Chapter

# Noise Exposure

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## Abstract

Noise exposure is a basic concept used to assess the risk of noise induced hearing loss in the workplace. It is very important, since loud noise is omnipresent in almost all human activity, especially in industry, construction, mining and transportation. The question to answer is how to determine the risk of a person performing in an environment where the noise levels, duration and frequency content change with time. The answer is obtained by measuring his noise exposure. Although the measurement itself is not complex or difficult, a proper knowledge of what exactly is the noise exposure and how to deal with the measurement result in fundamental to avoid getting wrong conclusions.


**Keywords:** loud noise, noise induced hearing loss, risk assessment, noise exposure, hearing loss prevention

## 1. Introduction

Occupational noise is the most common health hazard that is predominant in most workplaces. In a recent survey of working adults in Canada, 42% reported being exposed to hazardous noise levels in the workplace [1]. Exposure to excessive occupational noise can cause permanent hearing loss through sensory-neural damage in the cochlea. In general, hearing is first affected in a specific range of audible frequencies (3000 to 6000 Hz) and then spreads to higher and lower frequencies. Hearing loss is often accompanied by other long-term auditory effects, such as tinnitus (ringing in the ears); increased sensitivity to loud noise; and poorer frequency selectivity (i.e., decreased ability to hear sounds in background noise) compared to individuals with normal hearing. It can also cause other, non-auditory adverse effects, the most common been the cardiovascular (e.g., changes in heart rate, increasing blood pressure). Being a stressor, noise causes also important psychological effects [2].

Noise levels in the workplace vary in level, duration and frequency content. In general, they are of high levels and are persistent for most of the work shift. They can be continuous, impulsive or interrupted. From the frequency point of view, most are of the wide band type, although they can be rich in high or low frequencies, especially if vibrations are also present in the workplace.

Reduction of the sound levels and, consequently the risk of noise induced hearing loss is the objective of every hearing conservation program in the industrial world [3].

The approach to the reduction of the risk follows several steps. The first is finding and recognizing potentially hazardous areas in the workplace. This tends to be done as a result of personal, subjective observations, the principal been difficulties in understanding speech: people ask frequently questions and answers to be repeated. Complaints of excessive noise are also important indications that the noise may be so loud as to create a health risk. This first step is usually performed through a walk-through survey. Sometimes, spot noise level measurements are also done using a sound level meter.

Once the areas with high noise levels have been found, the next step is to quantify the risk. This is done by measuring the noise exposure of individuals or groups of workers working in those areas. This procedure is known as the exposure survey.

Also, the extent of the exposed population (number of exposed persons) is also quantified to find out the magnitud of the problem.

## 2. Why noise exposure

Noise exposure is a fundamental concept in assessing the risk from high noise levels.

It is universally accepted that hearing loss occurs as a consequence of long duration exposures to high noise levels. What is usually not too clear is how long the "long duration" is and how high are the "high noise levels". There is no, however discussion regarding that the effect is caused by a combination of both: duration and level. The concept of noise exposure combines both causes and that makes it so important. As mentioned above, in determining the risk of occupational hearing loss, measuring workers' noise exposure is an essential part of any hearing conservation program.

It all derives from an ISO standard [4] that estimates the probability of acquiring noise induced hearing loss after being exposed to a given noise exposure level for different periods of time. As an example, after 40 years of been exposed to 85 dBA for 8 hs a day, 50% of the population will acquire an average of extra 5 dB hearing loss between 500 Hz and 6 KHz, on top of the hearing loss due to age.

On the basis of the above statement, the limit of 85 dBA has been adopted almost internationally for a workday of 8 hs.

## 3. Standards and definitions

Reference [5] lists important standards from different institutions, related to noise exposure.

Noise exposure is a complex combination of sound levels a person has been exposed to and the duration of each one of those sound levels [5–8]. The closer analogy is to think in terms of noise energy that enters the persons' ears and damage the delicate organ of hearing. So, two variables are involved there: sound levels and time duration [9].

There are several concepts involved that need to be explained and defined. Their understanding is essential when dealing with this issue.

**Equivalent sound level, Leq, t in dBA** is the first of them. The easier way to understand it is as follows: In real life, sound levels constantly vary with time. They rise when the worker is using a power tool and diminish between operations, while changing continuously. Leq, t is a kind of an "average", constant sound level for the entire period of exposure (working) time, encompassing all "quiet" and "noisy" periods, with the same energy of the real one. It is defined as the value of a noise of constant sound level that contains the same total A-weighted acoustical energy as the sound of interest. In other words, while the real noise is of a varying sound level, the equivalent has a constant level of the same energy.

Now is the time to clarify the meaning of the letter "t" at the end of the Leq, t. It is there to signify that the Leq in question is for the period of time the worker has been exposed to.

Here we arrive at another important point that needs to be stated: whenever Leq is mentioned, the duration of the exposure (t), should also be stated. Otherwise the Leq has no meaning. This is not too difficult to understand as per the following example: suppose we have two workers. One of them is exposed every day to 90 dBA for 4 hs. The other one is exposed also to 90 dBA, but for 8 hs. It is obvious that the effect to the hearing of the second worker will be larger. In other words even though Leq,4 of the first is equal to the Leq,8 of the second, their effects are not the same.

The numerical definition of Leq, t is as follows: ten times the logarithm (base 10) of the time integral over a stated time, t hours, of the squared A-weighted sound pressure relative to 20 μPa, divided by that time.

**Noise exposure level, Lex, T, in dBA,** is another important measure. This is the one used to predict noise-induced hearing loss as per [4]. It is derived from the measured Leq,t by a simple adjustment to account for the longer or shorter duration of the workday on the workers' hearing. In other words, it answers the following question: what will be the value of Leq,t if the energy that entered the worker's ear during t hs would enter during 8 hs. By calculating Lex,T (with capital T), Leq,t for working days of different durations can be compared directly.

The following formula converts Leq,t into Lex,T:

$$Lex,\mathrm{T} = Leq,\mathrm{t} + 10\log\left(\mathrm{t}/\mathrm{T}\right) \tag{1}$$

Where: t is the duration of the actual exposure, in hr. and

T is the normalized duration, usually = 8 hr.

As an example, if a worker is exposed to 85 dBA for four hours a day (Leq,4), his exposure for a normalized 8 hs duration will be:

$$Lex,8 = Leq,4 + 10\log\left(\mathrm{t}/\mathrm{T}\right) = 85 + 10\log\left(4/8\right) = 82\ dBA. \tag{2}$$

If, on the contrary, he is exposed to 85 dBA for 12 hs (Leq,12), his exposure for a normalized 8 hs duration will be:

$$Lex,8 = Leq,12 + 10\log\left(\mathrm{t}/\mathrm{T}\right) = 85 + 10\log\left(12/8\right) = 87\ dBA. \tag{3}$$

The above example shows again how two workers with the same Leq,t, have different Leq,T and, consequently, different risk of hearing loss.

Mathematically, Lex,T is defined **as** ten times the logarithm (base 10) of the time integral of the squared A-weighted sound pressure relative to 20 μPa for the time actually worked, divided by T hours (usually the standardized shift duration of 8 h).

Finally, it has to be stated that while Leq,t is essentially measured, Leq,T is calculated from the Leq,t value. As it will be described further, the actual measuring instrument, the dosimeter, performs both the measurement and the calculation. Both values, Leq,t and Leq,T can be read on the same device. This greatly simplifies the task of the person performing the noise exposure survey. On the other hand, it can create misunderstandings if the operator does not has clear knowledge of the difference between Leq,t and Leq,T. As mentioned above, the one that is to be used when assessing the risk of hearing loss is the noise exposure level, Leq,T.

**Noise dose in %** is another important measure. Although the use of the noise dose is declining lately, many instruments still allow its measurement. The concept is familiar mainly to Occupational Hygienists and commonly used when dealing with hazardous substances. The idea is quite simple: it defines the relation between the amount of a substance absorbed by a person in a given period of time (usually 8 hs) and the maximum allowed by a local jurisdiction. For example, if this limit is set to 85 dBA for an exposure of 8 hs and the actual exposure for the same period of time has been 88 dBA, then his dose will be 200%[1].

The following equation allows for the calculation of Leq,t from a given dose[2]:

$$Leq,\mathrm{t} = 10\log\left(\mathrm{D}/100 \times 8/\mathrm{T}\right) + Lc \tag{4}$$

where D = dose in % for 8 h.

T = duration of the daily exposure in hours.

Lc = criterion sound level in dBA[3].

For example, a dose of 100% acquired during 4 hs (using Lc = 85 dBA) will result in

$$Leq,\mathrm{t} = 10\log\left(100/100\ \mathrm{x}\ 8/4\right) + 85 = 88\,dBA. \tag{5}$$

**Criterion level (LC) in dBA** is a constant sound level which, if it continues for the criterion duration (usually 8 hs), will result in the worker's allowable noise exposure. ISO (the International Organization for Standardization), as well as most Canadian provinces [10] and NIOSH (the USA National Institute for Occupational Safety and Health) [11] has adopted LC = 85 dBA for 8 hs.

**Exchange rate** is the increase (decrease) in sound level for which permissible exposure time is halved (doubled)[4]. ISO, most Canadian provinces and NIOSH has adopted 3 dB exchange rate. So, for instance, if a person is allowed to have Lex(8) = 85 dBA for 8 hs, he is also allowed to Lex(4) = 88 dBA for 4 hs.

## 4. Noise exposure measurements

There are two issues involved in the measurement of Leq,t: one is related to the instrumentation involved and the other deals with the measurement technique and procedures. Although managing the instrument itself is a relatively simple task, the measurement procedure requires basic knowledge of noise as well as practical knowledge regarding where to put the dosimeter, for how long to measure, etc. Measuring noise exposure of groups is more complex and requires some knowledge on statistics to be able to decide how many individuals to sample and for how long.

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[1] For this calculation it is assumed that every time the noise exposure increases 3 dB, the exposure is multiplied by two. This is known as "exchange rate" (in this case = 3)

[2] As a matter of fact, this calculation is also performed by the dosimeter. Therefore the operator can read the result of the measurement as a Dose as well as Leq,t or Lex,T.

[3] Lc is the maximum Lex,T, a person is allowed to be exposed for 8 hs, daily.

[4] The two common exchange rates used are 3 dB and 5 dB. Even where the 5 dB exchange rate is required in a Regulation, it is recommended that the 3 dB exchange rate be used as well since it provides a higher degree of protection (for exposure of 8 h) or less).

### 4.1 Instruments

Noise exposure can be measured using regular sound level meters and integrating sound level meters. However, there is a device specifically designed to measure Leq,t. It is the **noise dosimeter**. In its basic version it consists of an ¼" diameter microphone connected through a long cord to a container with the battery and the electronic components of the instrument. It also includs a readout device that allows for reading of the measured Leq,t. The microphone is to be attached close to the ear of the person whose exposure will be measured. The rest of the instrument is usually worn on the belt or in the shirt pocket (see photographs in **Figure 1a** and **b).**

a. Spartan Model 730 by Larson Davis. (3-dbadges case).

b. **dBadge2 IS (Pro)** by Casella

**Figure 1.**
*Dosimeters with separate microphones.*

Recently, manufactures have opted for compact, small size dosimeters called Noise Badges that contain both the microphone and the microprocessor of the instrument. By having the entire instrument in a single body, they eliminate the cord that is a nuisance and also can be a workplace hazard. Measurement results can still be read on the dosimeter itself. Thay can also be transmitted via Bluetooth technology to another device with facilities for recording for future use. This is especially handy when a noise exposure survey is carried out on several workers simultaneously, while each is carrying his own dosimeter. In some models, the receiver is also a charger for the batteries of all instruments. **Figure 2a** and **b** shows Noise Badges from two manufacturers.

There is a wide variety or instruments in the market, able to perform different measurements and calculations. They all belong to the following two basic types of dosimeters: **measuring** and logging.

**Measuring** dosimeters allow for the straight measurement of Leq,t and, eventually calculate Lex,T. Although most allow for reading the results on the instruments themselves, some others relay on a separate measurement device. This is done to keep the results visible to the operators only.

Dosimeters measure sound levels at predetermined intervals of time. **Measuring** dosimeters do not allow for extracting individual readings, just the final results at the end of the measurement period. **Logging** dosimeters, on the contrary, allow for the extraction of individual Leq,t. In such a way one can obtain the entire history of the sound levels at predetermined time intervals. The results can then be downloaded into a computing device and shown as a graph, spreadsheet, etc. By analyzing the partial data, one can follow their variation with time. Then, by knowing where the person was located at different times of the day or what kind of operation he was involved in, one can pinpoint the important noise sources or operations. Noise history is a powerful tool used for the design of noise controls in the workplace.

Another advantage of the logging dosimeters is that by studying the noise history one can determine if there have been abnormal events and then "clean" false results caused from malingering or noises not normal in the particular workplace.

### 4.2 Measurement techniques

#### *4.2.1 Individuals*

Measuring Leq,t of individuals using a dosimeter is a relatively simple exercise, generally explained in the manual supplied with the instrument[5]. Manuals contain also information on how to care and the main precautions that have to be taken to obtain proper results.

A most important task, often overlooked, is to inform the person(s) under test the reason for testing and how it will be done. In many instances not knowing the "why" and "how" lead to malingering and falls results. Often workers suspect that the instrument will in fact transmit their conversations to the supervisor. In other instances, some individuals created artificially loud noises to show levels that do not exist in reality.

After calibrating the instrument and ensuring that the batteries have enough charge to last during the testing period, the microphone of the dosimeter is attached close to the wearer's ear (generally on the shoulder or close by, and switched on.

[5] Instructions in this Section are absolutely basics. More detailed instructions are needed to perform correctly a noise exposure survey.


A. DC112 by CESVA

b) PRO DLX by Quest Technologies

**Figure 2.**
*Dosimeters with incorporated microphones (noise badges).*

Then the individual is sent to perform his tasks as usual. If the task is repetitive, then the measurement is done during a couple of repetitions, only. However, when the sound levels vary during the shift or if the worker works in different places, the measurement should last for the entire shift.

As mentioned above, if the measurement has been performed for the entire shift, then Lex,T is equal to Lex,t. In other words, the daily reading is his daily noise exposure, Lex,T. If that is not the case, then the Eq. [1] (page YYY) should be used to convert the measured Leq,t in Lex,T.

*4.2.2 Groups*

In many instances, there is a need to assess a group of workers that perform identical tasks or are located in the same environment. Providing each one of them with a dosimeter is not necessary or practical. There are procedures to be followed that reduce considerably the number of instruments needed and still obtain reliable, statistically significant results[6].

## 5. Lex,T for T different of 8 hs

Noise induced occupational hearing loss is the effect on a person being exposed to high noise levels for extended periods of time. Epidemiological data, used as bases for our present knowledge of hearing loss, were derived from populations working for many years in such high noise environments [12]. This is also the origin of the equal energy theory and the 3 dB exchange rate [13].

As explained above, when the measurement period t is different from T = 8 hs, Eq. 1 is to be used,. The formula is meant for 8 hs long work day where acoustical conditions repeat day after day, month after month, for the assumed 40 active years of a person.

Presently, in many occupations, the duration of the workday is 12 hs a day with several days off to equal to 40 hs a week or 80 hs every two weeks. The question is, shall we still use Eq. 1 with T = 8 hs? No official document exists for such a situation. However, common sense indicate that since the average duration of the workday is still T = 8 hs, (the average over the 2 or the 4 weeks), Eq. 1 is still valid and shall be used.

As an example [14], the total of hs worked by the musicians at the National Ballet of Canada is 350 hs. Therefore, the average Leq,t during their rehearsals/performances was corrected using Eq. 1 as follows:

$$Lex,\mathrm{T} = Leq,\mathrm{t} + 20\log \mathrm{t}/\mathrm{T} = Leq,\mathrm{t} + 10\log 350/2000 = Leq,\mathrm{t} - 7.56\, dBA \qquad (6)$$

Where t = 350 are the actual annual number of hours worked and.

T = 2000 the number of work hours in a year.

We do not really know what happens to ears exposed to 12 hs a day, for a 40 hs week. Nor we know about yearly exposures of less than 2000 hs, that is the average exposure resulting of 8 hs a day, 40 hs a week. We can only assume that the equal energy principle can be extended to cover exposures of different durations.

Using the equal energy principle, one can calculate exposures of different workday duration too. For example, if a worker whose workday is 8 hs and whose exposure measured for 5 hs was Leq,5 = 85 will be.

$$Lex,\mathrm{T} = Leq,\mathrm{t} + 20\log(\mathrm{t}/8) = 85 + 20\log(5/8) = 83\, dBA. \qquad (7)$$

[6] See Appendix B in Ref. [9]

However, if his workday is t = 12 hs, then

$$Lex,\mathrm{T} = 85 + 20\log(12/8) = 87\ dBA \tag{8}$$

In the case of temporary worker, that performs 350 hs a year, it will be t = 350 hs, T = 2000 hs and Eq. 1 will be

$$Lex.\mathrm{T} = 85 + 20\log(350/2000) = 77.4\ dB \tag{9}$$

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