Basic Noise Calculations

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AIMS

Who is this for?

This document is the companion document to "Occupational Noise Surveys".

The latter document relates how and what measurements need be taken and the type of noise measuring instrument required to comply with WorkSafeBC Regulation Part 7 Noise. Descriptions of the main noise descriptors and units are also in that document. This present document, however, is intended to explain how occupational noise measurements can be refined and used to obtain L_{EX}. Anyone who has worked through "Occupational Noise Surveys" may need the information in this document.

A little technical knowledge is useful but certainly not necessary as the calculations are limited to basic arithmetic operations.

Why are Noise Calculations Necessary?

WorkSafeBC Regulation Part 7 Noise requires that the noise exposure be reported for all workers exposed to sound levels in excess of L_{EX} = 85 dBA. Often the measurements alone are insufficient to produce an accurate value for L_{EX} . The measured results may require to be combined with other data or it may be subjected to some corrections (e.g. for shift length or artifacts which may have intruded upon the measurement).

The calculations can be done using basic arithmetic and the use of a nomograph or a Table found in Appendices 1 and 2 respectively. A scientific calculator, business calculator or Excel spreadsheet are useful for determining standard deviations when dealing with the noise sampling of groups of workers.

NOISE EXPOSURE DESCRIPTORS

Introduction

With occupational noise, we are concerned with workers' *noise exposure*. In the WorkSafeBC Regulation Part 7 Noise, a worker's noise exposure is expressed as:

- the daily energy-averaged sound level (L_{EX} in dBA)
- peak sound level in dBA

These terms are discussed in more detail in the report "Occupational Noise Surveys". However, the aim of the present document is to discuss L_{EX} calculations only.

A Review of Noise Descriptors

L_{eq}

L_{eq} is the **eq**uivalent steady sound **l**evel of a noise energy-averaged over time. Because occupational noise is often a complex signal, the noise level needs to be averaged over a minimum sample time. The sampling time can be as short as a few minutes if the noise signal is steady or repetitive over a short cycle; some jobs could require a full day's monitoring. Whatever the actual duration, it should be a representative sample of the entire exposure.

If the activity is not typical of the shift then either more sampling is required when the condition is fulfilled or corrections to your measurements may be required. Corrections for some situations are given in worked Examples

L_{EX}

L_{EX} is the noise **ex**posure level. L_{EX} is useful as a single number measure of the noise exposure in decibel form. L_{EX} is the sound level, energy-averaged over 8 hours, which would give the same daily noise exposure dose as the varying noise over a typical full shift. It is closely related to the L_{eq} which you actually.

In fact, L_{EX} could be regarded as being the measured L_{eq} with a small correction. Thus:

$$L_{ex} = L_{eq} + \text{correction for shift length}$$

where the correction is given by the chart below.

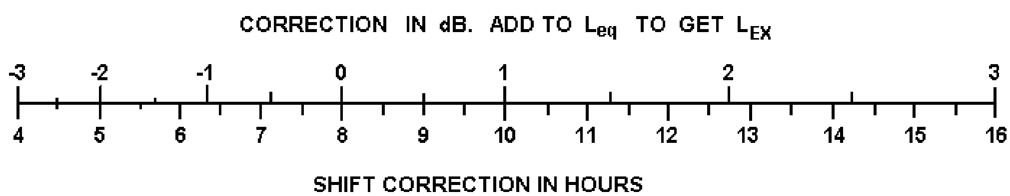


Figure 3. Shift Time Correction to L_{eq}

Derivation of L_{EX} from L_{eq} Measurement

Example

Measurements of a worker's noise exposure show L_{eq} = 89 dBA. His shift duration is 5 h. The noise level *sample* taken during the shift (perhaps dosimetry for 3¼ h was sufficient or even 15 minutes with an integrating sound level meter) to get the L_{eq}.

If the sample is **representative** of noise throughout the shift, then the measured L_{eq} is considered equal to the shift L_{eq}. Then, using the chart for the 5 h shift correction:

$$L_{EX} = 89 + (-2) = 87 \text{ dBA}$$

It's easier to compare a noise exposure level L_{EX} of 87 dBA with the permissible L_{EX} of 85 dBA rather than compare 89 dBA for 5 hours with 85 dBA for 8 hours.

Note: The shift time correction to L_{eq} is zero when the shift duration is 8 h.

L_{EX} of Non-standard Work Patterns

To obtain the appropriate L_{EX} correction for shift L_{eq}s which depart from the standard 8 hours/day, 5 days/week work pattern, the shift shall be assumed to have equivalent daily duration equal to the higher of:

- one fifth of the average number of hours worked per week, or
- the average number of hours worked per month divided by 21

Example

A mill worker does 4 shifts of 12 hours/week every week. For a typical shift the measured L_{eq} = 91.3 dBA.

Average number of hours worked per week	= 48 hours/week
Average shift length (5 day week)	= 48/5 = 9.6 hours/day.
9.6 h shift correction obtained from nomograph	= 0.8 dB

$L_{EX} = L_{eq} + 0.8$ dBA

= 91.3 +0.8 dBA

= 92 dBA

Noise Dose

Noise dose may be given in terms of a value relative to unity or 100% of an "acceptable" amount of noise.

Noise dose is another **single** descriptor for noise exposure. As with L_{EX}, it's easier to see that a noise dose of 160 % (87 dBA for 8 h) exceeds the permissible 100 % dose (85 dBA for 8 h). Also, noise calculations can be made simpler by using noise dose values instead of sound levels in decibels.

Note: In B.C., an exposure to sound level 85 dBA for 8 hours = 100 % noise dose

THE L_{eq} NOMOGRAPH and ITS USE

The nomograph in Appendix 1 relates L_{eq}, T, % Noise Dose and L_{EX}. The Table in Appendix 2 contains the same information in tabular form. The mathematical relationships are in Appendix 3.

The nomograph has 3 axes, headed “Measurement Duration” on the left, “Leq” on the right and a centre axis labelled “Noise Dose” on one side and “L_{EX}” on the other side. Some applications of the nomograph are given below; the Table of Appendix 2 could also be applied.

Example

L_{eq} = 77 dBA and its time of duration = 6 hours. Then the Noise Dose which would be obtained in that time can be found using the nomograph.

Find the point 77 dBA on the L_{eq} axis.
Find the point 6 hours on the Measurement Duration axis.
Join them with a straight line.

The line intersects with the Noise Dose/L_{EX} middle line at:

Noise Dose = 12 % and L_{EX} = 75.8 dBA

This means if you had a noise dosimeter running it would read: Noise Dose = 12% and L_{EX} = 75.8 dBA assuming the noise (77 dBA for 6 hours) is the only noise experienced.

Using the Nomograph to Synthesise Noise Exposure

Sometimes it is convenient to compile workers day-long noise exposures from component or “partial” exposures which make up the day.

Example

A woman works in a night club for 5 hours/night. During a typical evening, her noie exposure is taken with a personal noise dosimeter. It reads Leq = 88 dBA after 2 hours of sampling. Assuming this si a representative sampleof thenoise, we could predict thenoise dose the worker wouldacquire during the shift:

Noise dose after 3 hours = 50% (connect 88 dBA with 2 hours)
Noise dose per hour = 25 % (50 %/2)
Noise dose per 5 hour shift = 125 % (25 5 x 5)

Locate 125 % on the centre verticalline and read off the LEX = 86 dBA

The worker is over-exposed to noise because her LEX > 85 dBA

Example

A man works in the same club. Typically, he spends a total of 2 hours per night supervising in the kitchen where the average L_{eq} is 88 dBA. For another 4 hours per night he does administrative tasks in an office where the L_{eq} is 77 dBA and another 1 hour in the restaurant where the L_{eq} is 66 dBA.

We can combine the three “partial” exposures by finding the noise dose for each task:
Draw a line to connect L_{eq} = 88 dBA to time = 2 h. Read Noise Dose = 50 %
Draw a line to connect L_{eq} = 77 dBA to time = 4 h. Read Noise Dose = 8 %
Draw a line to connect L_{eq} = 66 dBA to time = 1 h. Read Noise Dose = 0 %
(The last data point is off the bottom of the nomograph)

His total Noise Dose for the day = 58 % (50 + 8)

Locate 58 % on the middle vertical line. Read off L_{EX} = 82.6 dBA

The worker’s L_{EX} is 83 dBA and he is not over-exposed.

Example

A worker in a pulp mill works 12 h shifts. A dosimeter is used to sample her noise exposure. The instrument registers a dose of 70 % in 7 hours. During this time, the worker was exposed to a representative sample of the noise.

Noise dose after 7 h = 70 %
Noise dose per hour = 10 % (70 %/7 hours = 10% per hour)
Noise dose in 12h shift = 120 % (10 % x 12 h)

Locate 120% on the middle vertical line. Read L_{EX} = 85.8 dBA (opposite side)

The worker has L_{EX} > 85 dBA. (Note, however, certain mills may have work patterns which need to be considered carefully. For example, with pulp mills the number of hours per month must be considered).

Example

Workers on a bottle-filling line are each sampled for 5 minutes for their noise exposure using an integrating sound level meter. Their L_{eq}s are given in the table below.

All workers practice job rotation, each doing every job for 2h in their 10 h shift. Their 10 h noise dose is the sum of their partial job noise doses in %.
The noise dose from each job ("partial" exposures) can be obtained from the nomograph, Appendix 1. The steps taken are summarized in the table below.

Job	L_{eq}	Duration, Hours	Noise Dose, %
depalletizer	91.5	2	113
filler	95	2	253
capper	97	2	401
labeller	87	2	40
packaging	84.5	2	23
	Sum	10	830

Then, we can find (all) the workers' shift L_{eq} and L_{EX}.

Using the nomograph:

Join dose 830 % to time 10 h, extend the straight line. Read L_{eq}= 93.2 dBA.
Join dose 830 % to time 8 h, extend the straight line. Read L_{EX} = 94 dBA **OR**
Locate the day's dose 830 % . Read L_{EX} = 94 dBA (middle vertical line).

All these workers are over-exposed because their L_{EX} > 85 dBA.

Adding a Noise Source

It is useful to be able to predict the increase in sound level due to adding noise sources.

Example

It is planned to introduce a furnace into a work place. The supplier informs that the sound level at a certain worker position will be 91 dBA from the furnace alone but it will only come on for a total of 1 hour/day. The worker's L_{EX} is already 82 dBA before its installation.

Join point L_{eq} = 82 dBA to time 8 h. (8 h implied with L_{EX}). Read Noise Dose = 50 %.
Join the point L_{eq} = 91 dBA to time 1 h.. Read Noise Dose = 100 %.

The total daily Noise Dose = 150%
Locate the day's dose 150 % on middle line.

Read L_{EX} = 86.8 dBA (middle vertical line).

The worker would be over-exposed if this furnace is introduced as L_{EX} > 85 dBA.

Removing a Noise Source (Correction for Artifacts)

If artifacts are identified as peaks in the sound level history, the sampled L_{eq} data may still be used with an appropriate correction. This involves subtraction of the unwanted component L_{eq}s in which the peak artifact occurred and recalculating (with the reduced sample time):

Example

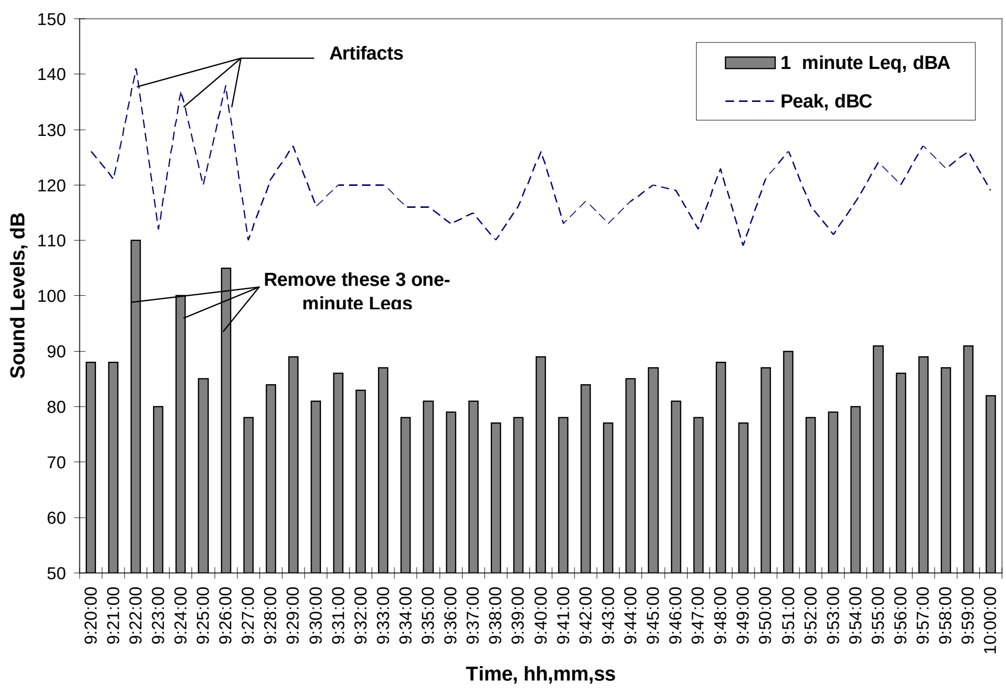
Suppose noise dosimetry has been obtained over 4½ h and L_{eq} = 89 dBA. The download shows three very intense peak events which were not of acoustical origin (they were generated when fitting the dosimeter). The download record shows (see graph below):

Artifact peak (141 dBC) occurred in a one minute period when L_{eq} = 110 dBA
Artifact peak (137 dBC) occurred in a one minute period when L_{eq} = 100 dBA
Artifact peak (138 dBC) occurred in a one minute period when L_{eq} = 105 dBA

Join the point L_{eq} = 110 dBA to time 1 minute. Read Noise Dose = 66 %.
Join the point L_{eq} = 101 dBA to time 1 minute. Read Noise Dose = 8 %.
Join the point L_{eq} = 105 dBA to time 1 minute. Read Noise Dose = 20 %.

The unwanted Noise Dose Total = 66 + 8 + 20 = 94 %

Part of Sound Level History Downloaded from a Noise Dosimeter



Initial noise dose before correction:
Join the point L_{eq} = 89 dBA to time 4.5 h. Read Noise Dose = 141 %.

Remaining Noise Dose after removing effect of unwanted artifacts = 47 % (141 - 94)

Recalculate the L_{eq} over 4.5 hours with the corrected noise dose:

Join the point Noise Dose = 47 % to time 4.5 hours. Read L_{eq} = 84.2 dBA (and not 89 dBA!).

The worker actually would NOT be over-exposed, after correction.

USE of TABLE (Appendix 2)

Example

Workers on a bottle-filling line are each sampled for 5 minutes for their noise exposure using an integrating sound level meter. Their L_{eq}s are:

depalletizing L_{eq} = 92 dBA
filler L_{eq} = 96 dBA
capper L_{eq} = 98 dBA
labeller L_{eq} = 87 dBA
packaging L_{eq} = 82 dBA

All workers practice job rotation, each doing every job for 2h in their 10 h shift. Their 10 h noise dose is the sum of their partial job noise doses in %.

The noise dose from each "partial" job exposures can be obtained from the Table, Appendix 2.

In the left most column find the row for "2 hours". Read the Noise Doses for each of the sound levels and enter into the table below (interpolation between colums will usually be necessary).

The steps taken are summarized in the table below.

Job	L_{eq}	Duration, Hours	Noise Dose, %
depalletizer	92	2	125
filler	96	2	315
capper	98	2	499
labeller	87	2	39.6
packaging	82	2	12.5
	Sum	10	991

All workers would have the same Noise Dose, 991 %. For their L_{EX} use the Table Appendix 2:

Find the 8 hour row (shaded) and look along it till you find a column with 991 in it. There isn't one, but there is 794 % (in the 94 dBA column) and 1260 % (in the the 96 dBA column). Some interpolation is necessary to decide upon the value of sound level between 94 and 96 dBA. Without doing some arithmetic it looks like the level would be close to 95 dBA.

With rounding, L_{EX} = 95 dBA

GROUP SAMPLING

Statistical methods can be used to reduce the noise sampling by considering workers as members of occupational groups. The sample size required depends upon the number of workers in the group, the target precision (say, ± 2dB) and the variability between one another's exposure (standard deviation) of the sample group's L_{EX} values and the confidence you have in the result (95 % or 19 times out of 20). One procedure is to:

- select at least three workers (at **random**) to represent the group and determine their individual L_{EX}s

- work out the standard deviation of the three L_{EX}s. (The standard deviation function is available on handheld scientific, business electronic calculators and computer spreadsheets and is a measure of the results' "scatter").
- consult the table below to find how large the sample **should have been** (that is how many workers) for the standard deviation you just calculated
- after sampling the larger number of workers, check back to see that the standard deviation of the L_{EX} values has not increased
- if the standard deviation is so large that a very large sample size is called for, consider subdividing the "group" into smaller, separate groups

Number of workers in group	**Standard Deviation of Sample L_{EX}s, dB**					
N	**2**	**3**	**4**	**5**	**6**	**7**
5 to 8	3	4	5	5	5	6
9 to 16	3	5	7	8	10	11
17 to 29	3	5	8	11	13	15
29 to 39	3	6	9	12	16	18
40 and more	3	6	9	13	17	20

Table: Number of workers to sample for precision ± 2 dB (95 % confidence)

See CSA Standard Z107.56-06 "*Procedures for the Measurement of Occupational Noise Exposure*".

Example

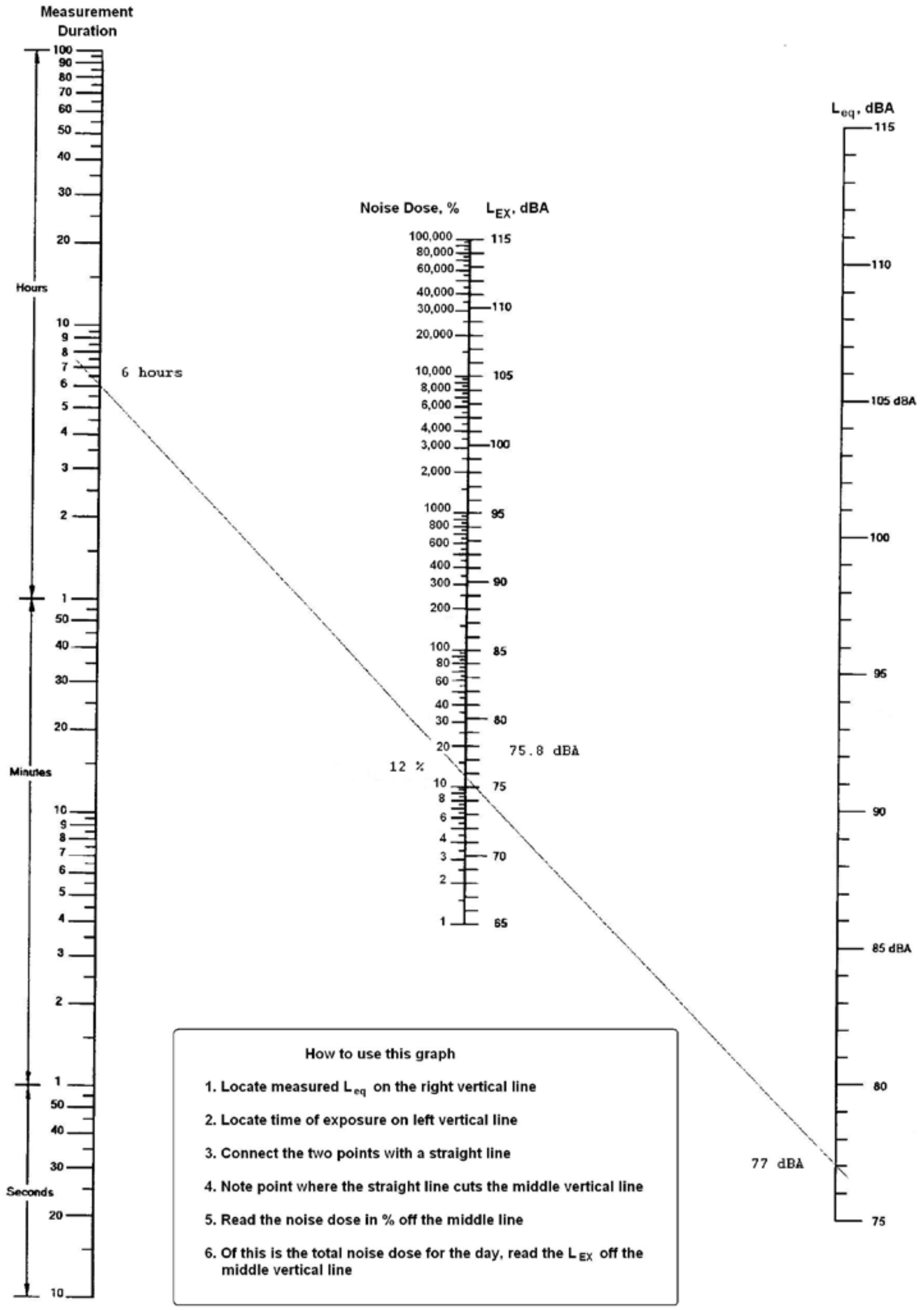
Consider a group of 12 workers. Three workers (chosen at random) were fitted with dosimeters and their L_{EX} values obtained by dosimetry were 95.5, 90 and 87.5 dBA (this is raw data so do no rounding yet!). This gives 91.0 dBA as the arithmetic mean with standard deviation of 4.1 dB.

Enter the table for a group size of 12 (in the row 9 to 16). The column with standard deviation of 4 dB shows we need to sample 7 workers for precision of $\pm$ 2 dB. A further 4 workers (selected at random) have additional L_{EX} values of 92, 85, 93 and 91 dBA.

The new mean of the seven L_{EX}s = 90.6 dBA, with standard deviation of 3.4 dB. Good! It's less than the original 4.1. We conclude:

Groups' mean L_{EX} = 90 ± 2 dBA to 95 % confidence.

APPENDIX 1



Nomograph of L_{eq}, L_{EX}, Noise Dose and Time

APPENDIX 2

Time	L_{eq} dBA																		
	80	**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**	**89**	**90**	**92**	**94**	**96**	**98**	**100**	**102**	**104**	**106**
1 minute	0.07	0.08	0.1	0.13	0.17	0.21	0.26	0.33	0.42	0.52	0.66	1.04	1.65	2.62	4.16	6.59	10.4	16.5	26.2
2 minutes	0.13	0.17	0.21	0.26	0.33	0.42	0.52	0.66	0.83	1.05	1.32	2.09	3.31	5.25	8.31	13.2	20.9	33.1	52.5
4 minutes	0.26	0.33	0.42	0.53	0.66	0.83	1.05	1.32	1.66	2.09	2.64	4.18	6.62	10.5	16.6	26.4	41.8	66.2	105
8 minutes	0.53	0.66	0.84	1.05	1.32	1.67	2.1	2.64	3.33	4.19	5.27	8.35	13.2	21	33.3	52.7	83.5	132	210
1/2 hour	1.98	2.49	3.13	3.94	4.96	6.25	7.87	9.91	12.5	15.7	19.8	31.3	49.6	78.7	125	198	313	496	787
1 hour	3.95	4.98	6.26	7.89	9.93	12.5	15.7	19.8	24.9	31.4	39.5	62.6	99.3	157	249	395	626	993	1570
2 hours	7.91	9.95	12.5	15.8	19.9	25	31.5	39.6	49.9	62.8	79.1	125	199	315	499	791	1250	1990	3150
3 hours	11.9	14.9	18.8	23.7	29.8	37.5	47.2	59.4	74.8	94.2	119	188	298	472	748	1190	1880	2980	4720
4 hours	15.8	19.9	25.1	31.5	39.7	50	62.9	79.2	99.8	126	158	251	397	629	998	1580	2510	3970	6290
5 hours	19.8	24.9	31.3	39.4	49.6	62.5	78.7	99.1	125	157	198	313	496	787	1250	1980	3130	4960	7870
6 hours	23.7	29.9	37.6	47.3	59.6	75	94.4	119	150	188	237	376	596	944	1500	2370	3760	5960	9440
7 hours	27.7	34.8	43.9	55.2	69.5	87.5	110	139	175	220	277	439	695	1100	1750	2770	4390	6950	11000
8 hours	31.6	39.8	50.1	63.1	79.4	100	126	158	200	251	316	501	794	1260	2000	3160	5010	7940	12600
9 hours	35.6	44.8	56.4	71	89.4	113	142	178	224	283	356	564	894	1420	2240	3560	5640	8940	14200
10 hours	39.5	49.8	62.6	78.9	99.3	125	157	198	249	314	395	626	993	1570	2490	3950	6260	9930	15700
11 hours	43.5	54.7	68.9	86.8	109	138	173	218	274	345	435	689	1090	1730	2740	4350	6890	10900	17300
12 hours	47.4	59.7	75.2	94.6	119	150	189	238	299	377	474	752	1190	1890	2990	4740	7520	11900	18900
13 hours	51.4	64.7	81.4	103	129	163	205	258	324	408	514	814	1290	2050	3240	5140	8140	12900	20500
14 hours	55.3	69.7	87.7	110	139	175	220	277	349	440	553	877	1390	2200	3490	5530	8770	13900	22000
15 hours	59.3	74.6	94	118	149	188	236	297	374	471	593	940	1490	2360	3740	5930	9400	14900	23600
16 hours	63.2	79.6	100	126	159	200	252	317	399	502	632	1000	1590	2520	3990	6320	10000	15900	25200

Table of L_{eq}, L_{EX}, Time and Noise Dose

If you have an L_{eq} and the averaging time, you can find the corresponding noise dose.
Example 1: L_{eq} = 95 dBA measured over 4 h, look down the column headed “95” and across the row headed “4” h. They intersect at noise dose = 5.1 Pa^2h.
If you know the total daily noise dose for a worker’s entire shift you can find the corresponding L_{EX}.**xample 2:** The total noise dose = 2.5 Pa^2h. Look along the (shaded) L_{EX} row until you find 2.5. Look up the column and find it is headed “89”. The worker’s L_{EX}= 89 dBA.

APPENDIX 3

Formulae for L_{eq}, L_{EX}, Time and Noise Dose

Dose = $100 \times T/8 \times 10^{(L_{eq}-85)/10}$ %

$L_{eq} = 10 \log_{10}\{(Dose/100) \times (8/T)\} + 85$ dBA

$L_{EX} = 10 \log_{10}\{Dose/100\} + 85$ dBA

$L_{EX} = 10 \log_{10}\{T/8\} + 85$ dBA

Where:

Dose = a noise exposure dose, in %, acquired in T hours
L_{eq} = A-weighted, sound level linearly energy averaged over T hours
L_{EX} = sound exposure level, A-weighted, sound level linearly energy averaged over 8 hours
T = the sampling time, in hours, of the measurement

Formulae for Sound level averages

Sometimes it is useful to combine steady sound levels regardless of their time of duration. For example with Group sampling, the average value of a collection of sound levels needs to be taken – in this case the arithmetic mean is needed. At other times an rms average may be called for e.g. with a number of L_{EX} values for the same worker.

Arithmetic Mean

The arithmetic mean or average of a number of sound levels is:

$$L_{mean} = \{L_1 + L_2 + L_3 + ... + L_n\}/n$$

Where:

L_i = the ith sound level of n sound levels

Use this to get the mean of a number of L_{EX} values of a sample of workers.

Energy-average

The energy-average (“effective” or rms) sound level is:

$$L_{rms} = 10 \log_{10} \{1/n\ [10^{L1/10} + 10^{L2/10} + 10^{L3/10} + ... + 10^{Ln/10}]\}$$

Use this formula to energy-average a number of sound levels e.g. L_{EX}s of the same worker on different days. Integrating noise meters do the same calculation to obtain the L_{eq} of a series of sound levels sampled at equally and closely spaced intervals.

Example

The averages of the three sound levels 88, 93 and 97 dBA are:

Arithmetic Mean: $L_{mean} = \{88 + 94 + 97\}/3$ = 93 dBA

Energy-average: L_{eq} $= 10 \log_{10} \{[10^{8.8} + 10^{9.4} + 10^{9.7}]/3\}$ = 94.3 dBA