

IH for the CSP 5: Noise Dosimetry

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OSHA

According to OSHA standards, exposure to a constant sound pressure level of 90 dBA is allowed for eight hours, i.e. the permissible exposure limit (PEL) for 90 dBA noise is eight hours. For each additional 5 dB, the allowed time is cut in half, e.g. 4 hours at 95 dBA, 2 hours at 100 dBA, etc. The value of 5 dB is called "the exchange rate." There is no limit to the allowed time for noise levels below 90 dBA (equation 1 does not apply). The level 90 dBA in this context is referred to as the "high threshold." The allowed time of exposure, T, in hours, to industrial noise at a given sound pressure level, SPL, is therefore given by,

$$T = \frac{8}{2^{(SPL-90 \text{ dBA})/5}},$$

or, after a little algebra,

$$T = 2^{(105 \text{ dBA} - SPL)/5} \quad 1$$

All sound pressure levels must be measured on the A-weighted scale. Measurements must be made within the hearing zone of the employee. The hearing zone is a sphere with a two-foot radius centered about the head. Placement of the dosimeter microphone must be according to manufacturer's instructions. Generally the microphone is attached to the outer end of the shoulder to minimize attenuation of noise by the head.

In industry, noise exposure to employees is seldom at a constant level. Sound pressure levels at each location vary in time, and employees move from one area to another during the work shift. In order to add the contributions of many short exposures to noise at varying sound pressure levels, the concept of noise dose was devised. For one exposure at a constant level, the dose, D, is simply the fraction of the allowed time represented by the exposure, or

$$D = \frac{C}{T} 100\% = \frac{C}{2^{(105 \text{ dBA} - SPL)/5}} 100\% \quad , \quad 2$$

where C is the time of exposure. It is customary to express dose as a percent. Remember, however, that "%" simply means "per hundred" or "divided by 100." Multiplying any quantity by 100% (100/100) is merely multiplying by 1. It does not change the value, and may be thought of as a unit conversion. For example, 75 % = 75/100 = 0.75 . There is no difference between 75% and 0.75.

When an employee is exposed to noise at different sound pressure levels, the total dose is obtained by adding up the contribution from each of many short exposures over which the sound pressure level was relatively constant, or

$$D = \left[\frac{C_1}{T_1} + \frac{C_2}{T_2} + \dots + \frac{C_n}{T_n} \right] 100\% , \quad 3$$

where C_i is the time of exposure to the i^{th} sound pressure level, and T_i is the time allowed at that sound pressure level. Since an infinite time is allowed at all sound pressures less than 90 dBA, all sound pressure levels less than 90 dBA are excluded from the calculation. In other words, the threshold for inclusion in the dose calculation is 90 dBA. The 90 dBA threshold is referred to as the “high” threshold. When the dose, calculated on the high threshold, exceeds 100%, it is said that an overexposure exists.

Example

Suppose an employee was exposed to the exact sound pressure levels given in the table below for the times listed.

SPL	Time
92 dBA	2 hr
89 dBA	2 hr
75 dBA	1 hr
99 dBA	1.5 hr
90 dBA	45 min

Because 89 dBA and 75 dBA are below the high threshold, 90 dBA, they are excluded from the high threshold dose calculation. Also, notice that equation 1 gives the time allowed in hours, for this unit to cancel in the dose calculation (dose is a dimensionless ratio) the time of exposure must be in hours. A conversion factor is used in the expression below. The high threshold dose, D_{HT} , is then,

$$D_{HT} = \frac{2}{2^{(105-92)/5}} + \frac{1.5}{2^{(105-99)/5}} + \frac{45/60}{2^{(105-90)/5}} = 1.08 = 108\% .$$

Since this value exceeds 1, or 100%, an over exposure was observed. It should be noted, however, that the exact level of exposure is never known in practice. There is always some uncertainty in measurements. When actual measurements are used to determine dose, care must be taken in interpreting the results.

TWA

There are two additional quantities which can be calculated from the total dose. They are the time-weighted average, TWA, and the equivalent sound pressure level, L_a . The TWA is not truly an average weighted for time. It is a sound pressure level such that if an employee were exposed to that level for exactly eight hours, the employee would have received the same dose as the measured dose. An equation for the TWA is found by solving equation 2 for SPL, and substituting 8 hours for C, or,

$$\text{TWA} = 90 \text{ dBA} + 16.61 \log D .$$

This equation is often written,

$$\text{TWA} = 90 \text{ dBA} + 16.61 \log [D/100] . \quad 4$$

The reader is reminded that if the dose is say 90%, then $D = 0.90$, not 90. The divisor of 100 should really be thought of as 100%. In the example above, the dose was found to be 108%, the TWA is therefore given by,

$$\text{TWA} = 90 + 16.61 \log (1.08) = 90.5 \text{ dBA} .$$

Notice that because dose only relates to measurements on the A-weighted scale, the TWA must have units dBA.

Equivalent SPL, L_a

The TWA is sometimes helpful in understanding the magnitude of a noise exposure. The TWA, however, can be misleading if the dose is not measured for a full eight-hour period. For example if an employee were exposed to 90 dBA for 4 hours the dose would be 50%, and the TWA would be only 85 dBA. Another "average" measure of sound pressure level based on dose is the equivalent sound pressure level, L_a , which takes into account the time of sampling. The equivalent sound pressure level is given by,

$$L_a = 90 \text{ dBA} + 16.61 \log \left[\frac{D}{t (12.5)} \right] , \quad 5$$

where t is the time of sampling in hours. When $t = 8$ hours, the divisor, $t (12.5) = 100$, and $L_a = \text{TWA}$. The equivalent sound pressure level is the best measure of the "average" sound pressure level during sampling. Again for the above example, the total time of sampling, including time spent below the threshold, was 7.25 hr. The equivalent sound pressure level is therefore,

$$L_a = 90 \text{ dBA} + 16.61 \log \left[\frac{108}{7.25 (12.5)} \right] = 91.2 \text{ dBA}$$

Notice, the numerator in the logarithm is 108, the dose expressed as a percent, not 1.08.

A word on round off errors, if the value 108 written for the dose is typed into the calculator, the L_a calculated would be 91.3 dBA, slightly different than the value shown above. The actual value displayed on the calculator for dose was 1.0765399. Since all these extra digits would only clutter up the presentation above (and your written reports in industry) the dose was simply recorded as 1.08. In all subsequent calculations, however, the exact value obtained must be used, else a round off error occurs. Store values in memory and use the stored values, not the written values. The difference between 91.2 and 91.3 may seem trivial and not worth considering, but in a court of law, nothing is too trivial to be beaten to death.

Hearing Conservation Programs

Besides requiring that all noise exposures be maintained below 100%, or 90 dBA TWA, OSHA standards also require that a hearing conservation program including exposure monitoring, audiometric testing, and training be maintained for all employees exposed at or above a TWA of 85 dBA, or 50% dose. Suppose an employee were exposed to 86 dBA for eight hours. Since every sound pressure level below 90 dBA is thrown out of the dose calculation, the dose would be zero, and the TWA would be $-\infty$. In order to enforce the intent of the standard, when determining if a hearing conservation program is required, dose is measured with an 80 dBA threshold, called the "low threshold." Only sound pressure levels below 80 dBA are excluded from the dose calculation on the low threshold. The high threshold, 90 dBA, is used to calculate dose in order to determine if an overexposure exists. The low threshold, 80 dBA is used to calculate dose in order to determine if a hearing conservation program is required.

Again returning to the example above, since the 89 dBA level observed for 2 hr is above the low threshold, it is included in the low threshold dose calculation. The low threshold dose, D_{LT} , is therefore,

$$D_{LT} = \frac{2}{2^{(105-92)/5}} + \frac{2}{2^{(105-89)/5}} + \frac{1.5}{2^{(105-99)/5}} + \frac{45/60}{2^{(105-90)/5}} = 1.29 = 129 \% .$$

The low threshold dose will always be equal to, or greater than, the high threshold dose. (Why?)

Another point bears mentioning here. The all of the above calculations were based on the 90 dBA TWA and 5 dBA exchange rate required by OSHA. Other agencies and recommending bodies have different recommendations. The American Conference of

Governmental Industrial Hygienists, ACGIH, recommends a TWA of 85 dBA and an exchange rate of 3 dBA. To determine compliance with ACGIH recommendations, the allowed time of exposure at a given sound pressure level, T_{ACGIH} , is given by,

$$T_{ACGIH} = \frac{8}{2^{(SPL-85 \text{ dBA})/3}} = 2^{(94 \text{ dBA} - SPL)/3} \quad . \quad 6$$

The Noise Dosimeter

The integrated noise dosimeter is in effect a sound level meter with the ability to rapidly make sound pressure level readings averaged over a short period of time, calculate the dose from each small exposure, and add up all the contributions to the dose over the sampling period. Most dosimeters measure dose on both the high and low threshold scales simultaneously. Most noise dosimeters can be set to measure dose on 3 dBA or 4 dBA exchange rates as well.

Historically, analog noise dosimeters were used which physically changed a storage cell so that total dose could be read out after sampling, much as a capacitor can be charged to later read out total current. These early noise dosimeters were unreliable and often failed during use. Backup measurements using a sound level meter had to be made throughout the exposure time. If the cells failed, the SLM measurements could still be used to estimate dose. If the cells did not fail, the SLM readings were used to verify, or add confidence to, the dosimeter results. Although modern integrated dosimeters are themselves in essence sound level meters, and do not suffer the reliability problems of their analog ancestors, the practice of backing up dosimeter data with separate SLM readings still continues today. In the legal arena, if you fail to backup your dosimetry with SLM readings, your sampling data may not have the same weight in the eyes of the court as sampling results which were backed up. Although not required scientifically, good industrial hygiene practice calls for SLM measurements of sound pressure levels to be made throughout the sampling period for noise dosimetry.

Although the most logical approach might be to use the SLM readings and times of measurement to calculate dose and to compare that dose to the dose read by the dosimeter, this is not the common practice. The SLM readings are "averaged" by the formula given below,

$$SPL_{AVE} = 90 + 16.61 \log \left[\frac{10^{(SPL_1 - 90 \text{ dBA})/16.61} + \dots + 10^{(SPL_n - 90 \text{ dBA})/16.61}}{n} \right] \quad , \quad 7$$

where SPL_i is the i^{th} sound pressure level recorded and n is the total number of SPL's recorded. The above equation is derived from the definition of the TWA (equation 4) and is intimately linked to the definition of the dose. Remember that dose is measured on two thresholds. Since this equation is related to the dose, it also must be calculated for both thresholds. Regardless of the number of SPL's excluded from the calculations (below the thresholds), n is always the total number of SPL's taken.

Consider, for example, a constant sound pressure level is being sampled. The above expression for the average will yield that constant level. If the total time of sampling is much less than eight hours, the TWA read by the dosimeter will be much below than that level. The equivalent sound pressure level, L_a , however, will yield the constant level and should be in good agreement with SPL_{AVE} . **The values calculated by equation 7 for high and low thresholds must be compared to L_a from the dosimeter on the respective thresholds.** If the difference is no more than 2 or 3 dBA, the results are usually considered to be in good agreement.

Noise dosimetry is normally conducted for as close to an 8-hour shift as possible. For the purpose of illustration, however, assume an employee was monitored for approximately one hour. After the first hour the noise dosimeter indicated the following,

Run Time	68 min	
	High Threshold	Low Threshold
Dose	24.3%	24.8%
TWA	79.8 dBA	80.0 dBA
L_a	93.9 dBA	94.0 dBA

The following six backup sound level meter readings were also taken (n=6),

80 dBA, 95 dBA, 99 dBA, 97 dBA, 98 dBA, 75 dBA .

Computationally, it is easiest to first calculate the sum of exponentials, SUM, in equation 7. Excluding the 80 dBA, and 75 dBA readings for the high threshold average, the sum is given by,

$$SUM = 10^{(95-90)/16.61} + 10^{(100-90)/16.61} + 10^{(97-90)/16.61} + 10^{(98-90)/16.61} = 11.67 .$$

The high threshold average, SLM_{HIGH} , is then,

$$\begin{aligned} SLM_{HIGH} &= 90 \text{ dBA} + 16.61 \log \left[\frac{SUM}{6} \right] \\ &= 90 \text{ dBA} + 16.61 \log \left[\frac{11.67}{6} \right] = 94.80 \text{ dBA} . \end{aligned}$$

Notice although only four sound pressure level readings are used in this calculation, the denominator in the logarithm term is still 6, because 6 readings were taken.

For the low threshold average, the 80 dBA reading is included, excluding only the 75 dBA reading. It is left as an exercise to show that the low threshold average is 94.95

dBA (SUM = 11.92).

The high and low threshold averages are seen to be in good agreement with L_a for both thresholds. Notice that these values are **not** in good agreement with the TWA's.

Experimental Uncertainty

The noise dosimeters most commonly used are class II instruments. This means that there is an uncertainty of ± 2 dBA in the SPL readings. If the dose measured is exactly 100%, it can not be stated with confidence whether or not an overexposure actually occurred. This uncertainty is accounted for by returning to the definition of dose. If an employee were exposed to exactly 90.0 dBA for eight hours, the dose received would be 100%. The class II dosimeter, however, could read as high as 92 dBA or as low as 88 dBA when actual SPL was 90 dBA. The range of doses that the dosimeter could read while the true dose is 100% is given by,

$$D_{MAX} = \frac{8 \text{ hrs}}{2^{(105-92)/5}} = 1.32 = 132 \% , \quad 8$$

and,

$$D_{MAX} = \frac{8 \text{ hrs}}{2^{(105-88)/5}} = 0.758 = 75.8 \% , \quad 9$$

Therefore if the dose measured is greater than 132% on the high threshold, it can be stated with 95% confidence that the true dose was greater than 100%, i.e. that an overexposure was observed. If the dose measured is less than 75.8% on the high threshold, it can be stated with 95% confidence that the true dose was less than 100%, i.e. that an overexposure was not observed. Similar arguments can be made about the necessity of a hearing conservation program. If the measured dose is greater than 66% on the low threshold, it can be stated with 95% confidence that the true dose is above 50% and a hearing conservation program is required by OSHA standards. If the measured dose is below 37.9% on the low threshold, it can be stated with 95% confidence that the true dose is below 50% and a hearing conservation program is not required by the standards.

When calibrating the noise dosimeter it must be remembered that this instrument is performing three functions, measuring sound pressure levels, measuring time, and calculating dose based on sound pressure level and time. Each of these three functions should be assessed independently during calibration. The sound pressure level of the calibrator as read by the dosimeter is first compared to the rated value of the calibrator.

The dosimeter is then set to run. At precisely the same time, a stopwatch is started. The dosimeter and the stopwatch are allowed to run for approximately 10 to 15 minutes and then stopped simultaneously. The run time as measured by the dosimeter is compared to the run time as measured by the stopwatch. Finally, the expected dose based on dosimeter SPL and run time is calculated and compared to the dose recorded by the dosimeter.