The Effect of Threshold on Noise Dosimeter Measurements

and Interpretation of Their Results

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ABSTRACT

Noise dose measurements may be taken with instruments that function quite differently. Accordingly, before performing any comparative analysis of noise data, it is imperative that the investigator knows what instrumentation was used, and how it was set in collecting the data.

This paper discusses the various functions of the noise dosimeter, and why data collected with instruments that function at one set threshold level may differ from that collected with an instrument that uses a different, or no threshold level.

An evaluation of data obtained from 2,631 occupational noise exposure measurements from the coal mining industry was used in compiling this paper. Personal noise dosimeters, capable of simultaneously determining noise 'doses with both high and low threshold levels, were used in collecting this data.

The results of the study are presented to illustrate the impact of the different threshold levels on simultaneous noise dose measurements and corresponding average sound levels.

Recommendations are made to provide assistance in selecting the threshold level of the dosimeter in order to achieve the desired objective of the noise dose measurement.

INTRODUCTION

Occupational noise exposure- limits in the United States have been promulgated for the majority of industries by the Occupational

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Safety and Health Administration[3] (OSHA) and specifically for the mining industry by the Mine Safety and Health Administration[4] (MSHA). These regulations specify how a worker's noise exposure is to be measured and/or calculated. Noise exposure can be expressed as the percentage of the "allowable" exposure level. This percentage is called a noise dose. By using a noise dose, it is easily determined if a worker's noise exposure has exceeded current legal exposure limits. Such an exposure would result in a noise dose greater than 100 percent.

These regulatory requirements introduce the concept of a threshold level, i.e., a level below which sound levels and exposure times are not included in the noise dose computation. Earshen[5] states "The concept of a threshold level rests on tenuous grounds but is well entrenched and its implications should be understood. Use of a threshold implies that exposure to sound above the threshold is potentially damaging but sound below the threshold abruptly becomes nonhazardous. No published evidence of such an effect exists. The use of threshold levels has its origin in administrative interpretation of regulatory practices."

Occupational noise exposure measurements are usually made either manually using a sound level meter and stopwatch (time study) and then calculating the exposure, or automatically using a personal noise dosimeter. For noise exposure determined from a sound level meter - stopwatch time study, a formula (equation 6) is used to compute the noise dose. Sound levels and corresponding exposure times are not included for sound levels less than the threshold level. The noise dosimeter automatically excludes sound levels and exposure times less than the threshold level.

A simplified block diagram of a generic noise dosimeter is shown in Figure 1. A noise dosimeter consists of a microphone that converts the sound pressure waves into an electrical signal. Amplifiers are provided to raise.the signal levels, and a weighting network is used to cause the frequency response of the instrument to approximate that of the ear (usually A-weighting). The squaring device is provided so that the square of the

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[3] 29 Code of Federal Regulations, 1910.95(a) through 1910.95(n).

[4] 30 Code of Federal Regulations, Subpart F, Part 70.500 - 70.511, and Subpart I, Part 71.800 - 71.805.

[5] Earshen, J.J. "Sound Measurement: Instrumentation and Noise Descriptors" in Noise & Hearing Conservation Manual, 4th ed., E.H. Berger, W.D. Ward, J.C. Morrill, and L.H. Royster, Eds., American Industrial Hygiene Association, 1986, page 67.

pressures is measured. The exponential averaging device provides
a FAST or SLOW response. The upper limit indicator shows when a
preset level (usually 115 dBA) has been exceeded. The exponent
circuit provides a specified exponent based on the selected
exchange rate. The threshold circuit prevents any levels less
than the threshold from being integrated. The integrator circuit
integrates the measurement over the entire measurement period.
An indicator circuit displays the results. The selection of an
appropriate threshold level, when using a noise dosimeter, must
be made in order to achieve a noise dose that conforms to the
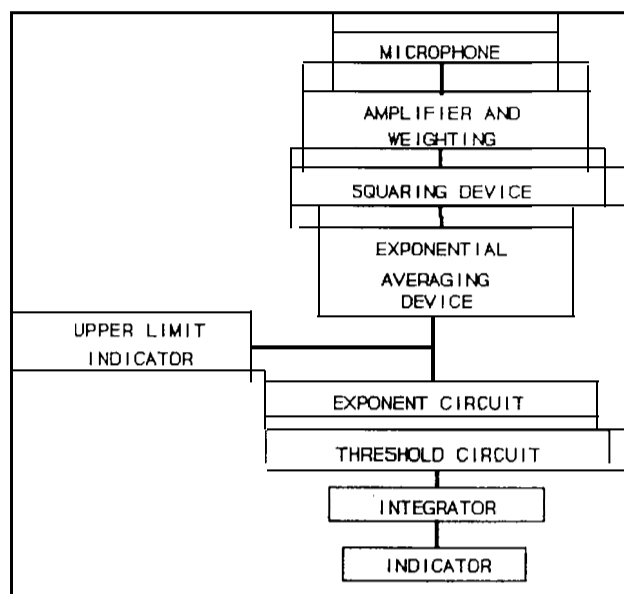specific regulatory requirement.

Figure 1 - BLOCK DIAGRAM OF 1
PERSONAL NOISE DOSIMETER

Most commercially available personal noise dosimeters permit the
selection of the threshold at various sound levels. Common
threshold selections are "no-threshold", 80, 85, and 90 dBA. One
selects the appropriate threshold required by the regulation.
For compliance purposes, both OSHA and MSHA currently require a
threshold level equal to the regulatory criterion sound level of
90 dBA. However, for hearing conservation purposes, OSHA
requires the use of a 90 dBA criterion level and an 80 dBA
threshold level.

A worker's noise exposure or noise dose is defined in equation (1).

$$D(Q) = \frac{100}{T_c} \int_0^T 10^{[L(t)-L_c]/q} dt \qquad (1)$$

WHERE:

$D(Q)$ = the percentage criterion exposure (Percentage Dose), for exchange rate Q;

T_c = criterion sound duration = 8 hours;

T = measurement duration in hours;

t = variable of integration (time);

$L(t)$ = SLOW A-weighted sound level(dBA), a function of time, when the sound level is greater than or equal to L_t or equals -infinity when the A-weighted sound level is less than 4;

L_t = threshold sound level (dBA);

= criterion sound level (dBA);

Q_c = exchange rate in decibels (3,4, or 5), and q=Q/log(2) or correspondingly (9.97, 13.29, or 16.61).

For discrete intervals of time, equation (1) can be rewritten as:

$$D(Q) = \frac{100}{T_c} \sum_{i=1}^n 10^{(L_i-L_c)/q} \Delta t_i \qquad (2)$$

where:

Δt_i = Exposure time during the ith time interval

and where:

$$\sum_{i=1}^n \Delta t_i = T \qquad (3)$$

The allowable exposure time, T,, at sound level L is given by:

$$T_L = \frac{T_c}{2^{((L-L_c)/q*\log 2)}} \qquad (4)$$

Using equation (4) in equation (2) and noting that

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$$10^x = 2^{x/\log 2} \qquad (5)$$

We obtain:

$$D(Q) = 100 \sum_{i=1}^{n} \frac{\Delta t_i}{T_{Li}} \qquad (6)$$

where:

T_{Li} = The allowable exposure time during the time interval At, and sound level L_i.

The average sound level during the sampling time, T, can be expressed as:

$$L_{AVG}(Q) = qLog\left[\frac{1}{T}\int_0^T 10^{(L(t)/q)}dt\right] = qlog\left[\frac{1}{T}*\sum_{i=1}^{n}10^{(L_i/q)}\Delta t_i\right] \qquad (7)$$

It can be seen in equations (2) and (7), for a given exchange rate Q, that by changing the threshold level L_t, the resulting dosage and average sound level changes. This becomes obvious by noting that in equations (2) and (7), the only terms included in the summation are for those time intervals where the sound level equals or exceeds the threshold level.

By using equation (1) in equation (7), a direct relation between the average sound level and dosage can be derived.

$$L_{avg} = L_C + q*\log\left[\frac{D(Q)}{100}*\frac{T_C}{T}\right] \qquad (8)$$

For a 90 dBA criterion level, a 90 dBA threshold level, and a 5 dB exchange rate this equates to:

$$L_{avg}(5) = 90 + 16.611*\log\left[\frac{D(5)}{100}*\frac{480}{T}\right] = 101.316 + 16.611*\log\left[\frac{D(5)}{T}\right] \qquad (9)$$

Where:

D = the noise dose in %
T = the measurement time in minutes

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From equation 9, the $L_{avg}(5)$ term will change when noise doses are entered that have been computed or measured with different threshold levels.

Determining the "allowable" exposure level is based on three parameters: 1) Threshold Level, 2) Criterion Level and 3) Exchange Rate. For this paper, the definition for each parameter and the value currently used by the Mine Safety and Health Administration (MSHA) is assumed unless stated. These values are:

> Threshold (or cutoff) Level - The noise level below which no dose is accumulated. MSHA uses 90 dBA.
>
> Criterion Level - The noise level which results in a dose of 100 percent during an 8 hour period. MSHA uses 90 dBA.
>
> Exchange Rate - The increase in noise level which results in a halving of the allowable exposure time. MSHA uses 5 dBA.

There are other parameters which are set by regulation that affect the overall noise exposure measurement such as weighting (MSHA uses A-weighting), and fast or slow response (MSHA uses slow response). This paper deals only with the threshold parameter.

Theoretically, when a noise dosimeter having a 90 dBA threshold is exposed to a 90.0 dBA sound level for eight hours, the threshold should have no effect, and the resultant noise dose should be 100%. On the contrary, for the same dosimeter, an 89.9999 dBA noise level measured for eight hours should result in the accumulation of no dose (0%). The threshold circuitry in modern noise dosimeters is designed to operate as a step function at the threshold level. In terms of the operation of the dosimeter around the threshold level, an error may be introduced into the measurement. Various standards that define and evaluate noise dosimeter operation attempt to limit the amount of error around the threshold level. In 1978, MSHA in the document entitled, IIMSHA Test Procedures and Acceptability Criteria for Noise Dosimeters [6]" specified that when a noise dosimeter is exposed to a test tone of 1,000 Hz. at sound levels of 88 dBA for one-hour, the accumulated noise dose must be 1.0 percent or less. Also, in 1978, the American National Standards Institute (ANSI)

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[6]Giardino, D.A., Seiler, J.P., and Yen, T.Y.,"MSHA Test Procedures and Acceptability Criteria For Noise Dosimeters", U.S. Department of Labor, Mine Safety and Health Administration, Informational Report IR-1072, 1978, 11 pages.

in its Specification for Personal Noise Dosimeters[7] included a
test for evaluating the threshold circuit of the noise dosimeter.
An evaluation of the sharpness of the threshold is required in
the current ANSI noise dosimeter standard'.

In order to understand the importance of the threshold and how it
operates, it is necessary to examine the operation of the
threshold for various types of input conditions. The following
theoretical discussion presents an ideal noise dosimeter with six
input scenarios. The sharpness of the threshold is assumed to be
perfect. For each case, the noise dose is determined, using
equation (6), for a high threshold level (HTL) equal to 90 dBA
and a low threshold level (LTL) equal to 80 dSA. The model
assumes a criterion level of 90 dBA and a 5-dB exchange rate.
Also, for each case, the average sound level is determined using
equation (9). The average sound level is that sound level over
the entire exposure time period that would yield the same total
noise exposure (dose).

Case 1 - The dosimeter is exposed
to a sound level of 75 dBA for 4
hours and to a sound level
greatly below 70 dBA for the
remaining 4 hours of the shift.
For Case 1, the input sound level
is well below both thresholds so
the HTL Dose equals the LTL Dose
and is 0.   Therefore, the average
sound levels are both 0.

    HTL DOSE=0%
    LTL DOSE=0%
   HTL L_{avg}=0 dBA
    LTL L_{avg}=0 dBA

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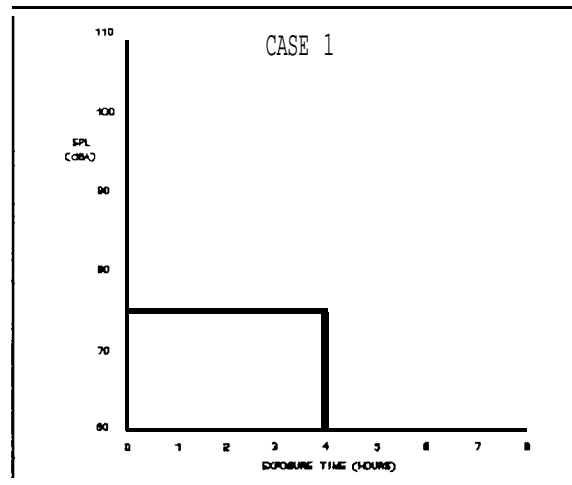
[7]American National Standards Institute, "American National
Standard Specification for Personal Noise Dosimeters", ANSI S1.25-
1978.

'American National Standards Institute, "American National
Standard Specification for Personal Noise Dosimeters", ANSI S1.25-
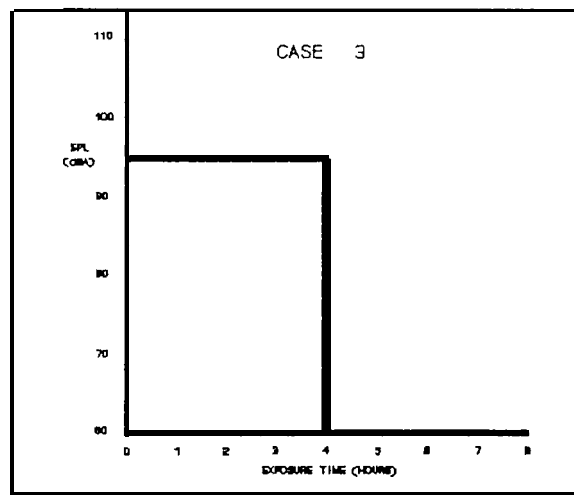1991 (ASA 98-1991).

Case 2 - The dosimeter is exposed to a sound level of 89 dBA for 4 hours and to a sound level greatly below 70 dBA for the remaining 4 hours of the shift. For Case 2, the input sound level exceeds the LTL, but not the HTL. The LTL average sound level is 5 dB less than the input since the sound level exceeded the LTL threshold for half the exposure time.

HTL DOSE=0%
LTL DOSE=43.5%
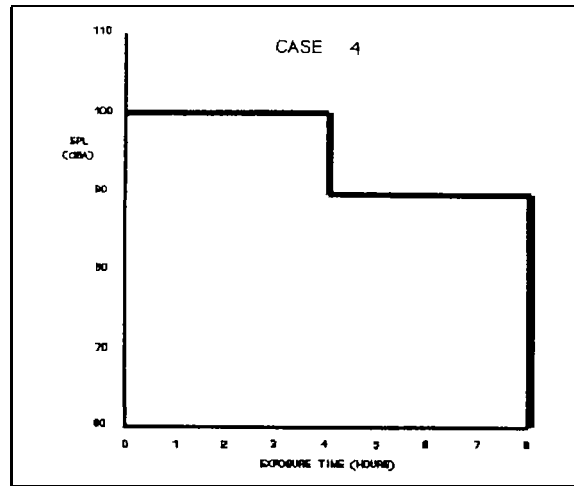HTL L_{avg}=0 dBA
LTL L_{avg}=84 dBA
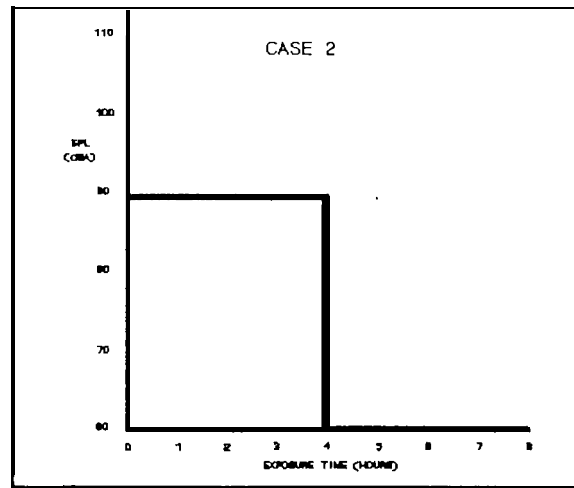
Case 3 - The dosimeter is exposed to a sound level of 95 dBA for 4 hours and to a sound level greatly below 70 dBA for the remaining 4 hours of the shift. For Case 3, the input sound level exceeds both the HTL and LTL for half the shift. The HTL and LTL doses are equal, and the HTL and LTL equivalent average sound levels are equal. Again, the average sound levels are 5 dB less than the input due to the exposure time relationship.

HTL DOSE=100%
LTL DOSE=100%
HTL L_{avg}=90 dBA
LTL L_{avg}=90 dBA

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Case 4 - The dosimeter is exposed
to a sound level of 100 dBA for 4
hours and to a sound level of 89
dBA for the remaining 4 hours of
the shift. For Case 4, the input
sound level exceeds both the HTL
and LTL for half the shift, but
for the second half of the shift,
only the LTL is exceeded. The
difference in the average HTL and
LTL sound levels is due to the
level-time relationships.

HTL DOSE=200%
LTL DOSE=243.5%
HTL L_{avg}=95 dBA
LTL L_{avg}=96.4 dBA

Case 5 - The dosimeter is exposed
to a sound level of 100 dBA for 4
hours and to a sound level of 95
dBA for the remaining 4 hours of
the shift. For Case 5, the input
sound level varies in each half
of the shift, but exceeds the
threshold in all cases. The HTL
and LTL doses are equal as are
the HTL and LTL average sound
levels.

HTL DOSE=300%
LTL DOSE=300%
HTL L_{avg}=97.9 dBA
LTL L_{avg}=97.9 dBA
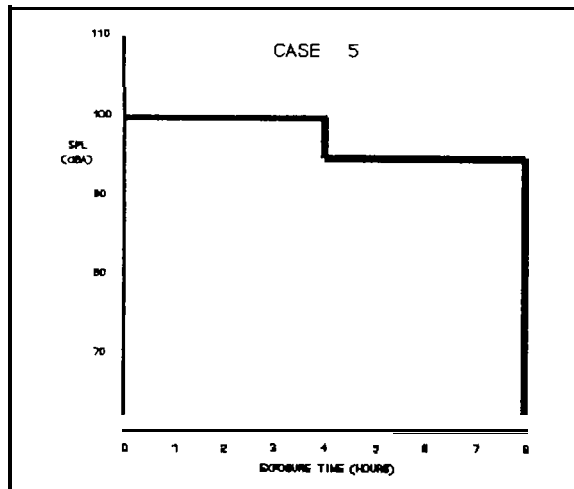
Case 6 - The dosimeter is exposed to a sound level of 100 dBA for the entire 8-hour shift. For Case 6, the input sound level exceeds both the HTL and LTL for the entire shift. The HTL and LTL doses are equal as are the HTL and LTL average sound levels.

HTL DOSE=400%
LTL DOSE=400%
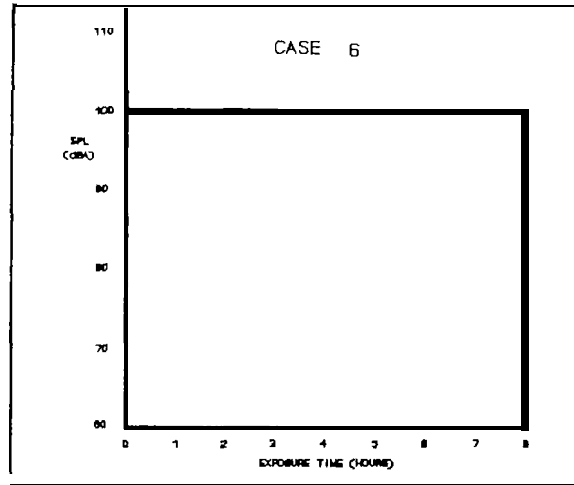HTL L_{avg}=100 dBA
LTL L_{avg}=100 dBA

Table 1 summarizes the noise dose and average sound levels for each of the six input scenarios for both high and low threshold conditions.

Table 1 - Computed Noise Doses and Average Sound Levels for the Six Input Scenarios as a Function of the Dosimeter Threshold

CASE	HTL DOSE %	LTL DOSE %	HTL Lg dBA	LTL L, dBA
1	0	0	0	0
2	0	43.5	0	84
3	100	100	90	90
4	200	243.5	95	96.4
5	300	300	97.9	97.9
6	400	400	100	100

From this theoretical discussion, the following can be concluded:

0   The LTL dose and LTL average sound level must always equal or exceed the HTL dose and corresponding HTL equivalent average sound level since the sound levels between the two thresholds are integrated into the LTL dose and average sound level.

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0   For the HTL dose and corresponding average sound level to
     equal the LTL dose and corresponding average sound level,
     all instantaneous sound levels must exceed the highest
     threshold or be below the lowest threshold for the entire
     shift, i.e, no part of the sound level temporal distribution
     can be between the two threshold levels.

As can be seen from table 1, the resultant doses and average
sound levels can vary during the course of an occupational noise
exposure measurement when a noise dosimeter is used. Knowing how
to select the proper threshold and how to interpret the data is
crucial when evaluating the results of a noise dosimeter
measurement.

                        FIELD EXPERIMENT

MSHA coal mine inspectors are required to conduct full-shift
noise surveys on miners that work in surface and underground coal
mines to determine non-compliance to the MSHA noise standard.
Upon the completion of each survey, the results of the survey are
to be reported on a MSHA 2000-84 Environmental Noise Report Form,
with a copy being sent to MSHA's Physical and Toxic Agents
Division, Pittsburgh, PA. This data is computerized and a
complete description of the program, including a summary
analysis, has been published in the literature'.

In conducting this inspection work, noise dosimeters are used for
field noise surveys. MSHA uses two models of noise dosimeters in
its enforcement program. One type of dosimeter has the
capability of simultaneously performing both the High and Low
threshold noise dose calculation. Over a three-year period, MSHA
inspectors were asked to report both the high and low threshold
dose readings.

There were 2631 instances where the coal mine inspectors reported
data containing both the high and low threshold noise doses. The
HTL and LTL doses were entered into a computer spreadsheet. The
dose difference was determined for each instance. The average
sound level was calculated for each HTL and LTL dose, using
equation (6) (assuming 480 minutes exposure time). Additionally,
the mean and standard deviation values were computed across the
2631 HTL doses, LTL doses, Dose differences, HTL L_{AVG}, LTL L_{AVG},
and L_{avg}. The summary statistics are shown in Table 2.

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     [1]Seiler, J.P., Valoski, M.P., and Crivaro, M.A., "Noise
Exposures in U.S. Coal Mines", U.S. Department of Labor, Mine
Safety and Health Administration, MSHA Informational Report IR-
1214, 1994..

TABLE 2 - Summary Statistics for the 2631 Field
Noise Dosimeter Surveys

PARAMETER	MEAN	STANDARD DEVIATION
HTL DOSE (%)	83.3	97.2
LTL DOSE (%)	103.4	95.4
DOSE DIFFERENCE (%)	20.1	15.1
HTL L_{AVG} (dBA)	85.2	7.9
LTL L_{avg} (dBA)	88.1	5.9
L_{DIFF} (dBA)	2.9	3.1

Table 2 shows that, on the average for the 2631 data points, the difference between the HTL and LTL doses was 20.1%. It also showed that there was a wide spread among the dose measurements. In terms of average sound level, the HTL and LTL equivalent average sound levels differed by 2.9 dBA with a standard deviation of 3.1 dBA.

Figure 2 is a scatter plot of the HTL L_{avg} versus the LTL L_{avg} data points for all 2631 data points. The graph shows the spread of the data. It also shows the effect of integration of the sound levels between 80 - 90 dBA. The data points are all to the left of the line where HTL L_{avg} = LTL L_{avg}, where the LTL L_{avg} is equal to or greater than the HTL L_{avg}. The spread in the data decreases significantly once the sound levels exceed the HTL thresholds as shown in the graph beyond HTL L_{avg} values of 90 dBA.
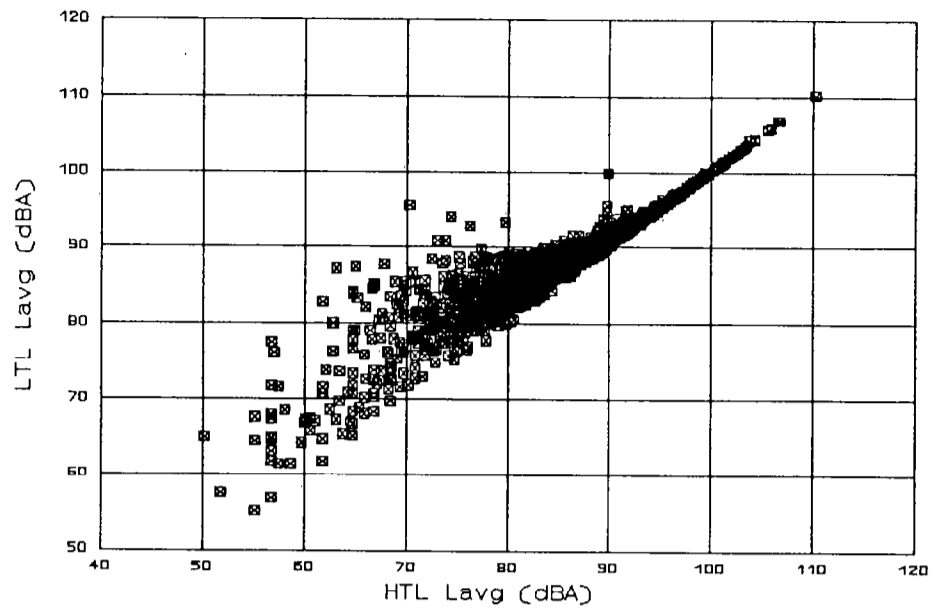
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LTL Lavg VS HTL Lavg

FIGURE 2 - SCATTER PLOT OF COLLECTED AVERAGE SOUND LEVEL DATA

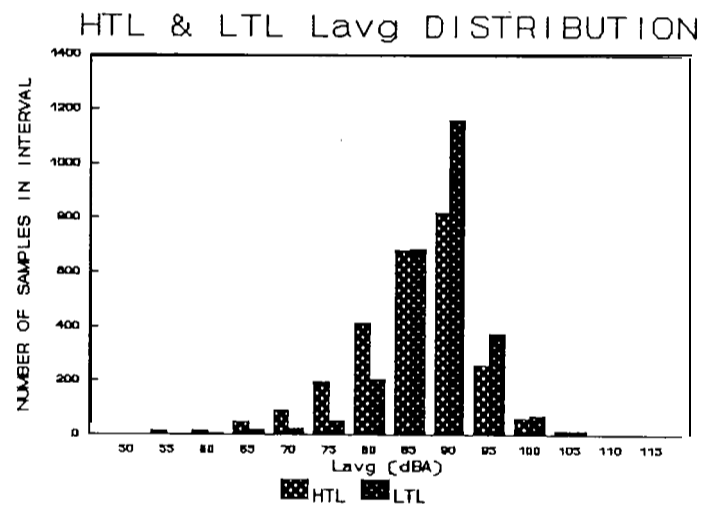Figure 3 presents the distribution of the average sound levels for the entire data base.

FIGURE 3 - DISTRIBUTION OF HTL-LTL DATA

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Figure 4 presents the cumulative distribution of the average
sound levels. As can be seen, the cumulative distributions
diverge at levels around and below the high threshold (90 dBA).
As expected, the cumulative distributions converge above the high
threshold level.
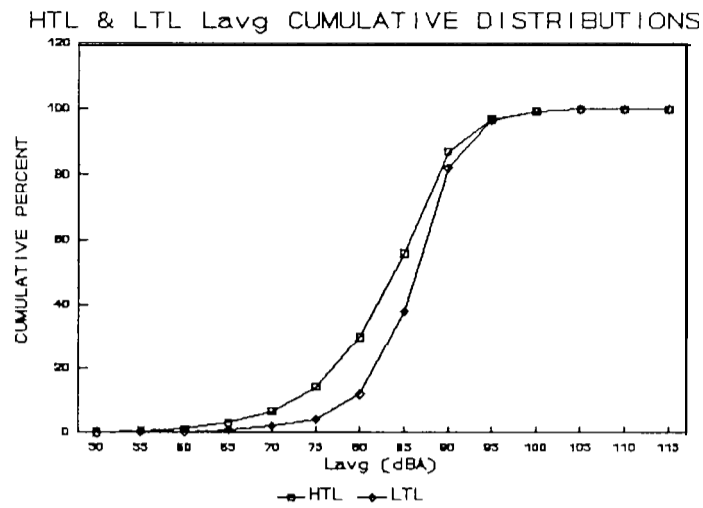
HTL & LTL Lavg CUMULATIVE DISTRIBUTIONS

FIGURE 4 - CUMULATIVE DISTRIBUTION OF
HTL-LTL DATA

Another manner in which to examine the effect of thresholds on
noise exposure measurements is to determine the percentage of
measurements that exceeds a specified noise exposure level for
the various thresholds. This information is shown in Table 3.

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TABLE 3 - THRESHOLD EFFECTS IN THE EXCEEDANCE OF SPECIFIED
NOISE EXPOSURE LEVELS

EXPOSURE LEVEL (% DOSE)	LTL DOSE NO. SAMPLES 2 EXPOSURE LEVEL (% OF SAMPLES)	HTL DOSE NO. SAMPLES 2 EXPOSURE LEVEL (% OF SAMPLES)
132%	5 5 6 (21.1%)	3 8 0 (14.4%)
100%	9 6 1 (36.5%)	6 8 7 (26.1%)
66%	1722 (65.5%)	1223 (46.5%)
50%	2051 (78.0%)	1532 (58.2%)

Note: The number of samples are 2631 noise surveys taken with noise dosimeters with dual thresholds.

It can be seen that as the exposure level increases, the percentage difference between HTL Dose and LTL Dose decreases, i.e., as the dose goes up, the sound levels that are integrated exceed the HTL threshold a greater percentage of time of the shift.

Consider the following hypothetical situation: The regulatory requirement for the institution of a hearing conservation program (HCP) could be triggered by noise dose measured with a dosimeter having a 90 dBA criterion level and 5 db exchange rate at a dose of 50%. From table 3, it can be concluded that 78% of the noise exposure surveys would indicate the need for a HCP if the requirement was to use an .80 dBA threshold level. Alternatively, if the requirement was to use a 90 dBA threshold level, 58.2% of the noise exposure surveys would indicate the need for a HCP . Significantly, an additional 19.8% of the surveys would require HCPs dependent on whether the high or low threshold levels were used to trigger the HCP requirement. The decision of which threshold level to use should be based on the damage-risk criteria that are implicitly accepted and must be taken into account in the survey methodology.

CONCLUSION AND RECOMMENDATIONS

The use of average sound level, L_{avg}, data based on back calculations from dosimetry data should be viewed with caution. The threshold setting of the dosimeter and the temporal distributions of the sound levels across the threshold level in conjunction with the exposure times above and below the threshold level will have a large impact on the noise dose and corresponding average sound level.

Noise exposures (doses) and average sound levels collected with instruments having differing thresholds cannot be directly compared. The data collected with a lower threshold will always be greater than or equal to that collected with the higher threshold. Additionally, data distributions and cumulative distributions formed from measurements having differing threshold levels cannot directly be compared.

The following recommendations should be followed:

1. When performing a dosimeter measurement for compliance reporting purposes, the threshold level specified in the regulation should be used with the understanding that any average sound level that is determined has associated limitations. However, when dosimeter surveys are performed that do not have to be reported to a regulatory agency, and a more conservative estimate than that assumed in the regulation is desired, then a threshold level lower than the one required in the regulation or no threshold level may be used.

2. If the desired objective of a dosimetry measurement is .to correlate back-calculated average sound level measurements with average sound levels collected with sound level meter type instruments or tape recorded data, then no-threshold or at least a threshold setting 20 dBA or more lower than the sound levels being measured should be used. The purpose of this recommendation is to minimize the threshold effect on the average sound level determination.

3. If the desired objective of conducting a dosimeter survey, using a dosimeter with dual threshold capabilities, is for both purposes shown above in 1 and 2, then the thresholds should be set accordingly.