STRATEGIES FOR NOISE SURVEYS

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7.1.  INTRODUCTION

7.1.1.  Definitions

$L_{\text{inst}}$ designates the instantaneous level indicated by a simple sound level meter set on FAST or SLOW as far as the averaging time is concerned. In recent times the $L_{\text{inst}}$ parameter has been replaced by the A-weighted equivalent level $L_{Aeq,T}$. This is the continuous level which, over a given period of time, $T$, would give the same amount of acoustical energy as the actual noise. This is the so called ISO equal energy principle. As mentioned in chapter 4, this is different from the so called OSHA principle (USA) according to which an exposure of duration $\Delta T$ at a noise level $L_{\text{dB(A)}}$ is equivalent to an exposure of duration $2\Delta T$ at a noise level $(L-5)_{\text{dB(A)}}$ (according to the ISO principle, it is equivalent to $(L-3)_{\text{dB(A)}}$ during $2\Delta T$).

Over a given period of time, personal dosimeters (personal sound exposure meters) offer usually the possibility of recording all or some of the following parameters:

- $L_{x\%}$ the noise level (in dB(A)) exceeded during $x\%$ of the time;
- $L_{\text{MAX}}$ the highest level (in dB(A)) exceeded during that period of time (in SLOW and FAST, depending upon the setting of the instrument);
- $L_{\text{peak}}$ the highest peak level (in dB).

For hearing conservation purposes or to estimate the individual risk of hearing loss of an exposed person, it is necessary to define an average level characterising the mean exposure of the person.
Two parameters are defined:

- the *daily noise exposure level* \( L_{EX,8h} \) (= \( L_{aeq,8h} = L_{EP,d} \)) which is the continuous level, in dB(A), which would, over a standard daily period of 8 hours, produce the same amount of acoustical energy as the actual daily exposure. This concept is used when the worker is exposed daily, for 5 days per week, to the same level.

- if this is not the case - for instance a work cycle of more than one day or less than 5 days per week - the concept of the *weekly noise exposure level*, \( L_{EX,w} \), is used: this is the continuous level, in dB(A), which over a standard weekly period of 40 hours, would produce the same amount of acoustical energy as the actual weekly exposure.

ISO standard 1999 introduces also the quantity, \( E_{A,T} \), which is used to characterise the total noise exposure in terms of \( \text{Pa}^2\cdot\text{h} \). This quantity is discussed in more detail in chapter 1. Note that many people use the units \( \text{Pa}^2\cdot\text{s} \times 10^{-3} \) (see Table 7.1).

The standard ISO/DIS 9612 (1995) indicates how to estimate the daily noise exposure level of a worker using a sample composed of \( n \) measurements having a noise level \( L_{Aeq,T_i} \), carried out with a specified integration time \( T_i \), where the total exposure time is,

\[
T = \sum_{i=1}^{n} T_i
\]

\[
L_{Aeq,T} = 10 \log_{10} \left( \frac{1}{n} \sum_{i=1}^{n} 10^{\frac{L_{Aeq,T_i}}{10}} \right)
\]  

(1)

\[
CL = t_{n-1} \sqrt{\frac{s^2}{n} + \frac{0.026s^2}{n-1}}
\]  

(2)

\[
s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (L_{Aeq,T_i} - L_m)^2}
\]  

(3)

\[
L_{CL} = L_{Aeq,T} - CL
\]  

(4)

\[
UCL = L_{Aeq,T} - CL
\]  

(5)

\[
L_{EX,8h} = L_{EP,d} = L_{aeq,8h} = L_{Aeq,T} + 10 \log_{10} \left( \frac{T}{T_0} \right)
\]  

(6)
In the equations, $L_m$ designates the arithmetic mean of the noise levels $L_{A_{eq,T}}$, $s$ is their standard deviation $t_n$, the value of Student's variable for $n-1$ degrees of freedom at a probability threshold of 95%, $T$ is the total duration of the daily exposure, and $T_0$ is the reference duration of 1 working day (i.e. 8 hours). $LCL$ and $UCL$ are respectively the lower and the upper confidence limit of the $L_{A_{eq,T}}$.

These relations apply the ISO criterion of equivalence ("Exchange Rate") between the noise level and the duration, set at +3 dB when the duration is reduced by half. American regulations from the OSHA use the 5 dB criterion. With the OSHA criterion, the daily noise exposure level is calculated by replacing the "ISO" constant equal to 10 in equation (1) with the "OSHA" constant, which is equal to 16.61.

(EDITORS’ NOTE: There is a new recommendation by NIOSH(1998) concerning the exchange rate, see Chapter 4)

Equation (2) is used to estimate the confidence interval of the average value, and was proposed for the case of a normal distribution of noise levels expressed in decibels to account for the fact that the addition of decibels is a complex procedure (Bastide, 1988). If the variance of the observed distribution is relatively small, the quadratic term in equation (2) has little impact and the relation becomes a classic estimator of the confidence interval of a normal distribution. Other methods that use additive quantities exist, including the expression of the received noise as a percentage of the permissible daily noise dose (OSHA method), and transformation of decibels into energy - expressed as $(\text{Pascal})^2 \times (\text{seconds})$ (ISO 1999 method). The calculation based on the energy method has been standardised (Germany, DIN 45641 , 1990), and includes an estimate of the confidence interval of the mean sound level.

Examples

A worker is exposed during 4 hours per day, 5 days a week, to a reproducible $L_{A_{eq,T}}$ level of 95 dB(A). Since he/she works 5 days a week, the concept of daily noise exposure level $L_{EX,8h}$ can be used and it is equal to $95 + 10 \log_{10}(4/8) = 92$ dB(A).

Another worker is exposed for 10 hours per day, 3 days per week to a reproducible $L_{A_{eq,T}}$ level of 95 dB(A). The concept of $L_{EX,8h}$ is this time not applicable and the $L_{EX,w}$ must be used. Being exposed during 30 hours to 95 dB(A) is equivalent to being exposed 40 hours to a noise intensity which is $30/40$ or 3/4 of the intensity corresponding to 95 dB(A). Since $10 \log(3/4) = 1.3$, $L_{EX,w}$ is equal to $95-1.3 = 93.7$ dB(A).

7.1.2. Objectives of the Survey

The type and the strategy of measurement will depend strongly on the objectives of the survey. Four different objectives can be pursued:
1. the determination of the noise emission of a given machine or ensemble of machines;
2. the identification, characterisation and ranking of noise sources;
3. the verification that a given worker is or is not exposed to a noise level above the legal limits (compliance);
4. the prediction of the individual risk of hearing loss.

These four objectives and what they imply will be discussed briefly.
7.1.2.1. Noise emission evaluation

Standards are available for the determination of the noise emission of machines in general or of specific items of equipment. Methods are described which deal with sound power, sound pressure and sound intensity. These series of International/European standards include precision, engineering and survey grade situations. These measurements are usually rather sophisticated and require great experience. They will not be described here, but are the subject of ISO standards.

7.1.2.2. Ranking of noise sources

Control of noise at the workplace does not necessarily concern the noisiest sources, but those that make the largest contribution to the total exposure; this takes into account not only the noise level but also the duration of exposure and the number of people exposed. It is therefore important to identify each source, or at least the most significant ones, and to establish the duration of exposure and the number of workers exposed.

7.1.2.3. Compliance

To check compliance of noisy areas with regulations, it is necessary to determine the $L_{EX,8h}$ or the $L_{EX,w} = L_{EP,w}$ according to the nature of the exposure. In this approach, the conclusions are as follows according to whether or not the noise exposure level exceeds or not the occupational exposure level (OEL = 85 or 90 dB(A) usually):

- $L_{EX,8h} < \textless OEL$: the working conditions are acceptable legally
- $L_{EX,8h} > \textgreater OEL$: the conditions are unacceptable and control measures must be implemented as soon as possible
- $L_{EX,8h} \approx \text{OEL}$: additional measurements are needed to determine whether $L_{EX,8h}$ is lower or higher than the OEL.

Paradoxically, if the objective is only compliance, more measurements are made if the exposure is around the OEL than when the exposure level is below or even above the OEL.

7.1.2.4. Risk evaluation

The ISO 1999 standard describes a model for the prediction of the distribution of the hearing loss at a given frequency, in a population of a given age, after a certain number of years of exposure to a $L_{EX,8h}$ level. From this standard, Figure 7.1 was derived; it gives, as a function of $L_{EX,8h}$, the percentage of the population aged 60 years, which, after 40 years of exposure, would develop mean hearing impairments (average 500 Hz, 1 kHz, 2 kHz, 3 kHz) greater than 25 dB.

The figure shows that the risk of hearing impairment increases quadratically as a function of $L_{EX,8h}$. Therefore, if the risk is to be estimated with a given accuracy (for instance $\pm 2\%$), the accuracy required for the evaluation of $L_{EX,8h}$ increases: for instance $88 \pm 2$ dB(A) but $94 \pm 1$ dB(A).
7.1.3. Types of Noise

It is useful to have available a typology of the exposure fluctuations to simplify the description and measurement of actual noise exposure. The nature, deterministic or otherwise, of the noise level variations and the amplitude of these variations are the two essential points that must be known to define this typology. The importance of this data is illustrated by the examples presented below.

Any modification of the production, the alternating of activities such as deliveries, the maintenance of machinery, or the momentary use of extremely noisy machinery generally lead to fluctuations in the noise exposure conditions. Such varying factors are usually not random, and can be used to divide the exposure time into different intervals that correspond to particular activities.

Occasionally, relatively rare acoustic events occur, and can produce noise levels significantly higher than the average for a limited time during the work-day (e.g. a few minutes at levels of at least 10 dB(A) over the average level). Such events occur, for example, when an operator uses a compressed air blower to clean a machine or clothing at the end of a shift; when an individual is obliged to intervene in close proximity to a noisy installation; when metallic pieces are being hammered, etc.

![Graph showing % risk vs. noise level]

Figure 7.1. Risk of hearing impairment (mean 0.5, 1, 2, 3 kHz, deficit > 25 dB) as a function of the daily noise exposure level, \( L_{\text{EX,8h}} \).

The importance of rare acoustic events in the measurement of noise exposure must be stressed. Even if the overall duration of such events is no longer than a few minutes, their contribution to the total daily noise exposure can be predominant. An example of this is given in Table 7.1 where a lathe operator in an engineering workshop periodically cleans the machine with a compressed air blower, thereby producing up to 105 dB(A). The average daily duration...
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of these cleaning periods is estimated to be of the order of 5 minutes.

However, as seen in the table, this type of cleaning can contribute 61% of the noise exposure, whereas the lathing, which is the principle activity of this worker, contributes only

Table 7.1. Example of a rare acoustic event: use of compressed air blower for the cleaning of a lathe.

<table>
<thead>
<tr>
<th>Activity, $i$</th>
<th>Daily Duration</th>
<th>Relative Duration</th>
<th>Noise Level</th>
<th>8 hour Noise Exposure Level</th>
<th>Noise Exposure during Activity $i$</th>
<th>Relative Noise Exposure of Activity $i$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_i$ (min)</td>
<td>$T/T_d$ (%)</td>
<td>$L_{Aeq,Ti}$ dB(A)</td>
<td>$E_{A,8h}$ $Pa^2.s.10^{-3}$</td>
<td>$E_{A,Ti}$ $Pa^2.s.10^{-3}$ (%)</td>
<td></td>
</tr>
<tr>
<td>1- Lathing</td>
<td>360</td>
<td>75%</td>
<td>84</td>
<td>2.89</td>
<td>2.17</td>
<td>35%</td>
</tr>
<tr>
<td>2- Cleaning with compressed air blower</td>
<td>5</td>
<td>1%</td>
<td>105</td>
<td>364</td>
<td>3.79</td>
<td>61%</td>
</tr>
<tr>
<td>3- Verifications</td>
<td>115</td>
<td>24%</td>
<td>80</td>
<td>1.15</td>
<td>0.28</td>
<td>4%</td>
</tr>
<tr>
<td>Entire day</td>
<td>480</td>
<td>100%</td>
<td>87.30</td>
<td>-</td>
<td>6.24</td>
<td>100%</td>
</tr>
</tbody>
</table>

The total noise exposure at this workplace is the sum of the 3 partial noise exposures. It is calculated using the quantities defined in the standard ISO 1999 (1990).

$E_{A,8h}$: Noise exposure for an 8-hour working day, expressed in $Pa^2.s \times 10^{-3}$. The standard gives the correspondence table of this value with an equivalent noise level $L_{Aeq,8h}$ expressed in dB(A).

$E_{A,Ti}$: Noise exposure of activity $i$, calculated as $E_{A,Ti} = E_{A,8h} \times T/T_d$

(where $T_d = 480$ min or 8h)

The average noise exposure over the shift is 87.3 dB(A), which, because of the use of the compressed air cleaner, is higher than the permissible exposure level of 85 dB(A).

To make it easier to account for factors likely to create significant fluctuations in the noise levels, Thiery et al. (1994) proposed a typology of exposure situations that defines the 5 types of exposure illustrated in Figure 7.2, which include:

- exposure to a steady (or quasi-steady) noise,
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- exposure to several steady noises, each having average levels separated by approximately 5 dB(A) and fixed durations,
- exposure to noise fluctuating in a repetitive cycle,
- exposure to a fluctuating noise that includes rare acoustic events that are predictable and easily identified,
- exposure to noise that fluctuates in a random, unpredictable manner.

N.B. A "steady" noise refers to a situation where, when each sample is integrated over a duration of one second (or using the "slow" setting on the sound level meter), the variations in the amplitude between samples are less than 5 dB(A).

7.1.4. The Three Steps of a Survey

As shown in Figure 7.3, the implementation of a strategy for the measurement of noise exposure that is adapted to different types of noise includes several steps. The first step consists of carrying out a preliminary study of the work place and the circumstances that govern the important variations in the level of noise exposure (Section 7.2). The second step deals with the definition of a measurement strategy and carrying out the measurements to quantify the noise exposures experienced by the workers (Section 7.3). The third step treats the interpretation of the results of the investigation (Section 7.4).

The justification for proceeding in the above manner is that it is impossible to know what exposure situations require special metrological efforts without a preliminary study. It has been shown (Damongeot, 1990) that "blind" sampling (i.e. noise measurements without any preliminary study) can lead to serious underestimation of the daily noise exposure levels (by up to 35 dB(A)) in the case of a rare acoustic event "forgotten" during the sampling. When the measurements reveal periods of over-exposure, it is necessary to not only evaluate the mean noise exposure level, but also to identify the causes of the over-exposure through a global analysis of the circumstances surrounding the real exposure.

7.2. PRELIMINARY SURVEY

As shown in Figure 7.3, related to the strategy for the evaluation of noise exposure, the preliminary survey has two particularly important objectives: to describe the circumstances surrounding the noise exposure; and to identify those factors which can cause systematic variations. A measurement strategy adapted to each exposure situation can then be developed based on this information.

The information required at this stage includes the number of exposed workers, the characteristics of their activities and the identification of any noise sources, the way in which the activities are organised and how they change as a function of time. This survey thus leads to the constitution of homogeneous exposure groups, and to the identification of characteristic time periods of the different exposure situations or stationary intervals, as proposed by Malchaire (1994).

It is also desirable to involve the workers in the preliminary survey in order to be able to take their real work situation into account, thereby rendering the study more complete and then validating the data collection scheme. Additionally, by associating the workers with the survey, they will be more aware of the risk of exposure to noise.
If noise measurements made prior to the current survey are available, they can be used to specify the aspects on which the preliminary survey should focus. Otherwise, a few measurements can be made at this stage to evaluate the noise variations, or to estimate the different ambient noise levels of the different workshops. The only real objective of the measurements made at this stage is to prepare the way for the real exposure measurements that will be carried out during the second phase of the survey.

7.2.1. Location and Identification of Noise Sources in the Work Environment

In any workplace it is essential to tour the premises with the assistance of someone familiar with the premises and the working practices.
Before doing any analysis, it is useful to identify the type and position of the different sources of noise that are present in the workshop. Locating any fixed machinery likely to be noisy will be made easier through the use of the plans of the layout of the workshop. This identification will also include any mobile machinery or vehicles, manual operations that cause noise, and of course, any operations, machinery or actions likely to cause rare acoustic events.

The machinery will generally go through several different operating modes during the working day for the following reasons:

- production can change from one day to the next;
- a given fabrication process can include many steps;
- machine settings can be altered;
- there can be alternating shut-down and production phases, etc.

Noise level fluctuations can be observed during a single working day, or over the course of several days. Knowledge of the different operating cycles of machines is necessary in order to evaluate their probable impact on the noise exposure of the workers, and to define a measurement strategy that can account for such non-random variations.

**Figure 7.3. Steps in the measurement of the noise exposure of workers.**

- **HEG:** Homogeneous Exposure Group
- **$L_{EX,d}$** = **$L_{EX,8h}$:** Daily Sound Exposure Level
- **PEL:** Permissible Exposure Level
- **LCL:** Lower Confidence Limit of Daily Exposure Level
- **UCL:** Upper Confidence Limit of Daily Sound Exposure Level

It is essential to have a workshop plan during the tour in order that information given can be transferred to the plan. The tour will also identify those areas where noise appears to be high and where noise appears to be a problem as perceived by the operators; in this instance the various
operators need to be involved with the discussions. Again this information can be transferred onto the plan.

In addition, the person carrying out the survey can identify those machines he or she perceives as giving rise to high noise levels which can be identified and noted on the plan for inclusion in the noise assessment.

Following completion of the initial tour, it is advisable to obtain agreement with managers and employees that the conditions encountered are normal/average for a days activity. This should form the basis for discussion in establishing the working system seen during the tour and an analysis of the working patterns; in particular in relation to those operators who have been previously identified as being included as subjects of the measurements for the noise assessment. The information gathered can be used for a variety of purposes such as:

- establishing high noise areas;
- identifying individual noise sources and their character;
- identifying the areas/machines making contributions to the exposures of persons;
- creating a plan in order to decide what to measure and how to measure and for how long;
- deciding whether individual operators can be assessed or whether one operator can be assessed as representative of a group or whether an area can be assessed and the information applied as representative of all operators in those areas; and
- choice of the instrumentation to be used

Too much information is not a problem; any excess can be discarded at the report stage.

7.2.2. Work Analysis

The objective of the task analysis is to precisely define the characteristics of the different exposures and to identify those factors responsible for any variations in the noise exposure. Four factors are essential to this:

- the situation of the operators (fixed post, mobile post inside fixed zone, no fixed post, etc.);
- the nature of the tasks carried out by each worker (or group of workers), and the temporal breakdown of these tasks;
- the worker's environment, which also depends on the activities of neighbouring workers; and
- the type of noise exposure, including, in particular, the identification of rare acoustic events likely to cause exposure to intense noises of short duration.

Frequently, a working routine includes habitual, stable activities, as well as non-habitual activities such as intervention on the machines, tuning or cleaning of machinery, etc. The task analysis must then include both types of activities since the non-habitual activities often increase the noise to which an individual is exposed.

To make sure that the investigator collects all of the necessary information, several methods have been developed (e.g. Royster et al., 1986; Gamba et al., 1992; Malchaire, 1994; Thiery et al., 1994). Two notices outlining the information judged indispensable at this stage are shown in Tables 7.2 and 7.3 (from Thiery et al., 1994).

When the individual workers are carrying out clearly distinct tasks, it is necessary to make a list of these tasks and to specify the nature of each one, the average amount of time spent per day on it, and the type of noise exposure. If the duration of these tasks varies from one day to the next, an estimate of the medium-term average duration is needed.
7.2.3. Noise Characterisation

Two types of qualitative information on the noise exposure are useful to prepare the measurement strategy, and to choose a measurement method:

- the type of noise encountered
- the level of the risk involved

7.2.3.1. Type of noise

When conducting noise surveys it is important to establish the character of the noise source, which will depend on the working environment under consideration. Prior knowledge of the character of the noise being assessed is critical when selecting the most appropriate measuring instrumentation. Noise can be characterised by the following terms:

- **Steady-Continuous**: e.g. cotton/textile mill where there is little variation in perceived level.
- **Non steady-fluctuating**: e.g. woodworking mill (particle board process) where the level rises sharply when boards are being cut; concrete block machines.
- **Impulsive and impact**: drop forge, hammer mill, power press shop.
- **Broadband**: constant energy in all frequencies (e.g. bottling plant).
- **Narrow band**: energy confined to discrete frequency.
- **Tonal**: Discrete low or high frequency.
- **Sudden bursts**: High energy and short duration.
- **Infra sound**: sound at frequencies below 20 Hz.
- **Ultra sound**: sound at frequencies above 20,000 Hz.

Many work environments represent combinations of the above noise types; for example, a metal working shop would have impact noise and broadband noise. During the preliminary survey, the plan of the premises can be used to identify those areas which have different noise characteristics.

The capability of instrumentation varies enormously and it is of extreme importance to select the instrumentation capable of capturing and analysing the noise source under consideration in order that the total sound energy making up the personal exposure is measured correctly. The instrument chosen must have the appropriate response capability. Most grade 1 meters have these capabilities but it may be that the use of tape-recorders will allow measurements to be carried out for analysis later.
Table 7.2. Example of a notice summarising all of the information relative to the population of exposed workers, by type of exposure.

<table>
<thead>
<tr>
<th>WORK/TASK ANALYSIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>to guide the noise exposure measurements</td>
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</tbody>
</table>

**Notice 1: GROUPS OF EXPOSED WORKERS**

*This step deals with each of the workshops where noise is a problem. Its purpose is to identify groups of workers having similar activities, and those having specific activities.*

In order to examine the different types of noise exposure, it is necessary to proceed step by step, taking into consideration 4 activity-related factors: the principle task, the time frame of the job, the location of the activity, and its nature.

1 - **Distribution of the staff as a function of their principle activity:**
   - Production/Handling/Maintenance/Other

2 - **Distribution of the staff as a function of the working time:**
   - Day shift/Night shift
   - Other specific times

3 - **Location of workstation:**
   - Fixed work places:
     - position on plan,
     - personnel concerned.
   - Surveillance of limited zone:
     - outline the limits on workshop plan,
     - personnel concerned.
   - Work places very mobile:
     - outline paths, zones of activity,
     - personnel concerned.
   - Located in many different sites:
     - List of different activities,
     - personnel concerned

4 - **Nature of activities carried out at each work place:**
   - Nature of the tasks really performed including the different production steps.
   - Personnel concerned.

**Using this information:**

- Regroup the workers (or work places) according to the type of exposure and define homogeneous exposure groups.
- Make a list of those workers having specific tasks.
- Verify that all exposed workers are accounted for.
- Evaluate each of them using Notice (2) based on the analysis of the circumstances of the noise exposure.
Table 7.3. Example of a notice summarising the information describing the circumstances of an exposure situation, used in preparing the measurement strategy.

<table>
<thead>
<tr>
<th>WORK/TASK ANALYSIS</th>
<th>to guide the noise exposure measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notice 2: ANALYSIS OF THE CIRCUMSTANCES OF THE NOISE EXPOSURE</td>
<td></td>
</tr>
</tbody>
</table>
For those workers having similar activities, or for those having specific activities, examine all of their task in order to identify the factors that determine the noise exposure and its variations as a function of time. |

1 - Identify the nature of noisy activities

a) During normal activities:
   - Use of machines, tools, vehicles...
   - Noisy manual operations.
   - Noise caused by activity at neighbouring work station.
   - Noise caused by fixed equipment (conveyors, compressors,...).

b) During exceptional activities:
   - Tasks carried out at the beginning and end of production (re-supplying, tool changes, trials, adjustments, product removal, repairs, etc).
   - Cleaning.
   - Repairs (Unblocking, etc).
   - Periods of heavy maintenance.

c) Identification of any eventual rare acoustic events:
   - Use of high flowrate compressed air blowers.
   - Presence of compressed air vents (valve outlets, compressor purges, etc).
   - Occasional metallic shocks (straightening, hammering etc).

2 - Situation of noisy activities during the work shift

a) During normal activities and exceptional tasks:
   - How are the different activities spread out over the working day?
   - What is their average daily duration?
   - When can important changes in noise exposure occur?
   - If the shop activity is cyclic, what is the average duration of a cycle?

b) If activities are not regular:
   - What activities, machines or operations are supposed to be the noisiest?
   - When do they occur?
   - How long do they last?

c) If rare acoustic events do occur:
   - When do they occur?
   - How long do they last and what is the daily frequency of these events?
7.2.3.2. Level of risk

Use of a three level risk scale provides guidance for the assessment of the level of risk.

**Level 1**
Daily noise exposure level definitely below 85 dB(A), the limit value generally recommended in hearing protection.

**Level 2**
Intermediate risk, lying between Levels 1 and 3.

**Level 3**
Daily noise exposure level definitely over 90 dB(A), the value for which it is recommended that technical measures should be taken to reduce noise exposure.

This scale is interpreted as follows:

- For level one, exposure measurement is not needed if it is essentially certain that the limit value will not be exceeded. However, if there is a slight doubt, or if impulse noises can occur, then the situation should automatically be classified as Level 2.

- For Level 2 cases, it is likely that an over-exposure will occur. Exposure measurements are therefore necessary, and must be sufficiently precise (to within "1 dB(A)) so that it is possible to conclude whether or not the limit exposure value has been exceeded.

- Over-exposure definitely occurs in Level 3. Exposure measurements must be carried out as in Level 2. However, in the event that the exposure exceeds the limit value by more than 5 dB(A), the precision can be relaxed a bit.

7.2.4. Homogeneous Exposure Groups

In many workshops, it is possible to split the population into Homogeneous Exposure Groups (HEG); i.e. groups of workers exposed to noise in conditions that can be considered similar. This method (Leidel et al., 1977; Hawkins et al. 1991) is typically used in industrial hygiene in order to reduce the number, and therefore the cost of exposure measurements. Different authors have proposed using this technique in the evaluation of noise exposure (e.g. Royster et al., 1986; Gamba et al., 1992; Malchaire, 1994; Thiery et al., 1994).

The definition of homogeneous exposure groups is based on the data collected during the task analysis discussed above. The objective of this stratification is to divide the workers up into the largest groups possible in such a fashion that there are no systematic exposure variations between the members of the group. This last constraint often leads to HEGs being defined for a specific task, and to the workers being classified into an HEG according to the specific exposure durations or to different stationary time intervals.

Certain workers are obviously exposed to variations in the noise level which cannot be foreseen. These could include setters, adjusters and maintenance staff etc.. These individuals cannot be put into a group with the other workers *a priori*, and individual, repeated measurements must therefore be made for them.

If the workshop consists of a variety of machines all performing different tasks then there will
be a need to measure at all machines and all operators. However if there are many operators in an area and all are affected by noise from one machine or process then it may be possible select one or two operators who are representative of the group.

In situations where many operators are working in a defined area and their activities require many movements it is reasonable to establish exposures on an area basis and apply the same level of exposure to all.

Agreement needs to reached with all personnel involved, whatever strategy is adopted.

7.2.5. Definition of Measurement Times

There are two specifications concerning the measurement of the daily noise exposure level contained in the standards ISO 1999 (1990) and ISO/DIS 9612 (1995):

− use as a reference the duration of one working day, fixed by convention at 8 hours,
− choose the duration and distribution of measurement periods in order to encompass all of the important variations in the noise levels at the different work stations.

To apply these specifications, one needs to estimate the importance of any variation in the noise exposure. This is precisely the goal of the typology of noise exposure situations presented above (see Sections 7.1.3 and 7.2.3), and indicates how to account for production cycles, rare acoustic events, activity changes, etc.

When the exposure is stable from one day to the next, i.e. no variations greater than 5 dB(A), the measurements can be spread out over a single day. However, this generally is not the case, and it is thus preferable to spread the measurements out over the course of at least three working days or three stationary time intervals.

In contrast, when the preliminary survey reveals that important variations can occur from one day to the next, it is necessary to spread the measurement intervals out over as many working days as possible.

If rare acoustic events are detected during the preliminary survey, or if an excessive noise exposure situation is likely to occur during the course of non-habitual activities (e.g. adjustments, intervention in case of incident, etc.), a specific exposure measurement must include these specific exposure intervals.

The need to establish the type of noise will affect the type and complexity of instrumentation necessary for exposure assessments.

All sounds resulting from operation of the machines or process must be included in the measurement irrespective of their character, level and event time.

Using the plan of the workplace (which identifies workstations and machines etc.) the positions to be used for measurements should be agreed upon. Measurements should be obtained at worker positions preferably without the worker present, but if this is not possible then at 0.10m from the ear of the worker.

There is no need to measure over the full working day but measurements must reflect the normal operating cycle of the process; i.e. all noises present during normal operation must be included in the cycle duration chosen.

The total daily exposure, i.e. $L_{A_{eq},8h}$, can be assessed by obtaining a sample $L_{A_{eq}}$ if the operator spends all 8 hours at the same location. If operators need to move about then measurements must be split into samples; i.e. all activities will have a sample $L_{A_{eq}}$ and a time period associated with it. Under these conditions the $L_{eq}$ value can be calculated using:
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\[ L_{Aeq} = 10 \log_{10} \left( \frac{1}{T_0} \int_0^{T_e} \left( \frac{p_A(t)}{p_0} \right)^2 \, dt \right) \]

where:
- \( L_{Aeq} \) = equivalent continuous sound level,
- \( T_0 \) = total working period (usually 8 hours)
- \( T_e \) = exposure period (hours)
- \( p_A(t) \) = time varying instantaneous A-weighted sound pressure (Pa)
- \( p_0 = 20 \mu Pa \)
- \( t \) = time (hours)

Some examples of representative exposure periods are as follows:

**Operator of a Band resaw**
At machines of this type it is usual to measure over the period needed to cut say four lengths of wood of the average processed. If different lengths of wood are processed (this means that the dominant noise level; i.e. that during cutting will exist for longer periods with long lengths) then there is a need to make an assessment of the average cutting times. In addition, if the operator and his assistant are responsible for moving processed material and replenishing stock to be processed, then these activities need to be included in the assessment period.

**Operator of Power Press**
At a machine of this type the measurement period should be representative such as to include all activities the operator carries out to process a batch of material; e.g. if the press is oil /automatically fed then a representative cycle can be chosen such as that required to process a coil of material or a portion of it.

If the operator is responsible for replenishing material then this activity should be included in the period of measurement.

**Operator at a position on a continuous process line.**
At positions such as these the measurement period should cover the time to process a complete batch of material, particularly if stock needs to be replaced.

Under general conditions a period of 10 minutes would normally suffice unless the preliminary tour identified circumstances where longer measurements were necessary.

**Varying cycles of operation or transient workers**
In situations in which cycles of operation are not repeatable and longer measurement times are necessary, then measurements should be carried out using logging dosimeters, unless the activities can be split into identifiable samples. In addition, if the operator is continually changing his or her movements, then again there may be a need to use logging dosimeters for the measurements. If logging dosimeters are used it may be necessary to select more than one operator (carrying out similar tasks) to support assessment results.

7.3. EXPOSURE EVALUATION

The measurement of the actual noise exposure is the second step in the evaluation procedure
presented in Figure 7.3. The measurement strategy is designed, and then measurements are carried out using as a basis the data collected during the preliminary survey.

Depending on the circumstances of the workshop/site to be evaluated; i.e. the size/type, the machines/processes in use and number of persons employed, the system of measurement and the gathering of information needs to organised to achieve the desired results. A strategy needs to be developed, which cannot be done unless, prior to measurements, it is known which workplaces are of interest, which machines are in use and which operator positions and activities need to be included in the assessment. This can only be done after establishing with the workshop manager and operators/machinists that the activities on the day of the assessment are typical of a normal day’s work.

7.3.1. Design of the Measurement Strategy

Occupational noise exposure is generally characterised by two factors: a large exposed population, and an exposure duration that can extend over the course of many working days. Under these conditions, the measurements can only be carried out for a well-defined sample of workers, during specific exposure intervals (for a given sample), using appropriate materials and techniques. The goal here is to minimise the number of measurements that have to be made to guarantee their representativeness, given the changes in activity and exposure identified in the preliminary survey.

It is essential to draw a plan of the workplace which identifies the machines/processes in use, the operator positions associated with the machines/processes and any other persons engaged in work activities. Information, relating to numbers of employees and their respective duties/tasks should be identified and logged; it is also essential to obtain the hours of exposure of each employee to each task/duty. It would be beneficial here to obtain agreement from each employee and the workshop manager prior to data collection.

Agreement on the information above is essential if the results of the exposure assessment are to be considered as representative of a normal day’s activities.

7.3.1.1. Choice of equipment

Having gathered the information detailed above, the appropriate instrumentation needs to be selected (see Chapter 6).

If the system of work is such that operators work at one machine only and do not move about in general then measurements can be taken alongside each operator. In some cases simple sound level meters will suffice, but if the cycle of operation of a machine is variable then there will be a need to use instruments capable of measuring $L_{Aeq}$ (A-weighted equivalent continuous noise level) or tape recorders which will record the noise during each cycle of operation with the tape available to be analysed at a later date in the laboratory/office. However if operator activity is such that they need to move about the workshop continually and these movements bring operators into contact with many noise sources for varying lengths of time, then the most convenient instrumentation will be Noise Dosimeters, which will log each person’s noise exposure on a continual basis and indicate an overall exposure level as a percentage dose.

100% dose equates to 90 dB(A) in most countries.

Extreme care is required to ensure that the correct exchange rate is built into the meters. The
current exchange rate in most countries is 3 dB; however in some countries a 5 dB exchange rate is used.

**With the 3 dB exchange rate a dose of 100% equates to 90 dB(A) and 200% equates to 93 dB(A) where as with the 5 dB exchange rate 200% equates to 95 dB(A)**

The personal dosimeter, (or personal sound exposure meter) worn by the subject, is indispensable in instances where the worker's activities include numerous and frequent movements, when work is done in confined spaces, or when the characteristics of the exposure are unpredictable. In other, more regular and more predictable exposure situations, an integrating sound level meter, operated by a technician, is sufficient.

The equipment used must provide two results: the value of the daily noise exposure level, and the number of times the regulatory sound pressure level was exceeded. They should also conform with the technical characteristics specified in standard ISO 9612:

- Personal-dosimeter conforming to the standard IEC 61252, and equipped with an overload indicator;
- Integrating sound level meter, class 2 minimum (IEC 60804).

### 7.3.1.2. Measurement strategy

Three procedures are available for the use of measuring devices, the characteristics of which are outlined in Figure 7.4.

**a) Continuous measurements**

Every exposure interval is continuously measured using a dosimeter worn by the subject.

**b) Sampling measurements, directed by an operator.**

The operator responsible for the measurements chooses when to begin sampling during the measurement process, and carries out the measurements using an integrated sound level meter. Each measurement lasts at least a few minutes, but a sufficiently large number of measurements is taken.

**c) Random sampling**

The random selection of measurement times during the observation intervals is one of the recommended methods of obtaining representative samples. A sufficiently large number of data points is taken (at least 10), and it must be verified that there are no systematic, non-random variations among the measured noise levels.

**How does one choose the method that is best adapted to the exposure situation at hand?**

Continuous measurements using a personal dosimeter can always be used. It is also the only method adapted to situations where the workers are highly mobile, or when they operate in confined spaces.

Sampling with an integrated sound level meter can be a sufficiently reliable method when exposure situations vary little as a function of time. Guided sampling techniques can be used in situations where the noise exposure has been previously evaluated and where there are some data available that can be used to avoid any bias in the sampling introduced by the operator’s selection of measurement times. Random sampling methods can be used for a wide range of applications,
but are the most difficult to implement.

Noise measurements/surveys are carried out to establish/identify on a workplace basis the type, the nature and the extent of the noise problem. The decision on where and what to measure will be based on the information gathered in relation to Section 7.2.

Some guidelines are outlined in the following paragraphs:

a) Individual operators who work at one machine all day:
Measure alongside the operator as near to the ear as possible without impeding his/her task. The measurement period should be such that any variation in noise level over a full operating cycle of the machine should be included in the measurement period. It is always useful to repeat measurements for confirmation.

b) Operators in a group who carry out similar tasks:
Select a typical operator and measure as in a) above. The measurement period should be such that all activities carried out by the group are included in the period. It would be useful here to carry out repeat measurements but using a different operator.

c) Operators who move about the workshop/process and as a result are affected by many noise sources:
It will be necessary here to use noise dosimeters attached to a person who represents a typical operator in relation to the tasks being performed. The dosimeter should be attached to the person with the microphone clipped to the collar or lapel of their overalls/working clothes. Use two operators as measurement subjects.

7.3.1.3. Sample characteristics

The sample of workers included in the measurement campaign should include the following:

- all of the workers (or work stations) exposed to complex, highly variable, or highly specific
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conditions, and whose cases should be treated individually;
• a sufficiently large number of workers, selected at random from each of the homogeneous exposure groups defined during the preliminary survey.

Defining the optimal sample size for each homogeneous exposure group \textit{a priori} is a delicate task that depends on several factors: the size of the group itself, the desired precision of the estimate, the predicted amplitude of the fluctuations in the noise level, and the variable to be estimated. An example of this is shown in Table 7.4 (from Leidel et al., 1977), which contains the sample size "n" needed to obtain from an homogeneous exposure group a sample which includes at least one worker among the 20% of the most exposed.

Table 7.4. Sample size "n" needed to ensure (at a 95% level of probability) that the sample will contain at least one worker in the top 20% of the exposed population constituting an Homogeneous Exposure Group (HEG) of \( N \) workers.

<table>
<thead>
<tr>
<th>Size of HEG ( N )</th>
<th>( N &gt; 7 )</th>
<th>7-8</th>
<th>9-11</th>
<th>12-14</th>
<th>15-18</th>
<th>19-26</th>
<th>27-43</th>
<th>44-50</th>
<th>( N &gt; 50 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size ( n )</td>
<td>( n = N )</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>14</td>
</tr>
</tbody>
</table>

The working time sampling is based on the position and duration of the time intervals, identified as being representative of the noise exposure of the different tasks identified during the preliminary survey.

When the integration time constant of the measurement devices used is adjustable, it is better to use a smaller value and an increased number of measurements in order to obtain a total specified measurement time since it is easier to detect high exposure levels that last only a very short time. An important point of practical interest to note when carrying out the measurements is that the integration time constant must remain constant from one sample to the next. If not, the variances of the measured values cannot be compared.

The sampling itself is necessarily associated with a method for the analysis of the results that includes the validation of the sample. This point will be discussed in detail below (Section 7.4), but the analysis might require an increase of the sample size already analysed, or a modification of the sampling design.

7.3.2. The Measurement Survey

This section details the measurement procedures necessary to complete the exposure evaluation.

7.3.2.1. Preparation

The measurement survey should be carried out with the objectives clearly defined and understood by all parties and maximum cooperation given to the survey team, the resulting report will be beneficial to all concerned and the information gathered can be used for a variety of purposes such as:
• establishing exposures;
• establishing high noise areas;
• ranking of individual noise sources;
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• establishing noise contours;
• identifying noise control requirements on an area/machine basis;
• identifying the areas/machines making contributions to the exposures of persons;
• identifying hearing conservation requirements;
• creation of records of noise levels, high noise areas and personal exposure patterns;
• basis for later review.

The calibration of the instrument must be verified (ISO/DIS 9612) on-site, before and after each series of measurements, using an acoustic calibrator that conforms to standardized specifications (CEI 942, class 2 minimum).

If a noise dosimeter is being used, the worker who will be wearing the device should be informed of any precautions related to the use of the device. The microphone attachment should be placed in a stable, non-hindering manner on the individual’s shoulder, or on the edge of a protective helmet.

Note: It is recommended that prior to starting measurements the following check-list procedure is followed.

CHECKLIST
• has a site plan been produced?
• are all sections identified?
• are all machines/processes correctly identified and located?
• are all personnel identified and allocated in their respective locations?
• have all areas been classified for type of noise?
• is the appropriate instrumentation available?
• is the instrumentation in good working order?
• are there sufficient batteries?
• is the calibrator functioning properly?
• is the microphone un-damaged?
• have the instruments to be used been checked for calibration /response within the prescribed period?
• is there adequate supply of information sheets for the number of personnel and activities?
• are the conditions in the workplace representative of normal activity?
• have all areas with noise levels above recommended limits been identified?
• has adequate and effective hearing protection been chosen and allocated to personnel on the basis of the results of the preliminary survey?

7.3.2.2. Measurements

Measurement requirements should be known to all survey personnel and data sheets indicating all previously gathered information completed before measurements commence. All data required to be obtained should be known by all personnel with the ultimate objective to obtain accurate and justifiable levels of personal noise exposures. Personnel should also be familiar with national exposure limits; i.e. daily exposures and peak levels and sufficient measurements should be made to facilitate comparison. These comparisons will indicate which personnel are at risk; i.e. likely to be affected by Noise Induced Hearing Loss (NIHL).

The position of the measuring microphone is very important during the exposure evaluation. The microphone must follow the worker under evaluation in all areas where his/her activities take place. This type of immission measurement is different from area measurements, or from
emission measurements (ISO 11690-1). The standard states that the microphone of the measuring device be maintained between 10 and 30 cm from the subject's ear (ISO 9612). If an integrating sound level meter is being used, the operator responsible for the measurements must make sure that this distance is respected in order to avoid any systematic errors.

It is possible that peak sound pressure levels will saturate (overload) the measuring device. If this occurs, it is preferable to discard the measurements and begin again with another instrument, or reset the controls (amplifier gains) of the current device in order to avoid saturating it.

**Note** - Following all measurements there is a need to check the meter response by re-calibrating the instrument. If there is any significant change in the calibration level, then all measurements just completed will need to be repeated and the batteries will need to be replaced.

**When using integrating sound level meters the meter should be reset after every measurement.**

### 7.3.2.3. Recordings

All measurements taken should be recorded on data sheets together with information relating to machines, operators, activities, conditions, locations and measurement times. In addition, all equipment used, together with model and type numbers, calibrators used and dates of last calibrations should be noted.

When listing data from measurements, any extra relevant information should also be recorded. This information should be part of the final report and should be made available to all interested personnel.

The detailed information recorded with each measurement should complete the information obtained during the preliminary survey, and should include:

- the identity of the worker and eventually that of his/her homogeneous exposure group,
- the date and time of the measurement, and the measurement time interval,
- the type of work being done,
- any observations that might help explain eventual variations in the noise level,
- the characteristics of the measurement device used (identification, frequency and time weightings),
- the results obtained (equivalent noise level, peak sound pressure level (C-weighted) and number of times the threshold value was exceeded).

The use of a C-weighted peak resolves a long standing problem with measurement of the peak. The term "unweighted peak" is undefined. Without specifying the low end cutoff frequency of the measurement devices, measurements with different devices could vary greatly. For example, an innocuous car door slam might cause a unweighted peak greater than 140 dB on some instruments but not on others. Use of C-weighting defines the frequency response of the instrument and eliminates very low frequency impulses and sounds. The C-weighting discounts such sounds. Thus, the harmless effect from a low-frequency impulse that comes from closing a car door or other such innocuous very low-frequency impulses can be more properly assessed. Infrasound exposures (exposures below 20 Hz) will also be better assessed. Such exposures are rare and, even if they could occur, are not likely to be dangerous, at levels found in industry directly, to a person's hearing or health.
7.4. INTERPRETATION AND REPORTING

All information collected, resulting from carrying out the measures outlined in 7.3.1 and 7.3.2 will allow decisions to be made on the aspects discussed in the following sections. The method for the interpretation of the results must validate the measurements carried out; indicate whether or not the limit value was exceeded; and evaluate the hearing hazard created by the noise exposure.

7.4.1. Validation of Results

Before drawing a conclusion relative to the exposed population from data collected in a sample it is necessary to ensure that the statistical hypotheses used in the sampling design were not rejected. To achieve this goal the following statistical tests can be used (Malchaire, 1994).

a) a correlation test to verify the temporal independence of the measured data
b) an analysis of variance, or comparison of the observed distribution to a normal distribution to validate the homogeneity of the exposure group.

The methods of analysis mentioned here are available in a range of statistical software. However, to make them somewhat more accessible in the area of industrial hygiene, new software packages are being made available (e.g. the ALTREX software package presented by Despres et al. 1995).

A statistical analysis can lead the investigator to one of several choices, shown schematically in Figure 7.3:

- the results obtained are conclusive,
- the series of measurements carried out were too scattered to allow a clear conclusion to be drawn.

If it is not possible to decide whether or not there is an over exposure, two solutions can be envisaged:

- continue the series of measurements, or
- redesign the sampling if a new factor could explain a part of the observed variance.

7.4.2. Compliance

In addition to establishing the exposures of all personnel in the workshop and whether they are at risk the information allows the company to assess whether they are complying with national regulations.

Exposure level limits and the actions required to be taken at the various levels differ from country to country; however, whatever levels are set national legislation requires compliance in some form. Take the example of the European Directive 86/188/EEC, this Directive which requires that member countries put in place certain actions if exposure levels are in excess of certain levels. These levels are: "1st action level 85 dB(A) \( L_{EXS} = L_{EP,d} \) (daily personal noise exposure)"; "2nd action level of 90 dB(A) \( L_{EP,d} \)" and a "peak action level of 200 pascals (140 dB(C))". To comply with this Directive, member countries would, following an assessment of exposure levels, take certain actions and would need to implement certain procedures and controls. Where there are no clear regulations in place, ISO/DIS 9612-1995 may be used.

The statistical interpretation of whether or not the regulatory thresholds have been exceeded can be performed as follows:

- there is no over-exposure if the upper confidence limit of the daily noise exposure level is
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7.4.3. Evaluation of the Risk of Hearing Impairment

Again there may be different attitudes to risk of NIHL; however in the UK, research carried out to support the legislation (produced to implement the European directive 86/188/EEC) and also research carried out to assess the effects of the proposed Directive, provided information on percentages of populations likely to suffer varying degrees of hearing loss depending on noise exposure level and length of exposure in years; see for example Tables 7.5 and 7.6.

The risk of hearing loss in a population of workers exposed to a continuous equivalent noise level \( L_{\text{Aeq,8h}} \) of between 85 and 100 dB(A) is described in the standard ISO 1999. The description of the risk is given in statistical terms, and varies as a function of the following parameters: age, sex, exposure duration and noise level. In an homogeneous population, the evaluation of the risk of hearing loss supposes that these parameters are known.

It is occasionally necessary to reconstitute a medium-term mean noise exposure level by associating different work stations with specific exposure durations. If each work station \( "i" \) is exposed to a level \( L_{\text{Aeq,Ti}} \) in dB(A) for a relative duration \( D_i \) (in%), the reconstituted noise level is:

\[
L_{\text{Aeq,T}} = 10\log_{10}\left(\sum_{i=1}^{n} \frac{D_i}{100} 10^{\frac{L_{\text{Aeq,Ti}}}{10}}\right)
\]

7.4.4. Evaluation of The Risk of Non-auditory Effects

Exposure to high noise levels may not produce NIHL but high exposure could produce many other effects. Non-auditory effects of noise may be many but some effects have been the subject of studies on the health and well-being of workers in relation to performance, efficiency and safety.

Noise can contribute to fatigue, loss of concentration and absenteeism, some aspects of these effects are as follows:
- influence on cardiovascular function
- increase in response time
- decrease in speech recognition
- decrease in the quality of work
- influencing the ability to hear warning sounds and resulting effects on safety
- disturbance of sleep-leading to deterioration in health

Research will continue in this area and other non-auditory effects may emerge for consideration.

Table 7.5. Hearing loss expected in a typical unselected mixed male/female population exposed to noise continuously from 20 years of age. (Based on HSE Contract Research Report No2/1988, with extrapolations.)

<table>
<thead>
<tr>
<th>Level (dB(A))</th>
<th>Exposure duration - years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>115</td>
<td>36+</td>
</tr>
<tr>
<td>105</td>
<td>20+</td>
</tr>
<tr>
<td>97</td>
<td>8</td>
</tr>
<tr>
<td>92</td>
<td>2</td>
</tr>
<tr>
<td>87</td>
<td>0</td>
</tr>
<tr>
<td>82</td>
<td>0</td>
</tr>
<tr>
<td>no noise exposure (take as 75dB(A))</td>
<td>0+</td>
</tr>
</tbody>
</table>

1A : % exceeding 30 dB hearing threshold level

<table>
<thead>
<tr>
<th>Level (dB(A))</th>
<th>Exposure duration - years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>115</td>
<td>11+</td>
</tr>
<tr>
<td>105</td>
<td>2+</td>
</tr>
<tr>
<td>97</td>
<td>0+</td>
</tr>
<tr>
<td>92</td>
<td>0+</td>
</tr>
<tr>
<td>87</td>
<td>0+</td>
</tr>
<tr>
<td>82</td>
<td>0+</td>
</tr>
<tr>
<td>no noise exposure (take as 75dB(A))</td>
<td>0+</td>
</tr>
</tbody>
</table>

1B : % exceeding 50 dB hearing threshold level
Table 7.6. Hearing loss expected in a typical male and female population exposed to noise without protection, continuously from the age 20. (From HSE Contract Research Report No. 29/1991)

<table>
<thead>
<tr>
<th>% reaching 30 dB hearing loss at age:³</th>
<th>Males¹</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No noise exposure²</td>
<td>85 dB(A)</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>----------</td>
<td>----------</td>
</tr>
<tr>
<td>40(i.e. 20 yrs. exposure)</td>
<td>5%</td>
<td>7%</td>
</tr>
<tr>
<td>60(i.e. 40 yrs. exposure)</td>
<td>28%</td>
<td>35%</td>
</tr>
<tr>
<td>% reaching 50 dB hearing loss at age:⁵</td>
<td>1%+</td>
<td>1%+</td>
</tr>
<tr>
<td></td>
<td>7%</td>
<td>7%</td>
</tr>
</tbody>
</table>

¹ At all ages males tend to have worse hearing than females. There is still scientific debate about how far this reflects real differences in resistance to noise damage and how far it is due to a tendency for males to lead lives more prone to accidental hearing damage.

² The contract report does not give estimates for less than 5% of the population because the author does not consider scientific data allows for reliable figures to be given. Estimates which might not be to reliable might be made by extrapolation of the figure in the table.

³ This is the level of hearing loss is recognised as the point at which there is impairment of hearing. Compensation by the UK government scheme (DSS) is payable for this amount of loss. At a lower level of loss a civil claim might be possible.

⁴ + : indicate values extrapolated from the values in the contract report.

⁵ A higher level of compensation under the UK scheme (DSS)

7.4.5. Use of the Information

Information; i.e. noise levels, exposure periods, operator locations machine/process details should be recorded on the data sheets attached (Figures 7.5-7.9) to which a copy of the workplace plan/layout information relating to the $L_{Aeq,8h}$ levels should be attached.

There are many uses for the information collected as a result of a full assessment and these are
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Detailed below:

- informs all workers of their exposure pattern/level
- it serves as a record for the employer
- identifies those operators whose exposure level is above nationally agreed limits
- indicates areas of high noise exposure
- identifies machines/processes producing high noise levels
- indicates to employers where noise control is necessary
- indicates areas where ear protection is required prior to noise control being implemented
- indicates those areas where ear protection will still be required after noise control as been applied
- allows identification of the most appropriate location for new machines/processes.

These records should be kept by the employer until a re-assessment is carried out; re-assessments should be carried out when activities change, processes are changed/renewed or when methods of production are changed.

7.4.6. Transfer of Information

Information gathered as a result of an assessment should be discussed by all parties; i.e. management, employees, unions and any medical personnel. The reasons for this are that all personnel will then be aware of the noise exposure situation; agreements on where to apply control measures can then be made that satisfy all concerned. Priorities and action can be agreed upon and supported by all concerned. Areas where ear protection is required can also be agreed upon and hearing conservation plans can be drawn up with the full cooperation of everyone concerned. An agreed hearing conservation and noise control plan will be more effective if all persons concerned in the operations of the workshop are committed to dealing with the problem.

Training in the use of ear protection can be given by medical staff; if there are no staff on the premises, arrangements can be made for employees to be provided with the training by outside agencies, and appropriate time off arrangements can be agreed upon. Periodic medical checks can also be agreed upon between all parties. Medical records can be established and updated whenever reviews take place.

Workshop plans can also be updated whenever changes to operations, work practices, personnel or machines take place.

After collecting all the information; i.e. noise levels, operator locations, machine/process details and identifying all this on the plan of the workplace and on the various sheets forming the report, a list of operators and their activities should be compiled and the levels of exposure ($L_{\text{Aeq,8hr}}$) allocated accordingly.

Areas identified as having noise exposure levels in excess of 90 dB(A) $L_{\text{eq,8hr}}$ should be designated noise hazard areas and clearly marked with signs indicating the hazard. Entry into these areas should be restricted unless personnel are equipped with adequate and effective hearing protection.

The areas so identified may need to be the subject of further measurement to establish the frequency spectra of the noise; in these cases instruments capable of measuring noise in OCTAVE BANDS will be necessary. After obtaining frequency data, the selection of hearing protection will need to be based on this information in accordance with Chapter 11. This information is also crucial when considering noise control systems.
7.4.7. Report Format

The report should be compiled and completed by the person in charge of the assessment. Care should be taken to include all information gathered during the exercise and the sheets attached fully completed (see Figures 7.5-7.9). It should be possible from studying the report to obtain information in relation to the following:

- name location and business of the company,
- number of personnel employed names and titles/job descriptions,
- type of work being done,
- any observations that might help explain eventual variations in the noise level,
- characteristics of the measurement device (identification, frequency and time weighting),
- the results obtained (equivalent noise level, peak sound pressure level (dB(C)) and number of times the threshold value was exceeded).

7.5. EXAMPLES OF SURVEYS

Surveys/assessments will vary depending on the circumstances of the workplace; i.e. there will be a variation in size, number and layout of machines/processes, operator positions, number of operators and systems of working.

Two example surveys are outlined below and in each case the method of measurement and assessment is explained.

7.5.1. Survey Example One

A small woodworking premises containing 3 machines, has a layout as shown in Figure 7.10. All information in relation to the REPORT sheet is to be completed.

The situation is as follows:
Machine - A is a Band Resaw
       B is a Multi-cutter Moulder
       C is a Thicknesser

All machines have a dedicated operator and each machine is used for 4 hours each day.

7.5.1.1. Gathering the information

Measurements are taken using an integrating sound level meter set to fast response dB(A) and $L_{eq}$, and calibrated before measurements begin. In this case, because all the machines can be in operation at the same time or working alone, it is essential to establish noise exposure levels of operators under all working situations which will indicate if a particular machine makes a contribution to the exposure level of operators at the other machines.

To establish this it is necessary to measure at the operator location of say machine A with that machine in operation only and then to repeat the measurements at machine A with machine B operating, then with machine C operating and with both machine B and machine C operating at the same time. This will then provide four sets of results which will need analysing to establish the exposure levels of each operator under each of the conditions of machine operation, where to concentrate noise control solutions and whether noise control carried out at one machine affects only that operator or whether it also reduces the exposure level of operators at other machines.
### COMPANY DETAILS

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| SIGNATURE             |                        |

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**Strategies for noise surveys**

Report (Figure 7.5)
### ASSESSMENT DETAILS
(Figure 7.6)

**AREA DETAIL**

<table>
<thead>
<tr>
<th>MACHINE</th>
<th>PROCESS/ACTIVITY</th>
<th>MEASUREMENT POSITION</th>
<th>LEVELS (dB(A))</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>OPERATOR</td>
<td>SPL dB(C)</td>
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<tr>
<td></td>
<td></td>
<td>OTHER</td>
<td>PEAK dB(C)</td>
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<tr>
<td></td>
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<td>SAMPLE $L_{Aeq}$</td>
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### FREQUENCY ANALYSIS (Figure 7.7)

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<th>FREQUENCY (Hz)</th>
<th>63</th>
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<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
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<tbody>
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EXPOSURE ASSESSMENT (Figure 7.8)

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<tr>
<th>LOCATION</th>
<th>EMPLOYEE</th>
<th>JOB TITLE</th>
<th>NOISE SOURCE</th>
<th>TIME EXPOSED</th>
<th>$L_{Aeq,8h}$</th>
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COMMENTS

EMPLOYEE EXPOSED ABOVE THE ACTION/LIMIT LEVELS OF $L_{Aeq,8h}$

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CONCLUSIONS AND ACTIONS (Figure 7.9)

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</tr>
<tr>
<td>5</td>
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<tr>
<td>6</td>
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</tbody>
</table>
Strategies for noise surveys

A - BAND RESAW MACHINE
B - MULTI-CUTTER MOULDER MACHINE
C - THICKNESSING MACHINE

OPERATOR POSITIONS

Figure 7.10. Woodworking machine shop - example 1.
STAGE ONE

Machine A - Operating Alone
Before measurement it is advisable to watch and listen to the variation in sound over a representative cycle; i.e. assess the time for the measurement period such that all variations are included in the measurement. Probably the cutting of 3 to 4 lengths of wood would be sufficient.

The resulting level shown by the meter as $L_{Aeq}$ would be sample $L_{Aeq}$ in dB(A) (see Figure 7.6). In this case the level is 96 dB(A).
This information is to be noted on the measurement sheet.

Machine B-Operating Alone

RESET METER

Measure as for machine A, note and record the level. In this case the level is 93 dB(A)

Machine C-Operating Alone

RESET METER

Measure as for machine A, note and record the level. In this case the level 99 dB(A).

RESET METER

STAGE TWO

Machine A-with Machine B Operating At the Same Time
Measure as for machine A, note and record the level. In this case the level is 96 dB(A) (i.e. no change in level). This indicates that the exposure level of operator A is not influenced by noise from machine B. Note that noise at operator A due to machine B is determined by the level of noise produced by machine B, the separation distance from machine A to machine B and the acoustical characteristics of the building.

RESET METER

Machine A-with Machine C Operating At The Same Time
Measure as before, note and record the level. In this case the level remains at 96 dB(A). This indicates that the operator at machine A is not influenced by noise from either machine B or machine C.

RESET METER

Machine B-with Machine A Operating At The Same Time
Measure as before, note and record the level. In this case the level at machine B is 94 dB(A); i.e. an increase of 1 dB(A); this is the contribution of noise from machine A on the operator of machine B. This also indicates that if machine B were not operating but machine A was, the
noise at the operator position of machine B due to machine A would be 87 dB(A) which is calculated using $\{10\log_{10}[10^{94/10} - 10^{93/10}]\}$. 

**RESET METER**

**Machine B**-with **Machine C** Operating At The Same Time

Measure as before note and record the level. In this case the level at machine B is 96 dB(A); i.e. an increase of 3 dB(A). This is the contribution of noise from machine C on the operator of machine B. This also indicates that if machine B were not operating but machine C was, the noise at the operator position of machine B due to machine C would be 93 dB(A) which is calculated using $\{10\log_{10}[10^{96/10} - 10^{93/10}]\}$. 

**RESET METER**

**Machine C**-with **Machine A** Operating At The Same Time

Measure as before note and record the level. In this case the level at machine C is 99 dB(A); i.e. no measurable change; therefore no significant contribution is made by machine A to the noise level at the operator of machine C. 

**RESET METER**

**Machine C**-with **Machine B** Operating At The Same Time

In this case the level is 99 dB(A); i.e. no measurable change, this indicates that machine B makes no significant contribution to the noise level at the operator of machine C. 

**RESET METER**

**STAGE THREE** (note:- after each measurement reset meter)

**Machine A**-with **Both Machines B And C** Operating

Measure at machine A with machines B and C operating at the same time. In this case the level is 96 dB(A); i.e. no measurable change. this indicates that machine C and machine B make no significant contribution to the level of exposure at the operator of machine A.

**Machine B**-with **Machines A and C** Operating

Measure at machine B with both B and C operating at the same time. In this case the level is 97 dB(A) which indicates that both machines A and C make a contribution to the noise exposure level of operator B.

**Machine C**-with **Both Machines A and B** Operating

Measure at machine C with both machines A and B operating at the same time. In this case the
level is 99 dB(A); i.e. no measurable change. This indicates that the noise from both machines A and B make no significant contribution to the exposure of operator C.

Assessment of $L_{Aeq,8h}$ levels. ($L_{EP,d}$, Daily personal noise exposure)

$L_{Aeq,8h}$ and exposure levels can be obtained as follows.

**OPERATOR-A**
The measurements indicated that the noise level in terms of sample $L_{Aeq}$ was 96 dB(A) during the representative cycle but information indicates that the machine is in use for 4 hours per day. Therefore using the formula:

$$f = \frac{T}{8} 10^{\left(L_{Aeq} - 90\right)/10} = 1.99$$

$$L_{EP,d} = 10 \log_{10} f + 90 = 92.99 \approx 93 \text{ dB(A)} = L_{Aeq,8h}$$

**OPERATOR-B**
The measurements indicated that the noise level in terms of sample $L_{Aeq}$ at machine B from machine B was 93 dB(A) but that the noise at this position due to machine A was 87 dB(A) and the noise from machine C was 93 dB(A). To obtain the total noise level for operator B we need to add all three contributions,

$$L_{Aeq} = 10 \log_{10} \left[10^{87/10} + 10^{93/10} + 10^{93/10}\right] = 97 \text{ dB(A)}$$

Again the exposure period is 4 hours per day; therefore from the above formula, $L_{Aeq,8h} = 94$ dB(A).

**OPERATOR-C**
This measurement indicated that the sample $L_{Aeq}$ level was 99 dB(A) and again the period of exposure was 4 hours per day. Therefore, using the previous formulae, $L_{Aeq,8h} = 96$ dB(A).

In relation to noise control which is to be applied over a period of time it is advisable to analyse the above information to target control in the area which will give the optimum benefit and in this case the machine to deal with first is machine C. The reason is that operator C receives 96 dB(A) from machine C and machine C makes a contribution to the exposure of operator B. So reducing the noise from machine C would benefit both operators of machines C and B.

As an example, assume noise from machine C is reduced by 10 dB(A) by providing a noise enclosure. Then the exposure of operator C would be reduced to 86 dB(A) and the exposure of operator B would be as follows:
Previously the exposure was made up of contributions from all machines as follows $87 + 93 + 93 = 97$ dB(A) and because use of the machine was 4 hours the exposure was 94 dB(A).

Now because of reducing the effect of C down to 83 dB(A), the new $L_{Aeq}$ level for operator B is

$$L_{Aeq} = 10 \log_{10} \left[ 10^{87/10} + 10^{93/10} + 10^{83/10} \right] = 94 \text{ dB(A)}$$

As before, use is 4 hours; therefore for operator B, the new $L_{EP,d} = L_{Aeq,8h} = 91$ dB(A), a reduction of 3 dB(A).

### 7.5.2. Survey Example Two

In this example, the premises involved is an Auto-Lathe workshop, which houses 20 lathes, the operation of which is carried out by four setter/operators. The preliminary discussions and tour of the workshop indicated that each setter/operator carries out similar duties. This needs to be confirmed by all involved, and if this is agreed we need only establish the exposure of one setter/operator as an example and we can then assume that the other three will have similar exposure levels.

Again all details of the report sheets should be completed and below is an explanation of the system to use to establish $L_{EP,d} = L_{Aeq,8h}$.

Obtain a copy or draw a plan of the workshop and identify the areas of work of one of the setter-operators. The plan of the workshop is shown in Figure 7.11.

Preliminary observations indicate that the size of the workshop is also important in this case (this is generally the case with Autolathe workshops) because the workshop is small, compact and all surfaces are hard reflecting surfaces; i.e. concrete floor, concrete walls or corrugated steel sheet walls, windows and corrugated steel sheet ceilings. Therefore other information to be collected during the survey should include the following:

- a measurement of the reverberation time (to establish the acoustic nature of the room),
- an octave band frequency analysis to assist selection of hearing protection.

### 7.5.2.1. Gathering the information

Discuss with all operators their normal activities on a typical day, identify on the plan the areas where noise level measurements are required. Following discussions, the operator chosen indicated he would carry out the following activities:-

A- setting machines- 2 hours-stationed at the machine head.
B- replenishing stock bars- 2 hours-stationed at the stock feed of machines
C- selecting tools and sharpening- 2 hours-stationed at the work-bench area
D- organising removal of finished goods- 2 hours-stationed at the exit of the workshop.

This information should be confirmed by all operators.
Figure 7.11. Autolathe workshop
Following a measurement survey using the integrating sound level meter and using the knowledge gained from observing the operator and discussions with the operator; i.e. the information above, the following levels were established:

A- At a typical machine head the noise level was 97 dB(A)
B- At a typical stock feed the noise level was 96 dB(A).
C- At the work-bench the noise level was 94 dB(A)
D- At the exit to the workshop the noise level was 93 dB(A).

Example 2.

Information should also be obtained regarding the nature and type of work being carried out by each machine; i.e. the material being used: steel, brass aluminium or copper? and the type of material; e.g. round bar, square bar or hexagon bar?. Previous experience indicates that square and hexagon steel bar produce the highest noise levels in the stock tubes and the cutting heads. Using the previous formulae, the exposures for activities A, B, C and D are as follows:-

\[
\begin{align*}
\text{A-fractional exposure is 1.3} & \quad f = 1.252 \\
\text{B-fractional exposure is 1.0} & \quad f = 0.995 \\
\text{C-fractional exposure is 0.7} & \quad f = 0.63 \\
\text{D-fractional exposure is 0.50} & \quad f = 0.5 \\
\end{align*}
\]

Total = 3.5

To obtain the total exposure and \(L_{EP,d}\) for 8 hours we use the 3.50 figure above for \(f\) and use our previous formula to calculate \(L_{EP,d}\) and \(L_{Aeq,8h} = 95.5\) dB(A) which is rounded to 96 dB(A). It can be said that under typical working conditions all four setter/operators have an exposure level of 96 dB(A).

An alternative system would be to use a noise dosimeter. After calibrating the instrument, it is attached to a setter-operator, the microphone being clipped to the lapel of the overalls. The dosimeter is then set to run and the operator carries out his/her normal tasks. At the end of the 8 hour period the instrument is then interrogated to establish the dose level- a dose of 100% equates to an level of 90 dB(A) averaged over 8 hours. With an exchange rate of a 3 dB increase being equivalent to a doubling of exposure time, a noise exposure level of 96 dB(A) would read as 400% noise dose.

For the example considered, the major activities making up the exposure levels were at locations A and B. The exposure levels at both places are due to the noise from the lathes at both the machining heads and the tail stocks. Thus, any noise control should be directed at the lathes. However the noise at both the other two positions, C and D, is also mainly due to the noise from the autolathes and the reflected sound from the floor, ceiling and walls.

7.5.2.2. Noise control options

Because there are 20 lathes, noise control has to be considered carefully. If all machines were to produce similar noise levels then applying noise control to 10 machines would only reduce the noise in the workshop by 3 dB(A). In addition the noise at the locations C and D would only be marginally affected.

Using the information gathered during the frequency analysis select the most appropriate
form of ear protection to be used. Identification of those machines used predominantly for machining steel square or hexagon bar should be carried out first and a list made. These machines should be fitted with liners in the stock tubes, which will restrict noise from the action of the stock bar on the casing of the tubes. If all machines can be considered for this treatment, then the degree of noise reduction will depend on the performance of the liners in reducing impact noise.

Investigate the possibility of fixing acoustic absorption material to the ceiling of the workshop to reduce reflected noise; this will have most effect at locations C and D.

REFERENCES


DIN 45641-1990. Mittelung von Schallpegeln


**INTERNATIONAL STANDARDS**

Titles of the following standards related to or referred to in this chapter one will find together with information on availability in chapter 12:

ISO 1999, ISO 9612,
IEC 60804, IEC 60942, IEC 61252.