex} is the $L_{eq,t}$ sound level corrected to 8 hours. Historically, 8 hours has been a typical workshift. An L_{ex} measurement is equal to $L_{eq,8h}$ — that is, equal to a measurement done over an 8-hour period.

You can calculate L_{ex} from a noise measurement of any duration. The allowable limit in the Regulation is 85 dBA L_{ex}.

We use L_{ex} because many workers don't typically work 8-hour shifts. For those workers, the measured $L_{eq,t}$ needs to be "corrected" to an 8-hour shift pattern to compare it to noise measurements of other durations and to make sure it's under the 85 dBA L_{ex} limit.

The graph below shows a 12-hour L_{eq} measurement compared to its L_{ex} (8-hour) equivalent. The wider block of 12 hours and the narrower block of 8 hours contain the same amount of sound energy. The L_{ex} of a 12-hour shift — or any shift longer than 8 hours — will always be greater than the measured $L_{eq,t}$. The L_{ex} of shifts shorter than 8 hours will always be less than the measured $L_{eq,t}$.

A 12-hour L_{eq} measurement and its L_{ex} (8-hour) equivalent



Maximum allowable exposure times

The exposure times in the following table (rounded to the nearest whole number) are based on the 3 dB exchange rate. The values in each row are all equal to the Regulation limit of 85 dBA L_{ex}.

Duration of exposure	Equivalent sound level, $L_{eq,t}$ (dBA)
16 h	82
12 h	84
8 h	85
4 h	88
2 h	91
1 h	94
30 min	97
15 min	100
7 min 30 s	103
3 min 45 s	106
1 min 50 s	109
1 min	112
30 s	115

Dosimeter

An instrument that a worker can wear for all or part of a workshift to measure that worker's noise exposure in $L_{eq,t}$ or L_{ex}.

Sound level meter (or integrating sound level meter)

An instrument, usually handheld or placed in an environment, that measures $L_{eq,t}$.

Noise dose

Noise dose is the noise exposure expressed as a percentage, where a 100% dose is the maximum acceptable amount. That is, a worker exposed to the daily limit of L_{ex} = 85 dBA (equivalent to 8 hours a day) receives a noise dose of 100%. The term *noise dose* isn't in the Regulation, but some people still use it to quantify a worker's noise exposure.

As with L_{ex}, it can be easier to compare noise doses — for example, comparing 160% to 100%. Experiencing 87 dBA for 8 hours is 160%, and experiencing 85 dBA for 8 hours is the maximum acceptable noise dose, i.e., 100%. Also, noise calculations can be simpler. The percentages can simply be added, whereas sound levels in decibels double every 3 dB.

In the table showing maximum allowable exposure times (see page 9), the values in each row are all equivalent — they have the same noise dose of 100%.

For more information on noise-dose values, see the appendixes.

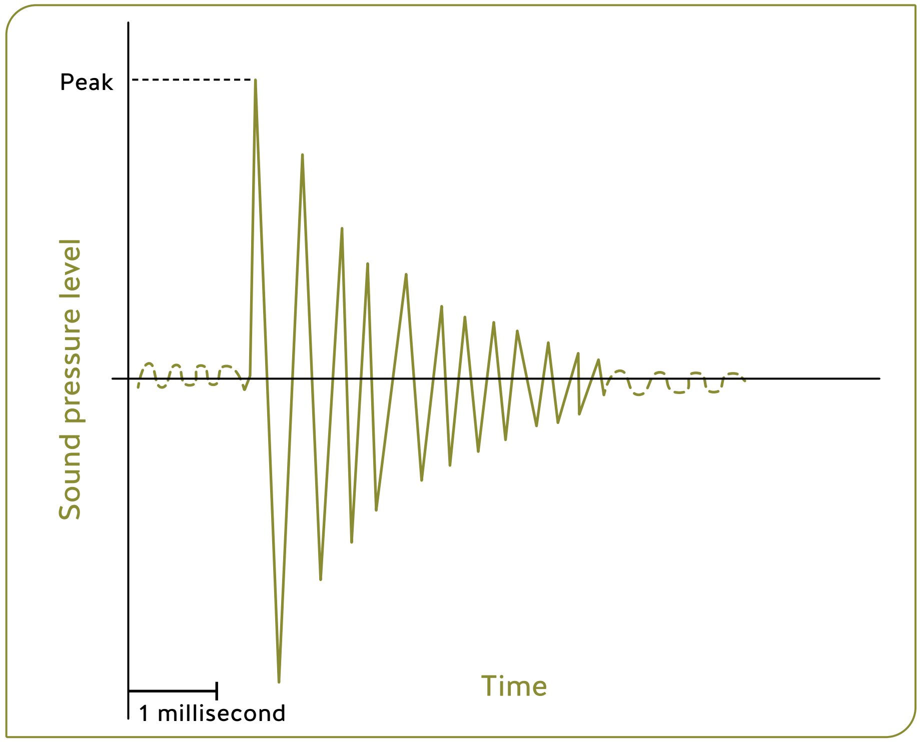
Peak level

Peak level is the maximum sound level measured when the instrument is set to the Peak response time and the C-weighting network. You must measure the peak sound level in situations where impact or impulse noises are a hearing hazard, as specified in Part 7 of the Regulation. The maximum allowable peak level is 140 dBC.

Impact noises happen most commonly when objects collide — for example, when forming metal or handling materials. Impulse noises include discharges from pneumatic cylinders and powder-actuated tools, as well as explosions.

The following graph shows how acoustic pressure from an impact can vary over time.

Acoustic pressure from an impact, with the peak measured at its highest point



You should only measure noise peaks with a noise-measuring instrument that has a Peak response time. The Impulse setting on some sound level meters isn't the same as Peak. Don't use the Impulse setting for peak-noise measurements.

Sample duration

A noise measurement should represent all the noise a worker is exposed to. Because it's only feasible to take samples, you'll need to figure out the appropriate sample duration.

Some jobs have stable noise levels and may only require measurement for an hour or two. Jobs where the noise level fluctuates a lot may require measurement for a full shift. In some cases, even a full day of monitoring isn't enough to accurately represent a worker's exposure.

If the work activity isn't typical for a shift, you may need either more measurements so they're more representative or corrections to your measurements. You'll find corrections for some situations in Part 3 — for example, see "Determine individual L_{ex} when noise exposure varies from day to day (energy-average)," page 42. Some situations are beyond this manual's scope.

Initial noise surveys

Not all workplaces need a formal noise survey. In some cases, an initial noise survey (also known as a walk-through survey) will provide enough information to determine whether you need additional measurements.

With an initial survey, you can find out the basic sound levels and the nature of the workplace noise. You can also find out if you need a more comprehensive formal noise survey (see pages 14–15).

Think of the initial survey as an inexpensive "red-flagging" exercise. Initial-survey reports should be concise but clear. You can use a summary table (see pages 46–47) as an initial report.

An initial noise survey will help you determine basic sound levels in your workplace.

What should you look for in an initial noise survey?

One way to start an initial survey is to walk through the workplace to get a sense of the noise. What are the types of noise — are they steady, intermittent, or impulse noises? The walk-through will also help you identify quiet areas, such as offices, that you won't need to consider further. You could also note the number of workers, the work patterns, the break times, and the shift changes. There could also be unusual conditions that could affect noise levels, such as a larger production level than usual or seasonal changes.

You must do a follow-up survey whenever you introduce, remove, or modify significant noise-making machinery, or when walls are added or removed.

Who can do initial noise surveys?

Even someone with little training can do an initial noise survey. It's a good idea to use a relatively inexpensive sound level meter or even a smartphone app (see "Smartphone apps," page 20). These can help you decide if you need to do a formal survey with a more sophisticated meter.

The following simple tests will give you a rough idea of sound levels. If you have to shout to be clearly understood by someone who is:

- 1 m (3 ft.) away (about an arm's length), the sound level is probably greater than 82 dBA
- 0.5 m (1½ ft.) away, the sound level is probably greater than 88 dBA

Formal noise surveys

Does the initial survey suggest that the noise-exposure level (L_{ex}) is likely greater than 85 dBA? If so, you should follow up with a formal noise survey. You should also do a formal survey in the following situations:

- You need more detailed information for methods to reduce noise exposure.
- You need more detailed information to help choose hearing protection.
- Peak sound levels are greater than 140 dBA (and they're genuine and not artifacts; see page 27).

Who can do formal noise surveys?

Noise surveyors should have the right equipment, know what to measure, and know how to interpret the resulting data.

Noise surveyors need to be familiar with the limitations and proper use of their noise-measuring instruments. This includes doing a field calibration and selecting the right settings for the response time, exchange rate, and weighting network. Surveyors should understand the relationship between intensity and duration, and the meaning of *exchange rate*. An increase in noise level can be "exchanged" against a decrease in exposure, resulting in the same exposure level (or noise dose). See "3 dB exchange rate," page 6.

Interpreting data is the most difficult part of the survey process. If the interpretation is flawed and the survey incorrectly identifies the exposure as acceptable, the worker's hearing could be at risk. On the other hand, if the survey incorrectly identifies the worker as being overexposed to noise, an employer could needlessly spend money trying to comply with the Regulation.

If you understand the information in this manual and have the appropriate equipment, you can tackle the job yourself. But if you're not going to conduct the survey yourself, you may still find this guide helpful for talking with a potential noise surveyor about your needs.

If you're looking to hire a noise surveyor, check the candidate's qualifications and references. Consider giving this manual to potential surveyors and then asking if they understand it and can comply with the requirements. You can also ask to see surveys they’ve prepared for other clients, a list of courses they’ve attended, and if they’re members of any relevant associations (such as the Canadian Registration Board of Occupational Hygienists or the American Industrial Hygiene Association).

Basic steps of a noise survey

Here are the basic steps for a formal occupational noise survey:

1. Determine the measurement conditions (see page 18 in Part 2).
2. Select a noise-measuring instrument (see pages 19–23 in Part 2).
3. Collect the data (see pages 24–29 in Part 2).
4. Record important details (see page 30 in Part 2).
5. Validate the measurements (see pages 25–29 in Part 2). Collect more data if necessary (repeat steps 3–5).
6. Calculate and analyze the results (see Part 3 and page 45 in Part 4).
7. Create a report (see pages 44–45 in Part 4).

Part 2: Conducting the measurements

Determine measurement conditions

Tell workers the purpose of the measurement

Let workers know that the survey isn't meant to infringe on their privacy. Sound level meters and noise dosimeters don't record speech or track location and motion. They just measure each worker's noise-exposure levels.

When determining measurement conditions, consider the acoustic environment, the work duties, and how to get a representative sample. Work activities and noise sources should be the same during measurement as in a typical workshift. The measurement should be long enough to be representative.

You can get the noise-exposure level of a worker by placing a dosimeter on that worker or on members of the group that worker belongs to.

If workers are involved in several different activities during a shift, you may need to measure noise levels for each activity and then calculate the overall exposure (see Part 3, "Noise calculations for analyzing noise exposure").

If the noise exposure changes over time (for example, because of seasonal or product variations), you'll need to repeat the measurements. You may need to combine results using the equations in the section "Calculate L_{ex} from several $L_{eq,t}$ measurements," pages 36–37.

It's important to decide which approach will give you the most representative sample. If you're going to conduct group measurements, see "Group sampling," page 29.

Select a noise-measuring instrument

Compare results from dosimeters and sound level meters

Dosimeters and integrating sound level meters can complement each other. You can use both types of instruments and compare the results to confirm your measurements.

Sound level meters and dosimeters

Noise-measuring instruments for a noise survey must meet the requirements of ANSI Standard S1.25-1991, *Specification for Personal Noise Dosimeters* (as per section 7.3 of the Regulation). This means that meters must be Class 2 or better. If a meter has no classification (or is an old Class 3), it isn't recognized as a noise-measuring instrument and must not be used for a formal noise survey. If in doubt, consult with the manufacturer.

You can use either a sound level meter or a dosimeter for an occupational noise survey. Sound level meters are handheld devices that can also be placed in a specific location. Dosimeters are worn by workers to see how exposures vary as they move around the workplace during a shift.

Sound level meters are typically used for short-term measurements of an area or work activity. Dosimeters are most useful when the work being measured can't be easily divided into discrete activities. They're also useful when the noise surveyor can't accompany the worker or when the work pattern is unpredictable.

Workers wear noise dosimeters over the shoulder or on the collar.

Requirements for noise-measuring instruments

To comply with CSA Standard Z107.56-18 and the Regulation, noise-measuring instruments must have the following features:

- An A-weighting network.
- At least a Class 2 tolerance.
- A crest factor capability of at least 30 dB measured at mid-range.
- A minimum dynamic range of 50 dB.
- A threshold level that can be set at 75 dB or lower. (Typically, during measurements the threshold should be set to 75 dB or Off.)

Some of these terms are described in more detail below.

If you can set the criterion level (the maximum noise limit), select 85 dBA to follow the exposure limit specified in the Regulation.

Smartphone apps

In most cases, smartphone apps aren't a substitute for sound level meters or dosimeters. Smartphone microphones and apps vary in accuracy and can't be calibrated properly.* They can, however, be used to show that more sound level testing is required, similar to area and spot measurements for the initial survey.

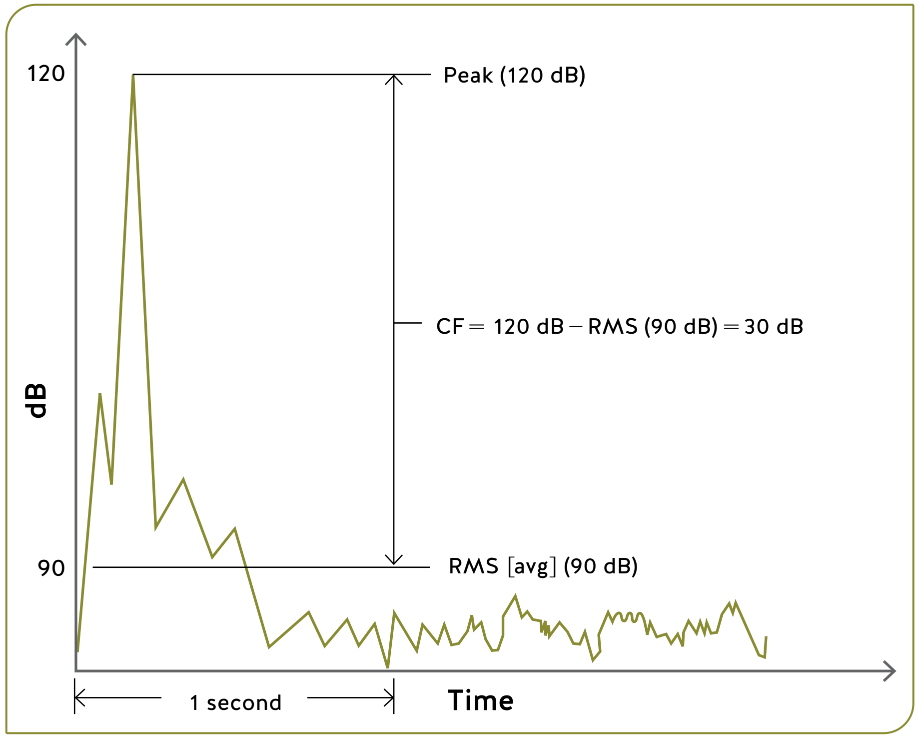
It's best to assume that the measurement has a large margin of error, as much as ±10 dB. This means that if a smartphone app measures 76 dBA, you should conduct measurements with a calibrated sound level meter. You may need to start a hearing conservation program.

* You can use a smartphone as a Class 2 sound level meter if it has a properly calibrated external microphone and the NIOSH (the National Institute for Occupational Safety and Health) sound level meter app. The NIOSH app is available only for iOS devices. For more information on meter classifications, see "Tolerance classification," page 22.

Crest factor

The difference in sound-pressure levels, in decibels, between the peak sound level and the average level measured over the same period of time. The crest factor indicates an instrument's ability to handle or process impact or impulse noises. The instrument manufacturer should specify the crest factor. A crest factor capability of at least 30 dB is recommended.

A measurement showing the crest factor (CF), based on a peak of 120 dB and average sound level of 90 dB



Criterion level (L_c)

The average sound level allowed over an 8-hour workshift (or equivalent). The criterion level is the exposure limit, which the Regulation specifies as 85 dBA over 8 hours, or 85 dBA L_{ex}. For dosimeters, the criterion level is the steady sound level at which a noise dosimeter will read 100% noise dose after an 8-hour exposure.

Dynamic range

The range of sound-pressure levels, in decibels, over which an instrument will operate according to the instrument's tolerance classification.

Instrument response time (or time constant)

The time it takes an instrument to register an input noise signal and provide a readout. The three response times and corresponding time constants typically available on dosimeters and sound level meters are Slow (1 second), Fast (125 milliseconds), and Peak (50 microseconds).

Overload

Occurs when the input noise level exceeds the instrument's range.

Threshold level

The sound level above which the noise dosimeter collects noise measurements, which are used to calculate the average noise level.

In other words, the level below which the instrument doesn't measure sound. The threshold level must be set at least 10 dB below the criterion level (therefore, between 0 and 75 dB, according to the Regulation). Also known as the cut-off level.

Tolerance classification

The class number tells you the overall precision of a sound level meter or noise dosimeter. To qualify for a certain class, the various parts of the instrument, such as the microphone, display, and weighting network, must meet standard specifications. Meters are classified as follows:

- **Class 0** meters are the most accurate. They have stricter tolerances (a lower acceptable level of error) than Class 1 meters.
- **Class 1** meters are used for precision measurements and research.
- **Class 2** meters are general-purpose meters.
- **Class 3** meters are the least accurate and are only useful for screening purposes.

CSA Standard Z107.56-18 requires the use of a meter that is Class 2 or better.

Classification is determined by national and international standards. Meters are sometimes marked as complying with standards. CSA Standard Z107.56-18 refers to the following:

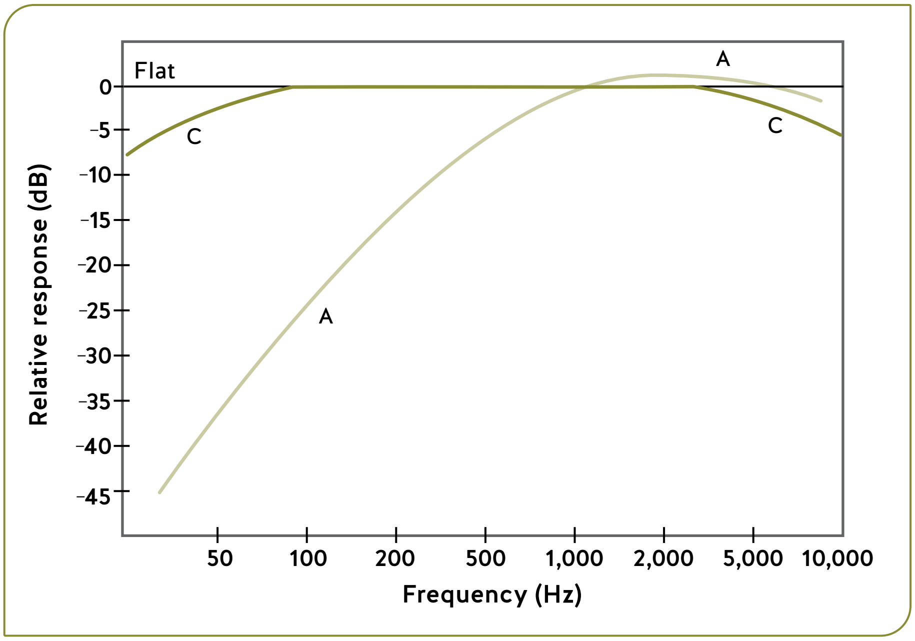
- ANSI Standard S1.25-1991 (R2017), *Specification for Personal Noise Dosimeters*
- ANSI Standard S1.4-1983 (R2006), *Specification for Sound Level Meters*
- IEC Standard 61672-1 (2014), *Electroacoustics – Sound Level Meters – Part 1: Specifications*
- IEC Standard 61672-2 (2014), *Electroacoustics – Sound Level Meters – Part 2: Pattern Evaluation Tests*
- British Standard EN 61252:1997, *Electroacoustics – Specifications for Personal Sound Exposure Meters*

Weighting network

Used to discriminate (include and exclude) different noise frequencies in a noise measurement. For example, the A-weighting network corresponds to the frequency response of the human ear. The C-weighting network is for peak measurements. It includes more low frequency noise and represents how the ear receives noise at high levels.

The following graph shows the filters for A and C weightings. A zero weighting (flat, or unweighted) would capture energy from all frequencies, while A weighting filters out low frequencies.

Standard weighted networks



Collect data

Setting up the instrument

Before you conduct measurements, select the appropriate settings for the sound level meter or dosimeter. Make sure the batteries have enough charge for the measurement duration.

Use protective devices, such as windshields, dust covers, or waterproof cases, when necessary.

Calibration

Meters must be calibrated before and after a survey.

It's important to calibrate noise-measuring equipment to make sure it's working properly and recording measurements accurately.

Field calibration
Field calibration is when you calibrate equipment with an acoustic calibrator. Follow the manufacturer's recommended procedure. Most field calibrators generate a noise signal of 114.0 dBA at 1,000 Hz. Do a field calibration before and after every noise survey. If it differs by more than 0.5 dB, you should consider the measurement suspect and reject it.

Factory calibration
Factory calibration is a complete calibration of the measuring equipment, including the acoustic calibrator used for field calibrations. Factory calibrations must be done in a properly equipped and accredited laboratory, either annually or as suggested by the manufacturer.

Using a dosimeter for personal measurements

Follow these guidelines for fitting a dosimeter:

- Position the microphone on the outside edge of the worker's shoulder.
- Follow the manufacturer's instructions for adjusting the microphone for the flattest frequency response.
- Make sure the microphone isn't blocked or covered.
- If the dosimeter has a microphone cable, fasten it securely so it won't affect the worker's safety.
- Secure the main body of the dosimeter to the worker's clothing (for example, in a pocket or in a pouch secured to a belt).
- Turn on the dosimeter only after it's securely positioned to avoid collecting noise during the fitting.

Using a sound level meter for personal measurements

Position the microphone in the worker's hearing zone, within 0.5 m (1½ ft.) of the outside edge of the worker's shoulder. If the worker is mobile, move the microphone with the worker. Avoid measuring within 1 m (3 ft.) of large noise-emitting sources or reflecting surfaces. Metal and tile are examples of reflecting surfaces. Anything that reflects light will also reflect sound.

Standing waves

A standing wave can occur when the noise being measured includes tones that consist of a single frequency. Tonal sound waves can interfere with each other and cause areas that have consistently higher or lower sound intensity. You know there's a standing wave when there are variations in sound level within the worker's hearing zone.

You can minimize a standing wave's effect by moving the microphone through the space likely to be occupied by the worker's head. When a worker wears a dosimeter, standing waves are less of an issue because workers typically move around while working.

Recognizing and evaluating peaks

As mentioned previously, a single peak level greater than 140 dBC would be an overexposure. You need to make sure that peaks are genuine. You can confirm peaks by measuring them directly with a peak-reading sound meter during exposure. Genuine peak levels greater than 140 dBC are rare, especially when the L_{ex} is less than 85 dBA.

High peak sound levels (130 dBA or more) during noise dosimetry can result from non-acoustic events, such as tapping the microphone. You need to identify these events, also known as artifacts (see pages 27–28). Otherwise, they can lead to workers being placed in comprehensive hearing conservation programs for hearing hazards that don't exist, as the noise may actually be below 85 dBA L_{ex}.

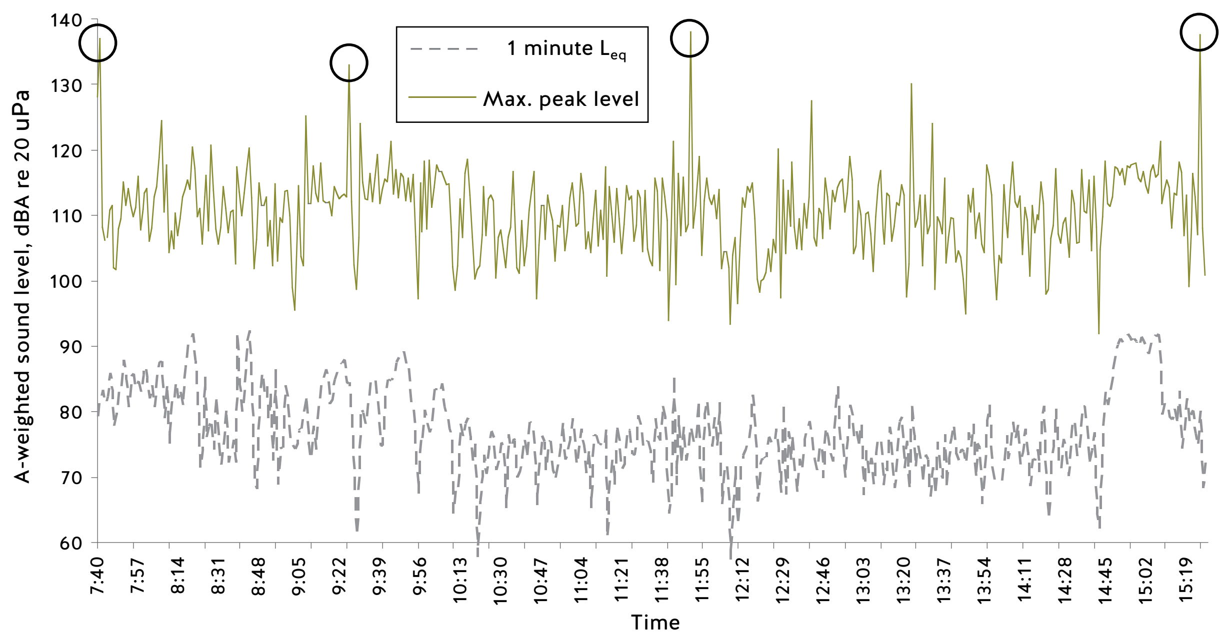
Typical high-level peaks include unsilenced pneumatic nail guns (130–135 dBC), shotgun noise (about 145 dBC), and rifle fire (150–160 dBC). Workers will certainly notice such peak noise levels if they're of genuine acoustic origin (especially when the L_{ex} is less than 85 dBA).

Surveyors should investigate high peak levels that haven't been witnessed. However, if there are no obvious sources of impact or impulse noise in the workplace, peak sound levels greater than about 130 dBC should be noted but can reasonably be assumed to be artifacts. You can ignore these peaks and remove them from your calculations in the following situations:

- The noise-measuring instrument detects fewer than 30 of these events in a shift, and the surveyor has not witnessed, investigated, and verified the events with a sound level meter equipped with a peak detector.
- The peaks occur at the beginning of the sample period while fitting the worker with the instrument or shortly after as the worker gets used to wearing it.
- The peaks occur near the end of the sample period while removing the instrument from the worker or just before switch-off.
- The peaks occur near the beginning or end of a washroom, coffee, or lunch break. Accidental high peaks often occur during these times.
- The surveyor has a reasonable suspicion that the worker has tampered with the instrument, deliberately or accidentally.

When you encounter peak measurements such as the ones circled in the following graph, ask yourself whether they are the result of perceived noise events. If they aren't, they are most likely artifacts, and you should remove them from your calculations.

Data logging dosimeter printout with peak artifacts



Controlling artifacts

You can avoid some artifacts by doing the following:

- See if the worker is likely to put on or remove personal protective equipment or clothing, such as a jacket.
- Switch on the dosimeter only after fitting it to the worker.
- Switch off the dosimeter before removing it from the worker.
- Use the dosimeter's "auto" function to start sampling 15 minutes after fitting and end sampling before retrieving it.

Artifacts

When tapped or rubbed near its microphone, a dosimeter can register high peak sound levels. These non-acoustic events are called *artifacts* and can occur when a surveyor fits or removes a dosimeter, for example. Artifacts are relatively rare, but if they aren't recognized they can lead to a wrong conclusion.

When you retrieve a dosimeter, it's a good idea to immediately see if the $L_{eq,t}$ and maximum peak levels appear reasonable before going further. If the dosimeter has recorded a peak greater than 140 dBC, try to identify the noise source. Does it happen daily? The worker being surveyed may be able to help.

When you're confident that the measurements represent the worker's noise exposure, you'll likely need to do some calculations. See Part 3, "Noise calculations for analyzing noise exposure."

Hints for collecting data

Here are some more things to consider when collecting data:

- If the worker took off the dosimeter at the end of the measurement without your supervision, check to see if it was left on. There have been instances of "exceedance" being traced to evening office cleaners bumping a dosimeter that a worker had left running on a desk.
- If the difference between the peak sound level and the $L_{eq,1min}$ is greater than 40 dB, be particularly suspicious and investigate.
- Artifact events may go unnoticed by workers, who will then report that all the measured noise was typical.
- If genuine intense peaks aren't typical of daily exposure, you can ignore them. Remember, you're looking for a representative measurement.
- Microphones placed close to workers' mouths can collect their speech and raise the L_{eq} above 85 dBA. If this happens, put the microphone at the edge of the worker's shoulder. This is especially important if the sound level is close to the criterion level of 85 dBA.
- Noise dosimetry (measurements taken with a dosimeter and not a sound level meter) isn't suitable for measuring peak sound levels because the surveyor isn't there for most of the measurement time.

When to repeat measurements

The measurement duration should be long enough to represent the noise-exposure level. If a single measurement is within 6 dB of the criterion level (from 79 to 91 dBA), you should repeat it or get a comparable measurement.

If a worker's job duties are similar throughout a shift, you can take two measurements on the same day — for example, in the morning and the afternoon. If the second measurement is within 2 dB of the first one, calculate the average using arithmetic. If it's more than 87 dB or less than 83 dB, you can safely say it's above or below the criterion level, and you don't need further measurements.

Otherwise, you should take more measurements. To see how many more you need, see "Sampling method and how to calculate exposure from repeated measurements or for a group," pages 60–63.

The calculation uses mean and standard deviation. It will also help you calculate the certainty or uncertainty of the measurement.

In some cases, the noise exposure changes over time because of variations in season or activity levels. Repeat the measurements to get samples from the different times. Again, see the "Sampling method" section to see how many measurements to take. To combine the results, see "Calculate L_{ex} from several $L_{eq,t}$ measurements," pages 36–37.

Measurements over several days

The above may not apply because the measurements over a single shift vary too much. If so, do one of the following:

- Take measurements over several shifts and combine them. See "Calculate L_{ex} from several $L_{eq,t}$ measurements," pages 36–37.
- Get a weekly exposure using the calculations in "Determine individual L_{ex} when noise exposure varies from day to day (energy-average)," page 42.

Group sampling

Try to include all workers in the noise survey. However, if many workers are doing similar tasks and are exposed to similar noise levels, you can use group sampling instead.

Group sampling uses statistical methods to reduce the number of measurements by considering workers as members of occupational groups. A group may consist of workers all working in the same room but doing different jobs or workers who are in the same trade doing similar work but in different locations.

To find out if you've taken enough measurements for workers in a group, see "Sampling method and how to calculate exposure from repeated measurements or for a group," pages 60–63. The calculation uses mean and standard deviation.

Record important details

Record the data and stop time before removing the instrument

Stop or pause the sound level meter or dosimeter, and record the data and stop time before removing the instrument from the worker or measurement location.

Record the following information:

- The make and serial number of the noise-measuring instrument
- Measurement start and end times
- The worker's identification
- Location of the measurement
- Pre- and post-calibration results

Also include the following:

- Most likely noise sources
- A sketch of the layout, showing the locations of machines and workstations
- Appropriate noise-control methods
- The condition of existing noise-control measures

When you collect information, talk to workers and supervisors to make sure the conditions are typical.

PART 3: Noise calculations for analyzing noise exposure

Add decibels

Decibel calculators and apps

You can find decibel calculators online or download an app for your smartphone. Test the calculator or app by adding 85 dBA and 85 dBA to see if it gives you an answer of 88 dBA.

Many of the calculations in Part 3 will require you to add decibels. Because the decibel scale is logarithmic, you can't simply add noise levels together to get a result. Remember that for every increase of 3 dB, the sound energy doubles (see "3 dB exchange rate," page 6). So 88 dB has twice as much energy as 85 dB. In other words, 85 dB + 85 dB = 88 dB.

Here is the formula for adding decibels. L_A is the total sound level (after the additions), L_1 is the first measurement, L_2 is the second, and so on.

$$L_A = 10 \log (10^{L_1/10} + 10^{L_2/10} + \ldots)$$

Example

A manufacturing facility has four injection-moulding machines that separately produce 79 dBA, 82 dBA, 84 dBA, and 88 dBA. What is the total noise level?

$$L_A = 10 \log (10^{79/10} + 10^{82/10} + 10^{84/10} + 10^{88/10}) = 90.5 \text{ dBA}$$

(round up to 91 dBA)

Rule of thumb

Adding two equal noise levels always results in a 3 dBA increase.

80 dBA + 80 dBA = 83 dBA

97 dBA + 97 dBA = 100 dBA

Add a noise source

It can be useful to estimate the increase in sound level when adding noise sources, such as when installing new equipment. Remember: Because noise levels are logarithmic, they can't simply be added (see "Add decibels," page 32). Use the formula below or a decibel calculator.

In the formula, L_A is the total sound level (after the addition), L_1 is the original noise level, and L_2 is the noise level of the new noise source. (If you have more than one new noise source, use L_2 for the first new noise source, L_3 for the second source, and so on.)

$$L_A = 10 \log (10^{L_1/10} + 10^{L_2/10} + \ldots)$$

Example

The noise level at a sawmill operator's workstation is 83 dBA. The company wants to buy an additional saw that will be installed at a nearby workstation. The saw manufacturer says that the new saw alone will generate a noise level of 90 dBA at this operator's workstation. What would the noise level at the operator's workstation be if the new saw was installed?

Answer

$L_A = 10 \log (10^{83/10} + 10^{90/10}) = 90.8$ dBA (round up to 91 dBA)

Use your web browser to do the math

You can enter math equations directly into your web browser. For example, if you type "10 log (2/6)" into the address bar or search bar, it should calculate the answer for you, which in this example is –4.77. For 10^9, you'll have to use the x^y button on the online calculator (google "calculator"). Type in 10 x^y 9.

Alternatively, you can type "10^9" into your browser. So, for the equation above, you would type in "10 log [10^(83/10) + 10^(90/10)]" or "10 log [(10^8.3) + (10^9)]."

Remove a noise source

It can be useful to estimate the noise level when removing a noise source or replacing equipment with a quieter model. The formula for removing a noise source is as follows, where L_{diff} is the sound level after subtracting a noise source (the difference). L_1 is the original noise level, and L_2 is the noise level of the noise source being removed:

$$L_{diff} = 10 \log (10^{L_1/10} - 10^{L_2/10})$$

Example

A sawmill company is moving one of their saws to a new location. An occupational hygienist has determined that the noise level (or L_1) at a sawmill operator's workstation is 91 dBA when the saw is operating. The hygienist has also determined that the saw alone generates a noise level (or L_2) of 86 dBA at the operator's workstation. What will the noise level at the operator's workstation be once the saw is removed from the area?

Answer

$$L_{diff} = 10 \log (10^{91/10} - 10^{86/10}) = 89.3 \text{ dBA (round down to 89 dBA)}$$

If the old saw was being replaced with a new saw, you could determine the noise level for the new saw using the formula from "Add a noise source," page 33.

Derive L_{ex} from an $L_{eq,t}$ measurement

As mentioned previously, you may not need to measure noise for an entire shift. In some cases, you can measure a shorter, representative time period and then calculate the L_{ex} from the $L_{eq,t}$.

Remember: $L_{eq,t}$ is the noise level averaged over the measurement time *t*. L_{ex} is the average noise level normalized to 8 hours.

Example

A 2-hour noise measurement was taken using a noise dosimeter for a worker at a vehicle-parts manufacturing plant. The 2 hours were representative of the entire shift. At the end of the measurement period, the dosimeter showed an $L_{eq,t}$ of 89 dBA.

What is the worker's L_{ex}?
With a representative measurement, $L_{eq,t} = L_{ex}$. The worker's L_{ex} is 89 dBA.

Explanation

The activities and tasks performed by the worker represent a typical shift. The measurement was long enough to account for the daily activities and changes in the acoustic environment experienced by the worker. The average noise level measured over the 2-hour measurement period can be assumed to be equal to the worker's noise-exposure level ($L_{eq,t} = L_{ex}$).

What is the worker's L_{ex} if the measurement is not representative?
The L_{ex} can't be determined if the measurement time doesn't represent the tasks performed by the worker for the entire shift. In this case, more measurements are needed. They can then be combined to determine the worker's L_{ex}.

Calculate L_{ex} from several $L_{eq,t}$ measurements

Does a worker do several different activities during a shift? Ideally, you should have the worker wear a dosimeter for the entire shift to measure the exposure level (L_{ex}). Another option is to get measurements from the various activities (taking several $L_{eq,t}$ measurements), and then calculate the L_{ex} from these samples.

Example

Workers at a beverage-production company rotate workstations throughout the day. The following table summarizes the duration of time and noise exposure for one worker at each of the workstations.

Task	Duration (hours)	$L_{eq,t}$ (dBA)
Filling	2	87
Capping	1	92
Labelling	2	89
Packaging	1	82

What is the worker's shift $L_{eq,t}$?
Noise-level measurements are logarithmic, so you can't get an average using arithmetic. Use this formula to calculate the $L_{eq,t}$ for multiple noise measurements:

$$L_{eq,t} = 10 \log [(t_1/t \times 10^{L_{eq,1}/10}) + (t_2/t \times 10^{L_{eq,2}/10}) + (...)]$$

Where:

$L_{eq,t}$ = average noise level over time t

t = total duration of all the measurements or tasks

t_i = measurement duration for the *ith* (first, second, third, etc.) measurement; can also be the duration of the task

$L_{eq,i}$ = measured noise level for the *ith* measurement

Answer

$L_{eq,6h} = 10 \log [(2/6 \times 10^{87/10}) + (1/6 \times 10^{92/10}) + (2/6 \times 10^{89/10}) + (1/6 \times 10^{82/10})]$

Therefore:

$L_{eq,6h} = 88.6$ dBA (round up to 89 dBA)

(For the L_{ex}, see "Explanation" below.)

Another way to consider the equation:

$L_{eq,6h} = [L_{eq,1} + 10 \log (t_1/t)] + [L_{eq,2} + 10 \log (t_2/t)] + \ldots$

This means that for each task, which is either 1 or 2 hours, we calculate the equivalent sound level (L_{eq}) over 6 hours:

- Filling: $L_{eq,6h} = 87 + 10 \log (2/6) = 82.2$ dBA
- Capping: $L_{eq,6h} = 92 + 10 \log (1/6) = 84.2$ dBA
- Labelling: $L_{eq,6h} = 89 + 10 \log (2/6) = 84.2$ dBA
- Packaging: $L_{eq,6h} = 82 + 10 \log (1/6) = 74.2$ dBA

We can then add these together using either the formula to add decibels (as explained on page 32) or a decibel calculator:

82.2 dBA + 84.2 dBA + 84.2 dBA + 74.2 dBA = 88.6 dBA, which we round up to 89 dBA

Therefore:

$L_{eq,6h} = 88.6$ dBA (round up to 89 dBA)

Explanation

The calculated $L_{eq,t}$ measurement for this example is for 6 hours.

However, the worker's shift is 8 hours. These 6 hours are representative, so the L_{ex} can be considered to be the same as the $L_{eq,t}$. Therefore, the L_{ex} would be 89 dBA.

If the worker doesn't work an 8-hour shift, however, you'll have to adjust for the workshift length. This is explained in the next section.

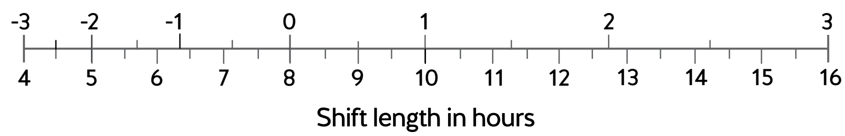
Make adjustments for workshift length

For shift lengths other than 8 hours, you can calculate the L_{ex} from the measured $L_{eq,t}$. Use a correction factor that accounts for the effects of shift lengths longer or shorter than the standard 8 hours. The formula looks like this:

$L_{ex} = L_{eq,t}$ + correction for shift length

The correction is shown in the figure below:

Correction in dBA. Add to $L_{eq,t}$ to get L_{ex}.



You can also calculate the L_{ex} for shifts other than 8 hours with the following formula:

$L_{ex} = L_{eq,t} + 10 \log (T/8)$

Where:

$L_{eq,t}$ = average noise level over time *t*

T = duration of shift (for shifts other than the standard 8 hours)

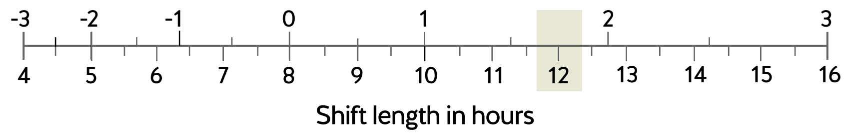
Note: The L_{ex} for shifts longer than 8 hours is greater than the measured $L_{eq,t}$. Conversely, the L_{ex} for shifts shorter than 8 hours is less than the measured $L_{eq,t}$.

Example

In the beverage-production company example on pages 36–37, the worker on an 8-hour shift has an L_{ex} of 89 dBA.

What is the worker's L_{ex} if the shift length is 12 hours?

Correction in dBA. Add to $L_{eq,t}$ to get L_{ex}.



Based on the above figure, the correction for a 12-hour shift is 1.75 dBA, so the worker's L_{ex} for the 12-hour shift is:

L_{ex} = 89 dBA + 1.75 dBA = 90.75 dBA (round up to 91 dBA)

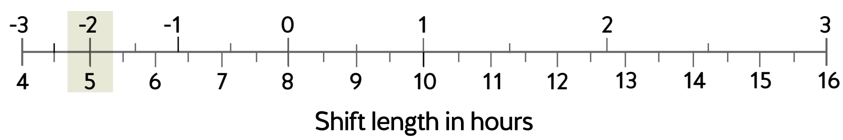
The worker's L_{ex} can also be calculated using the formula from above:

$L_{ex} = L_{eq,t} + 10 \log (T/8)$

$L_{ex} = 89 + 10 \log (12/8) = 89 + 1.76 = 90.76$ dBA (round up to 91 dBA)

What is the worker's L_{ex} if the shift length is 5 hours?

Correction in dBA. Add to $L_{eq,t}$ to get L_{ex}.



Based on this chart, the correction for a 5-hour shift is –2 dBA. The worker's L_{ex} for a 5-hour shift is:

89 dBA – 2 dBA = 87 dBA

Or using the formula from above:

$L_{ex} = L_{eq,t} + 10 \log (T/8)$

$L_{ex} = 89 + 10 \log (5/8) = 89 - 2.0 = 87$ dBA

Make adjustments for a non-typical work schedule

Sometimes a schedule differs from the typical work pattern of 8 hours a day, 5 days a week (or 21 days a month). You need to make the appropriate correction for such schedules. To calculate an equivalent daily duration, take the higher of the following:

- One-fifth of the number of hours worked per week. This is based on working all weeks in a month; if not, get an average.
- The number of hours worked per month (an average) divided by 21.

Example

A carpenter wears a noise dosimeter for 10 hours during a shift. At the end of the measurement period, the dosimeter shows an $L_{eq,10h}$ of 86 dBA. This worker works 12-hour shifts for 14 days followed by 14 days of no work. Assume that the dosimeter measurement is representative (i.e., the 10-hour measurement represents the noise level for the entire 12-hour shift) and this is a typical number of hours worked in a month.

First calculate one-fifth of the average weekly hours:

When working: Number of hours worked =
12 hours × 7 days = 84 hours a week

When not working: Number of hours worked =
0 hours × 7 days = 0 hours a week

Over a month, average number of hours worked per week =
(84 + 84 + 0 + 0)/4 weeks = 42 hours a week

Over a month, average number of hours worked per day =
42/5 = 8.4 hours a day

Then calculate the number of hours worked per month divided by 21:

84 hours × 2 weeks = 168 hours / 21 = 8 hours

The shift length is assumed to be the greater of 8.4 and 8 hours.

Using the formula above with T = 8.4 hours:

L_{ex} = 86 + 10 log (8.4/8) = 86 + 0.2 = 86.2 dBA (round down to 86 dBA)

Calculate L_{ex} averages

Root mean square (RMS)

RMS refers to the square root of the mean square. This is the arithmetic mean of the squares of a set of numbers.

When averaging a number of L_{ex} values for a worker to get that worker's "effective" L_{ex}, you need to calculate the average (or energy-average) of the various L_{ex} values. This average is also known as the root mean square (RMS) value. (The term *energy-average* is used to distinguish it from the average you calculate with arithmetic. You can compare the two below.)

Calculating energy-average

The energy-average (or RMS) sound level is:
$L_{RMS} = 10 \log [1/n (10^{L_1/10} + 10^{L_2/10} + 10^{L_3/10} + \ldots + 10^{L_n/10})]$

L_1 is the first measurement, L_2 is the second, and so on, and n is the total number of measurements.

If you entered this into a web browser to do the calculation, you would type in the following:
10 log (1/n(10^(L_1/10) + 10^(L_2/10) + 10^(L_3/10) + ...10^(L_n/10))

Use this formula to get the energy-average of a number of sound levels. You can use this formula to find the average of several L_{ex} measurements of the same individual worker on different days, or measurements of different individuals within a group for group-sampling calculations.

Calculating arithmetic mean

The arithmetic mean or average of a number of sound levels is:
$L_{mean} = (L_1 + L_2 + L_3 + \ldots)/n$

L_1 is the first measurement, L_2 is the second, and so on, and n is the total number of measurements. If each measurement is an L_{ex}, you can use this to get the mean L_{ex} for a group of workers.

Example

The average of the three sound levels 88 dBA, 94 dBA, and 97 dBA:
Energy-average: $L_{RMS} = 10 \log [(10^{88/10} + 10^{94/10} + 10^{97/10})/3] = 94.3$ dBA

If you entered this into a web browser to do the calculation, you would type in the following:
10 log [(10^8.8 + 10^9.4 + 10^9.7)/3]

Arithmetic mean: $L_{mean} = (88 + 94 + 97)/3 = 93.0$ dBA

Determine individual L_{ex} when noise exposure varies from day to day (energy-average)

When a worker is exposed to different noise levels each day, you can't calculate the L_{ex} from a single day of measurements. Instead, take separate measurements over a representative number of days. For these situations, use the concept of weekly noise exposure.

Weekly noise exposure is similar to daily noise exposure. Instead of being normalized over 8 hours, the noise exposure is normalized over a 5-day work week (8 hours per day, 40 hours per week).

When noise levels vary from day to day, the formula for calculating the weekly noise exposure is as follows:

L_{ex} = 10 log $[1/5(10^{L_1/10} + 10^{L_2/10} + \ldots 10^{L_n/10})]$

n = number of days worked per week

Example

A high school teacher teaches science and woodworking. Representative measurements are taken. On the science days, the measured L_{ex} is 80 dBA. On the woodworking days, the measured L_{ex} is 91 dBA. The teacher teaches science on Monday, Wednesday, and Friday, and woodworking on Tuesday and Thursday. What is the teacher's weekly L_{ex}?

L_{ex} = 10 log $[1/5(10^{80/10} + 10^{91/10} + 10^{80/10} + 10^{91/10} + 10^{80/10})]$

L_{ex} = 87.5 dBA

L_{ex} averaged over the 5-day work week = 87.5 dBA (round up to 88 dBA)

Part 4: Reporting the results

Your results and recommendations

Round your results

When you include results from your calculations, round final equivalent sound levels ($L_{eq,t}$) and noise-exposure levels (L_{ex}) to the nearest whole number. For example, if you measure 96.7 dBA, call it 97 dBA.

After you conduct noise measurements and calculate exposure levels, it's important to present the results and a set of recommendations.

What is a suitable method of summarizing the exposure data? There are several options, but a summary table (see pages 46–47) is often suitable. And to help people visualize the workstations and noise on a site, put the noise-exposure levels on a general layout of the plant (see the diagram on page 48).

A summary should be clear and easy to understand, without unnecessary information. Keep in mind why you did the survey in the first place — for example, to identify equipment that could be modified to reduce noise levels, or identify the workers who need to be part of a hearing conservation program.

A written report should also include the following:

- Dates and locations of measurements
- A statement that the measurements were taken under typical noise conditions (or otherwise)
- Details on the noise-measuring instruments, including make, model, serial number, and calibration record
- Workers' names, or a way for the employer to identify which workers the report is referring to
- The workers' job activities and lengths of shifts
- If the samples are shorter than 8 hours, whether the sample is representative of an entire 8-hour shift
- If the shifts aren't 8 hours long, calculations and analysis that reflect the length of exposure
- The dBA L_{ex}, which is information that is useful to the employer
- The equipment, areas, or tasks that exceed the noise-exposure limits
- The workers or jobs to be included in a hearing conservation program (as required by Part 7 of the Regulation), which would involve the following:
  - Training and education on the effects of noise on hearing
  - Annual hearing tests
  - Appropriate hearing protection (see CSA Standard Z94.2-14 for the recommended class)
  - Identification of areas to be posted with signs warning about high noise levels and how hearing protection is required

The report should also outline any corrections to the noise measurements to account for unusual or different levels of occupational activity. The calculation method should be indicated where you've used a partial noise exposure to calculate daily noise exposures. With a group of workers, you would have had to make a calculation based on a sample of noise exposures. Explain the sampling process and justify your statistical methodology.

Sample summary table

In the Comments column below, you'll see instances of "$L_{eq,t}$ has been converted to L_{ex}." See Part 3 for the formulas.

Company name: Peacham Pill Co. Ltd.

Division/department: Manufacturing

Address: 221A Holmes Street, Burnaby, BC V1E 2T4

Worker name or job	Number of workers	$L_{eq,t}$ (dBA)	Shift duration (hours)	L_{ex} (dBA)	Comments	Okay with regulations? (Y/N)	Recommendations
Bottling							
Feeder	1	81.5	10	83	• All measurements were for 4 hours and representative of entire day • $L_{eq,t}$ has been converted to L_{ex} • Steady noise for long periods • No significant impact noise	Y	Make hearing protection available.
Filler	1	85.5	10	87		N	Implement noise controls, such as engineering or administrative controls. Consider job rotation to reduce average L_{ex} to less than 85 dBA L_{ex}.
Capper	1	81	10	82		Y	Make hearing protection available.
Labeller	2	80	10	81		Y	No action required.
Packer	5	78.5	10	80		Y	No action required.
Tablet pressing							
Acme press #1	1	89	7	89	• L_{eq} 4 hours, representative of entire shift • $L_{eq,t}$ has been converted to L_{ex}	N	Hearing conservation and noise-control program.
Acme press #2	1	93.5	7	93	• 7-hour dosimetry • $L_{eq,t}$ has been converted to L_{ex} • Significant impact peaks = 133 dBC	N	Hearing conservation and noise-control program.
Acme press #3	1	93.5	8	94	• 4-hour dosimetry, representative of entire shift • Significant impact peaks = 138 dBC	N	Hearing conservation and noise-control program.

<table>
<tr><th>Worker name or job</th><th>Number of workers</th><th>$L_{eq,t}$ (dBA)</th><th>Shift duration (hours)</th><th>L_{ex} (dBA)</th><th>Comments</th><th>Okay with regulations? (Y/N)</th><th>Recommendations</th></tr>
<tr><td colspan="8">Shipping</td></tr>
<tr><td>Forklift</td><td>1</td><td>82.2</td><td>12</td><td>84</td><td rowspan="2">• 4-hour dosimetry, representative of entire shift
• $L_{eq,t}$ has been converted to L_{ex}
• Variable level
• No significant impact noise in shipping</td><td>Y</td><td>Make hearing protection available.
Install new muffler on forklift.</td></tr>
<tr><td>Truck driver</td><td>1</td><td>79</td><td>12</td><td>81</td><td>Y</td><td>No action required.</td></tr>
</table>

Noise surveyor: A.N. Other

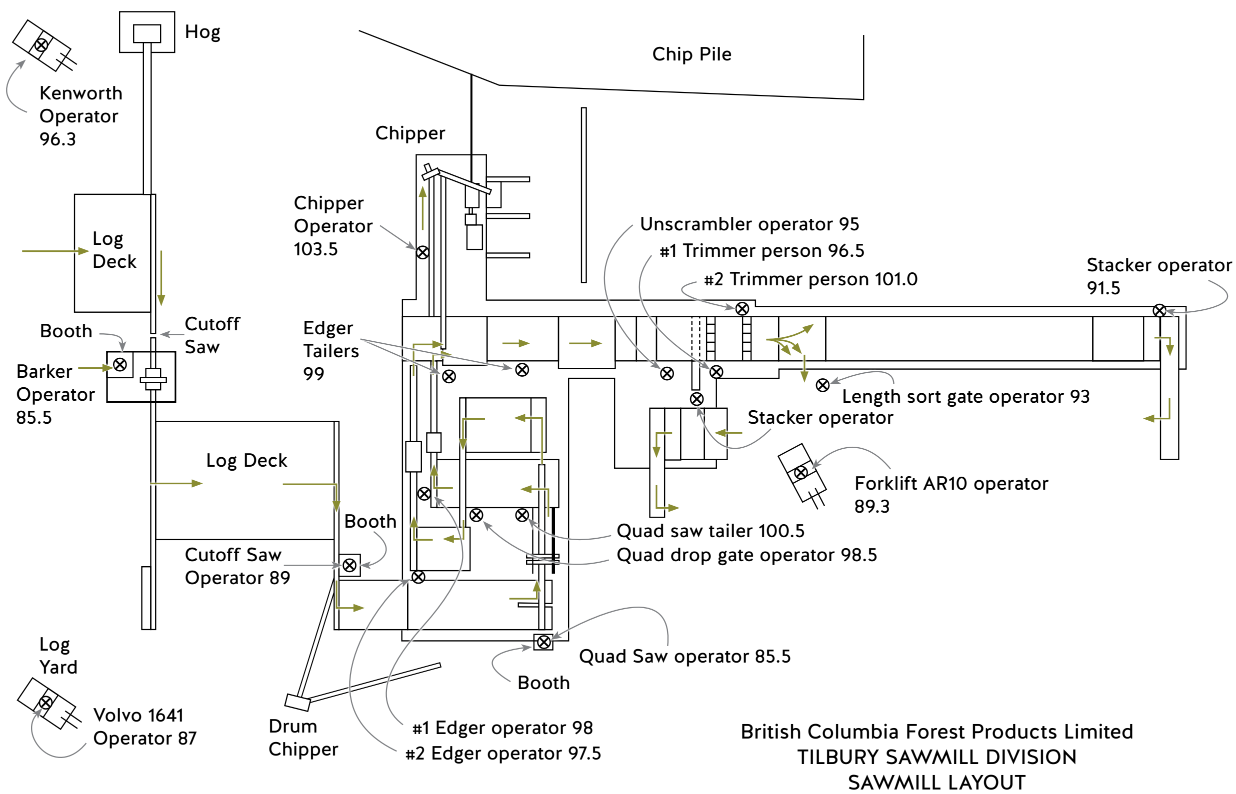
Sound level meter/dosimeter: Valiant **Model:** N1S/N: XYZ1234 **Signature:**

Calibrator: Valiant **Model:** N2S/N: ABC987 **Survey date:** September 5, 2018

Calibrated: January 15, 2018

Sample layout diagram showing noise-survey results

The following sample diagram shows L_{ex} (dBA) noise measurements for various jobs (or job titles) in a sawmill.



AN EXAMPLE OF A GENERAL LAYOUT DIAGRAM

Appendixes

Using a nomograph or table for L_{ex} calculations

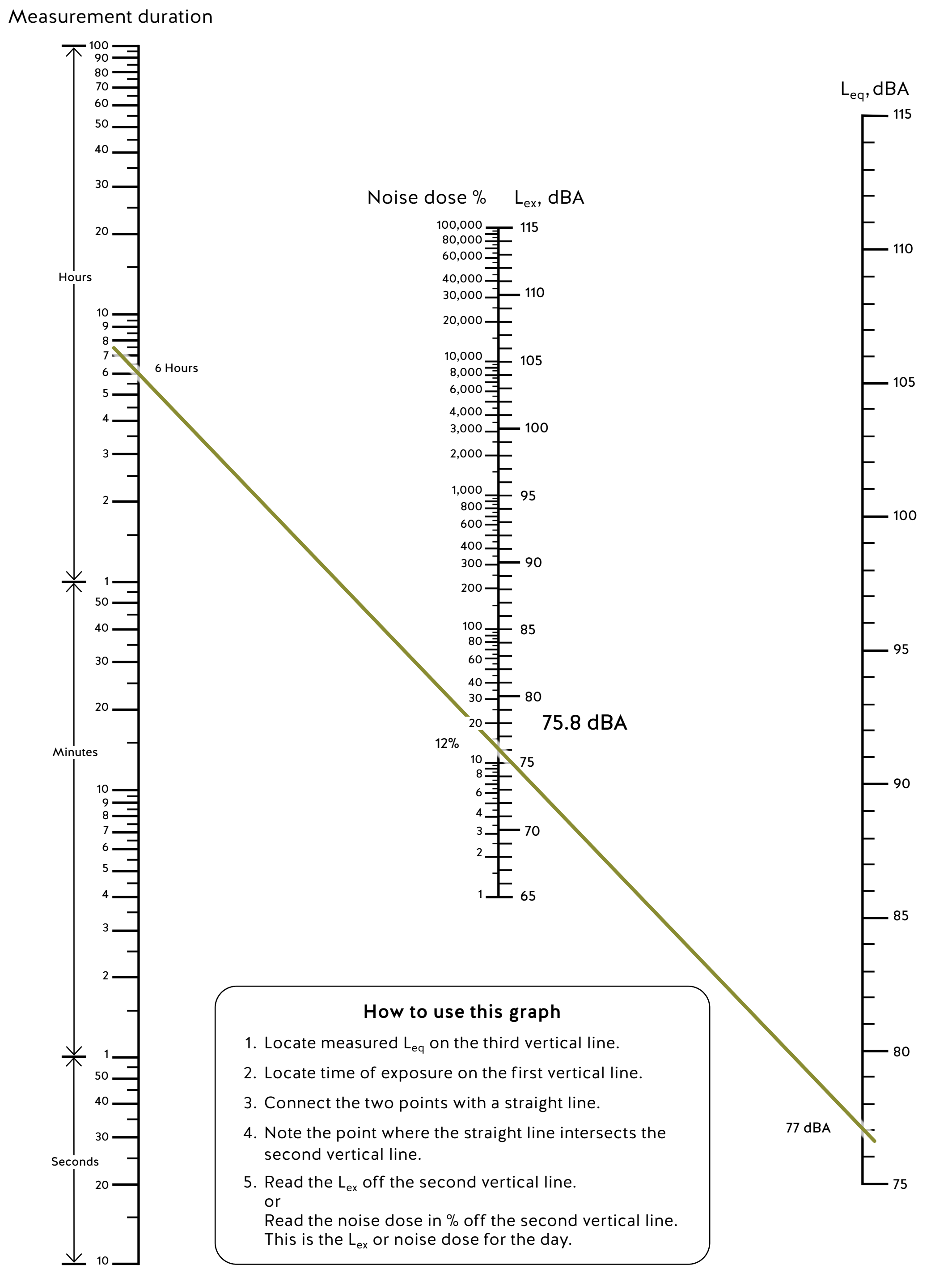
The graph and table on the next few pages show the relationship between measurement duration, L_{eq}, L_{ex}, and noise dose.

The graph on page 51 has three columns: Measurement Duration; Noise Dose and L_{ex}; and L_{eq}. You make a line between points on the first and third columns to find the value in the middle column. This kind of graph is called a nomograph or nomogram. We include examples of some ways to apply the nomograph.

You could also use the table on page 55.

The mathematical relationships are described in "Formulas for L_{eq}, L_{ex}, noise dose, and time," pages 57–59.

Nomograph with L_{eq}, L_{ex}, noise dose, and time



How to use this graph

1. Locate measured L_{eq} on the third vertical line.
2. Locate time of exposure on the first vertical line.
3. Connect the two points with a straight line.
4. Note the point where the straight line intersects the second vertical line.
5. Read the L_{ex} off the second vertical line.
   or
   Read the noise dose in % off the second vertical line.
   This is the L_{ex} or noise dose for the day.

Example using the nomograph

What is the noise dose that results from an L_{eq} of 77 dBA for a 6-hour duration?

1. Find 77 dBA in the L_{eq} column.
2. Find 6 hours in the Measurement Duration column.
3. Join the two points with a straight line.
4. The line goes across the Noise Dose/L_{ex} column:
   Noise dose = 12% and L_{ex} = 75.8 dBA.

If you had a noise dosimeter running, it would read:

Noise dose = 12% and L_{ex} = 75.8 dBA. This assumes that the noise (77 dBA for 6 hours) is the only noise the worker experienced.

Using the nomograph to synthesize noise exposure

Example 1
A worker works in a nightclub for 5 hours a night. During a typical night, the worker's noise exposure is measured with a personal noise dosimeter. It reads L_{eq} = 88 dBA after 2 hours of sampling. Assuming this is a representative sample, we could predict the worker's noise dose during the shift, as follows:

1. Noise dose after 2 hours = 50% (use the nomograph to connect 88 dBA with 2 hours).
2. Noise dose per hour = 50% / 2 hours = 25% per hour.
3. Noise dose per 5-hour shift = (25% per hour × 5 hours) = 125%.
4. Find 125% on the second vertical line, and get the corresponding L_{ex} = 86 dBA.

The worker is overexposed to noise because the L_{ex} is greater than 85 dBA.

Example 2
Sometimes you need to calculate a worker's full-shift exposure based on shorter or partial exposures throughout their shift. The shift involves different short-term tasks, each with a different measurement.

Another worker works in the same club. Typically, this worker spends 2 hours per night supervising in the kitchen, where the L_{eq} is 88 dBA. The worker does administrative tasks for 4 hours per night in an office, where the L_{eq} is 77 dBA, and spends 1 hour in the restaurant, where the L_{eq} is 66 dBA.

We can combine the three partial exposures by finding the noise dose for each task:

1. Draw a line to connect an L_{eq} of 88 dBA to 2 hours. The noise dose is 50%.
2. Draw a line to connect an L_{eq} of 77 dBA to 4 hours. The noise dose is 8%.
3. Draw a line to connect an L_{eq} of 66 dBA to 1 hour. The noise dose is 0%. (The last data point is off the bottom of the nomograph.)
4. The total noise dose for the day = 50% + 8% = 58%.
5. Find 58% in the second vertical line. Get the corresponding L_{ex} = close to 83 dBA.

The worker's L_{ex} is 83 dBA, so the worker isn't overexposed.

Example 3
Workers at a beverage company work on the bottle-filling line and rotate jobs. Each worker performs each job for 2 hours of a 10-hour shift.

The noise exposure of workers doing each job is measured for 5 minutes with an integrating sound level meter. Each worker's L_{eq} measurement is shown in the following table:

Job	L_{eq} (dBA)	Duration (hours)
Depalletizer	91.5	2
Filler	95	2
Capper	97	2
Labeller	87	2
Packager	84.5	2
	Sum	10

We then use the nomograph to get the noise dose from each job:

Job	L_{eq} (dBA)	Duration (hours)	Noise-dose estimate
Depalletizer	91.5	2	115%
Filler	95	2	250%
Capper	97	2	400%
Labeller	87	2	40%
Packager	84.5	2	20%
	Sum	**10**	**825%**

The total noise dose for 10 hours is the sum of the noise doses for each job. Here we've totalled 825%.

We can now find the $L_{eq,10h}$ and L_{ex} for (all) the workers' shifts.

We use the nomograph to do the following:

1. To get $L_{eq,10h}$: Join dose 825% to 10 hours, and extend the straight line. The $L_{eq,10h}$ is slightly more than 93 dBA.
2. To get L_{ex}: Join dose 825% to 8 hours and extend the straight line. The L_{ex} is 94 dBA.

OR

1. Find the day's dose of 825% in the second column.
   The L_{ex} is 94 dBA.

The workers are overexposed because their L_{ex} is greater than 85 dBA.

Note: Because we calculate the dose for the entire length of the shift, we would use the shift length as the Measurement Duration.

Table: L_{eq}, L_{ex}, noise dose, and time

If you have an L_{eq} and the averaging time, you can find the corresponding noise dose in the following table.

Time	L_{eq} (dBA)																	
	80	81	82	83	84	85	86	87	88	89	90	92	94	96	98	100	102	104	106
1 minute	0.07	0.08	0.1	0.13	0.17	0.21	0.26	0.33	0.42	0.52	0.66	1.04	1.65	2.62	4.16	6.59	10.4	16.5	26.2
2 minutes	0.13	0.17	0.21	0.26	0.33	0.42	0.52	0.66	0.83	1.05	1.32	2.09	3.31	5.25	8.31	13.2	20.9	33.1	52.5
4 minutes	0.26	0.33	0.42	0.53	0.66	0.83	1.05	1.32	1.66	2.09	2.64	4.18	6.62	10.5	16.6	26.4	41.8	66.2	105
8 minutes	0.53	0.66	0.84	1.05	1.32	1.67	2.1	2.64	3.33	4.19	5.27	8.35	13.2	21	33.3	52.7	83.5	132	210
½ hour	1.98	2.49	3.13	3.94	4.96	6.25	7.87	9.91	12.5	15.7	19.8	31.3	49.6	78.7	125	198	313	496	787
1 hour	3.95	4.98	6.26	7.89	9.93	12.5	15.7	19.8	24.9	31.4	39.5	62.6	99.3	157	249	395	626	993	1,570
2 hours	7.91	9.95	12.5	15.8	19.9	25	31.5	39.6	49.9	62.8	79.1	125	199	315	499	791	1,250	1,990	3,150
3 hours	11.9	14.9	18.8	23.7	29.8	37.5	47.2	59.4	74.8	94.2	119	188	298	472	748	1,190	1,880	2,980	4,720
4 hours	15.8	19.9	25.1	31.5	39.7	50	62.9	79.2	99.8	126	158	251	397	629	998	1,580	2,510	3,970	6,290
5 hours	19.8	24.9	31.3	39.4	49.6	62.5	78.7	99.1	125	157	198	313	496	787	1,250	1,980	3,130	4,960	7,870
6 hours	23.7	29.9	37.6	47.3	59.6	75	94.4	119	150	188	237	376	596	944	1,500	2,370	3,760	5,960	9,440
7 hours	27.7	34.8	43.9	55.2	69.5	87.5	110	139	175	220	277	439	695	1,100	1,750	2,770	4,390	6,950	11,000
8 hours	31.6	39.8	50.1	63.1	79.4	100	126	158	200	251	316	501	794	1,260	2,000	3,160	5,010	7,940	12,600
9 hours	35.6	44.8	56.4	71	89.4	113	142	178	224	283	356	564	894	1,420	2,240	3,560	5,640	8,940	14,200
10 hours	39.5	49.8	62.6	78.9	99.3	125	157	198	249	314	395	626	993	1,570	2,490	3,950	6,260	9,930	15,700
11 hours	43.5	54.7	68.9	86.8	109	138	173	218	274	345	435	689	1,090	1,730	2,740	4,350	6,890	10,900	17,300
12 hours	47.4	59.7	75.2	94.6	119	150	189	238	299	377	474	752	1,190	1,890	2,990	4,740	7,520	11,900	18,900
13 hours	51.4	64.7	81.4	103	129	163	205	258	324	408	514	814	1,290	2,050	3,240	5,140	8,140	12,900	20,500
14 hours	55.3	69.7	87.7	110	139	175	220	277	349	440	553	877	1,390	2,200	3,490	5,530	8,770	13,900	22,000
15 hours	59.3	74.6	94	118	149	188	236	297	374	471	593	940	1,490	2,360	3,740	5,930	9,400	14,900	23,600
16 hours	63.2	79.6	100	126	159	200	252	317	399	502	632	1,000	1,590	2,520	3,990	6,320	10,000	15,900	25,200

Example using the table

We can use the same example of beverage-company workers on a bottle-filling line that we used above with the nomograph. The workers practise job rotation, each doing every job for 2 hours in their 10-hour shift.

You can use the table on page 55 to determine the noise dose from each job. Find the row for 2 hours. The noise dose for each sound level has been entered in the table below. There was some interpolating between columns.

Job	L_{eq} (dBA)	Duration (hours)	Noise-dose estimate
Depalletizer	91.5	2	102%
Filler	95	2	257%
Capper	97	2	407%
Labeller	87	2	39.6%
Packager	84.5	2	22.5%
	Sum	**10**	**828%**

All workers would have a noise dose of 828%.

For their L_{ex}, go to the 8-hour row (shaded), and look along it until you find 828%. There is only 794% in the 94 dBA column and 1260% in the 96 dBA column. You'll have to interpolate the value of the sound level between 94 and 96 dBA.

Without interpolating, you can estimate the L_{ex} to be about 95 dBA.

With interpolating, L_{ex} = 94.1 dBA.

Formulas for L_{eq}, L_{ex}, noise dose, and time

When we used the nomograph and table in the previous sections, we got slightly different results for the example of workers in a beverage company. With the nomograph, we estimated an L_{ex} of 94 dBA, and with the table we estimated an L_{ex} of 95 dBA. Because both the nomograph and the table require some estimating, they're not as accurate as doing actual noise calculations. You can use the nomograph and table to answer basic questions such as "Is a worker overexposed?" But if you want more accurate results, use the following formulas.

1. To find the dose associated with an $L_{eq,t}$ measurement:
   $\text{Dose} = 100 \times t/8 \times 10^{(L_{eq,t} - 85)/10}$
2. To find the $L_{eq,t}$ associated with a noise dose:
   $L_{eq,t} = 10 \log [(\text{Dose}/100) \times (8/t)] + 85$ dBA
3. To find the L_{ex} associated with a noise dose:
   $L_{ex} = 10 \log (\text{Dose}/100) + 85$ dBA
4. To determine the L_{ex} from an $L_{eq,t}$ when the shift length is not 8 hours:
   $L_{ex} = L_{eq,t} + 10 \log (T/8)$

Where:

Dose = noise-exposure dose, in %, acquired over time *t*

$L_{eq,t}$ = A-weighted sound level, energy-averaged over time *t*

L_{ex} = A-weighted sound exposure, energy-averaged over 8 hours

t = duration of the measurement

T = duration of the worker's shift

Example

Using the above formulas and the same example of workers rotating job duties at a beverage company, you can get a more accurate result for the $L_{eq,10h}$ and L_{ex}.

Noise-dose calculation

Start by calculating the noise dose for the first 2 hours spent at the depalletizer position.

$$\text{Dose} = 100 \times \frac{T}{8} \times 10^{(L_{eq,t}-85)/10} \Rightarrow \text{Depalletizer}$$

$$\text{Dose} = 100 \times \frac{2}{8} \times 10^{(91.5-85)/10}$$

$$= 111.7 \text{ (round up to } 112\%)$$

Enter the noise dose for the depalletizer job (112%) into the Noise-Dose Estimate column in the table. Do the same calculation to get the noise doses for each of the other jobs.

Job	L_{eq} (dBA)	Duration (hours)	Noise-dose estimate
Depalletizer	91.5	2	112%
Filler	95	2	250%
Capper	97	2	396%
Labeller	87	2	40%
Packager	84.5	2	8%
	Sum	**10**	**806%**

The total noise dose of all the jobs is 806%.

L_{eq} for a 10-hour shift

Use the second formula and this total dose above to calculate the L_{eq} for 10 hours.

Total dose = 806%

$$L_{eq,t} = 10 \log [(\text{Dose}/100) \times (8/T)] + 85 \text{ dBA}$$

$$L_{eq,10h} = 10 \log_{10} [(806/100) \times (8/10)] + 85 \text{ dBA}$$

$$= 93.1 \text{ dBA (round down to 93 dBA)}$$

The L_{eq} for the 10-hour shift is 93 dBA.

L_{ex} based on a 10-hour shift

To calculate the L_{ex}, use either of the following:

- The third formula (from page 57) and the 806% total dose (from page 58)
  or
- The fourth formula (from page 57) and the 93 dBA $L_{eq,10h}$ (from page 58)

Third formula and 806% total dose:

L_{ex} = 10 log (Dose/100) + 85

L_{ex} = 10 log (806/100) + 85

L_{ex} = 94.1 dBA (round down to 94 dBA)

Fourth formula and 93 dBA $L_{eq,10h}$:

$L_{ex} = L_{eq,t} + 10 \log(T/8)$

$L_{ex} = 93 + 10 \log(10/8)$

L_{ex} = 94 dBA

Sampling method and how to calculate exposure from repeated measurements or for a group

You can use this method to figure out whether you've taken enough samples or you need to take more. You can use it for group measurements or repeated measurements for a single worker. This method also involves calculating the average exposure and the associated uncertainty.

This sampling method is consistent with CSA Standard Z107.56-18. We updated the method from the previous edition to make repeated and group measurements more accurate and precise. We've also allowed for the calculation of the 95% confidence interval.

Method

1. For a group, measure the L_{ex} for at least five workers in the group with the highest noise exposure. Their noise exposure should also be similar. If the exposure varies significantly within the group, it should be split into separate groups.

   For a single worker, take at least five representative measurements.
2. Calculate the average noise level (energy-average) of the group (L_{group}) or the single worker's measurements using the formula on page 41.
3. Calculate the standard deviation. Use a scientific calculator or Excel spreadsheet.
4. Calculate *P*, which is the required precision. L_c is the criterion level (85 dBA).
   $P = L_c - L_{group}$
5. Is *P* a positive value? This means the majority of samples are underexposed. Use the table on page 62 to get the required sample size.
6. Is *P* a negative value? This means the majority of samples are overexposed. Use the table on page 63 to get the uncertainty in the measurement.

In step 4, if the number of samples isn't enough, take more and add them to the original samples, and repeat steps 1 to 4. If you've taken enough samples, use the table on page 63 to get the uncertainty in the measurement.

Note: If *P* is negative, L_{group} is greater than L_c. According to the Regulation, you must implement a hearing conservation program.

Example

There are 25 workers at an electronics-recycling facility. The on-site occupational hygienist takes seven personal-noise dosimetry measurements. The L_{ex} results are 83, 80, 79, 81, 80, 77, and 82.

1. Calculate the energy-average noise level, L_{group}.

   $L_{group} = 10 \log [1/7 (10^{83/10} + 10^{80/10} + 10^{79/10} + 10^{77/10} + 10^{82/10})] = 80.6$
2. Calculate the standard deviation. You may want to use a scientific calculator or Excel spreadsheet.

   $s = 1.97$
3. Calculate the required precision, *P*.

   $P = 85 - 80.6 = 4.4$
4. Because the calculated *P* is a positive value, use the table on page 62 to make sure you have taken enough samples. For a *P* of 4.4 and a standard deviation of 1.97, the table says that five samples are required, so you don't need any more samples.
5. The site hygienist can conclude with 95% certainty that L_{group} is less than L_c. Now we can use the table on page 63 to determine the uncertainty of the measurement. For seven samples and a standard deviation of 1.97, the table says the uncertainty is 2.0. The hygienist can conclude that the 95% upper confidence limit is 80.6 dBA + 2.0 = 82.6 dBA. The hygienist can conclude with 95% certainty that L_{group} is less than 82.6 dBA and therefore below the 85 dBA limit.

Note: If *P* is negative and L_{group} is greater than L_c, the noise exposure is over the L_{ex} limit of 85 dBA. A hearing conservation program must be implemented, as specified in section 7.5 of the Regulation.

Table for positive *P* values

Sample size needed for 95% confidence for required precision, *P*, for a set of measured L_{ex} values with standard deviation, *s*.

	Standard deviation of measured values, *s* dB											
***P* dB**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
0	split*	split*	split*	split*	split*	split*	split*	split*	split*	split*	split*	split*
1	5	6	11	18	27	split*	split*	split*	split*	split*	split*	split*
2	5	5	5	7	10	14	19	25	split*	split*	split*	split*
3	5	5	5	5	7	9	14	18	23	28	5	split*
4	5	5	5	5	5	7	8	10	13	16	18	23
5	5	5	5	5	5	6	7	8	10	12	14	17
6	5	5	5	5	5	5	6	7	8	10	12	14
7	5	5	5	5	5	6	6	6	7	9	10	12
8	5	5	5	5	5	5	5	6	7	8	9	10
9	5	5	5	5	5	5	5	6	6	7	8	9
10	5	5	5	5	5	5	5	5	6	7	8	9
12	5	5	5	5	5	5	5	5	5	6	7	7
14	5	5	5	5	5	5	5	5	5	5	6	7
16	5	5	5	5	5	5	5	5	5	5	6	6
18	5	5	5	5	5	5	5	5	5	5	5	6
>20	5	5	5	5	5	5	5	5	5	5	5	5

Notes:

1. Split requires *n* greater than 30 samples. Either sample all group members, or investigate tasks to determine if it is appropriate to split the group into homogeneous subgroups, or to perform a task-based analysis.
2. This table is a reorganization of the table on page 63.

Table for negative *P* values

Uncertainty (one-sided 95% confidence interval) of noise-level sampling, in decibels, applicable to a set of measured L_{ex} values with standard deviation, *s*, where *n* = sample size.

	Standard deviation of measured values, *s* dB											
n	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6
5	0.5	1.1	1.9	2.8	4.0	5.4	7.2	9.1	11.4	13.9	16.7	19.9
6	0.4	1.0	1.6	2.3	3.2	4.2	5.5	6.9	8.6	10.4	12.4	14.6
7	0.4	0.8	1.3	2.0	2.7	3.5	4.5	5.7	7.1	8.4	10.1	11.6
8	0.4	0.8	1.2	1.7	2.4	3.1	3.9	4.9	6.0	7.2	8.6	10.0
9	0.3	0.7	1.1	1.6	2.1	2.8	3.5	4.3	5.3	6.3	7.5	8.9
10	0.3	0.6	1.0	1.4	1.9	2.5	3.2	3.9	4.8	5.7	6.7	7.9
12	0.3	0.6	0.9	1.3	1.7	2.2	2.7	3.4	4.0	4.8	5.8	6.6
14	0.2	0.5	0.8	1.1	1.5	1.9	2.4	3.0	3.6	4.2	5.0	5.8
16	0.2	0.5	0.8	1.0	1.4	1.8	2.2	2.7	3.2	3.8	4.5	5.3
18	0.2	0.4	0.7	1.0	1.3	1.6	2.0	2.5	2.9	3.5	4.1	4.7
20	0.2	0.4	0.6	0.9	1.2	1.5	1.9	2.3	1.7	3.2	3.8	4.4
25	0.2	0.4	0.6	0.8	1.0	1.3	1.6	2.0	2.3	2.8	3.3	3.8
30	0.2	0.3	0.5	0.7	0.9	1.2	1.4	1.7	2.1	2.4	2.8	3.3

Notes:

1. For *n* less than 5, use values in Table C.4 in ISO 9612 with a multiplier of 1.645.
2. The details in this table are taken from *Grzebyk and Thiery* (2003).

Notes

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