INTRODUCTION

This booklet has been produced as a guide to acoustic parameters and is intended for people who are not experts in sound measurement.

Some of the parameters calculated on sound measuring instruments are often mis-interpreted. By referring to this guide it is hoped that you will become a proficient user of your instrument and more knowledgeable when measuring sound and writing reports. As Castle manufactures a large range of instruments, some of the terms mentioned in this guide may not apply to your instrument.

While this guide will help you understand the basic parameters of acoustics, you may be interested to know about our Competent Person courses. The course is designed specifically for industry and requires a maximum of three days attendance. The course has a high practical content and involves a work based project. To find out more please contact Castle.

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A Guide to Acoustical Terms and Units

1.1 Sound Pressure Level (SPL).

Sound level meters measure acoustic pressure, and by international agreement they are calibrated in decibels (dB). The Sound Pressure Level in decibels is defined as:

$$SPL = 20LOG\frac{P}{P_o} \qquad \text{Eq 1}$$

Where: P is the measured ***r m s*** sound pressure
P_O is the reference ***rms*** sound pressure.
i.e.$2x10^{-5}$ Nm $^{-2}$ (or 20μ Pa).

Note that the decibel is a ratio of two quantities which have dimensions of power, and is not a unit.

The reference sound pressure P_O is by agreement taken as 20 μPa, which is the minimum audible pressure to a person with 'normal' hearing. The use of a logarithmic scale, such as the decibel permits the wide range of audible sound pressures (approximately 1,000,000 to 1) to be compressed into a scale of 120 units. Hence a faint whisper may be measured as 20dBA where as a chipping hammer of a road workman may produce 105dBA.

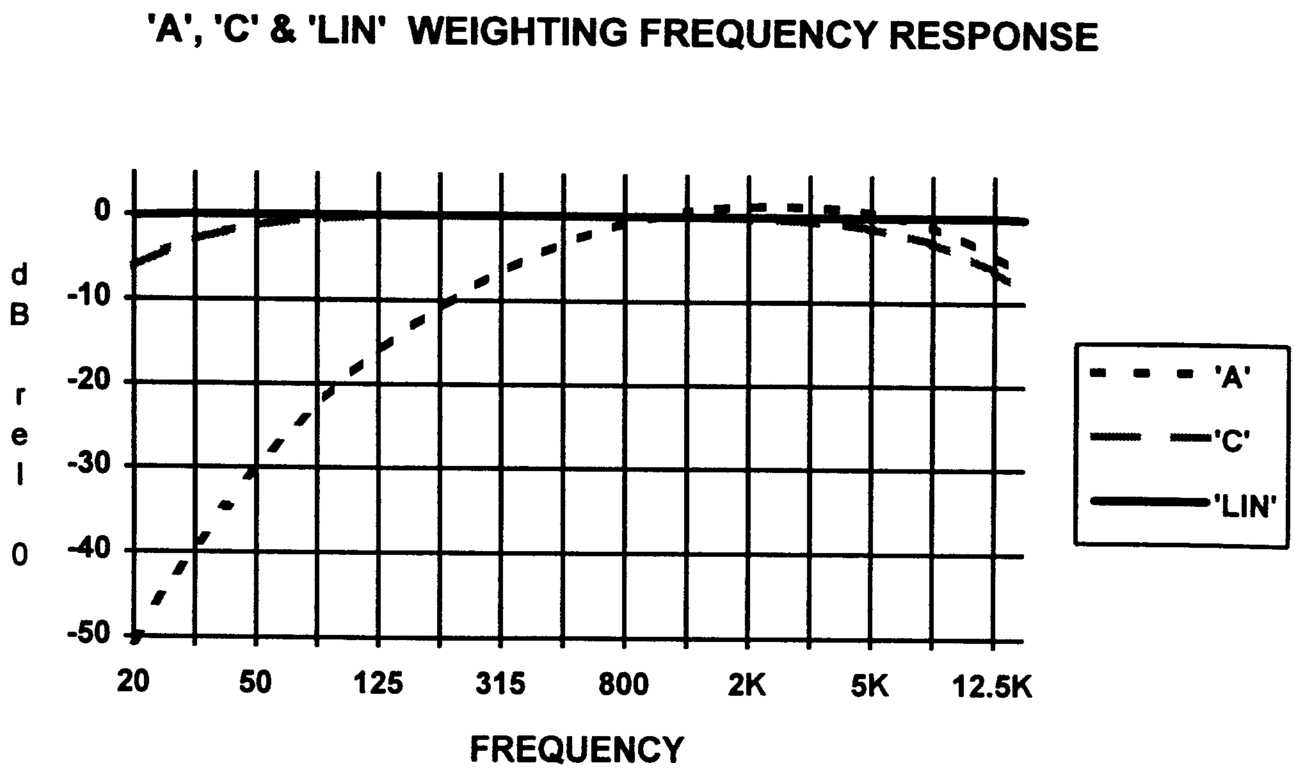
1.2 Standardised frequency curves

Because the ear is relatively insensitive to very low and very high frequencies, sound level meters have by international agreement weighted frequency responses. Hence different frequency weightings will produce for the same sound source different SPL readings.

Castle sound level meters may have any one of three frequency weightings.

- 'A' weighting, which best expresses the human ears response to loudness is the most commonly used frequency weighting.
- 'C' weighting, this is often used to ascertain the acoustic emissions of machines it has a much broader spectrum than that of the 'A' weighting curve.
- Linear weighting (or LIN, it is some times termed unweighted). It may vary between differing instruments as its characteristics are very dependent on the quality of the microphone and its pre-amplifier. It is often used in conjunction with octave band filters. A typical linear response would be flat from 20 Hz to 16KHz.

Fig 1



1.3 Time weighting - Fast, Slow, Impulse and Peak

It is important to understand that the SPL is an rms (root mean square) quantity and is therefore averaged within the constraints of an averaging time constant. These time constants are helpfully termed , Slow, Fast and Impulse and are sometimes referred to as the time weighting.

The SPL therefore is not only affected by the frequency weighting but by the time weighting of the instrument also. Hence by selecting **Slow** on the sound level meter a sharp rise in noise will be shown as a gradual rise in the SPL, alternatively a sharp fall in noise will be shown as a gradual decrease in the SPL. By using the **Fast** weighting on the instrument in both of the above scenarios the SPL will rise and fall on a more rapid scale. The **Impulse** response is not as commonly used as the above, it is used in situations of sharp impulsive noises typically a piling operation may require an impulse time weighting. It has a very fast rise time but a very slow exponential fall time.
The **Peak** weighting is very different from Slow, Fast and Impulse weighting in that it is not an rms quantity. It is simply the crest of the sound pressure level and it is shown as the highest Peak achieved within the measuring period. The rise time of the Peak is extremely sharp and it is not uncommon for the Peak to be much higher than the SPL(rms).

1.4 Lmax, Lmin, Peak.

Lmax is the highest rms sound pressure level within the measuring period (with slow, fast or impulse time weighting selected).

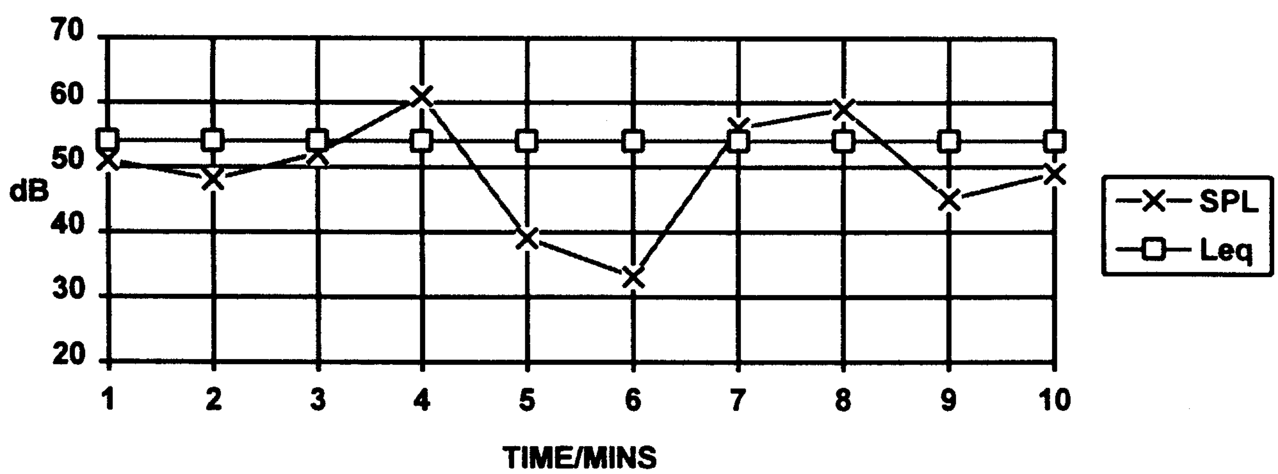
Lmin is the lowest rms sound pressure level within the measuring period (with slow or fast time weighting selected).

Peak is the crest (linear) of the sound pressure within the measuring period, not rms.

1.5 L_{eq}, Equivalent Continuous Sound Pressure Level.

L_{eq} is the constant noise level that would result in the same total sound energy being produced over a given period. It can be measured in either Linear, A-Weighted or C-Weighted mode. Figure 2 shows L_{eq} diagrammatically.

Fig 2



L_{eq} can be described mathematically by the following equation:

$$L_{eq} = 10\log_{10}\frac{1}{T_M}\int_0^{T_M}\left[\frac{P(t)}{P_o}\right]^2 dt \qquad \text{Eq 2}$$

Where: L_{eq} is the equivalent continuous linear-weighted sound pressure level re 20 μPa, determined over a measured time interval T_M (sec's).

$P(t)$ is the instantaneous sound pressure of the sound signal.
P_o is the reference sound pressure of 20 μPa.

When the instantaneous A-weighted sound pressure (P_A) of the sound signal is introduced, then the equivalent continuous A-weighted sound pressure level determined over time interval T_M is as follows:

$$L_{Aeq} = 10\log_{10}\frac{1}{T_M}\int_0^{T_M}\left[\frac{P_A(t)}{P_o}\right]^2 dt \qquad \text{Eq 3}$$

In practice when measuring noise it is possible to take Leq readings with your instrument of short duration i.e. <5 minutes providing all variations of noise emissions are covered. If the measured environment changes greatly then the longer the Leq measurement is taken, the more accurate the measurement.

1.6 SEL, Sound Exposure Level or (L_{EA})

$$SEL = 10\log_{10}\int_0^{T_M}\left[\frac{P(t)}{P_o}\right]^2 dt \qquad \text{Eq 4}$$

Where T_M is measured in seconds. This is in effect an Leq normalised to 1 second. It can be used to compare the energy of noise events which have different time duration's.

1.7 L10 ,L50 ,L90 Percentile Levels.

Percentile levels are used greatly when measuring environmental noise, i.e. that which may pollute the environment.

L*n*, where *n* may be anything from 1 to 99 is that noise level exceeded for *n* % of the measurement time. By definition of percentiles, L1 must be greater than or equal to L2 which must be greater than or equal to L3 etc. It is often the case that only a few Ln values are ever used.

Fig 3

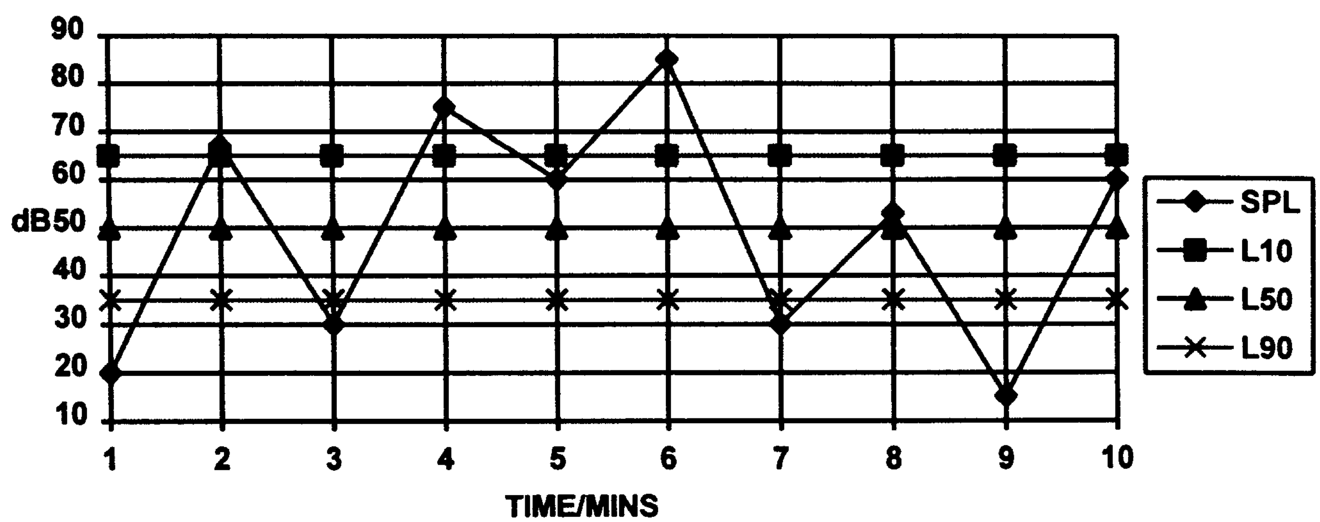


Figure 3 shows L10, L50 and L90.

L10 is the noise level exceeded for 10% of the measurement duration. This is often used to give an indication of the upper limit of fluctuating noise, such as that from road traffic.

L50 is the noise level exceeded for 50% of the measurement duration.

L90 is the noise level exceeded for 90% of the measurement duration.

These L*n* indices (L10, L50, L90) are the ones most frequently used and have the following significance:

L90 is taken to be the ambient or background noise level as used for example in BS4142: 'Rating industrial noise affecting mixed residential and industrial areas'.

(L10-L90) is often used to give a prediction of noise nuisance as noise with a widely varying level is more annoying than a constant noise level. (L10-L90) is used in such noise indices as Traffic Noise Index:

$$TNI = 4\,[L10 - L90] + L90 - 30 \qquad \text{Eq 5}$$

L50 is simply the 'middle point' exceeded for 50% of the measurement duration and has been incorporated in some American Community Noise Assessments.

1.8 $L_{EP'd}$ Daily Personal Noise Exposure.

$L_{EP'd}$ is a measure of exposure and depends not only on the sound pressure level but also on the duration of the noise exposure. $L_{EP'd}$ is the measure of noise exposure used in the 'Noise at Work Regulations 1989' currently in force in the UK. It is intended to be used to measure the daily exposure of a worker, therefore is dependent on shift duration. Note the similarity between this definition (Eq 6) and that of L_{eq} (Eq 3). Since $L_{EP'd}$ is normalised to 8 hours the $L_{EP'd}$ would equal the 8 hour L_{eq} of a worker exposed for 8 hours.

$$L_{EP'd} = 10\log_{10}\frac{1}{28800}\int_0^{T_M}\left[\frac{P_A(t)}{P_o}\right]^2 dt \qquad \text{Eq 6}$$

1.8.1. $L_{EP'd}$ = 90dB(A).
This represents a continuous constant level exposure to a noise of 90dB(A) for 8 hours.

1.8.2. When the $L_{EP'd}$ = 90dB(A). Then the $L_{EP'd}$ is the equivalent of 100% DOSE (see section 1.6, assuming criterion of 90 dBA).

Note that $L_{EP'd}$ is a logarithmic measurement as opposed to DOSE which is a linear function. Hence DOSE can be added arithmetically but since $L_{EP'd}$ is logarithmic, values cannot be added arithmetically.

The relationship between $L_{EP'd}$ and DOSE is given by the following equations:

$$L_{EP'd} = 90 + 10.\log_{10}[DOSE/100] \qquad \text{Eq 7}$$

$$L_{EP'd} = L_{eq} + 10.\log_{10}[t/T] \qquad \text{Eq 8}$$

Where: t = logging time
T=8 hours reference (28,800 sec's)

Each time the sound level increases the $L_{EP'd}$ increases. If the exposure time doubles, say 4 hours to 8 hours, the $L_{EP'd}$ increases by 3dB.

Some Castle instruments use the term Projected $L_{EP'd}$ this is only valid if the exposure duration of the worker is 8 hours. Otherwise use must be made of either the $L_{EP'd}$ which will be valid if worn for the full shift i.e. exposure, or by calculation methods using equations 7 and 8

Example:

A machine operator is exposed to a constant equivalent level (L_{Aeq}) of 84.0 dBA. What is the $L_{EP'd}$ of the operator if he works i)a shift of 8 hours, ii) a shift of 10 hours, iii) a shift of 6 hours?

Note that the sound level is constant i.e. 84.0 dBA throughout the working shift. Using Eq 8 the following can be calculated.

i) $L_{EP'd} = 84 + 10\log(8/8) = 84$ dBA. Note this is equal to the L_{Aeq}, since the exposure duration is 8 hours.

ii) $L_{EP'd} = 84 + 10\log 10/8 = 84.97$ dBA

iii) $L_{EP'd} = 84 + 10\log 6/8 = 82.75$ dBA

1.9 DOSE.

DOSE is a measure of noise exposure similar to $L_{EP'd}$, in the UK DOSE is best described with the following statement:

100% DOSE = 90dBA for 8 hours

In other countries DOSE may be specified differently

i.e. 100% DOSE = 85dBA for 8 hours may also be specified.

Tables 1.9.1, 1.9.2 & 1.9.3 give examples of how DOSE is related to exposure time and $L_{EP'd}$ (assuming 100%DOSE = 90 dBA for 8 hours.)

Table 1.9.1. Effect of changing SPL

SPL (dBA)	*Exposure Time (hours)*	*Dose (%)*	*$L_{EP'd}$ (dBA)*
99	8	800	99
96	8	400	96
93	8	200	93
90	8	100	90
87	8	50	87
84	8	25	84

Table 1.9.2. Effect of changing exposure time.

SPL (dBA)	*Exposure Time (hours)*	*Dose (%)*	*$L_{EP'd}$ (dBA)*
90	16	200	93
90	12	150	91.76
90	8	100	90
90	4	50	87
90	2	25	84
90	1	12.5	81

Table 1.9.3. Effect of changing SPL and exposure time.

SPL (dBA)	*Exposure Time (hours)*	*Dose (%)*	*$L_{EP'd}$ (dBA)*
93	4	100	90
90	8	100	90
85	8	31.6	85
87	4	25	84
84	4	12.5	81

Each time the sound level increases by 3dB the DOSE doubles given the same exposure time, similarly if the sound level decreases by 3dB the DOSE will halve for the same exposure time.

Doubling the exposure time doubles the DOSE and halving the exposure time halves the DOSE given the same sound level.

Figure 4a and 4b. show how the DOSE and $L_{EP'd}$ would increase over a period of time with a fixed sound level of 90 dBA.

Fig 4a

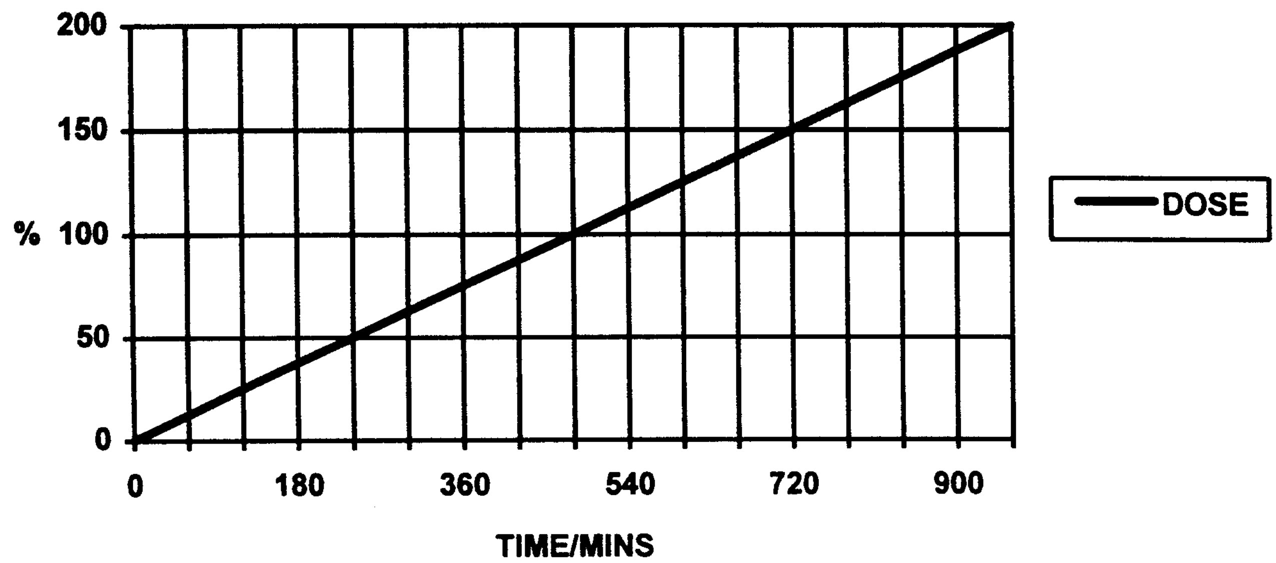
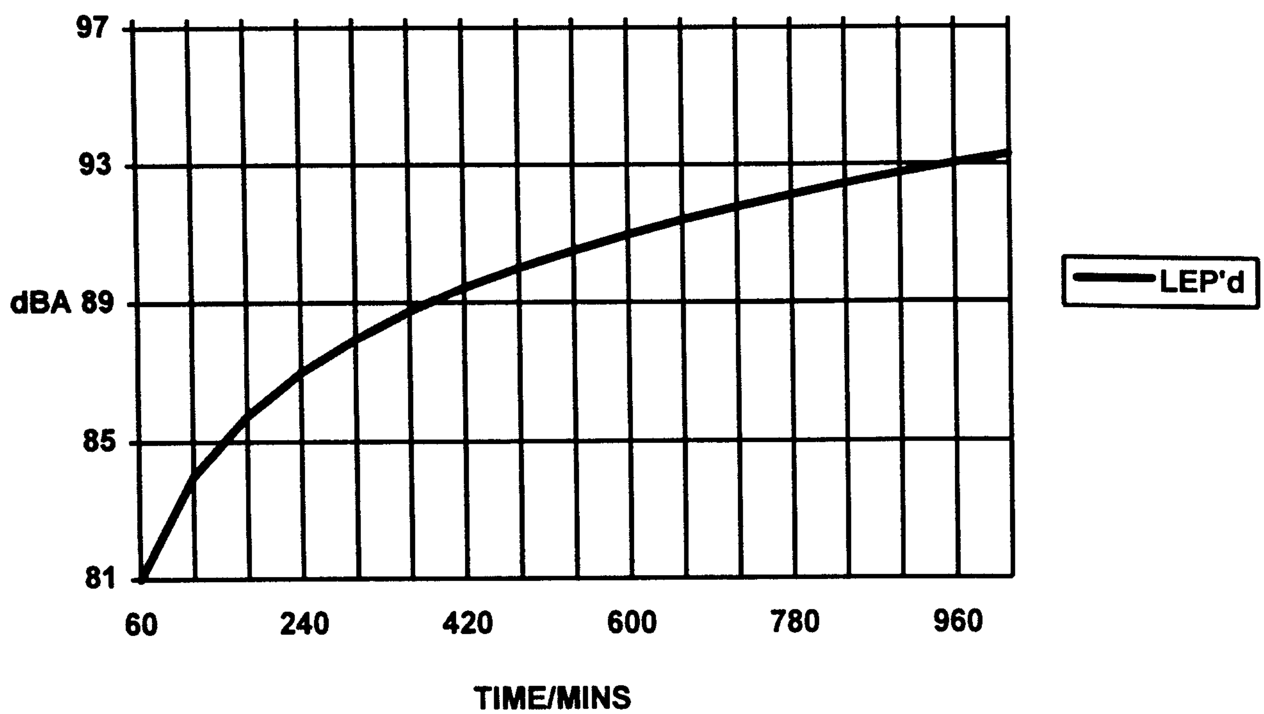

200
150
% 100
50
0
0
180
360
540
720
900
TIME/MINS
DOSE

Fig 4b


97
93
dBA 89
85
81
60
240
420
600
780
960
TIME/MINS
LEP'd

The operation of dose can be mathematically described by Eq 9 which relates the percentage exposure D to the integrated sound power.

$$D = \frac{100}{T_c} \int_0^T \uparrow\left(\frac{L - L_c}{q}\right) dt \qquad \text{Eq 9}$$

Where:

$\uparrow$ represents the anti-log
D = Percentage exposure (%).
T_c= Criterion sound duration (usually 8 hours).
T = Measurement duration in (hr)
L = Weighted sound level
L_c= Criterion sound level (usually dB(A))
q (Exchange rate parameter (dB))
=10 for an exchange rate of 3 dB
=5/log(2) for an exchange rate of 5 dB

With respect to L_c, criterion levels of 90 and 85 dB(A) are most often used.

For discrete time intervals at a constant sound level Eq 9 can be rewritten

$$D = \frac{100}{T_c} t_i 10^{\left(\frac{L_i - L_c}{q}\right)} \qquad \text{Eq 10}$$

Where:

Li = Weighted sound pressure level in the ith time interval
ti = Time spent in the ith interval (hr)

Example:

Calculate the daily (8 hr) noise exposure of a machine operator where the noise levels are constant at i)90 dB(A) and ii)100 dB(A). Use an exchange rate of 3dB and a criterion level of 90 dB(A).

Since the sound level is constant throughout the day, i.e. 90 dB(A) equation 10 reduces to:
i) t_i = 8 hr, T_c =8 hr, L_i = 90 dB(A), L_c = 90 dB(A), q =10.

$$D = 100.10^{\frac{0}{q}} = 100\%$$

ii) L=100 dB(A).

$$D = 100.10^{\frac{10}{10}} = 100x10 = 1000\%$$

The dose can be converted to an Leq.

$$L_{eq} = L_c + 10.\log_{10}[(D/100).(T_c/T_M)] \qquad \text{Eq 11}$$

Where: L_{eq} = the equivalent continuous sound level, with A weighting, from the time T_M.
L_c = Typically 90 dBA in the UK sometimes 85dBA in other countries.
D = indicated dose index (%).
T_c = reference time base 8 hours.
T_M = measurement time in hours.

1.10 Projected DOSE

DOSE measurements usually require the noise exposure to be measured over a full 8 hour working day. This can be simplified by using Projected DOSE.

Projected DOSE allows the present accumulated DOSE over the elapsed logged time duration to be projected forward to give the predicted 8 hour dose.

For example, if you had been logging for 30 minutes with an accumulated DOSE of 5%, the Projected DOSE would show:
5% x 8 hours/0.5 hours = 80% DOSE.

i.e. you would receive an 80% DOSE if you were to stay in this area with the same equivalent level of noise for the full 8 hours.

The following should be taken into consideration when reporting Projected DOSE figures:

1. The Projected DOSE assumes that the current DOSE rate will remain constant, i.e. the sound level does not change over the measurement period compared to the total 8 hour period.

2. The Projected DOSE will be more accurate if the measurement duration is as long as possible. There is an inhibit on Projected DOSE on Castle instruments to stop projections being made without a reasonable measurement duration having elapsed.

3. DOSE, and therefore Projected DOSE are measured with 'A' frequency weighting selected.

4. If, say, a 12 hour day is worked the 8 hour Projected DOSE should simply be multiplied by 1.5 (i.e. 12/8) to calculate what the DOSE would be after 12 hours.

2.0 Octave band measurement

Octave band measurement is used when the frequency composition of a sound field is needed to be determined. Octave analysis is used in noise control, hearing protection and sometimes in environmental noise issues. Ten octave bands are commonly used for this purpose, (31Hz, 63Hz, 125Hz, 250Hz, 500Hz, 1KHz, 2KHz, 4KHz, 8KHz and 16KHz). Although they are defined by the centre frequency, the filter characteristics are quite broad and internationally standardised. An octave filter effectively attenuates frequencies which are greater than 1.414 and less than 0.707 of the centre frequency.
E.g. The 2KHz filter stretches from 1.41 KHz to 2.82KHz.

Noise control - Octave band measurements are most often performed with an unweighted filter network i.e. Linear, so that the distribution of the energy source can be assessed. Although the work in the noise control field is often best left to the specialist as noise control measures may involve treating multiple noise sources each exhibiting complex modes of vibration.

Hearing protection - Although there are other methods for assessing the effectiveness of hearing protection for the worker, the most widely used is that of octave analysis. When measuring noise for an assessment of hearing damage/prevention to a worker it is best to use the A weighting filter in conjunction with octave analysis, as it is easier to see which frequencies contribute most significantly to the A weighted SPL.

It is normal for hearing protection manufacturer's to quote the octave band attenuation of their devices typically in the eight octave bands 63Hz, 125Hz, 250Hz, 500Hz, 1KHz, 2KHz, 4KHz, 8KHz. They may quote the mean attenuation and the standard deviation of the test results (or simply quote the APL [Assumed Protection Level] for each frequency). The APL is commonly acknowledged to be

APL = Mean value - 1 standard deviation. Eq 12

e.g. BILSOM 727
Attenuation in dB's

Frequency /Hz	63	125	250	500	1K	2K	4K	8K
Mean Value/dB	16.8	13.9	19.9	29.7	35.8	35.9	35.9	37.4
Standard deviation/dB	2.9	3.3	2.9	2.7	2.9	2.2	3.9	4.4
Assumed Protection/dB	13.9	10.6	17.0	27.0	33.0	33.8	36.1	33.1

A number of methods can then be used to arrive at a single figure for the assumed protected SPL (dBA). This goes beyond the scope of the this guide and can be performed with ease either by calculation or by acoustic applications software such as dBdata4XL ©.

Environmental - Octave band levels are sometimes plotted on an NR curve to assess the NR value of rooms. The curves give compensation for the degree of annoyance of each ocatve band. An explanation of the background of NR curves goes beyond the scope of this guide .

3.0 A Glossary of Acoustical Terms

This section describes and defines many terms used in acoustics.

Term:	***Unit or Abbreviation:***	***Definition***
Decibels	**dB**	Ten times the logarithm (to base 10) of the ratio of two mean square values of sound pressure.
Frequency	**Hz**	The number of cyclical variations per unit time
Octave Bands	**Hz**	Frequency ranges in which the upper limit of each band is twice the lower limit. Octave bands are identified by their geometric mean frequency or centre frequency.
Sound Power	**W**	The acoustic power of a sound source expressed in Watts.
Sound Power Level	**L_W**	The acoustic power radiated from a given sound source as related to a reference power level (typically 10^{-12} W); expressed in decibel as: $L_W = 10\log_{10}(\frac{W}{10^{-12}})dB$ or

Term:	*Unit or Abbreviation:*	*Definition*
		$L_W = 10\log_{10} W + 120dB$ W = acoustic power in Watts. i.e. 1 Watt = 120 dB for L_W
Sound Pressure	**P**	Fluctuations in air pressure caused by the presence of sound waves.
Sound Pressure Level	**SPL**	The ratio expressed in decibels of mean - square sound pressure to a reference mean - square pressure which by convention has been selected to be equal to the assumed threshold of hearing. $SPL = 20\log_{10}(\frac{P}{P_o})$ Where: SPL = Sound Pressure Level P = Root Mean Square sound pressure $P_o = 2 \times 10^{-5}\ Nm^{-2}$ $= 20\mu Pa$ (R M S)
Spectrum	-	A term that refers to the frequency response.
Weighting Network	**A - dB(A)**	An electronic filter in a sound level meter which approximates under defused conditions the frequency response of the human ear. The A - Weighting network is the one most commonly used.

Term:	*Unit or Abbreviation:*	*Definition*
Equivalent Continuous A -Weighted Sound Pressure Level	L_{AeqT}	The value of the A - weighted sound pressure level in decibels of continuous steady sound pressure level that within a specified time interval, T,
Dose	**D**	Noise dose is a percentage number where: 100% Dose = 90 dB(A) for 8 hours. Note that not only is the sound level important (90 dBA) but also the time a person was exposed (8 hours).
Dose per Hour	**DOHR**	Designed to show the Dose exposure over each hour.
Projected Dose	**Proj D**	Projected dose allows the present accumulated dose over the present logged time duration to be projected forward to give the predicted 8 hour dose. This assumes the logged dose rate remains constant over the 8 hour period. A time inhibit on Castle instruments prevents projections being made if the measurement duration is less than five minutes.

Term:	*Unit or Abbreviation:*	*Definition*
Noise Exposure	$L_{EP'd}$	Personal noise exposure, usually referred to a daily 8 hour rate. "Exposed" means exposed whilst at work; expressed in dB(A) $L_{EP'd} = 10\log_{10}\frac{1}{T_o}\int_0^{T_e}[\frac{P_A(t)}{P_o}]^2 dt$ Where: T_e = the duration of the person's personal exposure to sound. T_o = 8 hours = 28800 seconds. P_o = 20 µPa P_A = the time - varying value of A weighted instantaneous sound pressure in Pascal's in the undisturbed field in air at atmospheric pressure to which the person is exposed.
Percentile Sound Levels	L_N	The dB(A) level exceeded N% of the time.
	L_{90}	The dB(A) level exceeded 90% of the time.
	L_{10}	The dB(A) level exceeded 10% of the time, commonly used to estimate traffic noise level.