APPENDICES

APPENDIX A—GLOSSARY

A-weighting: A measurement scale that approximates the "loudness" of tones relative to a 40-dB sound pressure level, 1,000-Hz reference tone. A-weighting is said to best fit the frequency response of the human ear: when a sound dosimeter is set to A-weighting, it responds to the frequency components of sound much like your ear responds. A-weighting has the added advantage of being correlated with annoyance measures and is most responsive to the mid-frequencies, 500 Hz to 4,000 Hz.

B-weighting: B-weighting is similar to A-weighting but with less attenuation. B-weighting was an attempt to approximate human perception of loudness for moderately high sound pressure levels. It is now outdated and no longer used.

C-weighting: A measurement scale that approximates the "loudness" of tones relative to a 90-dB sound pressure level, 1,000-Hz reference tone. C-weighting has the added advantage of providing a relatively "flat" measurement scale that includes very low frequencies.

Criterion level: The continuous equivalent 8-hour A-weighted sound level (as dBA) that constitutes 100% of an allowable noise exposure (dose)—in other words, the permissible exposure limit. For OSHA purposes, this is 90 dB, averaged over 8 hours on the A scale of a standard dosimeter set on slow response.

Dose (%): Related to the criterion level, a dose reading of 100% is the maximum allowable exposure to accumulated noise. For OSHA, 100% dose occurs for an average sound level of 90 dB over an 8-hour period (or an equivalent exposure). If a TWA reading is used rather than the average sound level, the time period is no longer explicitly needed. A TWA of 90 dB is the equivalent of 100% dose. The dose doubles every time the TWA increases by the exchange rate. Table A–1 shows the relationship between dose and the corresponding 8-hour TWA exposure.

> *Example:* OSHA uses an exchange rate of 5 dB. Suppose the TWA is 100 dB for an 8-hour exposure. The dose doubles for each 5-dB increase over the criterion level of 90 dB. The resulting dose is therefore 400%. With an 8-hour TWA of 80 dB, the dose would halve for each 5 dB below the criterion level. The resulting dose would be 25%. When taking noise samples of duration shorter than the full workday, dose is an easy number to work with because it is linear with respect to time.
>
> *Example:* If a 0.5-hour screening sample results in 9% dose and the workday is 7.5 hours long, the estimated dose for the full workday would be 135% (7.5 ÷ 0.5 × 9%). This is computed making the assumption that the sampled noise will continue at the same levels for the full 7.5-hour workday. While short-term dose measurements cannot be used to support a citation, they can be effectively used as a screening tool to determine whether full-shift sampling is warranted.
>
> *Example:* A worker is employed in a high noise area for half an hour each day, and the remainder of the 8-hour workday is spent in a quiet office area. If the worker is exposed to 93 dBA for half an hour, the dosimeter will read 10%. Because no additional dose will be accumulated while working in the quiet office area, the equivalent 8-hour TWA will be 73.4 dBA, as shown in Table A–1.

Table A–1. Conversion Between Percent Noise Dose and 8-Hour TWA Sound Level

Dose (% Noise Exposure)	8-Hour TWA (dBA)
10	73.4
25	80
50	85
75	87.9
100	90
150	92.9
200	95
300	97.9
400	100
500	101.6
600	102.9
800	105
1000	106.6
1600	110
3200	115
6400	120

* When measured with a 5-dB exchange rate and a 90-dBA PEL.

** Additional data points are provided in Table A–1 in Appendix A, Section II of the noise standard (29 CFR 1910.95), particularly in the 80–999% dose range.

Exceedence level: The level exceeded by the measured noise level for an identified fraction of time. Exceedence levels may be calculated for many time fractions over the course of a shift and are typically expressed with percentages (L%). For example, an L40 equal to 73 dB would mean that for 40% of the run time, the decibel level was higher than 73 dB.

Exchange rate (or doubling rate): The increase or decrease in decibels corresponding to twice (or half) the noise dose. For example, if the exchange rate is 5 dB, 90 dB produces twice the noise dose that 85 dB produces (assuming that duration is constant). The OSHA exchange rate is 5 dB (see Table D-2 of the construction noise standard, 29 CFR 1926.52, and Tables G-16 and G-16a of the general industry noise standard, 29 CFR 1910.95).

Only instruments using a 5-dB exchange rate may be used for OSHA compliance measurements. CSHOs should be aware that the following organizations use noise dosimeters with a 3-dB exchange rate: NIOSH, EPA, ACGIH, and most foreign governments. The U.S. Department of Defense (DOD) previously used a 4-dB exchange rate; however, all branches (except the U.S. Navy) now have adopted the 3-dB exchange rate.

Hertz (Hz): Unit of vibration frequency, numerically equal to cycles per second.

Impact noise (or impulsive noise): Impact noise is created by the impact of one surface on another and is of a short duration. Impulsive noise is typically an air noise that has a short duration, such as the shooting of a firearm or the explosion of a firework. The standard states that exposure to impulsive or impact noise should not exceed a **140-dB** peak sound pressure level. Impulsive or impact noises are considered to be much more harmful to hearing than continuous noises. In construction, most of the 500,000 workers who are exposed to hazardous noise levels are also exposed to impulsive and impact noise sources on worksites. Impulsive and impact noise is typified by a sound that rapidly rises to a sharp peak and then quickly fades. Both are transient noises of brief duration and high intensity. The sound may or may not have a "ringing" quality (such as a striking a hammer on a metal plate or a gunshot in a reverberant room). Impulsive noise can be repetitive or a single event (like a sonic boom); if impulses occur in very rapid succession (such as with some jack hammers), it is not described as impulsive or impact noise.

Intensity of sound: Intensity of sound is measured in watts per square meter. To calculate the intensity level in decibels, find the ratio of the intensity (I) of sound to the threshold intensity (I_0).

$$dB = 10 \log_{10} \frac{I}{I_0}$$

L_{avg} (or LAVG): The average sound level measured over the run time of measurement. This becomes a bit confusing when thresholds are used, because the average does not include any sound below the threshold. Sound is measured in the logarithmic scale of decibels, so the average cannot be computed by simply adding the levels and dividing by the number of samples. When averaging decibels, short durations of high levels can significantly contribute to the average level.

> *Example:* Assume the threshold is set to 80 dB and the exchange rate is 5 dB (the settings of OSHA's Hearing Conservation Amendment). Consider taking a 1-hour noise measurement in an office where the A-weighted sound level was typically between 50 dB and 70 dB. If the sound level never exceeded the 80-dB threshold during the 1-hour period, then the LAVG would not indicate any reading at all. If 80 dB was exceeded for only a few seconds due to a telephone ringing near the instrument, then only those seconds will contribute to the LAVG, resulting in a level perhaps around 40 dB (notably lower than the actual levels in the environment).

LDN: Representing the day/night sound level, this measurement is a 24-hour average sound level, where 10 dB is added to all of the readings taken between 10 p.m. and 7 a.m. This is primarily used in community noise regulations where there is a 10-dB "penalty" for nighttime noise but is not used to evaluate compliance with OSHA standards, as it is not an occupational issue.

L_{eq}: The true equivalent sound level measured over the run time. L_{EQ} is functionally the same as L_{AVG}, except that it is only used when the exchange rate is set to 3 dB and the threshold is zero.

Linear weighting: A weighting most commonly found on upper model sound level meters, typically used when performing octave band filtering analysis.

Max level: The highest weighted sound level that occurred, also allowing for the response time to which the meter is set. If the meter is set for A-weighting with slow response, the max level is the highest A-weighted sound that occurred when applying the slow response time.

Noise dosimeter: A type of sound level meter that measures the dose of noise. This instrument can calculate the daily noise dose based on a full workshift of measurements, or a dose from a shorter sample. The operator can select different noise dose criteria, exchange rates, and thresholds.

Octave bands: Sounds that contain energy over a wide range of frequencies are divided into sections called bands, each one octave. A common standard division is in 10 octave bands identified by their center frequencies, 31.5; 63; 250; 500; 1,000; 2,000; and 4,000 Hz. For each octave band, the frequency of the lower band limit is one-half the frequency of the upper band limit. This is the most common type of frequency analysis performed for workplace exposure evaluation and control. An alternative frequency band, the *one-third octave band*, is defined as a frequency band such that the upper band-edge frequency, f_2, is the cube root of two times the lower band frequency, f_1: $f_2 = (2)^{1/3} f_1$. The level of detail provided by one-third octave bands, however, is rarely required for occupational noise evaluation and control.

Peak noise: The highest instantaneous sound level that a microphone detects. Unlike the max level, the peak is detected independently of the slow or fast response for which the unit is set.

> *Example:* The peak circuitry is very sensitive. Test this by simply blowing across the microphone. You will notice that the peak reading may be 120 dB or greater. When you take a long-term noise sample (such as a typical 8-hour workday sample for OSHA compliance), the peak level is often very high. Because brushing the microphone over a shirt collar or accidentally bumping it can cause such a high reading, the user must be careful not to place too much emphasis on the reading.

Permissible exposure limit (PEL): The A-weighted sound level at which exposure for a criterion time, typically 8 hours, accumulates a 100% noise dose. Only sounds 90 dBA and higher are integrated into the PEL (i.e., the threshold level is 90 dBA).

Receiver: A person exposed to noise that originates at a noise source. If the receiver is exposed to a hazardous noise level, the exposure can be reduced through various noise-control methods.

Response: Instruments that measure time-varying signals are limited in how fast they can respond to changes in the input signal. Sound dosimeters can operate with a wide variety of response times, but the industry has chosen two particular response times to standardize measurements. These are known as the slow and fast response times. OSHA, the Mine Safety and Health Administration, and ACGIH all require the slow response for sound dosimetry. The standardized time constant for the slow response is 1 second.

Sound level meter: An instrument that converts sound pressure in air into corresponding electronic signals. The signals may be filtered to correspond to certain sound weightings (e.g., A-weighted scale, C-weighted scale).

Threshold level: The A-weighted sound level at which a personal noise dosimeter begins to integrate noise into a measured exposure. For example, if the threshold level on a sound level meter is set at 80 dBA, it will capture and integrate into the computation of dose all noise in the worker's hearing zone that equals or exceeds 80 dBA. Sound levels below this threshold would not be included in the computation of noise dose. Use an 80-dBA threshold for measurements related to hearing conservation programs and a 90-dBA threshold for exposure results related to the need for engineering or administrative controls.

The hypothetical exposure situations shown in Table A–2 illustrate the relationship between criterion level, threshold, and exchange rate and show the importance of using a dosimeter with an 80-dBA threshold to characterize a worker's noise exposure. For example, an instrument with a 90-dBA threshold will not capture any noise below that level and will thus give a readout of 0%, even if the worker being measured is actually being exposed to 89 dBA for 8 hours (i.e., to 87% of the allowable noise dose over any 8-hour period).

Table A–2. Effect of Threshold Settings on Dosimeter Readout		
Exposure Conditions	**Dosimeter With Threshold Set at 80 dBA (percent of measured dose)**	**Dosimeter With Threshold Set at 90 dBA (percent of measured dose)**
90 dBA for 8 hours	100.0%	100.0%
89 dBA for 8 hours	87.0%	0.0%
85 dBA for 8 hours	50.0%	0.0%
80 dBA for 8 hours	25.0%	0.0%
79 dBA for 8 hours	0.0%	0.0%
90 dBA for 4 hours plus 80 dBA for 4 hours	62.5%	50.0%
90 dBA for 7 hours plus 89 dBA for 1 hour	98.4%	87.5%
100 dBA for 2 hours plus 89 dBA for 6 hours	165.3%	100.0%

Assumes 5 dB exchange rate, 90 dBA PEL, ideal threshold activation, and continuous sound levels.

Time-weighted average (TWA): A constant sound level lasting 8 hours that would result in the equivalent sound energy as the noise that was sampled. TWA always averages the sampled sound over an 8-hour period. This average starts at zero and grows. It is less than the L_{avg} for a duration of less than 8 hours, is exactly equal to the L_{avg} at 8 hours, and grows higher than the L_{avg} after 8 hours.

> *Example:* Think of a TWA as having a large 8-hour container that stores sound energy. If you run a dosimeter for 2 hours, your L_{avg} is the average level for those 2 hours—consider this a smaller 2-hour container filled with sound energy. For TWA, take the 2-hour container and pour that energy into the 8-hour container. The TWA level will be lower. Again, TWA is always based on the 8-hour container. When measuring using OSHA's guidelines, TWA is the proper number to report if the full workshift was measured.

Type 1/Type 2 (or Class 1 and Class 2): Two different accuracy specifications for noise measurements. Type 1 measurements are accurate to approximately ±1dB and Type 2 measurements are accurate to approximately ±2dB. The accuracy of the measurements varies, however, depending on the frequency of the sound being measured.

Z-weighting: An unweighted measurement scale that does not apply any attenuation or weighting to any frequency. Instead, this scale provides a flat response across the entire spectrum from 10 Hz to 20,000 Hz, making it useful for octave band analysis and evaluating engineering controls.

Acknowledgments: Dennis Driscoll, Raeco, 3M/Quest.

APPENDIX B—SAMPLE EQUATIONS AND CALCULATIONS

B.1 Sound Pressure Level

The human ear can hear a broad range of sound pressures. Because of this, the sound pressure level (L_p) is measured in decibels (dB) on a logarithmic scale that compresses the values into a manageable range. In contrast, direct pressure is measured in pascals (Pa). L_p is calculated as 10 times the logarithm of the square of the ratio of the instantaneous pressure fluctuations (above and below atmospheric pressure) to the reference pressure:

$$L_p = 10 \times \log_{10}(P/P_{ref})^2$$

Where P is the instantaneous sound pressure, in units Pa, and P_{ref} is the reference pressure level, defined as the quietest noise a healthy young person can hear (20 µPa).

Example: If a piece of equipment has a sound pressure of 2 Pa, the sound pressure level is calculated:

$$L_p = 20 \log_{10} (2/0.00002) = 20 \log_{10}(100{,}000) = 20 \times 5.0 = 100 \text{ dB}$$

B.2 Sound Power Level

Sound power level (L_w) is similar in concept to the wattage of a light bulb. In fact, L_w is measured in watts (W). Unlike L_p, L_w does not depend on the distance from the noise source. The sound power level is calculated using the following equation:

$$L_w = 10 \times \log_{10}(W/W_{ref})$$

Where W is the acoustic power in watts and W_{ref} is the reference acoustic power, 10^{-12}.

Example: The sound power level associated with a typical face-to-face conversation, which may have a sound power of 0.00001 W, is calculated:

$$L_w = 10 \times \log_{10}(0.00001/10^{-12}) = 70 \text{ dB}$$

B.3 Combining and Averaging Sound Levels

Decibels are measured using a logarithmic scale, which means decibels cannot be added arithmetically. For example, if two noise sources are each producing 90 dB right next to each other, the combined noise sound level will be 93 dB, as opposed to 180 dB. The following equation should be used to calculate the sum of sound pressure levels, sound intensity levels, or sound power levels:

$$\text{Total L} = 10 \times \log_{10}\left(\sum_1^n 10^{Ln/10}\right)$$

Often, using this equation to quickly sum sound levels when there is no calculator or computer available is difficult. The following table can be used to estimate a sum of various sound levels:

Difference Between Two Levels to Be Added	Amount to Add to Higher Level to Find the Sum
0–1 dB	3 dB
2–4 dB	2 dB
5–9 dB	1 dB
10 dB	0 dB

Example: There are three noise sources immediately adjacent to one another, each producing a sound level of 95 dB. The combined sound level can be found using the table above. The difference between the first two noise sources is 0 dB, which means the sum will be 95 + 3 = 98 dB. The difference between 98 dB and the remaining noise source (95 dB) is 3, which means the sum will be 98 + 2 = 100 dB.

B.4 Adding Noise Exposure Durations to Determine Compliance with OSHA Standards

Under OSHA standards, workers are not permitted to be exposed to an 8-hour TWA equal to or greater than 90 dBA. OSHA uses a 5-dBA exchange rate, meaning the noise level doubles with each additional 5 dBA. The following chart shows how long workers are permitted to be exposed to specific noise levels:

Permissible Duration (Hours per Day)	Sound Level (dBA, Slow Response)
16	85
8	90
4	95
2	100
1½	102
1	105
½	110
¼ or less	115

The values in the chart above are from Table G-16 in the general industry standard, 29 CFR 1910.95. To calculate a permissible duration that is not addressed in this chart, use the following equation:

$$T = \frac{8}{2^{(L-90)/5}}$$

Where T is the permissible duration (in hours) and L is the measured sound level (in dBA).

A worker's daily noise exposure typically comes from multiple sources, which have different noise levels for different durations. When adding different noise levels from various noise sources, only noise levels exceeding 80 dBA should be considered. The combined effect of these noise sources can be estimated using the following equation:

$$\text{Sum} = C_1/T_1 + C_2/T_2 + C_3/T_3 + C_n/T_n$$

Where C_n is the total duration of exposure at a specific noise level, and T_n is the total duration of noise permitted at that decibel level. If the sum equals or exceeds "1," the combined noise level is greater than the allowable level. If the sum is less than "1," the combined noise level is less than the allowable level.

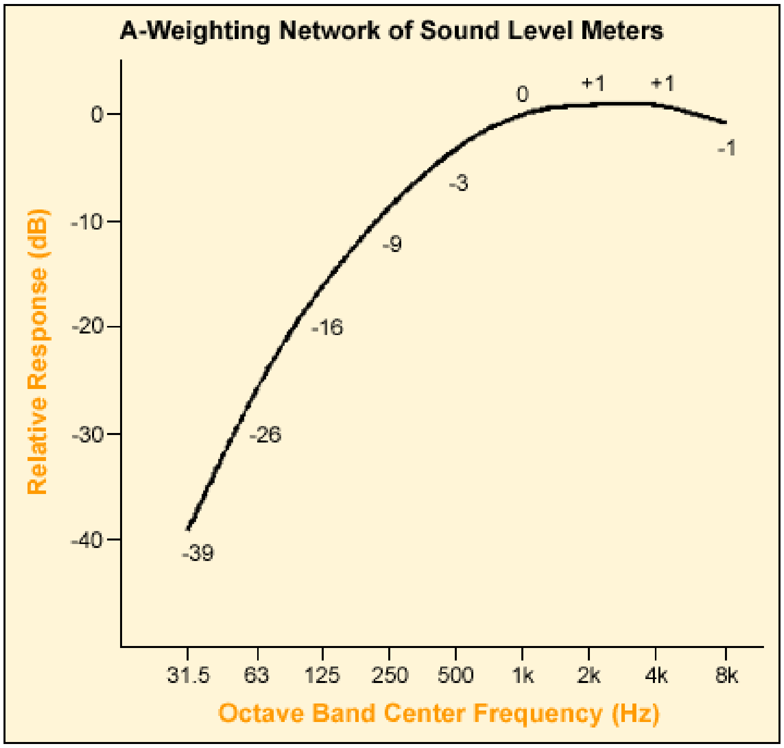
Example: A worker in a machine shop is exposed to 95 dBA for 2 hours, 69 to 78 dBA for 4 hours (including a 15-minute break and 45-minute lunch), and 90 dBA for 3 additional hours.

Example: Worker's Activity	Time	Measured Sound Level
Milling machine	6:00 a.m.–8:00 a.m.	95 dBA
Break room	8:00 a.m.–8:15 a.m.	69 dBA
Parts department	8:15 a.m.–11:15 a.m.	78 dBA
Lunch (in break room, 45 min.)	11:15 a.m.–12:00 noon	69 dBA
Milling assist	12:00 noon–3:00 p.m.	90 dBA

To determine if the worker's noise exposure exceeds a 90 dBA TWA, use the previous equation. Because the noise levels in the break room (69 dBA) and parts department (78 dBA) are below 80 dBA, these periods of the day are not included in the calculation. According to the chart above, workers are permitted to be exposed to 95 dBA for 4 hours per day and 90 dBA for 8 hours per day. Calculate the ratio of actual exposure duration to permissible exposure duration for each time segment and add them: 2/4 + 3/8 = 7/8. The resulting value (7/8) is less than 1; therefore, this worker's exposure does not exceed the 90 dBA TWA. However, a separate calculation would be required to determine if a hearing conservation program is required.

B.5 Calculating the Equivalent A-Weighted Sound Level (L_A)

Occasionally, it is necessary to convert a set of octave band sound pressure levels into an equivalent A-weighted sound level. This is easily done by applying the A-scale correction factors for the nine standard octave center frequencies and combining the corrected values by decibel addition. The A-scale correction factors are the values of the A-weighting network at the center of each particular octave band. The value derived by combining the corrected values for each octave band is designated the A-weighted sound level (dBA).



Example:

Octave Band Center Frequency (Hz)	Example L_p (dB)	A-Scale Correction Factor (dB) *	Corrected Values (dB)**
31.5	94	-39	55
63	95	-26	69
125	92	-16	76
250	95	-9	86
500	97	-3	94
1,000	97	0	97
2,000	102	+1	103
4,000	97	+1	98
8,000	92	-1	91

* Look up on A-weighted network chart for each value L_p.
** L_p corrected to the A-scale = Li.

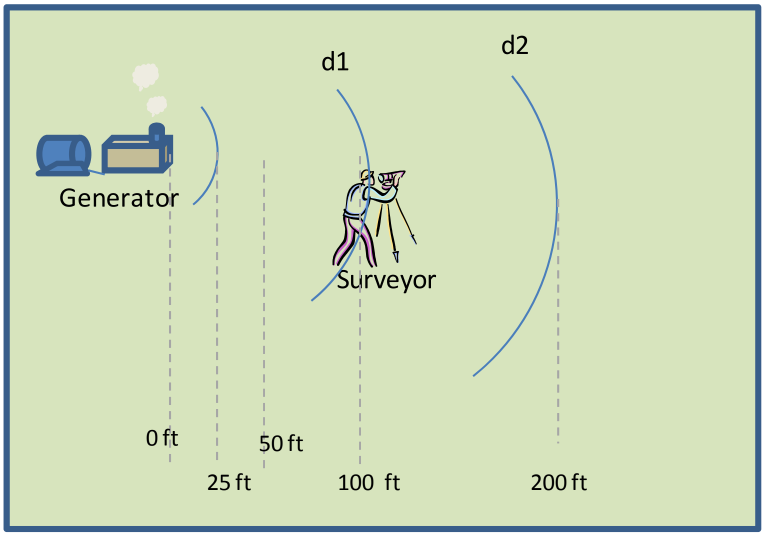
The A-weighted sound level is calculated by combining the corrected band levels:

$$L_A = 10 \times \log_{10} \left(\sum_1^n 10^{Li/10}\right) = 10 \times \log \left(10^{5.5} + 10^{6.9} + 10^{7.6} + 10^{8.6} + 10^{9.4} + 10^{9.7} + 10^{10.3} + 10^{9.8} + 10^{9.1}\right) = 105 \text{ dBA}$$

Where L_A is the A-weighted sound level and *Li* is the corrected decibel level value for each individual octave band.

B.6 Calculating Sound Pressure Level at a Distance

If a sound is generated at a point source in a free field, meaning there are no walls or other obstructions, the sound pressure level, L_p, will be reduced by 6 dB each time the distance from the noise source is doubled. Alternatively, L_p will increase by 6 dB in a free field each time the distance to the noise source is halved. Consider the following example:



Example: A worker is surveying an open field, which has a diesel generator running in the middle of it. The worker is 100 ft from the generator and is exposed to a noise level of 85 dBA. When the worker is 25 ft from the generator, the noise level will be 97 dBA. At 200 ft from the generator the worker will be exposed to a noise level of 79 dBA.

Calculating the sound pressure level at a specific distance from a noise source is often useful. The following equation allows one to calculate the sound pressure level at any distance from a noise source in a free field:

$L_{pd2} = L_{pd1} + 20 \times \log(d1/d2)$

Where L_{pd2} is the sound pressure level at the new distance from the noise source, L_{pd1} is the sound pressure level at the original distance, *d1* is the original distance, and *d2* is the new distance.

Example: The sound pressure level of an aircraft engine in the middle of an open runway is 120 dBA at a distance of 50 ft from the receiver. The sound pressure level at a distance of 80 ft is calculated using the equation above. L_{pd1} is 120 dBA, *d1* is 50 ft, and *d2* is 80 ft. Therefore, L_{pd2} is 120 + 20 × log(50/80), which is 116 dBA.

B.7 Reducing the Action Level for Extended Workshifts

If a worker works longer than an 8-hour shift, the action level (AL) for hearing conservation is reduced proportionally from 85 dBA using the following equation:

$$AL = 16.61 \log_{10}\left(\frac{50}{12.5 \times hours\ worked}\right) + 90$$

Example: A worker works a 10.75-hour shift in a car parts manufacturing plant. What will be the worker's reduced AL?

$$AL = 16.61 \log_{10}\left(\frac{50}{12.5 \times 10.75}\right) + 90 = 82.9\ dBA$$

B.8 <u>Converting a Single Dose Measurement to an 8-hour TWA Sound Level</u>

A dose measurement can be converted to an 8-hour TWA sound level using the following equation:

$$TWA = 16.61 \log_{10}\frac{dose}{100} + 90$$

Where the dose is a percentage and the TWA is on an A-weighted scale.

A factory hires a health and safety consultant to measure the noise exposure of the workers. The consultant writes a report that states that workers are exposed to a 183% dose, according to the general industry standard, CFR 29 1910.95. Convert this dose into an 8-hour TWA.

$$TWA = 16.61 \log_{10}\frac{183}{100} + 90 = 94.4\ dBA$$

APPENDIX C—ULTRASOUND

Ultrasound is any sound whose frequency is too high for the human ear to hear. (The upper frequency that the human ear can detect is approximately 15 to 20 kilohertz, or kHz, although some people can detect higher frequencies, and the highest frequency a person can detect normally declines with age.) Most of the audible noise associated with ultrasonic sources, such as ultrasonic welders or ultrasonic cleaners, consists of subharmonics. Even though the ultrasound itself is inaudible, the subharmonics it generates can affect hearing and produce other health effects.

C.1 Health Effects and Threshold Limit Values (TLVs®)

> *Subharmonics are sound waves with frequencies that are a fraction (e.g., one-half, one-quarter) of the original ultrasound frequency. Because they are lower than the ultrasound, the human ear can detect them.*

Research indicates that ultrasonic noise has little effect on general health unless there is direct body contact with a radiating ultrasonic source. Reported cases of headache and nausea associated with airborne ultrasonic exposures appear to have been caused by high levels of audible noise from source subharmonics.

The American Conference of Governmental Industrial Hygienists (ACGIH®) has established permissible ultrasound exposure levels. These recommended limits (set at the middle frequencies of the one-third octave bands from 10 kHz to 100 kHz) are designed to prevent possible hearing loss caused by the subharmonics of the set frequencies, rather than the ultrasound itself. These exposure levels represent conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse effects on their ability to hear and understand normal speech. (Table C–1)

ACGIH also offers recommendations for measuring or verifying ultrasound levels, which requires a precision sound level meter equipped with a suitable microphone of adequate frequency response and a third-octave filter. CSHOs considering evaluating ultrasound levels should consult the CTC for assistance in selecting a suitable instrument.

ACGIH also notes that:

> *Subjective annoyance and discomfort may occur at levels between 75 and 105 dB for the frequencies from 10 kHz to 20 kHz especially if they are tonal in nature. Hearing protection or engineering controls may be needed to prevent subjective effects. Tonal sounds in frequencies below 10 kHz might also need to be reduced to 80 dB.* (ACGHI, 2012)

Table C–1. Select Examples of Threshold Limit Values for Ultrasound Measured in Air

1/3 Octave Band Frequency (kHz)	Ceiling Values (dB) [a, b]	8-Hour TWA (dB) [a, b]
10	105	88
20	105	94
25	110[a]	—
50	115[a]	—

[a] re: 20 µ Pa (head in air)
[b] ACGIH set the ceiling values assuming that the worker has no direct contact with the ultrasound source, but that the worker does have contact with water or other media that can transfer the sound waves.

For additional information on ultrasound exposure levels, ceiling values, and 8-hour TWAs that apply to other frequencies, as well as ceiling values measured underwater, refer to the complete ACGIH TLV for ultrasound (see ACGIH. 2012. Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices. American Conference of Governmental Industrial Hygienists).

C.2 Controls

High-frequency noise is highly directional and is associated with short wavelengths. This means that it is easily reflected or blocked by any type of barrier. The wavelength of a 16-kHz tone, for example, is about 3/4 inch. A modest barrier, extending just 1 to 2 inches beyond the source, is generally sufficient to reflect noise of approximately the same frequency away from a nearby worker. High-frequency audible noise is also easily absorbed by many acoustical materials, such as glass fiber or foam.

C.3 International Ultrasound Exposure Limit Recommendations

Over the past decades, several countries have set exposure limits or recommended levels for ultrasound at various frequencies. The differences in limits are great and reflect differences in the interpretation and analysis of studies on ultrasound and human health. Table C–2 lists ceiling values measured in air in dB, as opposed to 8-hour TWAs or ceiling values measured in water in dB. Though ultrasonic frequencies are not audible to the human ear, it is clear that the international community is concerned about the effects that subharmonic frequencies have on human health.

Table C–2. Examples of International Occupational Exposure Sound Pressure Level Ceiling Limits (in dB) for 1/3-Octave Bands

Frequency (kHz)	Decibel Limits Proposed By:					
	Japan (1971)	USSR (1975)	Sweden (1978)	ACGIH (2003)	Canada (1991)	European Union (2002)
8	90	—	—	—	—	—
10	90	—	—	105	—	—
12.5	90	75	—	105	—	—
16	90	85	—	105	75	—
20	110	110	105	105	75	105
25	110	110	110	110	110	105
31.5	110	110	115	115	110	115
40	110	110	115	115	110	115
50	110	110	115	115	110	115

Adapted from: Health Canada. 2008. *Guidelines for the Safe Use of Ultrasound: Part II—Industrial & Commercial Applications—Safety Code 24.* http://www.hc-sc.gc.ca/ewh-semt/pubs/radiation/safety-code_24-securite/guidelines-principes-eng.php.

For a detailed review of ultrasound effects on human hearing, published literature, international ultrasound standards, and recommendations for future directions, see:

Lawton, B.W. 2001. Damage to Human Hearing by Airborne Sound of Very High Frequency or Ultrasonic Frequency. Health and Safety Executive. http://www.hse.gov.uk/research/crr_pdf/2001/crr01343.pdf.

The report concludes: There is not sufficient data in the literature to support, or even contemplate, a dose response relation between occupational exposure to VHF noise and resultant hearing risk.

APPENDIX D—COMBINED EXPOSURE TO NOISE AND OTOTOXIC SUBSTANCES

Ototoxic substances came gradually to the attention of occupational health and safety professionals in the 1970s, when the ototoxicity of several industrial chemicals, including solvents, was recognized. The possibility of noise/solvent interaction was raised more recently, when Bergström and Nyström (1986) published the results of a 20-year epidemiological follow-up study in Sweden, started in 1958 and involving regular hearing tests in workers. Interestingly, a large proportion of workers employed in the chemicals divisions of companies suffered from hearing impairment, although noise levels were significantly lower than those in sawmills and paper pulp production. The authors suspected that industrial solvents were an additional causative factor in hearing loss.

Workers are commonly exposed to multiple agents. Physiological interactions with some mixed exposures can lead to an increase in the severity of harmful effects. This applies not only to the combination of interfering chemical substances, but also in certain cases to the co-action of chemical and physical factors. In this case, effects of ototoxic substances on ear function can be aggravated by noise, which remains a well-established cause of hearing impairment.

According to the European Agency for Safety and Health at Work (2009), experiments with rats have shown that combined exposure to noise and solvents induced synergistic adverse effects on hearing. “Good evidence” has been accumulated on the adverse effects on hearing of the following solvents:

Toluene, ethylbenzene, n-propylbenzene

Styrene and methylstyrenes

Trichloroethylene

p-Xylene

n-Hexane

Carbon disulfide

The rat cochlea is sensitive to aromatic solvents, unlike that of the guinea pig or chinchilla (Campo et al., 1993; Cappaert et al., 2003; Davis et al., 2002; Fechter, 1993). These findings have been attributed to metabolic and other toxicokinetic differences (Campo and Maguin, 2006; Davis et al., 2002; Gagnaire et al., 2007). Because of their metabolism, rats are considered comparatively good animal models for the investigation of the ototoxic properties of aromatic solvents in humans (Campo and Maguin, 2006; Kishi et al., 1988).

Examples of relevant literature on interactions between noise and specific substances include:

Toluene (Brandt-Lassen et al. , 2000; Johnson et al., 1988; Lataye and Campo, 1997; Lund and Kristiansen, 2008)

Styrene (Lataye et al., 2000; Lataye et al., 2005; Mäkitie et al., 2003)

Ethylbenzene (Cappaert et al., 2001)

Trichloroethylene (Muijser et al., 2000)

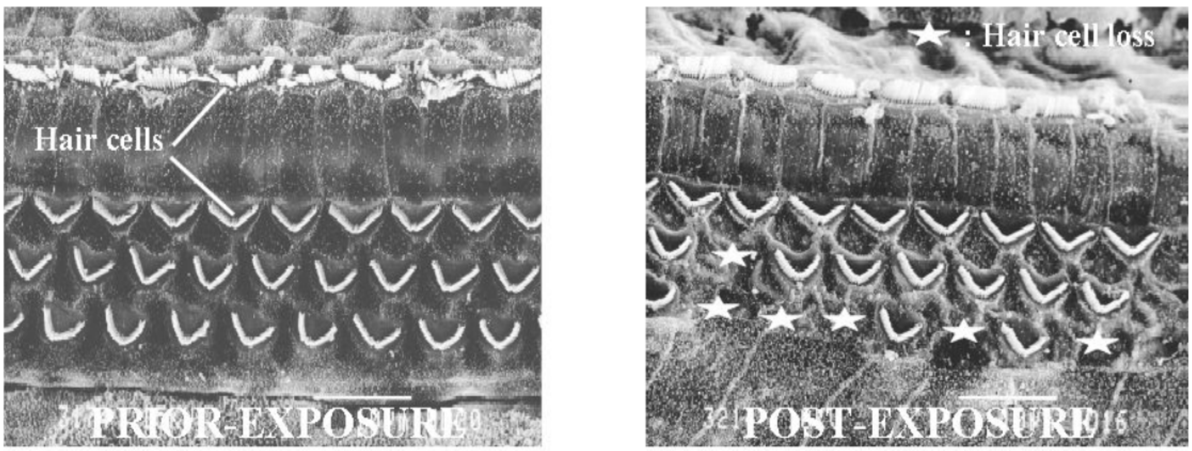
Carbon monoxide (Lacerda et al., 2005)

Lead (CDC-HHE, 2011)

Lataye et al. (2005) found interactive effects of noise at 85 dB with a styrene exposure concentration of 400 parts per million (ppm).[4] In general, though, high levels of noise and high concentrations of solvents were used in most of these investigations. Because of these special conditions, extrapolation to occupational exposure conditions can be challenging (Cary et al., 1997).

Investigators suggest that exposure to these solvents can provoke irreversible hearing impairment, with the cochlear hair cells (organ of Corti) being considered a target tissue for these solvents (Figure 5; Campo et al., 2007).

Scanning electron micrograph of a rat organ of Corti prior to (left panel) and after (right panel) toluene exposure (from European Agency for Safety and Health, 2009, as published in Lataye et al., in 1999).



Although the cochlea suffers damage, particularly during co-exposure, recent studies have reported that solvents reduce the protective role played by the middle-ear acoustic reflex, an involuntary muscle contraction that normally occurs in response to high-intensity sound stimuli. A disturbance of this reflex would allow more acoustic energy into the inner ear (Campo et al., 2007; Lataye et al., 2007; Maguin et al., 2009).

A number of epidemiological studies have investigated the relationship between hearing impairments and co-exposure to both noise and industrial solvents (Chang et al., 2003; De Barba et al., 2005; Johnson et al., 2006; Kim et al., 2005; Morata, 1989; Morata et al., 1993, 2002; Morioka et al., 2000; Prasher et al., 2005; Sliwinska-Kowalska et al., 2003, 2005). Due to confounding factors, straightforward conclusions could not easily be drawn from these studies. However, the evidence of additive or synergistic ototoxic effects due to combined exposure to noise and solvents is very strong (Lawton et al., 2006; Hoet and Lison, 2008).

A recent longitudinal study (Schäper et al., 2003; Schäper et al., 2008) on the relationship between hearing impairment measured by pure tone audiometry and occupational exposure to toluene and noise has not found ototoxic effects in workers exposed to a concentration of toluene lower than 50 ppm. The observed hearing loss was associated only with noise intensity. However, the use of hearing protection was not taken into account in the conclusions relative to the potential interaction between noise and toluene on hearing.

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[4] *To put this exposure level in perspective, 29 CFR 1910.1000, Table Z-2, lists OSHA's 8-hour time-weighted average permissible exposure limit for styrene as 100 ppm, with a 200 ppm peak, and up to 600 ppm permitted for no more than 5 minutes in a 3-hour period.*

A clear relationship between solvent and hearing impairment is difficult to assess through the available epidemiological studies. The workplace environments where noise and solvents can be simultaneously present are typically complex (for example, see critical review of Lawton et al., 2006; Hoet and Lison, 2008). Quite often, the workers were exposed to multiple substances. Furthermore, most of these studies had a cross-sectional design that featured a number of weaknesses in the interpretation of the findings. For instance, chronic effects were related to currently measured exposures. In some cases, the exposure concentrations measured at the time of the study were markedly lower than those ascertained in past years (Morata et al., 1993).

All in all, there are limited data on dose-response relationships or clear effects on auditory thresholds in humans (for reviews, see Lawton et al., 2006; Hoet and Lison, 2008). However, animal data clearly show an effect. Further human studies are needed for clarification of these issues. However, in the interim, one cannot rule out a likely relationship between solvent exposure and hearing impairments.

Overall, in combined exposure to noise and organic solvents, interactive effects may be observed depending on the parameters of noise (intensity, impulsiveness) and the solvent exposure concentrations. In cases of concomitant exposures, animal studies suggest that solvents might exacerbate noise-induced impairments even though the noise intensity is below the permissible limit value.

The text in this appendix is adapted from a comprehensive review of solvent/noise interaction, published as:

European Agency for Safety and Health. 2009. Combined Exposure to Noise and Ototoxic Substances. http://osha.europa.eu/en/publications/literature_reviews/combined-exposure-to-noise-and-ototoxic-substances. [Reproduction of this report is authorized, provided the source is acknowledged.]

Other useful review articles on solvent noise interactions:

Campo, P. 2000. Noise and Solvent, Alcohol and Solvent: Two Dangerous Interactions on Auditory Function. http://www.noiseandhealth.org/article.asp?issn=1463-1741;year=2000;volume=3;issue=9;spage=49;epage=57;aulast=Campo.

Kim, J. 2005. Combined Effects of Noise and Mixed Solvents Exposure on the Hearing Function Among Workers in the Aviation Industry. http://www.jniosh.go.jp/en/indu_hel/pdf/43-3-22.pdf. (Introduction includes a good overview of other studies on the same topic.)

Volpin, A. 2006. Interactions Between Solvents and Noise: State of the Art. http://www.ncbi.nlm.nih.gov/pubmed/16705885. (Link is to abstract.)

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APPENDIX E—NOISE REDUCTION RATING

[This appendix will be replaced when the new NRR scheme is promulgated]

Noise Reduction Ratings

When OSHA promulgated its Hearing Conservation Amendment in 1983, it incorporated the EPA labeling requirements for hearing protectors (40 CFR 211), which required manufacturers to identify the noise reduction capability of all hearing protectors on the hearing protector package. This measure is referred to as the noise reduction rating (NRR). It is a laboratory-derived numerical estimate of the attenuation achieved by the protector. It became evident that the amount of protection users were receiving in the workplace with the prescribed hearing protectors did not correlate with the attenuation indicated by the NRR. OSHA acknowledged that in most cases, this number overstated the protection afforded to workers and required the application for certain circumstances of a safety factor of 50% to the NRR, above and beyond the 7 dB subtraction called for when using A-weighted measurements. For example, consider a worker who is exposed to 98 dBA for 8 hours and whose hearing protectors have an NRR of 25 dB. We can estimate the worker's resultant exposure using the 50% safety factor. The worker's resultant exposure is 89 dBA in this case.

The 50% safety factor adjusts labeled NRR values for workplace conditions and is used when considering whether engineering controls are to be implemented.

Estimated dBA exposure = TWA(dBA) – [(25-7) x 50%] = 89 dBA

Though using the 50% safety factor produces the most reliable result, it is not used for enforcement purposes. For enforcement purposes, CSHOs should subtract 7 dB from the NRR without considering the 50% safety factor.

Single/Double Hearing Protection

Dual hearing protection involves wearing two forms of hearing protection simultaneously (e.g. earplugs and ear muffs). The noise exposure for workers wearing dual protection may be estimated by the following method: Determine the hearing protector with the higher rated NRR (NRRh) and subtract 7 dB if using A-weighted sound level data. Add 5 dB to this field-adjusted NRR to account for the use of the second hearing protector. Subtract the remainder from the TWA. It is important to note that using such double protection will add only 5 dB of attenuation. For an example of a calculation of dual hearing protection, see Appendix IV:C. Methods for Estimating HPD Attenuation of the OSHA Noise eTool.

For a more extensive discussion of how to use the NRR, see the NIOSH website. NIOSH has developed guidelines for calculating and using the NRR in various circumstances. (http://www2a.cdc.gov/hp-devices/pdfs/calculation.pdf: Method for Calculating and Using Noise Reduction Rating-NRR)

APPENDIX F—EVALUATING NOISE EXPOSURE OF WORKERS WEARING SOUND-GENERATING HEADSETS

F.1 Workers at Risk

Workers can be overexposed to noise when they wear communications headsets as part of their work. Clerical personnel, aircraft pilots and other cockpit personnel, air traffic controllers, emergency personnel, reservation clerks, receptionists, and telephone operators are just a few examples of the more than 3 million workers who can be exposed to high noise levels via communications headsets. For a person wearing a sound-generating headset, the sound/noise exists predominantly between the eardrum and the headset. Because of the amplification properties of the human ear, the sound that exists inside the ear while wearing a headset is quite different from ambient levels.

Probe microphones and similar devices allow sound levels to be measured inside the ear. Most people, however, find that inserting a probe microphone into their ear canal is uncomfortable and object to wearing a probe for an 8-hour workday. In addition, a probe can damage the eardrum, meaning that the person inserting it requires professional training. For these reasons, probe microphones should not be used for compliance purposes.

*A **head and torso simulator** (HATS) is a head-and-shoulder mannequin with calibrated "ears" fitted with sophisticated acoustical sensing instrumentation. Manufacturers produce HATS for various specialized purposes. The HATS should match its intended purpose.*

F.2 Methodology

A method of monitoring worker exposure without invading the ear canal has been developed. This sampling method evaluates the noise dose that a worker receives during the actual workday while wearing an insert-type headset, a monaural or binaural muff, or a monaural or binaural foam headset. The technique involves directly measuring the sound pressure level of a headset similar to the workers using a *head and torso simulator* (HATS) that can measure acoustic signals at the eardrum point. The electrical signal input to the worker's headset is split into two, both identical to the original. One signal is fed to the worker's headset and the other is fed to the similar headset (the monitoring headset). The monitoring headset is placed on the HATS so that it is being "worn" in the same manner as the worker's headset. The signal measured from the HATS ear is fed to a set of electrical filters (an audio equalizer) that carries out the HATS eardrum-to-diffuse-field transfer function. The output from the electrical filters is then fed to a noise dosimeter. The dosimeter reads the noise exposure dose in percentage. The percentage dose can be then calculated to a time-weighted average (TWA) noise exposure level in dBA.

The term diffuse field refers to sound that comes from all directions, such as from a source and also many sound-reflecting surfaces (reverberant sound). Most factory production rooms are diffuse fields.

In contrast, a free field is a space with no echo or reflected sound, such as a location outdoors, away from any structures. In a free field, all sound comes from a single direction, the point where the sound source is located.

Note that the monitoring headset must be acquired before sampling can begin. It should be identical in brand and model to the headset worn by the worker. Both the worker's and the monitoring headsets should be characterized (i.e., frequency response and sensitivity) and recorded.

After the TWA level is calculated from the measurement, add to the result the sensitivity difference between the worker's and the monitoring headsets.

Example:

TWA from the measurement = 73 dBA
Sensitivity difference = worker's headset sensitivity – monitoring headset sensitivity = -3 dB
Worker's daily noise exposure level = 73 + (-3) = 70 dBA

Contact the OSHA Salt Lake Technical Center for more information.

F.3 Acoustic Limited Devices

Laboratory evaluations have determined that headsets can be categorized in two basic groups:

Those without any form of electronic limiting device.

Those with some form of limiting device built into the headset.

Most modern telecommunication headsets use sophisticated limiting circuits. Some personal audio headsets (e.g., for MP3 players) also have this capability. Headsets with acoustic limiting devices that are functioning as designed have been shown, in both laboratory and field tests, to provide enough protection to keep worker noise exposures below OSHA permissible noise levels. In some work environments, however, headsets without limiting devices have caused worker noise exposures to exceed the levels permitted by OSHA.

For more information, see OSHA's letter of interpretation dated 4/14/1987—Use of Walkman Radio, Tape, or CD Players and Their Effect When Hearing Protection is in Use.

APPENDIX G—ALTERNATIVES FOR EVALUATING BENEFITS AND COSTS OF NOISE CONTROL

Several sources have offered more detailed methods for evaluating the costs of noise and benefits of noise control. These methods involve diverse interpretations of how the costs of noise exposure are calculated, based on the individual needs of the organization for which the method was developed. They also include various additional steps and tools to help refine the organization's priorities or to help standardize the process. Section V.C—Economic Feasibility of Noise-Control Engineering presents one method for evaluating the feasibility of noise engineering controls, published by OSHA Region III. This appendix reviews four alternatives for evaluating the benefits and costs of noise control:

- American Industrial Hygiene Association (AIHA)—Benefits and Costs of Noise Control. In: The Noise Manual (AIHA, 2003; or latest edition); in the 2003 edition, see Chapter 9, "Noise Control Engineering"
- Additional detail: Driscoll, "The Economics of Noise Control Engineering Versus the Hearing Conservation Program"
- Example: Colgate-Palmolive, winner, 2012 Safe-in-Sound award
- National Aeronautics and Space Administration (NASA)—Buy-Quiet Roadmap

G.1 AIHA—Benefits and Costs of Noise Control

In *The Noise Manual*, Chapter 9, AIHA outlines a procedure for comparing the benefits and costs of noise control (Driscoll and Royster, 2003).

G.1.1 The Noise Manual

The AIHA chapter recognizes that employers wonder:

> *"What magnitude of noise reduction in the employees' TWA is possible, and is it worth doing?" That is, if an employee's TWA can be reduced by 3 dBA using noise control, should it be achieved?*

The chapter encourages the reader to consider the potential magnitude of noise reduction and then prioritize efforts using a series of steps.

The first step is identifying realistic short- and long-term goals. A short-term goal could be to reduce the noise exposure of the most highly exposed workers to a level that makes it easier to protect them (e.g., with administrative controls or personal protective equipment). A long-term goal could be to reduce all noise exposure to nonhazardous levels, which can result in cost savings by eliminating the need for hearing conservation programs and additional worker compensation expenses.

To set priorities, AIHA suggests that important

> ***General Guidelines:***
>
> *General guideline 1: Most organizations will find that hearing conservation program costs average $350 to $400 per program participant per year.*
>
> *General guideline 2: Workers' compensation costs for hearing loss average about 0.2% of payroll. (Workers' compensation averages about 2% of payroll; 10% percent of that is associated with hearing loss compensation.)*
>
> *General guideline 3: Reducing compressed air pressure and volume used can reduce noise levels substantially and can also save on energy costs. It is almost always cost-effective. Other good opportunities for noise reduction are associated with routine maintenance and machine guarding (why not build in noise reduction at the same time?).*
>
> *General guideline 4: "As a criteria for an acoustical maintenance program, each machine should typically operate within 2 dBA of the minimum sound level of which it is optimally capable."*
>
> *Sources: Driscoll, 2010, 2012.*

considerations include:

- The number of workers affected by the noise source or sources.
- The potential for the noise to significantly damage their hearing.
- The characteristics of the noise, which can affect the control options. (Is it a pure tone? Impulse noise?)
- How likely it is that the intervention will succeed in meeting the organization's goals.
- Whether the control method will increase, decrease, or have a neutral effect on productivity.
- The estimated cost of the control, including purchase, installation, and maintenance.

Promoting a systematic evaluation, AIHA offers various factors that an employer can assign to these considerations and then process using an equation that divides the product of these factors by the estimated cost.

G.1.2 Additional Detail: Driscoll—The Economics of Noise Control Engineering Versus the Hearing Conservation Program

One of the authors of *The Noise Manual (AIHA, 2003, or latest edition)* chapter, Dennis Driscoll, has outlined a method for determining the cost of a hearing conservation program in more detail. This method considers 18 costs in the annual hearing conservation program cost:

- Number of participants in the hearing conservation program
- Hearing protection devices
- Noise surveys
- Audiometric testing
- Audiometric follow-up and retests
- Recordability determination
- Worker training materials
- Calibration of acoustical instrumentation
- Calibration of audiometers
- Worker training time
- Worker hearing test time
- Hearing conservation program administrative time
- Maintenance of acoustical instrumentation
- Lost production
- Space allocation
- Expense to certify CAOHC (Council for Accreditation in Occupational Hearing Conservation) technicians
- Medical record retention
- Workers' compensation

General guidelines provided by AIHA:

General guideline 1: Whenever possible, include noise control at the design phase (equipment or facilities). Considering noise exposure only at a later stage and then retrofitting existing equipment can cost more than 10 times as much as designing the noise control before construction begins. The cost of purchasing new production equipment comes into play somewhere between the two.

General guideline 2: Include maintenance expenses in the cost estimate—unless more specific information is available, assume that these can run about 5% per year (e.g., for 10 years).

Source: Driscoll and Royster, 2003.

Using this method, the cost of the hearing conservation program does not include machinery (present or future).

In 2010 and 2011, approximately 100 professional industrial hygienists were given an opportunity to complete a worksheet on the costs of the HCP at their organizations. This exercise was part of a workshop on the economics of noise control engineering versus the hearing conservation program (Driscoll, 2010).

The worksheet results were quite consistent in showing that, using these 18 points as cost criteria, the majority of organizations spent $350 to $400 per year per worker in the hearing conservation program. Results for a few organizations, however, were substantially higher. The highest costs tended to be associated with fixed daily fees for services provided at multiple remote locations where few workers were employed (the highest hearing conservation program cost reported was $1,800 per worker per year). Costs were lower when these fixed fees, such as for audiometry van service to remote facilities, could be averaged over a larger number of workers. However, in general, the total hearing conservation program cost was not notably different for small organizations compared with large organizations.

In its next edition (estimated in 2013), AIHA's *The Noise Manual* will be updated to include some of these points.

G.1.3 Example: Colgate-Palmolive—Winner of the 2012 Safe-In-Sound Award

NIOSH has partnered with the National Hearing Conservation Association (NHCA) to create an award for excellence in hearing loss prevention. This award is called the Safe-In-Sound award. Colgate-Palmolive won the 2012 Safe-In-Sound award through an extensive effort to reduce noise exposure in its facilities around the world (NIOSH, 2012).

With the assistance of a noise-control engineer and following the general principles outlined by AIHA, Colgate-Palmolive identified and prioritized noise sources. The process revealed that compressed air accounted for approximately 30% of the noise at production facilities and required approximately 15% of the energy. To help solve both problems, the company created "Noise, Energy & Maintenance" teams to help the company optimize system operation, minimize leaks, and assist workers in using compressed air appropriately. They planned to execute two noise reduction projects per year at many sites.

> ***General guidelines:***
>
> *General guideline 1: Plan to complete two noise-control projects per year.*
>
> *General guideline 2: Noise reduction projects often have additional benefits, such as reduced energy requirements, cleaner facilities, and improved machinery performance or service life.*
>
> *Sources: Driscoll, 2010, 2012. Colgate-Palmolive, 2012.*

As of 2012, the company had completed 250 noise reduction projects across 60 facilities, investing $2 million. The results averaged approximately 6 dBA noise reduction per project (and up to 22 dBA for some projects). Noise exposure was reduced for more than 5,000 workers through these projects (the math suggests that this equates to an average cost of $400 per worker). Many of these projects also resulted in energy savings, cleaner facilities, and improved equipment life. One of Colgate-Palmolive's goals is to create a "Zero Hearing Protection" site. Because the company uses the ACGIH-TLV criteria (i.e., 85 dBA with 3 dBA doubling rate) or the local regulation, whichever is more stringent, this goal will reduce worker noise exposure to levels well below OSHA's permissible exposure limit (PEL) and action level (AL).

In an online presentation, Colgate-Palmolive provides a photojournal of noise-control projects and reports on the dBA levels before and after modifications. View this presentation at http://www.safeinsound.us/swf/colgate/index.html.

G.2 NASA—Buy-Quiet Roadmap

NASA developed a comprehensive program to guide quieter equipment purchases. This program, termed the "Buy-Quiet Process Roadmap," is part of the NASA EARLAB Auditory Demonstration Laboratory website.

The Roadmap includes a simple spreadsheet application to help calculate the cost/benefit ratio for potential noise reduction projects. A white paper explains the approach used to determine the costs of exposing a person to noise for the length of a career (Nelson, 2012).

This method uses the following factors to estimate the cost of noise exposure:

- The TWA noise exposure (presumed constant over time).
- The net present value (NPV) of potential disability claims at the end of 30 years.
- The NPV of hearing aids and batteries that might be needed after retirement.
- The NPV of the hearing conservation program and personal protective equipment during the career.

> ***General guidelines:***
>
> *General guideline 1: The cost of a dual-ear, full-disability claim across the United States reported in The Noise Manual (Berger et al., 2003) averages approximately $66,000 in 2011 dollars (assuming a long-term average of 4.2% inflation).*
>
> *General guideline 2: The net present value of the hearing conservation program and personal protective equipment (hearing-protective devices) may be set to $0 for TWAs below the AL.*
>
> *Source: Nelson, 2012*

The white paper offers the following note about use of the NPV:

> *The economic benefit of noise control is estimated by comparing the reduction of the net present value of noise exposure to the cost of the corresponding noise-control effort.*
>
> *For purposes of this paper, the discount rate for the NPV calculation is assumed to be 0% (inflation neutral). The NPV is then just the sum of the expected expenditures in today's dollars. This assumption translates in practice to the expectation that all inflated future costs will be paid with equally-inflated future dollars out of available cash accounts.*

The white paper cites a 2006 study commissioned by the U.S. Navy titled *Long-term Cost Benefit of Noise Control on Ships* (Bowes et al., 2006). Extrapolating the cost per year and adjusting for inflation, the NPV of the hearing conservation program was determined to be $1,300 per year, or $38,000 for 30 years. This value is incorporated into NASA's cost/benefit calculations for noise-control projects.

G.3 References

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APPENDIX H—JOB AID: STEPS AND CHECKLISTS FOR CONDUCTING A NOISE INSPECTION

H.1 Pre-Inspection Activities

1. CSHO receives an assignment with potential exposures to noise.

2. CSHO prepares for inspection:

   a. Calibrates noise equipment and documents calibration for sound level meter (SLM), noise dosimeters, and octave band analyzer (OBA).

   b. Brings necessary OSHA forms to record measurements.

3. CSHO researches previous history on company (e.g., previous noise citations).

H.2 Opening Conference

Note: Attempt to open early in the day, as close to the commencement of the workday as possible (this will not always be possible). Especially if the inspection is a complaint, hold an abbreviated opening, and then proceed directly to the complaint or referral area to deploy dosimeters, take initial SLM readings, and conduct a rough sketch of the area.

1. Explain purpose, nature, and scope of inspection.

2. CSHO requests the following records/information for review, if available:

   a. 300 Logs—Check for recordable hearing losses in the Hearing Loss Column (M)(5).

   b. Audiograms for the previous 3 years.

      i. Determine if any worker should be recorded on 300 Logs (both situations must exist in same ear: STS and 25 dB above audiometric zero).

   c. Employer noise sampling data.

   d. Departments/areas where noise may be an issue.

   e. Training records for hearing conservation program.

   f. Schematic diagram of facility (for noise mapping).

3. Ask if hearing protection is required or voluntary anywhere in the facility.

   a. If so, document type of hearing protection provided to workers.

4. Question union representative on noise and hearing conservation efforts.

H.3 Walkaround

1. CSHO will conduct noise screening to determine whether dosimetry is necessary. Remember to lead by example! Conscientiously wear your hearing protection and other appropriate personal protective equipment consistently and correctly during your inspection.

a. Record noise levels on schematic diagram or draw your own floor plan of area(s) where screening was conducted.

b. Document sources of noise (e.g., machines, processes).

c. Take SLM measurements in worker's hearing zone (2-foot diameter sphere around head) and document those results.

d. Take photos of workers with improperly worn earplugs and workers in noisy areas without hearing protection (interview these workers later).

Building rapport is important. Use a conversational tone and take an interest in what is going on. This approach will foster a practical dialog and helpful information exchange.

2. CSHO will interview workers in elevated noise areas >80 dBA.

a. Examples of questions to ask workers related to noise:

i. In your opinion, is today a typical noise exposure day?

ii. In your opinion, what are the loudest jobs at work?

iii. So, tell me, when you first started working here or when they first gave you hearing protection, what happened?

iv. Did you get a choice as to what type? What types are available?

v. Did anyone explain why you have hearing protection and where and when you need to use it? How did they do that?

vi. (Depending on the type of hearing protection used, the questioning might go different ways--e.g., disposable, muffs, reusable plugs).

vii. Are you supposed to wear hearing protection? If so, how often? (Note: If worker answers "no," ask why he/she doesn't wear it).

viii. Are there certain jobs or areas where you must wear hearing protection?

ix. In what areas in the facility are you required to wear hearing protection?

x. Does anyone check to see if you are wearing your hearing protection? What happens if you are not?

xi. Do you routinely get new hearing protection when it wears out?

xii. Were you fitted for your hearing protection?

CSHOs shouldn't feel that they are limited to scripted questions but should be flexible to pursue relevant leads and unanticipated responses. It may be helpful to comment on observations, particularly at the time and in the area of the observation (e.g., I see some people wearing earplugs and others not using anything. Why is that?).

xiii. Were you trained on how to wear your hearing protection properly? (Have worker demonstrate wearing hearing protection)

xiv. Were you trained on how to use and care for your hearing protection? (Note the content of training and date of training)

xv. Have you ever been given a hearing test while working here?

xvi. About how often do you get hearing tests?

xvii. If so, when was your last audiogram given?

xviii. Who administers your audiogram?

xix. Do you have problems hearing (e.g., tinnitus, TTS)?

xx. What is the frequency and duration of noise exposure?

xxi. When would be the best day to return to sample for noise? (Note: You want the worst typical noise exposure day to sample—when the most machines are running)

xxii. If the CSHO returns to conduct full-shift sampling, ask workers these additional questions:

1. How often do you work on this machine? (e.g., hrs./day, days/week, days/month)

2. How many pieces are produced/generated per day?

3. Do the noise levels vary with customer specifications for specific materials?

xxiii. Has the company made any effort to reduce noise levels?

xxiv. What is your opinion of the practicality of control measures?

3. If noise-screening results indicate elevated noise levels (e.g., 80 dBA or above), be prepared to sample on the day of the opening. **Develop a noise-sampling strategy** based on screening results

> *CSHOs should try TO DO DOSIMETRY THE DAY OF THE OPENING! Sometimes a return trip is necessary, but as a general rule, one should be able to start sampling ASAP. It takes very little time to deploy the dosimeters, and significant data are lost by not seizing the opportunity. You typically can get 6+ hours in these situations, which often is sufficient to support a citation. Another option is to open later in the day and do a full-shift sample in the evening. Second shift is a great time to sample, as these are often the less experienced employees and supervisors, and it is not unusual to find more problems in the after-management, normal-working-hours shifts.*

> *Look at dosimeter readings. If you have an overexposure, make sure it is well documented. However, if the projected dose exceeds or was close to the PEL, and sampling time was inadequate, then return for full-shift sampling. If the projected dose was well below the PEL and AL, then the complaint was addressed in a defensible fashion, and sampling can end if no other hazards are observed.*

and worker interviews. Note: It's amazing how many machines tend to go out of service when a facility knows that you are returning to do sampling. Typically you can get 6+ hours, which is often sufficient to support a citation. However, if a return trip is necessary, the CSHO will notify the employer that he/she will need to set up full-shift sampling for another day to assess the noise levels at the facility.

4. Indicate to the employer how many workers you would like to sample and in what areas of the facility; this will permit them to make appropriate arrangements.

5. Schedule a date to return to the facility for full-shift sampling (Note: Make sure that it's a typical exposure day, representative of the routine high noise levels that you recorded during your noise screening).

6. If workers are on an extended workshift, then you must calculate a revised AL using the formula in Section IV.B.2—Extended Workshifts in this chapter.

H.4 Full-Shift Sampling

1. Pre-calibrate noise dosimeters, sound level meters, and octave band analyzers; fully document calibration on proper OSHA forms.

2. At the start of workshift, or immediately after an abbreviated opening conference, place noise dosimeters on workers. If related to a complaint or referral, be careful to first select workers who will address any specific concerns in the referral or complaint, as these items must be addressed. The other workers should be selected based on highest anticipated exposures.

    a. Explain to each worker being sampled who you are, why you are there, and the purpose of the dosimeter. Emphasize that the dosimeter is not a speech recording device. Explain, as part of the documentation, that you will be taking pictures of them doing their work and to show how the dosimeter was worn.

    b. When the dosimeter is positioned (generally at the waist), clip the microphone to the worker's shirt collar at the shoulder, close to the worker's ear. Clips should be placed in accordance with manufacturer's instructions. Position and secure any excess microphone cable to avoid snagging or inconveniencing the worker. If practical, the cord should run under the worker's shirt or coat. If possible, place the microphone on the side of the worker closest to the primary noise source, if there is one.

    c. Once the dosimeter is in place, ask the worker if it feels all right, confirm that the cord is not in the way of their work, and emphasize that the worker should continue to work in a routine manner.

    d. Tell the worker that you will check back regularly and to let you know right away if there is a problem with the unit or with wearing it. Instruct the worker being sampled not to remove the dosimeter unless absolutely necessary, and not to cover the microphone with a coat or outer garment or move the microphone from its installed position. Let the worker know when the dosimeter will be removed. For example, explain to the worker that you will be collecting the noise dosimeters prior to lunch, and then after lunch, you will resume sampling them.

        i. If workers eat in their work area and lunch is part of the 8-hour workshift, you might consider leaving the dosimeter on during lunch.

e. Record necessary information about the worker (e.g., job title, name of department, job description, type of hearing protection worn, length of employment, frequency and duration of noise exposure) on the appropriate OSHA form.

Always document the type of hearing protection worn by the worker. When the type and model of personal protective equipment is not recorded on the sampling sheet, it is difficult to confirm that the hearing protection's NRR is adequate to protect the worker from the measured

f. Explain to the workers that you will be checking the noise dosimeter throughout the day (to ensure that the microphone is oriented properly) and taking direct reading measurements with your SLM in their hearing zone.

g. Record the time you turned on the noise dosimeter(s).

3. During dosimeter sampling, to evaluate the noise hazard(s), document the following types of noise inspection data for each worker sampled:

a. Take at least 10 periodic SLM measurements in each sampled worker's hearing zone, and obtain and note SLM readings (A- and C-weighted) during different phases of the work performed by the worker during the shift. Take enough readings to identify work cycles and the contribution of different noise sources from machine(s) and/or processes. Take notes to identify the level of each noise source (fully document on appropriate OSHA form). A and C readings will assist in determining noise-control measures. Octave band readings are a better alternative. Examples of noise sources might include adjacent workers/machines; compressed air blow-off; and metal on metal from punching/sawing/drilling, hydraulics, electric motors, rollers, parts falling into bins, and grinders. More readings should be taken when noise levels fluctuate widely. Hone in on noise sources by following noise gradients (take note of where SLM levels increase). It is often possible to identify the parts of the machine or process that are the major contributors to overall noise levels by following these gradients. Thus, these are the most important to address with appropriate controls. It might just take tightening some bolts or installing a new dampening gasket to significantly reduce the noise.

b. Ask workers periodically during sampling if this is a typical work day for noise exposure. (Note: If the CSHO finds out it is a light day for noise exposure and no overexposure exists, he or she might need to come back another day to sample.) If workers are not at their workstations when you do your checks, it is important to follow up and determine where they were and what they were doing for that part of the shift, and ask whether it is unusual for them to work elsewhere.

c. Include a brief description of the machine and/or process contributing to the noise levels.

i. Record octave band analysis readings only if they have significant identified noise source(s) (e.g., exposures >132% dose) so this information can be provided to the employer to assist in determining the type of engineering controls.

d. Record the condition of the machine (find out who performs maintenance on machine/equipment and review any maintenance records).

e. Record machine operation (e.g., speed, cycle, part/min).

f. List noise sources for worker (primary, secondary, tertiary).

g. Identify existing controls.

h. Measure distance from worker to the primary noise source.

i. Ask whether the worker's presence in the noise field is required for the job.

j. Ask questions about hearing protection (type, properly worn, worn at all times, choices of hearing protection offered, is the attenuation sufficient for the worker's noise exposure?).

k. Observe how worker is wearing hearing protection (e.g., foam plugs); if worn incorrectly take a picture. In addition to noting the type of hearing protectors the sampled worker is wearing, it is also important to note whether:

   i. Other workers in the area are wearing hearing protection.

   ii. Workers passing through the work area (e.g., maintenance workers) are wearing hearing protection.

   iii. Supervisors in the area are wearing hearing protection.

   iv. Hearing protection is worn correctly.

   v. Workers are observed traveling from one noise area to another in the facility.

Try to have a company representative accompany you during the data collection part of the inspection. It is an opportunity to present the findings in a hands-on manner on the plant floor (almost like a hands-on pre-closing conference). It reduces confusion at the closing and misunderstanding of the citations, and it improves communication. It is also a time to get useful employer statements (e.g., Yes, this has been a long-standing problem, but corporate doesn't want to spend the money now; That just broke, we have a new muffler on order, I can show you the PO); achieve consensus on possible fixes; and point out problems that the employer may really not have known about. It is also a good time for practical instruction so that the employer walks away with an understanding of the problem, its significance, and possible solutions.

l. Record the size and shape of the room.

m. Note surface materials on floors, walls, and ceilings, and any acoustical treatment.

n. Take photos of the overall operation/machine as well as photos of noise source(s) and where worker(s) is in relation to the noise source(s).

o. Make an initial determination of potential noise controls. If you are recommending engineering controls, you need to take tape measurements while in the facility to determine square footage of acoustical controls and to see if barriers, booths, and other components will fit. Cost comparison calculations depend on these measurements.

4. End of normal 8-hour shift:

   a. Remove dosimeters and record time on OSHA form.

   b. Ask worker if this was an average work day for noise exposure (normal production day vs. sampled day production).

   c. Record results of dosimeter sampling on appropriate readout worksheet.

   d. If this is an extended shift, it is important to document the exposure just before or at the 8-hour mark to provide the 8-hour TWA exposure for comparison against the PEL. One can document zero exposure during lunch and subtract that from the sampling time if the dosimeter is not turned off (make sure there are no loud noises during lunch that can contribute to the noise dose [e.g., radio turned high in car or lunchroom]). Once the 8-hour exposure is determined, you should continue to allow the dosimeter to collect data to determine the severity (e.g., continual noise exposure during last 2 hours of a 10-hour shift can increase severity of the citation) based on full extended-shift sampling.

   One could demonstrate a calculation where the CSHO allowed the dosimeter to accumulate for 8.5 hours (e.g., not collecting it at lunch and not documenting the exposure during the lunch break), and with significant noise in the first 5 minutes and last 5 minutes of the slightly extended workshift, and never be over the 8-hour PEL. This is the reason to take SLM measurements throughout the workshift to fully

   e. Complete all information on OSHA noise survey report.

   f. Post-calibrate noise equipment and fully document calibration; this is often done after leaving the site.

5. Notify employer of noise sample results prior to leaving worksite and note the employer's opinion of practicality of control measures.

6. Review relevant records (e.g., hearing conservation program).

7. Conduct additional interviews with employer and worker regarding employer's hearing conservation program and feasibility of engineering controls.

8. Request copies of manufacturer's instructions on machine(s) and/or processes contributing to high noise levels (can help to establish knowledge and assist with determining potential engineering controls).

9. Explain to employer that you will arrange for a closing conference with him/her to review your inspection findings.

H.5 Post-Inspection Activities

1. There are several scenarios (e.g., given in the OSHA FOM [CPL 02-00-148] and CPL 02-02-035 [Guidelines for Noise Enforcement: Appendix A]) for how to enforce our noise standard. Based on the specific inspection, the CSHO needs to select the correct scenario that applies to that situation. For example, if noise exposures are >132% dose, or an equivalent 8-hour TWA exposure of 92 dBA (90-dBA threshold), and feasible engineering controls are cost-effective, then cite 1910.95(b)(1) and conduct the following:

    a. Perform a cost comparison using your regional office's cost estimation for the average cost of a hearing conservation program. As of 2011, the national average annual cost of a hearing conservation program is approximately $350 per worker.

    b. Research examples of technically feasible engineering controls for the specific machine and/or process contributing to the noise levels. Start with the equipment manufacturer.

    c. Start with easy solutions first.

    d. Once the engineering control has been determined, contact noise-control manufacturers to obtain prices for doing your cost comparison for determining economic feasibility (engineering controls vs. hearing conservation program). Region III's Directive: STD 1-4.1A "Enforcement of the Occupational Noise Exposure Standards, 29 CFR 1910.95, 1926.52, and 1926.101, Inspection Procedures and Interpretive Guidance" can be used to provide assistance with the cost comparison process. Located at http://intranet.osha.gov/Region3/ref/noise.pdf.

2. After the cost comparison is complete and it has been determined that the cost of engineering controls is less than the cost of a hearing conservation program, write a citation for 29 CFR 1910.95(b)(1). In addition, cite for any deficiencies in the employer's hearing conservation program.

3. Another scenario may involve an 8-hour TWA exposure >100 dBA (90 dBA threshold), and hearing protection alone may not reliably reduce noise levels to levels specified in Tables G-16 or G-16a of the standard (economic feasibility or cost comparison is not necessary in this situation). The CSHO researches examples of technically feasible engineering controls for the specific machine and/or process contributing to the noise levels. Start with easy solutions first. Once examples of controls have been determined, write a citation for 29 CFR 1910.95(b)(1). In addition, cite for any deficiencies in the employer's hearing conservation program.

4. Another scenario may involve 8-hour TWA exposures between 85 dBA and 90 dBA (80-dBA threshold). The employer has an existing hearing conservation program. The CSHO shall review the existing program and cite for any deficiencies in the program. Cite 1910.95(c)(1) and deficient elements of the program.

During the closing conference, it is important to explain how each of the proposed citations presents a hazard and why you are proposing it. It is in everyone's best interest to understand the significance of the hazard and not just that it is a violation. Employers react more favorably when there are no surprises in the citations. It is also important to listen at the closing; there may be information that can affect the citation.

5. Another scenario could involve 8-hour TWA exposures between 85 dBA and 90 dBA (80-dBA threshold), but the employer has no existing hearing conservation program. The CSHO shall cite 1910.95(c)(1) only.

H.6 Closing Conference

1. Discuss apparent violations.
2. Provide copy of sample results.
3. Discuss abatement (e.g., review engineering controls that you are recommending).
4. Discuss possible citations.
5. Discuss informal conference.
6. Discuss contesting.
7. Discuss posting requirements.

H.7 Follow-up Inspection

Once abatement has been completed; the CSHO will conduct a follow-up inspection to verify the effectiveness of the engineering controls.

The specific penalties should not be discussed--just the possibility that there may be penalties assessed as a result of the inspection.

H.8 Example questions to ask employer about hearing conservation and noise:

- What are your loudest areas of the facility and the loudest operations?
- Do you know what the sources of noise are here?
- Where does the noise come from?
- What is your role in the hearing conservation program at this facility?
- Is there is list of departments included in the hearing conservation program?
- Do you do any training related to noise? If so, how is this accomplished?
- Do you have records that support your training on noise?
- What type of noise monitoring have you done? (Ask for copy of results).
- How often do you conduct audiometric testing on your workers?
- Do you keep audiometric test results? To make sure your hearing conservation program is effective, we will need to look at the audiometric test results for your workers to make sure everyone is included who needs to be.
- Can you think of anyone who has had an STS or has had some hearing difficulties? (Note: Explain to the employer what an STS is.)

- Do you have a list of those workers who had an STS during the past year?
- Who performs the audiometric testing? (Note: Obtain name of company and address.)
- Could we see copies of calibration of the audiometric booth? (if testing is conducted on site)
- What types of hearing protection are available?
- Is hearing protection required to be worn or voluntary?
- If required, who enforces the use of hearing protection?
- Who conducts the training for hearing?
- Have you evaluated the attenuation of the hearing protection offered here?
- How are hearing losses recorded?
- Who determines which hearing loss cases are recorded?

This job aid is intended to provide CSHOs with a nonmandatory approach to conducting noise inspections. CSHOs may use this job aid, may modify the job aid, or may use any approach they feel is the most appropriate for the inspection. This job aid does not set any new OSHA policies or requirements.

APPENDIX I—JOB AID: QUICK START QUEST NOISEPRO DOSIMETER INSTRUCTIONS

Turn On:

1. Turn on unit by pressing and releasing **On/Off/ESC** key. The display will initialize and sequence to the “\START” screen.

2. If “**LOBAT**” is in display, put fresh batteries in the unit.

Reset:

3. Press and hold **RESET** soft key; the display counts down from 5 and indicates “Deleting All Studies” on display. A solid box icon in lower right corner of the display means data has been erased from the unit. NOTE: Resetting the unit erases all previously stored data from memory.

Verify Current Setup:

4. From the START menu go to SETUP menu using the ▲▼ arrow keys and press ↵ key. Press the corresponding soft key for **DOSE1**. An asterisk denotes the current active setup for the selected DOSIMETER. DOSE1 should be set up for ***OSHA HC**. Press ↵ key to view the selected setup. The selected setup menu offers the options to: View/Set Parameters, View/Set Range, View/Set Weighting, and Save to Dosimeter 1. Use the ▲▼ arrow keys to select the desired item.

5. In this example, select **VIEW/SET PARAMETERS**. Press ↵ key to VIEW/SET PARAMETERS. Make sure RESPONSE is SLOW, EXCHANGE RATE IS 5 dB, CRITERION LEVEL IS 90dB, CRITERION TIME IS 8 hr., and THRESHOLD is 80 dB. Press the **On/Off ESC** key **three** times to exit. Now repeat the steps above for **DOSE2,** which should be set up for ***OSHA PEL**. The only difference is for the PARAMETERS, where the THRESHOLD should be set for 90 dB. Press the **On/Off ESC** key **three** times to exit.

Pre-Calibrate:

6. Turn on calibrator and check LOBAT indicator. Replace batteries if needed.

7. Insert unit’s microphone (remove windscreen) into calibrator, using Quest adapter 053-884.

8. From the START menu, press and release **CAL** softkey and the **“\CAL”** screen appears. With **CALIBRATE** highlighted, press ↵ key and the PRE-CALIBRATION screen appears. Note: If POST-CALIBRATION screen appears, the data has not been cleared from the NoisePro. If required, use the ▲▼ arrow keys to adjust the displayed value to match the calibrator output. Press ↵ key to save (store) the calibration. Unit will perform self-calibration and return to “\CAL” screen.

9. Document Pre-calibration on OSHA 92 form.

10. Press and release the **On/Off/ESC** key to return to “START” screen.

Collect Data:

11. Clip microphone, with windscreen attached to the top of the shoulder, away from the neck. Clip meter onto individual’s belt on the side opposite the microphone. Try to run the microphone cable underneath clothing to prevent it from catching on anything.

12. Press the **RUN/PAUSE** key to begin data collection. The run icon “▶” will appear in the lower right corner of the display. While the test is running, you can view current data on the display of the NoisePro.

End Study:

13. Press **RUN/PAUSE** key to stop study. The pause icon “**II**” will appear in the lower right corner of the display.

14. Remove the microphone and NoisePro from the subject. Tip: It’s best not to handle the microphone while the NoisePro is collecting data (in Run mode).

Review Data:

15. From the “START” screen, highlight “**VIEW SESSION**” and press the ↵ key. Press the various soft keys for **AVG**, **DOSE,** and **SUMRY** to obtain data and data summary. In addition, the arrow keys ▲▼ will scroll through SPL, PEAK, MAX, MIN, LAVG, TWA, PTWA, DOSE, PDOSE, and RTIME (Run Time) information. Use the ◀ ▶ arrow keys to toggle between HC-1910.95(c) and PEL-1910.95(b)(1) data.

16. Note: **“STUDIES”** are sound level measurements separated by paused periods that allow time for work breaks, lunch period, or to store measurements for separate evaluation (i.e., different job tasks). Studies are grouped together in a session. A typical session consists of the recording of multiple studies in a work day. “**VIEW SESSION”** will give you derived values based on results for **all studies** in the **SESSION**.

17. Example #1: A typical workshift: you would start/run the dosimeter at 7:00 a.m. and pause for lunch at 12:00 p.m. Start/run again at 12:30 p.m. and stop at 3:30 p.m. There are two studies in the same session.

18. Example #2: A worker performs three different job tasks throughout an 8-hour shift. The CSHO wants to know the respective exposure levels for each task, so the dosimeter is paused after each task and the data is recorded. There are three studies in the same session.

19. Record the data on a Quest dosimeter readout worksheet and complete the lower portion of the OSHA-92 form (Dosimeter Data and Exposure Summary sections).

Post-Calibrate Instrument:

20. From the start screen, press and release **CAL** soft key; the "\CAL" screen appears with CALIBRATE highlighted. Turn on the calibrator and insert the unit's microphone into the calibrator using appropriate adapter. Press ↵ key and the POST-CALIBRATION screen appears. Note: In a POST-CALIBRATION, you are not allowed to adjust the SPL value. Press ↵ key to save (store) the POST-CABLIBRATION value. The "\CAL" screen will show the most recent PRE- and POST-calibrations that have been performed.

21. Document Post-calibration on OSHA 92 form.

Turn Off:

22. Turn off unit by pressing and holding **On/Off/ESC** key until the display counts down from 5 and then shows a black box and shuts off.

SUMMARY of OSHA NOISE REQUIREMENTS

OSHA Noise Limits	**Dose to Determine Noncompliance***	**OSHA-92 Codes**
Hearing Conservation Program: AL = 85 dBA (50% Dose)	66%	8111
Engineering Controls: PEL** = 90 dBA (100% Dose)	132%	8110

* Greater than or equal to the indicated dose.

** The permissible exposure limit (PEL) is also known as the criterion level. The criterion level is the continuous equivalent 8-hour A-weighted sound level that constitutes 100% of an allowable noise exposure.

APPENDIX J—REVIEWING AUDIOGRAMS

Compare the most recent audiogram with the baseline audiogram. If a Standard Threshold Shift (STS) is observed, review data for intervening years to determine when the STS occurred. The baseline audiogram is usually, but not always, the first audiogram. If a later audiogram shows lower hearing thresholds, that would be the baseline. If a persistent STS is identified, the audiogram after the STS is identified would be adopted as the revised baseline for future comparisons.

Evaluate data for each ear separately. A threshold shift can occur in one ear and not the other. Use threshold data only for the three required frequencies, which are 2,000, 3,000, and 4,000 Hz. For each audiogram, compare to the baseline and take the average of the difference in threshold at the three required frequencies. If the average is less than 10 dB, no STS has occurred. If the average is greater than or equal to 10 dB, the age correction values must be applied to determine whether an STS has occurred.

To apply the age correction values, subtract the age correction value for the worker's age at the time of the baseline audiogram from their age at the time of the suspected threshold shift. Subtract the difference in the age correction values from the difference between the current and baseline audiograms. Take the average of the age-corrected threshold shifts at the three required frequencies; if the average is greater than or equal to 10 dB, an STS has occurred.

Example #1: A 45-year-old male worker has the following audiogram information:

	Test Frequency, Left Ear (Hz)					Test Frequency, Right Ear (Hz)				
Test year	1,000	2,000	3,000	4,000	6,000	1,000	2,000	3,000	4,000	6,000
Baseline (1990)	3	5	4	0	2	1	3	5	1	4
Current year (2008)	14	14	12	9	13	12	14	18	12	9

The data for the left ear show that the threshold shifted by less than 10 dB at all required frequencies. Thus, an STS could not have occurred in the left ear because the average change at the required frequencies is less than 10 dB. Data for 1,000 Hz and 6,000 Hz are not included in the determination of whether an STS has occurred. For the right ear, a shift of at least 10 dB occurred at each of the required frequencies, so the average will be greater than 10 dB. (The difference in hearing thresholds between the current and baseline audiograms is 11, 13, and 11 dB at 2,000, 3,000, and 4000 Hz, respectively.) It is now necessary to apply the age correction values from Table F-1 in Appendix F of 1910.95.

Age Correction Values for Males (from Table F-1 in Appendix F of 1910.95)			
	2,000 Hz	3,000 Hz	4,000 Hz
Age 27 (1990)	4	6	7
Age 45 (2008)	7	13	18
Difference in age correction values	**3**	**7**	**9**

Age-Corrected Threshold Shift (Right Ear)			
	2,000 Hz	3,000 Hz	4,000 Hz
Threshold shifts from baseline	11	13	11
Difference in age correction values	3	7	9
Age-corrected threshold shift	**8**	**6**	**2**

Since all age-corrected changes in hearing threshold are less than 10, the average will be less than 10. No STS has occurred.

<u>Example #2</u>: A 50-year-old female worker with 10 years of service has the following audiometric data:

	Test Frequency, Left Ear (Hz)					Test Frequency, Right Ear (Hz)				
Test year	1,000	**2,000**	**3,000**	**4,000**	6,000	1,000	**2,000**	**3,000**	**4,000**	6,000
Baseline	10	**7**	**8**	**8**	15	11	**8**	**9**	**9**	13
Current year	12	**17**	**18**	**16**	17	13	**17**	**21**	**25**	17

The average threshold shift for the left ear is (10+10+8)/3=9.33. Since the average for the left ear is less than 10, no STS has occurred.

The average threshold shift for the right ear is (9+12+16)/3=12.33; the age correction values must be applied to determine whether an STS has occurred.

Age Correction Values for Females (from Table F-1 in Appendix F of 1910.95)			
	2,000 Hz	3,000 Hz	4,000 Hz
Age 50 (current year)	10	11	12
Age 40 (baseline)	7	8	8
Difference in age correction values	**3**	**3**	**4**

Age-Corrected Threshold Shift (current year, age 50)			
	Test Frequency, Left Ear (Hz)		
	2,000	3,000	4,000
Threshold shifts from baseline	9	12	16
Difference in age correction values	3	3	4
Age-corrected threshold shift	**6**	**9**	**8**

The age-corrected average is (6+9+8)/3=7.66. Since this is less than 10, no STS has occurred.

<u>Example #3</u>: Selected audiometric test data for a 35-year-old female worker with 10 years of service:

	Test Frequency, Left Ear (Hz)					Test Frequency, Right Ear (Hz)				
Test year	1,000	**2,000**	**3,000**	**4,000**	6,000	1,000	**2,000**	**3,000**	**4,000**	6,000
Baseline	8	**9**	**13**	**14**	18	12	**15**	**15**	**11**	15
Current year	18	**19**	**22**	**23**	25	20	**24**	**27**	**30**	35

For the left ear, the shifts at the required frequencies are 10 dB, 9 dB, and 9 dB, respectively. No STS can occur because the average is less than 10 dB. For the right ear, the values are 9 dB, 12 dB, and 19 dB; (9+12+19)/3=13.33. Since the average is greater than or equal to 10 dB, the age correction values need to be applied.

Age Correction Values for Females (from Table F-1 in Appendix F of 1910.95)			
	2,000 Hz	3,000 Hz	4,000 Hz
Age 35 (current year)	6	7	7
Age 25 (baseline)	5	4	4
Difference in age correction values	**1**	**3**	**3**

Age-Corrected Threshold Shift: Current Year, Age 35, Right Ear			
	Test Frequency, Left Ear (Hz)		
	2,000	3,000	4,000
Threshold shifts from baseline	9	12	19
Difference in age correction values	1	3	3
Age-corrected threshold shift	**8**	**9**	**16**

The average threshold shift is (8+9+16)/3=11. Since the average shift is greater than or equal to 10 dB, an STS has occurred, even though two of the values are less than 10. Also, note that the worker's current average hearing threshold for the right ear is (24+27+30)/3=27. Since this exceeds 25, both conditions are met (an STS has occurred and the hearing threshold for the right ear is greater than or equal to 25 dB); therefore, the case is recordable. Review the OSHA 300 Log to determine whether the case was recorded.

Example #4: Selected audiometric test data for a 40-year-old male worker:

	Test Frequency, Left Ear (Hz)					Test Frequency, Right Ear (Hz)				
Test Year	1,000	**2,000**	**3,000**	**4,000**	6,000	1,000	**2,000**	**3,000**	**4,000**	6,000
Age 20	5	**4**	**6**	**8**	8	5	**3**	**4**	**5**	8
Age 25	5	**3**	**5**	**7**	9	6	**6**	**7**	**7**	9
Age 30	12	**9**	**11**	**10**	15	8	**12**	**14**	**13**	17
Age 35	17	**15**	**19**	**18**	20	16	**18**	**17**	**21**	23
Age 40 (current year)	21	**25**	**30**	**33**	36	18	**22**	**25**	**25**	27

Review the data and observe that the lowest thresholds for the left ear occur in the second audiogram (at 2,000, 3,000, and 4,000 Hz). Use age 25 as the baseline for the left ear. For the right ear, use the first audiogram as the baseline because it has the lowest thresholds.

Next, compare the current year audiogram with the baseline. Observe that for each ear, at the required frequencies, all changes in threshold exceed 10 dB, so the averages will exceed 10 dB for each ear. The age correction factors must now be applied to determine whether an STS occurred.

Age Correction Values (from Table F-1 in Appendix F of 1910.95)			
	2,000 Hz	3,000 Hz	4,000 Hz
Age 20 (*use for right ear*)	3	4	5
Age 25 (*use for left ear*)	3	5	7
Age 40	6	10	14
Difference in age correction values, left ear	3	5	7
Difference in age correction values, right ear	3	6	9

Age-Corrected Threshold Shift (current year, age 40)						
	Test Frequency, Left Ear (Hz)			Test Frequency, Right Ear (Hz)		
	2,000	3,000	4,000	2,000	3,000	4,000
Threshold shifts from baseline	22	25	26	19	21	20
Difference in age correction values	3	5	7	3	6	9
Age-corrected threshold shift	**19**	**20**	**19**	**16**	**15**	**11**

In scanning the data for the left ear, the average threshold shift will exceed 10 dB but not 25 dB. An STS has occurred but not an OSHA-recordable case. The average STS is: (19+20+19)/3=19.33 dB. Likewise, for the right ear, the average shift will be greater than 10 dB but less than 25 dB. An STS has occurred for the right ear but not an OSHA-recordable case. The average is (16+15+11)/3=14.

Since the STS is much larger than 10 dB for both ears, it is prudent to examine data from the intervening years to determine when the STS occurred. In scanning the data for age 30 for the left ear, none of the shifts exceed 10 dB before age correction, so the STS did not occur at that interval. In scanning the data for age 35, the shifts were 12 dB, 14 dB, and 11 dB. The age correction values will need to be applied.

Age Correction Values (from Table F-1 in Appendix F of 1910.95)			
	2,000 Hz	3,000 Hz	4,000 Hz
Age 25	3	5	7
Age 35	5	8	11
Difference in age correction values, left ear	**2**	**3**	**4**

Age-Corrected Threshold Shift (age 35, left ear)			
	Test Frequency, Left Ear (Hz)		
	2,000	3,000	4,000
Threshold shifts from baseline	12	14	11
Difference in age correction values	2	3	4
Age-corrected threshold shift	**10**	**11**	**7**

The average age-corrected threshold shift at age 35 for the left ear was (10+11+7)/3 =9.33. No STS occurred in that interval. There is no need to adopt a revised baseline for that interval.

For the right ear, review data for the intervening years to determine when the STS occurred. For age 25, all shifts were less than 10 dB. For age 30, the shifts were 9 dB, 10 dB, and 8 dB. Since the average is less than 10 dB, no STS occurred. For age 35, all shifts were well above 10 dB, so the age correction values will need to be applied.

Age Correction Values (from Table F-1 in Appendix F of 1910.95)			
	2,000 Hz	3,000 Hz	4,000 Hz
Age 20	3	4	5
Age 35	5	8	11
Difference in age correction values, right ear	**2**	**4**	**6**

Age-Corrected Threshold Shift (age 35, right ear)			
	Test Frequency, Right Ear (Hz)		
	2,000	3,000	4,000
Threshold shifts from baseline	15	13	16
Difference in age correction values	2	4	6
Age-corrected threshold shift	**13**	**9**	**10**

The age-corrected standard threshold shift for the right ear is (13+9+10)/3=10.66. The STS occurred at age 35. The audiogram for age 35 should be adopted as the revised baseline.

In scanning the data for the left ear, the average threshold shift will exceed 10 dB but not 25 dB. An STS has occurred but not an OSHA-recordable case. The average STS is: (19+20+19)/3=19.33 dB. Likewise, for the right ear, the average shift will be greater than 10 dB but less than 25 dB. An STS has occurred for the right ear but not an OSHA-recordable case. The average is (16+15+11)/3=14.

Since the STS is much larger than 10 dB for both ears, it is prudent to examine data from the intervening years to determine when the STS occurred. In scanning the data for age 30 for the left ear, none of the shifts exceed 10 dB before age correction, so the STS did not occur at that interval. In scanning the data for age 35, the shifts were 12 dB, 14 dB, and 11 dB. The age correction values will need to be applied.

Age Correction Values (from Table F-1 in Appendix F of 1910.95)			
	2,000 Hz	3,000 Hz	4,000 Hz
Age 25	3	5	7
Age 35	5	8	11
Difference in age correction values, left ear	**2**	**3**	**4**

Age-Corrected Threshold Shift (age 35, left ear)			
	Test Frequency, Left Ear (Hz)		
	2,000	3,000	4,000
Threshold shifts from baseline	12	14	11
Difference in age correction values	2	3	4
Age-corrected threshold shift	**10**	**11**	**7**

The average age-corrected threshold shift at age 35 for the left ear was (10+11+7)/3 =9.33. No STS occurred in that interval. There is no need to adopt a revised baseline for that interval.

For the right ear, review data for the intervening years to determine when the STS occurred. For age 25, all shifts were less than 10 dB. For age 30, the shifts were 9 dB, 10 dB, and 8 dB. Since the average is less than 10 dB, no STS occurred. For age 35, all shifts were well above 10 dB, so the age correction values will need to be applied.

Age Correction Values (from Table F-1 in Appendix F of 1910.95)			
	2,000 Hz	3,000 Hz	4,000 Hz
Age 20	3	4	5
Age 35	5	8	11
Difference in age correction values, right ear	**2**	**4**	**6**

Age-Corrected Threshold Shift (age 35, right ear)			
	Test Frequency, Right Ear (Hz)		
	2,000	3,000	4,000
Threshold shifts from baseline	15	13	16
Difference in age correction values	2	4	6
Age-corrected threshold shift	**13**	**9**	**10**

The age-corrected standard threshold shift for the right ear is (13+9+10)/3=10.66. The STS occurred at age 35. The audiogram for age 35 should be adopted as the revised baseline.

APPENDIX K—THREE WAYS TO JUMP-START A NOISE CONTROL PROGRAM

This presentation provides practical suggestions for reducing excessive noise from three sources.

1. Pneumatic or compressed air sources.

2. Elevated sound levels from sources that can be reduced through maintenance for noise control.

3. Machinery noise sources that can be controlled by considering noise while improving machine guarding.

These three sources are some of the most frequent causes of excessive workplace noise. Controlling these sources can have a marked impact on the overall noise-exposure levels that workers experience.

The following slides are an excerpt from a presentation by Dennis Driscoll, P.E., during a course held at the 2011 Professional Conference on Industrial Hygiene. The slides are reprinted here with the author's permission.

Additionally, these three items will provide the greatest noise reduction per dollar invested, and can even have an economic payback through energy savings and life expectancy of equipment.

A Few Key Steps to Jump Start Your Noise Control Program

(Success builds success)

Impediments and Road Blocks

- Lack of time, background, money, and/or confidence to get started.
- Resistance, indifference, and/or lukewarm support from above.
- Resistance, indifference, and/or lukewarm support from below (operators/mechanics).

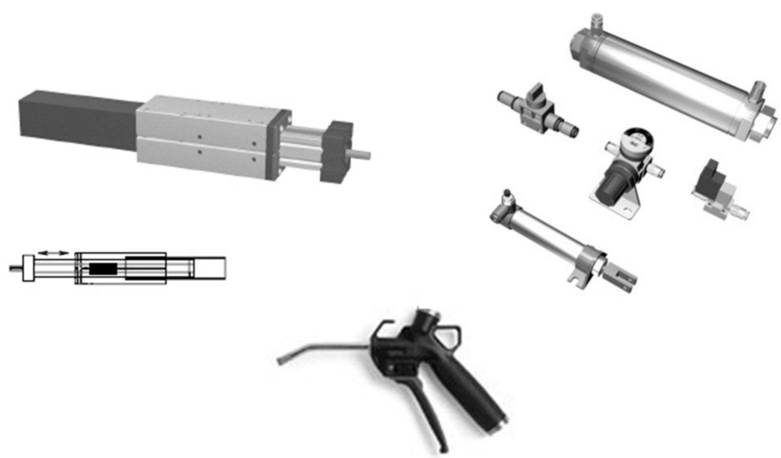
Impediments and Road Blocks

- Let’s look at three (3) homeruns we can all manage:

1. Pneumatic or compressed air sources,
2. Maintenance for noise control, and
3. Improving machine guarding.

These three items will provide the greatest noise reduction per dollar invested, and can even have a payback in dollars through energy savings and life expectancy of equipment.

Pneumatic and Compressed Air Systems



Dennis P. Driscoll, P.E.
Associates In Acoustics, Inc.
DDriscoll@AssociatesInAcoustics.com

Pneumatic and Compressed Air Systems

- The Usage of compressed air is often a plant-wide noise issue in manufacturing plants.
- Compressed air can easily be responsible for 25-33% of a plant's noise problems.
- Compressed air noise is probably the easiest source to control.
- Getting a handle on compressed air usage and noise can have significant financial and energy savings over time.

Pneumatic and Compressed Air Systems

Pneumatic or compressed air systems are used to:

- Operate or motivate equipment, using devices such as air cylinders, air valves, solenoids, etc.
- Air jets and nozzles, including hand-held air guns, are used to move parts/product, blow-off debris, close flaps on corrugated containers (boxes/cases), or similar service-type actions.

Pneumatic and Compressed Air Systems

Noise generated by compressed air is caused by turbulence due to the mixing of gases with widely different velocities.

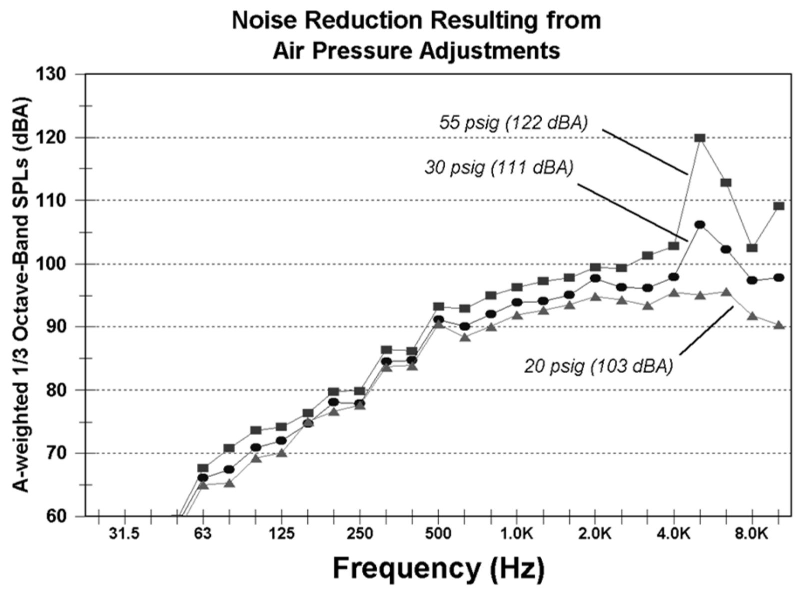
Additional turbulence is created as the compressed air blows against objects, such as parts or sections of the machinery.

Pneumatic and Compressed Air Systems

The shearing action occurring in the mixing region results in excessive noise, where the sound level is proportional velocity of air flow raised to the 8th power.

$$\text{Sound Level} \propto V^8$$

Therefore, the 1st Step toward controlling compressed air noise is to reduce the air velocity to as low as practical and maintaining that setting.



Pneumatic and Compressed Air Systems

The 2nd Step is to treat all open-ended discharge lines and ports, including standard air jets and nozzles with commercially-available quiet-design nozzles or pneumatic silencers.

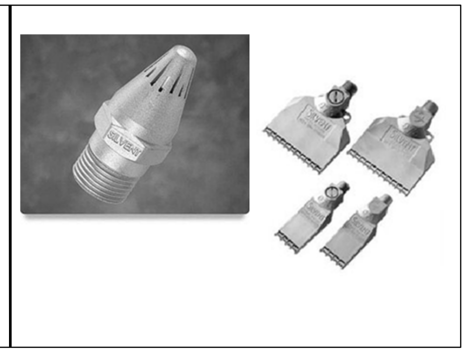
Care must be exercised to ensure the type of device used meets the service needs at the plant.

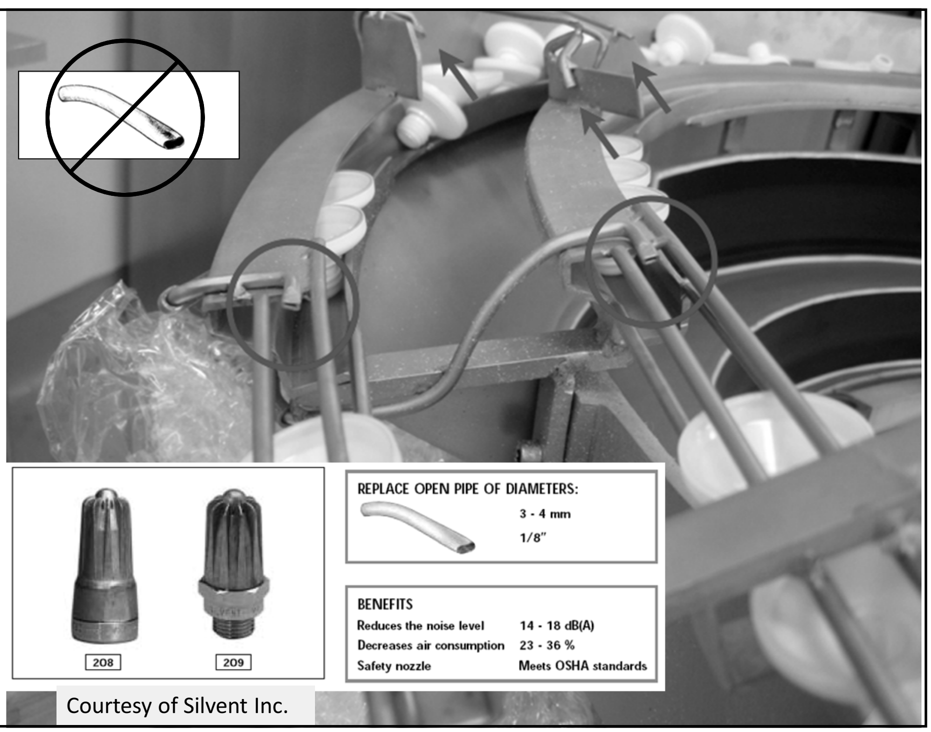
Dennis P. Driscoll, P.E.
Associates In Acoustics, Inc.
DDriscoll@AssociatesInAcoustics.com

Pneumatic and Compressed Air Systems

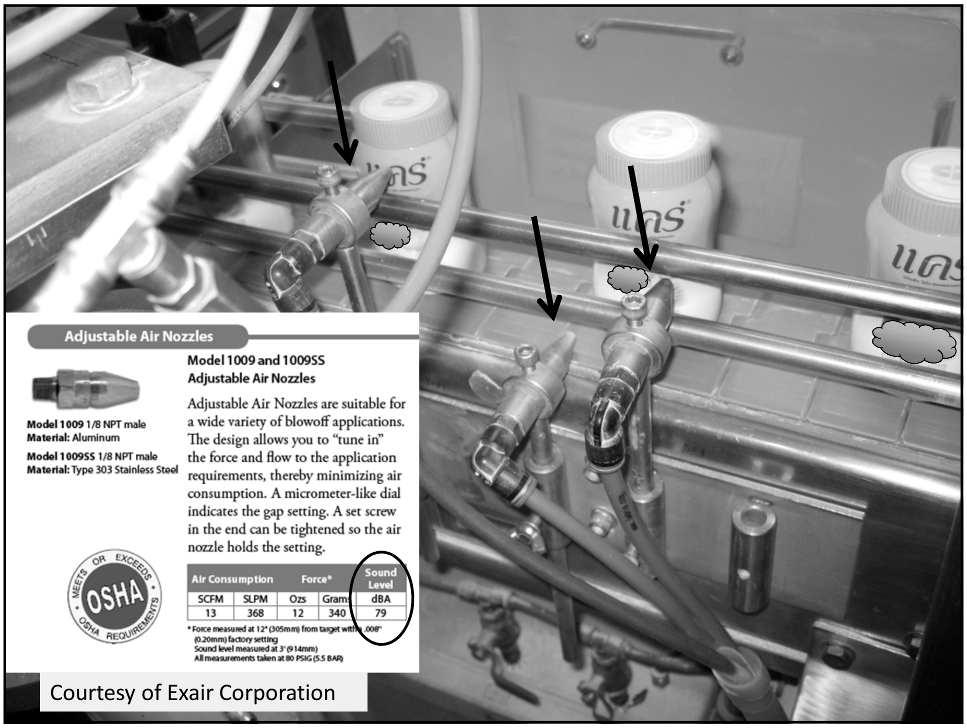
There are two categories of devices:

1. Air exhaust, and
2. Service-type devices





Dennis P. Driscoll, P.E.
Associates In Acoustics, Inc.
DDriscoll@AssociatesInAcoustics.com



Pneumatic and Compressed Air Systems

And there is an energy cost savings, too:

- For example, blowing compressed air through a 10mm open pipe at a pressure of 5 bars uses 185 Nm^3/hr.
- At an average cost of $0.015 (U.S. Dollars) per 1 Nm^3/hr, and an estimated use time of 40%, this equates to 704 hours of consumption per year. Therefore, the annual cost for the open pile is: 185 Nm^3/hr x $0.015 x 704 hours = $1953.60.

Dennis P. Driscoll, P.E.
Associates In Acoustics, Inc.
DDriscoll@AssociatesInAcoustics.com

Pneumatic and Compressed Air Systems

And there is an energy cost savings, too:

- Next, using a Silvent 705 quiet-design nozzle provides the same air-flow service, but only uses 95 Nm^3/hr. This results in an annual cost of $1003.20. Therefore, the savings is:

Open Pipe		Quiet-design Nozzle		Annual Savings
$1953.60	—	$1003.20	=	$950.40 *Per Nozzle!!!!*

AND, provides 20 dBA of attenuation.

Pneumatic and Compressed Air Systems

- Manufacturers of quiet-design compressed air devices:
  - Silvent, Inc. (www.silvent.com)
  - Exair Corporation (www.exair.com)
  - Vortec (www.vortec.com)
  - Allied Witan Company (www.alwitco.com)
  - McGill Air Pressure Corp. (www.mcgillairpressure.com)

Pneumatic and Compressed Air Systems

Contact any number of these manufacturers and:

1. Request a free-of-charge survey and audit of all compressed air devices used at the plant.
2. Recommendations and cost estimates for retrofitting all air sources.
3. Calculation of the energy savings and break-even point for retrofit investment.

Pneumatic and Compressed Air Systems

Summary

Steps for minimizing compressed air noise:

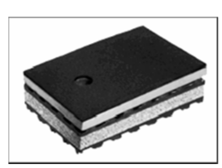
1. Optimize air pressure settings for all pneumatic devices, document and maintain settings over time.
2. Identify and repair compressed air leaks from sources such as valves, cracked hoses, failed seals, etc.
3. Use programmable logic controllers (PLC) that integrate all digital sensors along a production line that can shut off the delivery of compressed air when the line or device is off line.
4. Should Step 1-3 not be sufficient, then retrofit all compressed air devices (service and non-service type).

Acoustical Maintenance

Acoustical Maintenance

1. To achieve the goal of reducing worker noise exposures sufficiently to eliminate the need for hearing protection or the HCP, it will require a combination of noise control measures and then maintaining these controls over time.



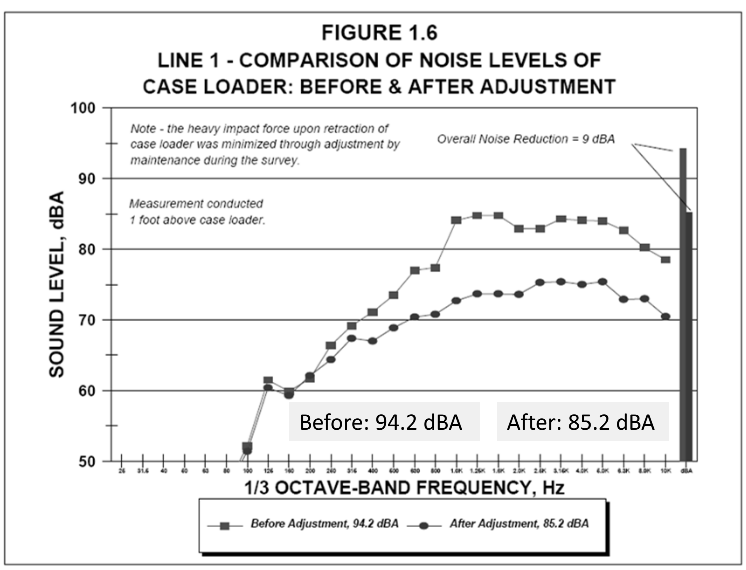



Dennis P. Driscoll, P.E.
Associates In Acoustics, Inc.
DDriscoll@AssociatesInAcoustics.com

Acoustical Maintenance

2. In addition, a critical component in the long-term success of the noise control program is to vigilantly keep manufacturing equipment in optimal working condition.
   – This will help minimize the noise generated, AND it will also minimize the wear and tear on equipment, which improves its life expectancy. Hence, there is a *hidden* cost savings that can be difficult to quantify, but needs to be at least recognized as a benefit.

Acoustical Maintenance



Dennis P. Driscoll, P.E.
Associates In Acoustics, Inc.
DDriscoll@AssociatesInAcoustics.com

Acoustical Maintenance

- Maintaining all equipment and noise controls at their optimum performance condition needs to be an on-going effort.
- Hand in hand with general mechanical maintenance, which improves the performance and life-span of any piece of equipment, an *acoustical maintenance program will help ensure the equipment remains within the noise limits intended by the company, or as the equipment should generate under optimal working conditions.*

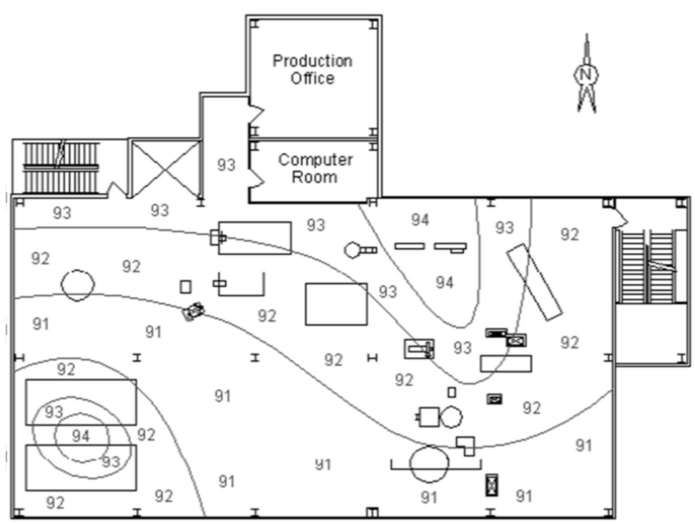
Acoustical Maintenance

- As criteria for an acoustical maintenance program, each machine should typically operate within 2 dBA of the minimum sound level of which it is optimally capable.
- Plus, when equipment is maintained in good working order, from a noise exposure standpoint the added benefit is that it will minimize the time workers need to spend in the direct sound field of the machine while performing any service requirements.

Acoustical Maintenance

To assist with implementing an effective acoustical maintenance program, the following elements are presented:

- Conduct an initial baseline sound level survey for each machine in good working order while operating under normal conditions. This should consist of documenting the A-weighted sound level at fixed locations for each machine or production line.



Example Noise Contour Map

Acoustical Maintenance

- Periodically (bi-monthly, quarterly, or at least semi-annually) conduct a general sound survey of each machine, and compare the operating sound level with the baseline sound level data.
- If noise generating elements are identified, or the sound levels indicate at least an increase over the baseline data of 2 dBA, then appropriate repair should be performed, and

Acoustical Maintenance

- Maintenance and operating personnel should be trained to observe and listen for potential noise sources outside the norm for the equipment of concern. They should become familiar with the noise generating mechanisms of each machine and with the visual inspection procedures.

Acoustical Maintenance

- When a noise-producing problem is identified during a visual and auditory inspection, the problem should be corrected immediately if it involves only a minor malfunction or adjustment, and even if the equipment appears to be operating normally. If the problem requires more extensive attention, then it should be labeled or tagged at the problem location and be scheduled for service during the next maintenance round.

Acoustical Maintenance

- Successful implementation of an acoustical maintenance program will ensure the correction of simple and often overlooked noise problems. This process alone will yield significant benefits in both the long-term life of the equipment and minimizing the noise exposure risk to employees.

Dennis P. Driscoll, P.E.
Associates In Acoustics, Inc.
DDriscoll@AssociatesInAcoustics.com

Machine Guarding

If you must guard, then
let's go all the way!!

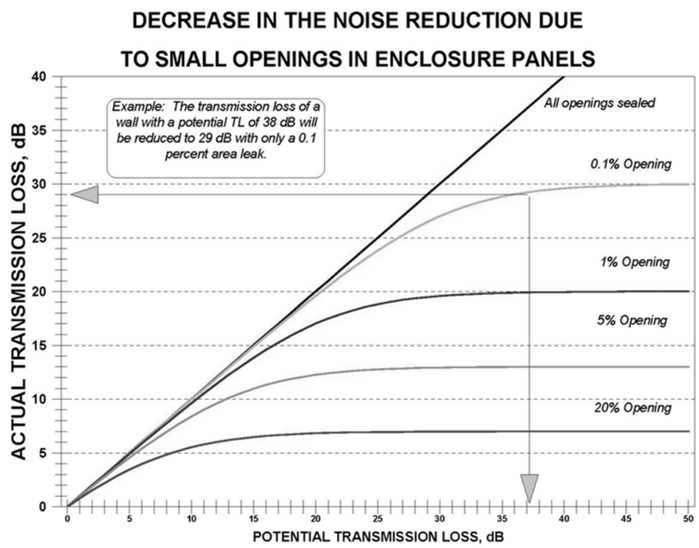
Machine Guarding and Acoustical Benefits

Polycarbonate Safety Enclosures

Seal off all small gaps and openings along all polycarbonate panel edges and the adjacent framework, and the bottom edge of the machine cabinet to the floor.

Dennis P. Driscoll, P.E.
Associates In Acoustics, Inc.
DDriscoll@AssociatesInAcoustics.com

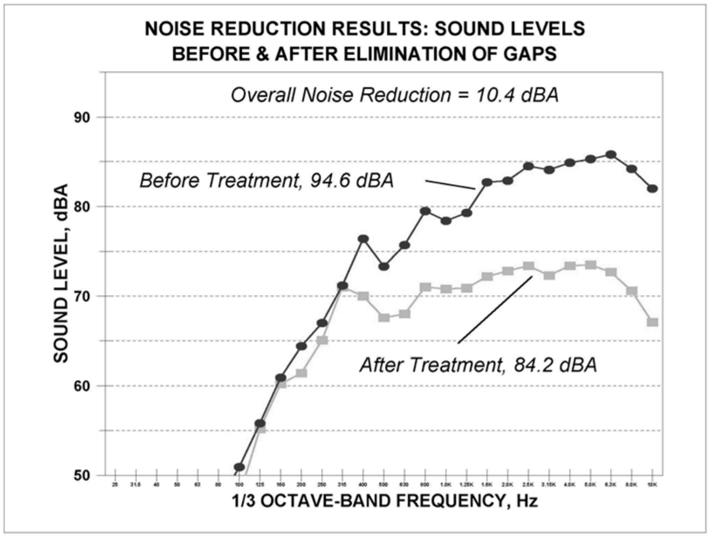
Machine Guarding and Acoustical Benefits



Machine Guarding and Acoustical Benefits

Dennis P. Driscoll, P.E.
Associates In Acoustics, Inc.
DDriscoll@AssociatesInAcoustics.com

Machine Guarding and Acoustical Benefits

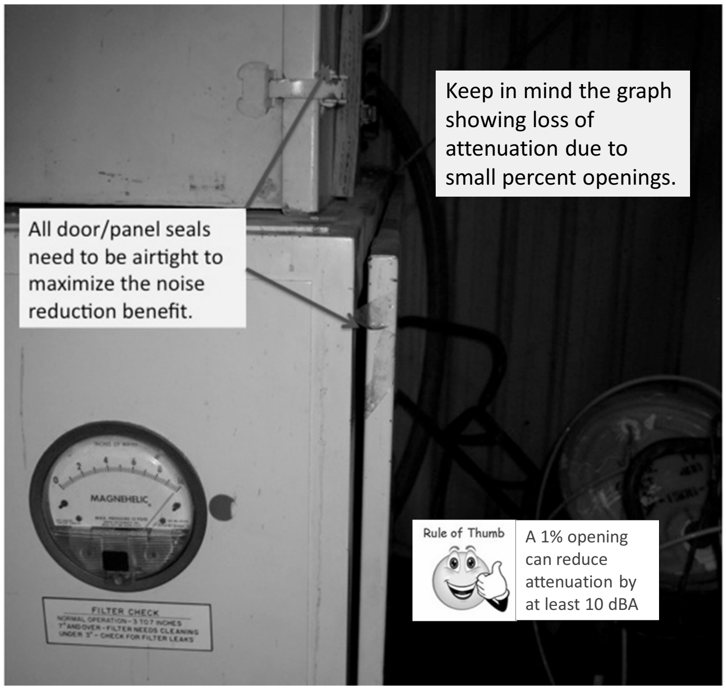


Machine Guarding and Acoustical Benefits

Polycarbonate Safety Enclosures

Seal off all small gaps and openings along all polycarbonate panel edges and the adjacent framework, and the bottom edge of the machine cabinet to the floor.

Dennis P. Driscoll, P.E.
Associates In Acoustics, Inc.
DDriscoll@AssociatesInAcoustics.com



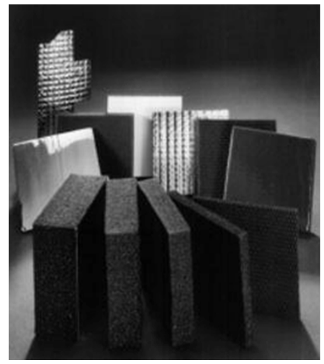
Machine Guarding and Acoustical Benefits

1. For all existing polycarbonate guards, tightly seal, or at least minimize, all gaps or openings between the panel edges and their frame, and between all adjacent metal frame sections.
2. For sealing polycarbonate enclosures with large openings, such as gaps between the floor and bottom edge of the machine cabinet, use a dense but flexible barrier material.

Dennis P. Driscoll, P.E.
Associates In Acoustics, Inc.
DDriscoll@AssociatesInAcoustics.com

Machine Guarding and Acoustical Benefits

3. Install at least some sound absorption material to at least 25% of any available surface areas inside the enclosures. The material's location in not critical, as it just needs to be inside the enclosure.



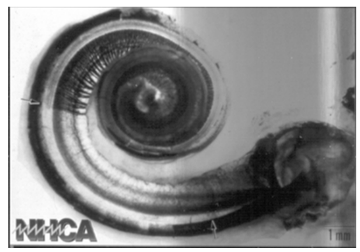
Three Significant Homeruns

1. Get a handle on pneumatic and compressed air devices and machine controls,
2. Implement an Acoustical Maintenance Program to maintain existing noise controls and keep machinery in good working order, and
3. Go all the way with machine guarding to include the acoustical benefits (pennies on the dollar).

Dennis P. Driscoll, P.E.
Associates In Acoustics, Inc.
DDriscoll@AssociatesInAcoustics.com

Summary

- You have the tools to quantify the cost of a HCP, prioritize noise control projects, and to determine the return on investment toward eliminating the need for a HCP.
- NIHL is 100% preventable.
- I challenge you to be the key individual that makes a difference in the lives of workers at your location(s).



Dennis P. Driscoll, P.E.
Associates In Acoustics, Inc.
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