OSHA Technical Manual

NOISE

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I. INTRODUCTION

Noise, or unwanted sound, is one of the most common occupational hazards in American workplaces. The National Institute for Occupational Safety and Health (NIOSH) estimates that 30 million workers in the United States are exposed to hazardous noise. Exposure to high levels of noise may cause hearing loss, create physical and psychological stress, reduce productivity, interfere with communication, and contribute to accidents and injuries by making it difficult to hear warning signals.

This chapter provides technical information and guidance to help Compliance Safety and Health Officers (CSHOs) evaluate noise hazards in the workplace. The content is based on currently available research publications, OSHA standards, and consensus standards.

The chapter is divided into six main sections. Following this introduction, the second section provides background information about noise and noise regulations and an overview of noise controls. The third section describes worksite noise evaluations, including noise measurement equipment, noise evaluation procedures, and noise sampling. The fourth section offers investigative guidelines (including methods for planning the investigation) and outlines a strategy for conducting noise evaluations. The fifth section describes noise hazard abatement and control, including engineering and administrative controls, hearing protection, noise conservation programs, cost comparisons between noise hazard abatement options, and case studies. The final two sections provide references used to produce this chapter and resources for obtaining additional information. Following the main sections, the appendices provide a glossary of terms, sample calculations, and expanded discussion of certain topics introduced in the chapter.

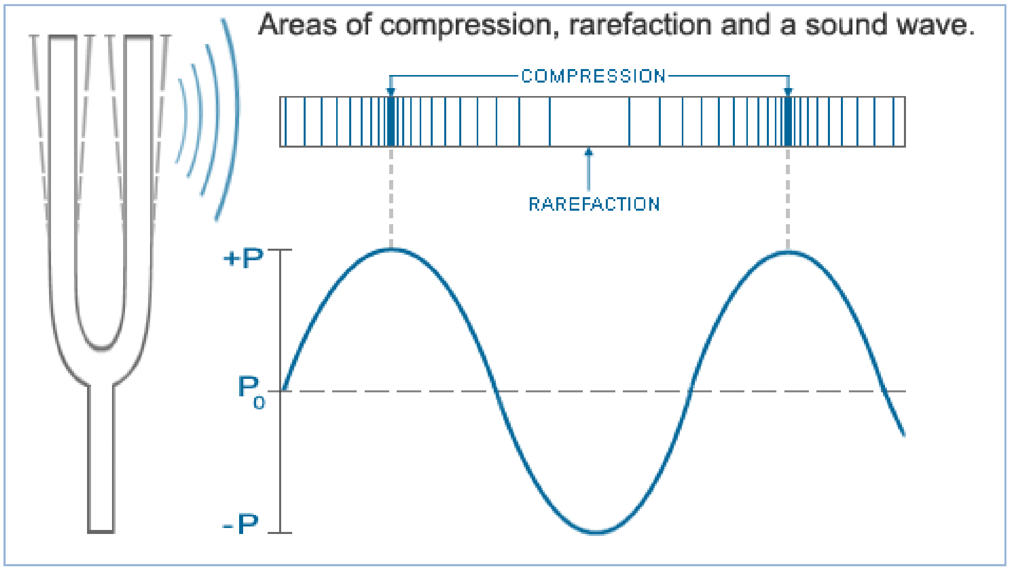
II. BACKGROUND INFORMATION

A. What Is Noise?

Occupational noise can be any sound in any work environment.

A textbook definition of sound is “a rapid variation of atmospheric pressure caused by some disturbance of the air.” Sound propagates as a wave of positive pressure disturbances (compressions) and negative pressure disturbances (rarefactions), as shown in Figure 1. Sound can travel through any elastic medium (e.g., air, water, wood, metal).

Figure 1. Sound Waves



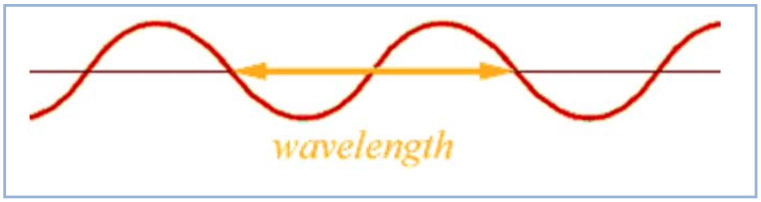
When air molecules are set to vibrate, the ear perceives the variations in pressure as sound (OTM/Driscoll). The vibrations are converted into mechanical energy by the middle ear, subsequently moving microscopic hairs in the inner ear, which in turn convert the sound waves into nerve impulses. If the vibrations are too intense, over time these microscopic hairs can be damaged, causing hearing loss. Noise is unwanted sound. In the workplace, sound that is intense enough to damage hearing is unwanted and, therefore, is considered to be noise.

Several key terms describe the qualities of sound. These qualities influence how it affects hearing and health, how it is measured, and how it can be controlled. Effective occupational noise investigations require the investigator to understand these basic terms.

B. Basic Qualities of Sound

1. Wavelength

Figure 2. Wavelength



The wavelength (λ) is the distance traveled by a sound wave during one sound pressure cycle, as shown in Figure 2. The wavelength of sound is usually measured in meters or feet. Wavelength is important for designing engineering controls. For example, a sound-absorbing material will perform most effectively if its thickness is at least one-quarter the wavelength.

2. Frequency

Frequency, *f,* is a measure of the number of vibrations (i.e., sound pressure cycles) that occur per second. It is measured in hertz (Hz), where one Hz is equal to one cycle per second.

Sound frequency is perceived as pitch (i.e., how high or low a tone is). The frequency range sensed by the ear varies considerably among individuals. A young person with normal hearing can hear frequencies between approximately 20 Hz and 20,000 Hz. As a person gets older, the highest frequency that he or she can detect tends to decrease.

Human speech frequencies are in the range of 500 Hz to 4,000 Hz. This is significant because hearing loss in this range will interfere with conversational speech. The portions of the ear that detect frequencies between 3,000 Hz and 4,000 Hz are the earliest to be affected by exposure to noise. Audiograms often display a 4,000-Hz "Notch" in patients who are developing the beginning stages of sensorineural hearing loss.

3. Speed

The speed at which sound travels, *c,* is determined primarily by the density and the compressibility of the medium through which it is traveling. The speed of sound is typically measured in meters per second or feet per second.

Speed increases as the density of the medium increases and its elasticity decreases. For example:

- In air, the speed of sound is approximately 344 meters per second (1,130 feet per second) at standard temperature and pressure.
- In liquids and solids, the speed of sound is much higher. The speed of sound is about 1,500 meters per second in water and 5,000 meters per second in steel.

The **frequency, wavelength,** and **speed** of a sound wave are related by the equation

$$c = f\lambda$$

Where c = speed of sound in meters or feet per second, f = frequency in Hz, and λ = wavelength in meters or feet.

4. Sound Pressure

The vibrations associated with sound are detected as slight variations in pressure. The range of sound pressures perceived as sound is extremely large, beginning with a very weak pressure causing faint sounds and increasing to noise so loud that it causes pain.

The threshold of hearing is the quietest sound that can typically be heard by a young person with undamaged hearing. This varies somewhat among individuals but is typically in the micropascal range. The reference sound pressure is the standardized threshold of hearing and is defined as 20 micropascals (0.0002 microbars) at 1,000 Hz.

The threshold of pain, or the greatest sound pressure that can be perceived without pain, is approximately 10 million times greater than the threshold of hearing. It is, therefore, more convenient to use a relative (e.g., logarithmic) scale of sound pressure rather than an absolute scale (OTM/Driscoll).

5. *Decibels*

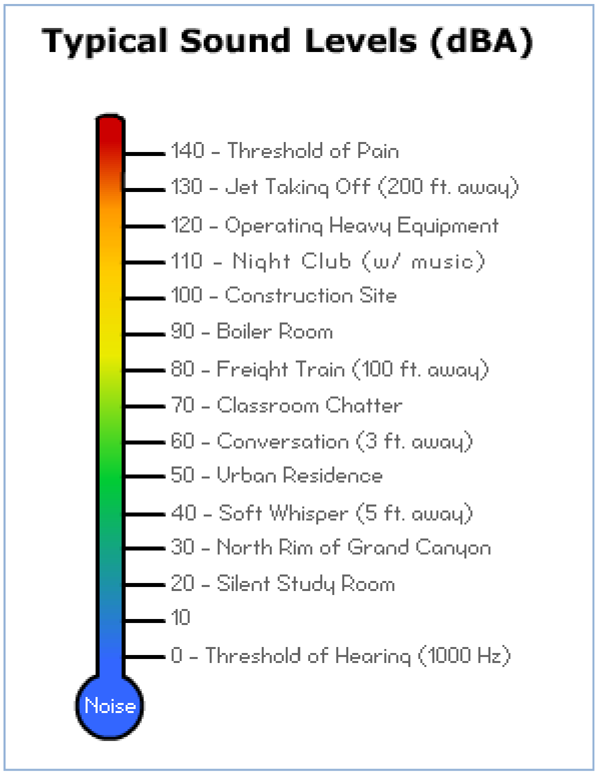
Noise is measured in units of sound pressure called decibels (dB), named after Alexander Graham Bell. The decibel notation is implied any time a “sound level” or "sound pressure level" is mentioned.

Decibels are measured on a logarithmic scale: a small change in the number of decibels indicates a huge change in the amount of noise and the potential damage to a person’s hearing.

The decibel scale is convenient because it compresses sound pressures important to human hearing into a manageable scale. By definition, 0 dB is set at the reference sound pressure (20 micropascals at 1,000 Hz, as stated earlier). At the upper end of human hearing, noise causes pain, which occurs at sound pressures of about 10 million times that of the threshold of hearing. On the decibel scale, the threshold of pain occurs at 140 dB. This range of 0 dB to 140 dB is not the entire range of sound, but is the range relevant to human hearing.

Click here to compare the decibel levels generated by familiar noise sources.

Figure 3. Decibel Scale



(OTM/Driscoll)

(Figure 3)

Decibels are logarithmic values, so it is not proper to add them by normal algebraic addition. See Appendix B for information on the cumulative effects of multiple sound sources on the decibel level.

The decibel is a dimensionless unit; however, the concepts of distance and three-dimensional space are important to understanding how noise spreads through an environment and how it can be controlled. Sound fields and sound power are terms used in describing these concepts.

6. *Sound Fields*

Many noise-control problems require a practical knowledge of the relationships between:

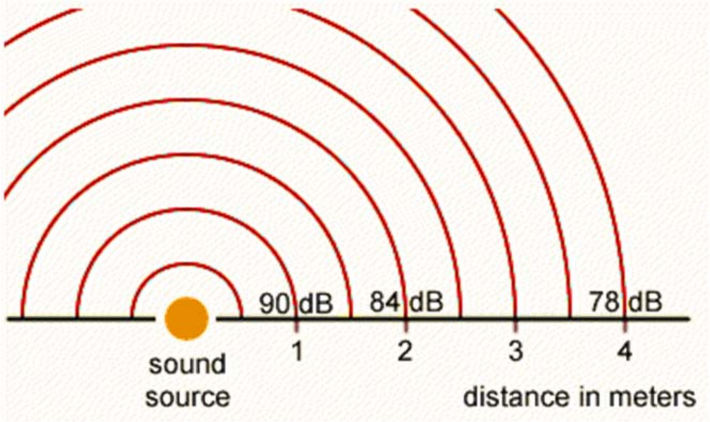
- A sound *field* (a region in which sound is propagating) and two related concepts.
- *Sound* pressure (influenced by the energy [in terms of pressure] emitted from the sound source, the distance from the sound source, and the surrounding environment).
- Sound *power* (sound energy emitted from a sound source and not influenced by the surrounding environment).

Sound fields are categorized as near field or far field, a distinction that is important to the reliability of measurements. The *near field* is the space immediately around the noise source, sometimes defined as within the wavelength of the lowest frequency component (e.g., a little more than 4 feet for a 25-Hz tone, about 1 foot for a 1,000-Hz tone, and less than 7 inches for a 2,000-Hz tone). Sound pressure measurements obtained with standard instruments within the near field are not reliable because small changes in position can result in big differences in the readings.

The far field is the space outside the near field, meaning that the far field begins at a point at least one wavelength distance from the noise source. Standard sound level meters (i.e., type I and type II) are reliable in this field, but the measurements are influenced by whether the noise is simply originating from a source (*free field*) or being reflected back from surrounding surfaces (*reverberant field*).

A free field is a region in which there are no reflected sound waves. In a free field, sound radiates into space from a source uniformly in all directions. The sound pressure produced by the source is the same in every direction at equal distances from the point source. As a principle of physics, the sound pressure level decreases 6 dB, on a Z-weighted (i.e., unweighted) scale, each time the distance from the point source is doubled. This is a common way of expressing the inverse-square law in acoustics and is shown in Figure 4.

Figure 4. Sound Pressure Levels in a Free Field

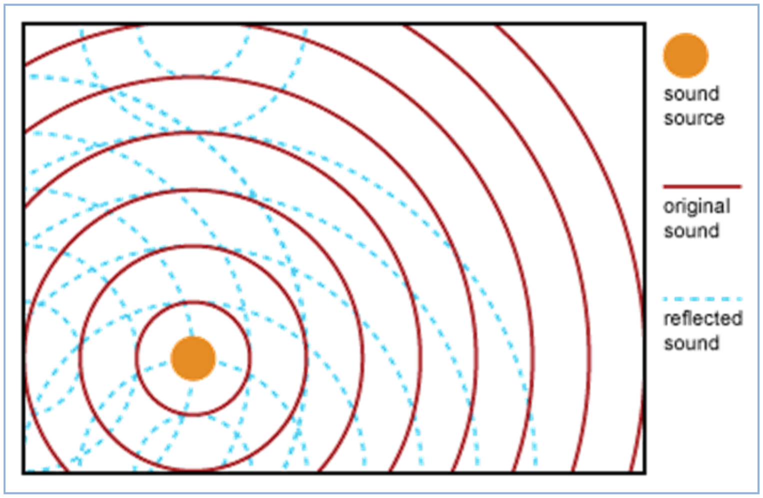


If a point source in a free field produces a sound pressure level of 90 dB at a distance of 1 meter, the sound pressure level is 84 dB at 2 meters, 78 dB at 4 meters, and so forth. This principle holds true regardless of the units used to measure distance.

Free field conditions are necessary for certain tests, where outdoor measurements are often impractical. Some tests need to be performed in special rooms called free field or anechoic (echo-free) chambers, which have sound-absorbing walls, floors, and ceilings that reflect practically no sound.

In spaces defined by walls, however, sound fields are more complex. When sound-reflecting objects such as walls or machinery are introduced into the sound field, the wave picture changes completely. Sound reverberates, reflecting back into the room rather than continuing to spread away from the source. Most industrial operations and many construction tasks occur under these conditions. Figure 5 diagrams sound radiating from a sound source and shows how reflected sound (dashed lines) complicates the situation.

Figure 5. Original and Reflected Sound Waves



The net result is a change in the intensity of the sound. The sound pressure does not decrease as rapidly as it would in a free field. In other words, it decreases by less than 6 dB each time the distance from the sound source doubles.

Far from the noise source—unless the boundaries are very absorbing—the reflected sound dominates. This region is called the *reverberant field*. If the sound pressure levels in a reverberant field are uniform throughout the room, and the sound waves travel in all directions with equal probability, the sound is said to be diffuse.

In actual practice, however, perfectly free fields and reverberant fields rarely exist—most sound fields are something in between.

7. Sound Power

Up to this point, this discussion has focused on sound *pressure*. Sound *power,* however, is an equally important concept. Sound power, usually measured in watts, is the amount of energy per unit of time that radiates from a source in the form of an acoustic wave. Generally, sound power cannot be measured directly, but modern instruments make it possible to measure the output at a point that is a known distance from the source.

Understanding the relationship between sound pressure and sound power is essential to predicting what noise problems will be created when particular sound sources are placed in working environments. An important consideration might be how close workers will be working to the source of sound. As a general rule, doubling the sound power increases the noise level by 3 dB.

As sound power radiates from a point source in free space, it is distributed over a spherical surface so that at any given point, there exists a certain sound power per unit area. This is designated as intensity, *I,* and is expressed in units of watts per square meter.

Sound intensity is heard as loudness, which can be perceived differently depending on the individual and his or her distance from the source and the characteristics of the surrounding space. As the distance from the sound source increases, the sound intensity decreases. The sound power coming from the source remains constant, but the spherical surface over which the power is spread increases—so the power is less intense. In other words, the *sound power* level of a source is independent of the environment. However, the *sound pressure* level at some distance, *r,* from the source depends on that distance and the sound-absorbing characteristics of the environment (OTM/Driscoll).

8. Filtering

Most noise is not a pure tone, but rather consists of many frequencies simultaneously emitted from the source. To properly represent the total noise of a source, it is usually necessary to break it down into its frequency components. One reason for this is that people react differently to low-frequency and high-frequency sounds. Additionally, for the same sound pressure level, high-frequency noise is much more disturbing and more capable of producing hearing loss than low-frequency noise. Engineering solutions to reduce or control noise are different for low-frequency and high-frequency noise. As a general guideline, low-frequency noise is more difficult to control.

Certain instruments that measure sound level can determine the frequency distribution of a sound by passing that sound successively through several different electronic filters that separate the sound into nine octaves on a frequency scale. Two of the most common reasons for filtering a sound include 1) determining its most prevalent frequencies (or octaves) to help engineers better know how to control the sound and 2) adjusting the sound level reading using one of several available weighting methods. These weighting methods (e.g., the A-weighted network, or scale) are intended to indicate perceived loudness and provide a rating of industrial noise that indicates the impact that particular noise has on human hearing. The following paragraphs provide more detailed information.

9. Octave Bands (Frequency Bands)

Octave bands, a type of frequency band, are a convenient way to measure and describe the various frequencies that are part of a sound. A frequency band is said to be an octave in width when its upper band-edge frequency, f_2, is twice the lower band-edge frequency, f_1: $f_2 = 2 f_1$.

Each *octave band* is named for its center frequency (geometric mean), calculated as follows: $f_c = (f_1 f_2)^{1/2}$, where f_c = center frequency and f_1 and f_2 are the lower and upper frequency band limits, respectively. The center, lower, and upper frequencies for the commonly used octave bands are listed in Table II–1.

Table II–1. Octave Band Filters and Frequency Range

Lower Band Limit (Hz)	Band Center Frequency (Geometric Mean in Hz)	Upper Band Limit (Hz)
22	**31.5**	44
44	**63**	88
88	**125**	177
177	**250**	354
354	**500**	707
707	**1,000**	1,414
1,414	**2,000**	2,828
2,828	**4,000**	5,656
5,656	**8,000**	11,312
11,312	**16,000**	22,624

Each octave band is named for its center frequency.

The width of a full octave band (its bandwidth) is equal to the upper band limit minus the lower band limit. For more detailed frequency analysis, the octaves can be divided into one-third octave bands; however, this level of detail is not typically required for evaluation and control of workplace noise.

Electronic instruments called octave band analyzers filter sound to measure the sound pressure (as dB) contributed by each octave band. These analyzers either attach to a type 1 sound level meter or are integral to the meter. Both the analyzers and sound level meters are discussed further in Section III.

10. Loudness and Weighting Networks

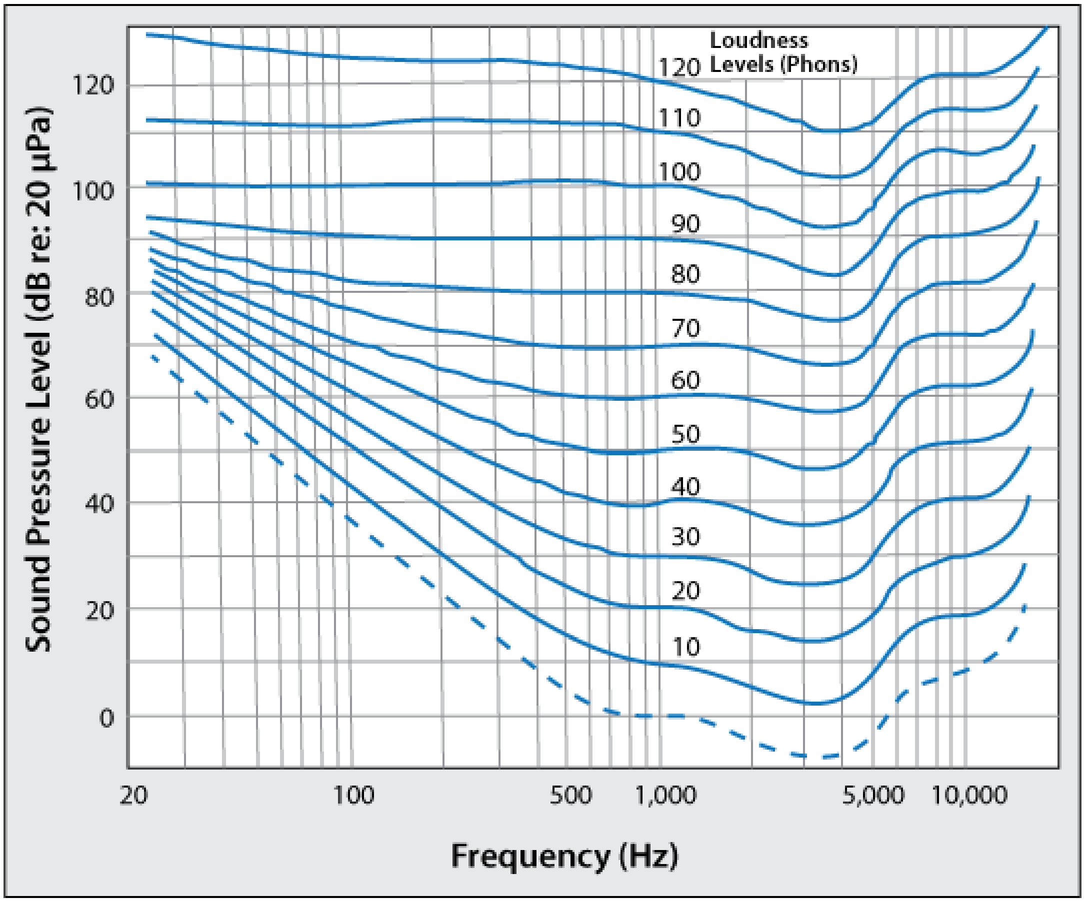
Loudness is the subjective human response to sound. It depends primarily on sound pressure but is also influenced by frequency.

Three different internationally standardized characteristics are used for sound measurement: weighting networks A, C, and Z (or "zero" weighting). The A and C weighting networks are the sound level meter's means of responding to some frequencies more than others. The very low frequencies are discriminated against (attenuated) quite severely by the A-network and hardly attenuated at all by the C-network. Sound levels (dB) measured using these weighting scales are designated by the appropriate letter (i.e., dBA or dBC).

The A-weighted sound level measurement is thought to provide a rating of industrial noise that indicates the injurious effects such noise has on human hearing and has been adopted by OSHA in its noise standards (OTM/Driscoll). In contrast, the Z-weighted measurement is an unweighted scale (introduced as an international standard in 2003), which provides a flat response across the entire frequency spectrum from 10 Hz to 20,000 Hz. The C-weighted scale is used as an alternative to the Z-weighted measurement (on older sound level meters on which Z-weighting is not an option), particularly for characterizing low-frequency sounds capable of inducing vibrations in buildings or other structures. A previous B-weighted scale is no longer used.

The networks evolved from experiments designed to determine the response of the human ear to sound, reported in 1933 by a pair of investigators named Fletcher and Munson. Their study presented a 1,000-Hz reference tone and a test tone alternately to the test subjects (young men), who were asked to adjust the level of the test tone until it sounded as loud as the reference tone. The results of these experiments yielded the frequently cited Fletcher-Munson, or "equal-loudness," contours, which are displayed in Figure 6.

Figure 6. The Fletcher-Munson Contours



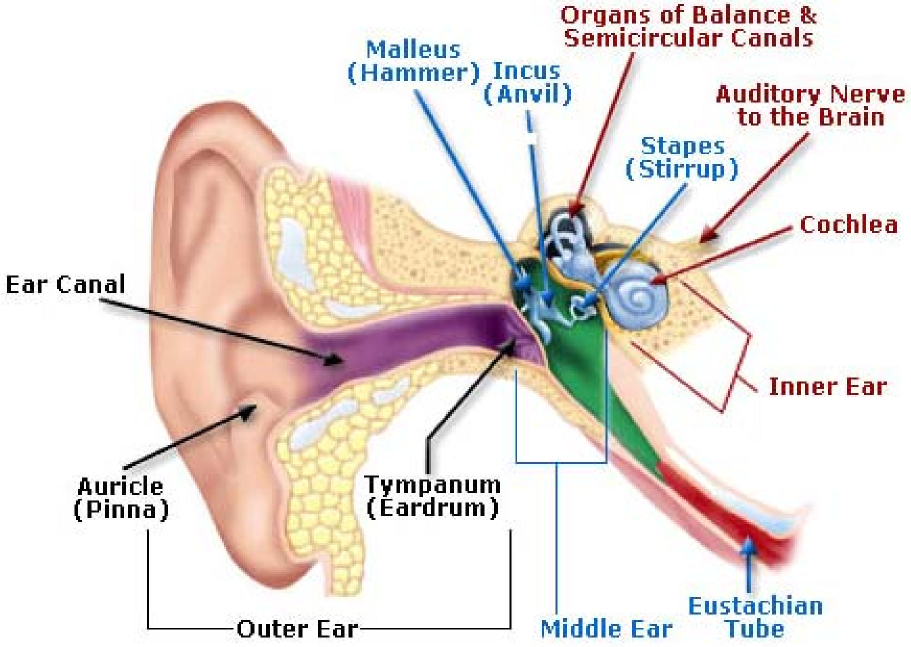
These contours represent the sound pressure level necessary at each frequency to produce the same loudness response in the average listener. The nonlinearity of the ear's response is represented by the changing contour shapes as the sound pressure level is increased (a phenomenon that is particularly noticeable at low frequencies). The lower, dashed curve indicates the threshold of hearing and represents the sound-pressure level necessary to trigger the sensation of hearing in the average listener. Among healthy individuals, the actual threshold may vary by as much as 10 decibels in either direction.

Ultrasound is not listed in Figure 6 because it has a frequency that is too high to be audible to the human ear. See Appendix C for more information about ultrasound and its potential health effects and threshold limit values.

C. How We Hear

The ear is the organ that makes hearing possible. It can be divided into three sections: the external or outer ear, the middle ear, and the inner ear. Figure 7 shows the parts of the ear.

Figure 7. Anatomy of the Human Ear



(OTM/Driscoll)

The function of the ear is to gather, transmit, and perceive sounds from the environment. This involves three stages:

- Stage 1: *Modification* of the acoustic wave by the outer ear, which receives the wave and directs it to the eardrum. Sound reaches the eardrum as variations in air pressure.
- Stage 2: *Conversion and amplification* of the modified acoustic wave to a vibration of the eardrum. These vibrations are amplified by the ossicles, small bones located in the middle ear that transmit sound pressure to the inner ear. The vibrations are then transmitted as wave energy through the liquid of the inner ear (the cochlea).
- Stage 3: *Transformation* of the mechanical movement of the wave into nerve impulses that will travel to the brain, which then perceives and interprets the impulse as sound. The cilia of nerve cells in the inner ear, called *hair cells*, respond to the location of movement of the basilar membrane and, depending on their position in the decreasing radius of the spiral-shaped cochlea, activate the auditory nerve to transmit information that the brain can interpret as pitch and loudness.

Impaired function at any of these stages will affect hearing.

Additional information on the outer ear, middle ear, and inner ear is available in OSHA's eTool [Links to Noise eTool (App I:B)].

D. Hearing Loss

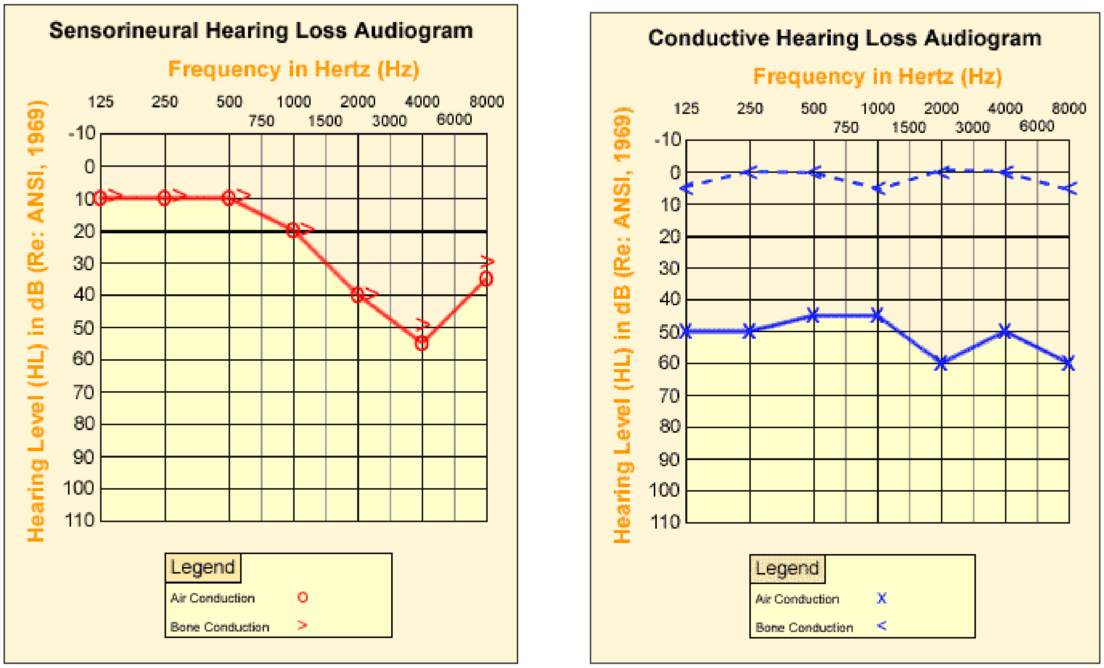
To categorize different types of hearing loss, the impairment is often described as either conductive or sensorineural, or a combination of the two.

Conductive [links to Noise eTool App I:C-1] hearing loss results from any condition in the outer or middle ear that interferes with sound passing to the inner ear. Excessive wax in the auditory canal, a ruptured eardrum, and other conditions of the outer or middle ear can produce conductive hearing loss. Although work-related conductive hearing loss is not common, it can occur when an accident results in a head injury or penetration of the eardrum by a sharp object, or by any event that ruptures the eardrum or breaks the ossicular chain formed by the small bones in the middle ear (e.g., impulsive noise caused by explosives or firearms). Conductive hearing loss may be reversible through medical or surgical treatment. It is characterized by relatively uniformly reduced hearing across all frequencies in tests of the ear, with no reduction during hearing tests that transmit sound through bone conduction.

Sensorineural [links to Noise eTool App I:C-2] hearing loss is a permanent condition that usually cannot be treated medically or surgically and is associated with irreversible damage to the inner ear. The normal aging process and excessive noise exposure are both notable causes of sensorineural hearing loss. Studies show that exposure to noise damages the sensory hair cells that line the cochlea. Even moderate noise can cause twisting and swelling of hair cells and biochemical changes that reduce the hair cell sensitivity to mechanical motion, resulting in auditory fatigue. As the severity of the noise exposure increases, hair cells and supporting cells disintegrate and the associated nerve fibers eventually disappear. Occupational noise exposure is a significant cause of sensorineural hearing loss, which appears on sequential audiograms as declining sensitivity to sound, typically first at high frequencies (above 2,000 Hz), and then lower frequencies as damage continues. Often the audiogram of a person with sensorineural hearing loss will show a “Notch” at 4,000 Hz. This is a dip in the person’s hearing level at 4,000 Hz and is an early indicator of sensorineural hearing loss. Results are the same for hearing tests of the ear and bone conduction testing. Sensorineural hearing loss can also result from other causes, such as viruses (e.g., mumps), congenital defects, and some medications.

Figure 8 shows the typical audiogram patterns for people with conductive and sensorineural hearing loss.

Figure 8. Audiograms



Additional information[Links to Noise eTool] on hearing loss is also available in OSHA's eTool. Appendices 1:C-1 and 1:C-2 of the eTool provide additional examples of conditions that cause these types of hearing loss. Also, download the NIOSH "Hearing Loss Simulator" to understand more about the effects of noise exposure and age on hearing.

It is important to note that some hearing loss occurs over time as a normal condition of aging. Termed *presbycusis,* this gradual sensorineural loss decreases a person's ability to hear high frequencies. Presbycusis can make it difficult to diagnose noise-related hearing loss in older people because both affect the upper range of an audiogram. An 8,000-Hz "Notch" in an audiogram often indicates that the hearing loss is aged-related as opposed to noise-induced. As humans begin losing their hearing, they often first lose the ability to detect quiet sounds in this pitch range.

E. Effects of Excessive Occupational Noise Exposure

Workplace noise affects the human body in various ways. The most well-known is hearing loss, but work in a noisy environment also can have other effects.

1. Auditory Effects

Although noise-induced hearing loss is one of the most common occupational illnesses, it is often ignored because there are no visible effects. It usually develops over a long period of time, and, except in very rare cases, there is no pain. What does occur is a progressive loss of communication, socialization, and responsiveness to the environment. In its early stages (when hearing loss is above 2,000 Hz), it affects the ability to understand or discriminate speech. As it progresses to the lower frequencies, it begins to affect the ability to hear sounds in general.

The primary effects of workplace noise exposure include noise-induced temporary threshold shift, noise-induced permanent threshold shift, acoustic trauma, and tinnitus. A noise-induced *temporary threshold shift* is a short-term decrease in hearing sensitivity that displays as a downward shift in the audiogram output. It returns to the pre-exposed level in a matter of hours or days, assuming there is not continued exposure to excessive noise.

If noise exposure continues, the shift can become a noise-induced permanent threshold shift, which is a decrease in hearing sensitivity that is not expected to improve over time. A *standard threshold shift* is a change in hearing thresholds of an average of 10 dB or more at 2,000, 3,000, and 4,000 Hz in either ear when compared to a baseline audiogram. Employers can conduct a follow-up audiogram within 30 days to confirm whether the standard threshold shift is permanent. Under 29 CFR 1910.95(g)(8), if workers experience standard threshold shifts, employers are required to fit or refit the workers with hearing protectors, train them in the use of the hearing protectors, and require the workers to use them. Recording criteria for cases involving occupational hearing loss can be found in 29 CFR 1904.10.

The effects of excessive noise exposure are made worse when workers have extended shifts (longer than 8 hours). With extended shifts, the duration of the noise exposure is longer and the amount of time between shifts is shorter. This means that the ears have less time to recover between noisy shifts. As a result, short-term effects, such as temporary threshold shifts, can become permanent more quickly than would occur with standard 8-hour workdays.

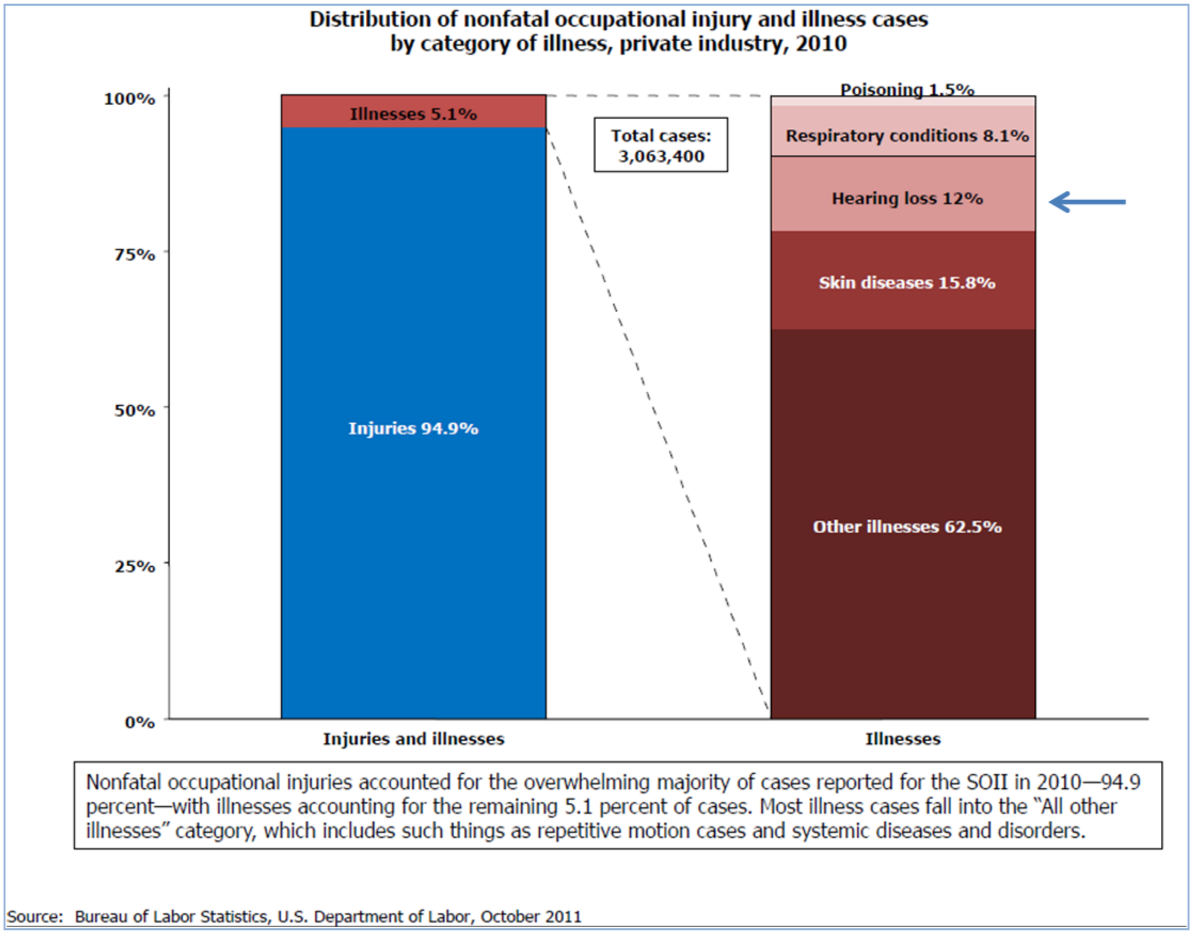
Tinnitus, or "ringing in the ears," can occur after long-term exposure to high sound levels, or sometimes from short-term exposure to very high sound levels, such as gunshots. Many other physical and physiological conditions also cause tinnitus. Regardless of the cause, this condition is actually a disturbance produced by the inner ear and interpreted by the brain as sound. Individuals with tinnitus describe it as a hum, buzz, roar, ring, or whistle, which can be short term or permanent.

Acoustic trauma refers to a temporary or permanent hearing loss due to a sudden, intense acoustic or noise event, such as an explosion.

2. Worker Illness and Injury Reports

The U.S. Bureau of Labor Statistics (BLS) publishes annual statistics for occupational injuries (including hearing loss) reported by employers as part of required recordkeeping. The BLS data show that hearing loss represented 12% of the occupational illnesses reported in 2010 (Figure 9). This represents more than 18,000 workers who experienced significant loss of hearing due to workplace noise exposure.

Figure 9. Distribution of Occupational Injury and Illness Cases



Nonfatal occupational injuries accounted for the overwhelming majority of cases reported for the SOII in 2010—94.9 percent—with illnesses accounting for the remaining 5.1 percent of cases. Most illness cases fall into the "All other illnesses" category, which includes such things as repetitive motion cases and systemic diseases and disorders.

Source: Bureau of Labor Statistics, U.S. Department of Labor, October 2011

3. *Other Effects*

Other consequences of excessive workplace noise exposure include interference with communications and performance. Workers might find it difficult to understand speech or auditory signals in areas with high noise levels. Noisy environments also lead to a sense of isolation, annoyance, difficulty concentrating, lowered morale, reduced efficiency, absenteeism, and accidents.

> *As a general guideline, the work area is too noisy if a worker cannot make himself understood without raising his or her voice while talking to a co-worker 3 feet away.*

In some individuals, excessive noise exposure can contribute to other physical effects. These can include muscle tension and increased blood pressure (hypertension). Noise exposure can also cause a stress reaction, interfere with sleep, and cause fatigue.

F. Ultrasonics

Ultrasound is high-frequency sound that is inaudible (i.e., cannot be heard) by the human ear. However, it still might affect hearing and produce other health effects. For more information, see Appendix C.

Factors to consider regarding ultrasonics include:

- The upper frequency of audibility of the human ear is approximately 15 to 20 kilohertz (kHz). This is not a set limit: some individuals may have higher or lower (usually lower) limits. The frequency limit normally declines with age.
- Most of the audible noise associated with ultrasonic sources, such as ultrasonic welders or ultrasonic cleaners, consists of subharmonics of the machine's major ultrasonic frequencies.

Example: *Many ultrasonic welders have a fundamental operating frequency of 20 kHz, a sound that is at the upper frequency of audibility of the human ear. However, a good deal of noise may be present at 10 kHz, the first subharmonic frequency of the 20-kHz operating frequency, which is audible to most people.*

G. Noise and Solvent Interactions

Animal experiments have indicated that combined exposure to noise and solvents induces synergistic adverse effects on hearing. Experimental studies have explored specific substances, including toluene, styrene, ethylbenzene, and trichloroethylene.

A number of epidemiological studies have investigated the noise–solvent relationship in humans. Overall, the evidence strongly suggests that combined exposure to noise and organic solvents can have interactive effects (either additive or synergistic), in which solvents exacerbate noise-induced impairments even though the noise intensity is below the permissible limit value. In addition to the synergistic effects with solvents, noise may also have additive, potentiating, or synergistic ototoxicity with asphyxiants (such as carbon monoxide) and metals (such as lead). See Appendix D for additional information and additional sources of information on this topic.

About IMIS Data

In reviewing IMIS data, note that the exposure levels are not necessarily typical of all worksites and occupations within an industry. Rather, IMIS provides insight regarding the noise exposure levels for workers in the jobs that OSHA monitored while visiting workplaces. Typically, OSHA identified those jobs as having some potential for noise exposure.

H. Affected Industries and Workers

1. Affected Industries

Workplace noise exposure is widespread. Analysis of OSHA's Integrated Management Information System (IMIS) data for 1979 through 2006 showed that workers were exposed to hazardous noise levels in every major industry sector.[1] Although this time span covers many years, the recent decade is well represented: 58,297 (27%) of the personal noise exposure levels in IMIS were measured in 2000 or later.

Table II–2 through II–5 summarize the noise measurements obtained by OSHA in each major industry sector. These tables also present the median noise levels and the percentage of noise measurements

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[1] *This period encompasses the entire IMIS record for noise through 2006. The data were first inspected, and individual records with internal inconsistencies were removed. One example of an inconsistency is a record coded as a personal noise result with units other than dB or percentage dose (e.g., a value coded as a noise result with units inadvertently entered as mg/m^3 would have been removed before analysis). The final dataset contained 224,339 personal noise exposure records.*

over either the action level (AL), 85 dBA, or the permissible exposure limit (PEL), 90 dBA.[2] The data appear in separate tables because OSHA uses different criteria for the AL and PEL. Each noise measurement entered into IMIS is related to either the AL or the PEL, depending on the threshold level designated during dosimeter setup.

OSHA obtained the vast majority of IMIS noise exposure records in manufacturing facilities. Manufacturing is among the loudest industries, with 43% of the IMIS noise samples exceeding the PEL of 90 dBA time-weighted average (TWA). In addition, 47% of the samples taken in the construction industry exceeded the PEL. The IMIS exposure records for the manufacturing industry are presented by three-digit North American Industrial Classification System (NAICS) codes in two tables (Table II–4 and II–5) (relative to the AL and PEL, respectively).

In addition to median decibels and percent over the PEL, Table II–5 shows the distribution of manufacturing industry dosimetry measurements at the PEL and higher (by decibel level).

Table II–2. Noise Measurements Exceeding the AL, IMIS (1979–2006)

Industry	Total Records	Median dBA	% Over the AL
Agriculture	206	86.83	64%
Utilities	396	82.82	36%
Mining	40	88.04	78%
Construction	1,382	86.91	62%
Manufacturing	80,120	87.32	67%
Wholesale/retail	2,908	85.61	54%
Transportation	1,190	82.63	36%
Finance	71	78.20	27%
Services	5,107	83.90	44%
All other private sector	34	90.58	88%
Government	935	83.68	44%

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[2] *Please note that workplace sampling is required, and the historical data displayed should not be used to justify whether or not to monitor for overexposure to noise.*

Table II–3. Noise Measurements Exceeding the PEL, IMIS (1979–2006)

Industry	Total Records	Median dBA	% Over the PEL
Agriculture	354	86.80	33%
Utilities	513	81.19	19%
Mining	56	85.55	27%
Construction	3,133	89.22	47%
Manufacturing	116,983	88.74	43%
Wholesale/retail	3,342	86.67	33%
Transportation	1,261	80.89	16%
Finance	88	75.20	15%
Services	5,167	83.21	23%
All other private sector	231	89.76	47%
Government	822	82.29	23%

Table II–4. Manufacturing Industry Noise Measurements Obtained Using AL Criteria, IMIS (1979–2006)

NAICS	NAICS Title	Total Records	Median dBA	% Over the AL
311	Food Manufacturing	6,100	88.60	79%
312	Beverage and Tobacco Product Manufacturing	34	87.39	85%
314	Textile Product Mills	1,749	87.32	69%
315	Apparel Manufacturing	817	82.73	36%
316	Leather and Allied Product Manufacturing	406	86.56	61%
321	Wood Product Manufacturing	9,836	89.34	79%
322	Paper Manufacturing	2,879	86.90	65%
323	Printing and Related Support Activities	2,256	84.08	43%
324	Petroleum and Coal Products Manufacturing	217	86.32	57%
325	Chemical Manufacturing	1,762	85.56	54%
326	Plastics and Rubber Products Manufacturing	6,381	86.39	61%
327	Nonmetallic Mineral Product Manufacturing	4,034	87.00	63%
331	Primary Metal Manufacturing	6,306	89.25	80%
332	Fabricated Metal Product Manufacturing	15,248	87.60	69%
333	Machinery Manufacturing	7,514	85.47	53%
334	Computer and Electronic Product Manufacturing	219	85.00	50%
335	Electrical Equipment, Appliance, and Component Manufacturing	2,679	85.84	57%
336	Transportation Equipment Manufacturing	5,660	87.38	67%
337	Furniture and Related Product Manufacturing	3,867	86.83	64%
339	Miscellaneous Manufacturing	2,156	85.62	55%

Table II–5. Manufacturing Industry Noise Measurements Obtained Using PEL Criteria, IMIS (1979–2006)

NAICS	NAICS Title	Total Records	Median dBA	% Over the PEL		% Noise Measurements in dB Range

						90 to 94 dB	95 to 100 dBA	100 to 104 dBA	105 dBA+
311	Food Manufacturing	9,070	89.51	47%		34%	11%	2%	0%
312	Beverage and Tobacco Product Manufacturing	40	85.64	25%		25%	0%	0%	0%
314	Textile Product Mills	2,790	89.40	47%		31%	11%	4%	1%
315	Apparel Manufacturing	828	81.32	12%		9%	4%	0%	0%
316	Leather and Allied Product Manufacturing	551	89.71	48%		35%	11%	2%	0%
321	Wood Product Manufacturing	16,330	91.72	60%		30%	22%	7%	1%
322	Paper Manufacturing	4,344	87.90	38%		28%	8%	1%	0%
323	Printing and Related Support Activities	2,620	82.22	17%		15%	2%	0%	0%
324	Petroleum and Coal Products Manufacturing	376	86.72	27%		22%	5%	1%	0%
325	Chemical Manufacturing	2,611	85.20	24%		18%	5%	1%	0%
326	Plastics and Rubber Products Manufacturing	7,627	86.07	30%		21%	6%	2%	0%
327	Nonmetallic Mineral Product Manufacturing	5,772	88.39	41%		26%	10%	4%	1%
331	Primary Metal Manufacturing	13,196	91.32	58%		34%	19%	5%	1%
332	Fabricated Metal Product Manufacturing	20,549	88.86	44%		27%	13%	3%	1%
333	Machinery Manufacturing	10,156	86.22	31%		21%	8%	2%	0%
334	Computer and Electronic Product Manufacturing	360	85.28	29%		23%	6%	1%	0%
335	Electrical Equipment, Appliance, and Component Manufacturing	3,889	86.54	32%		22%	8%	2%	0%
336	Transportation Equipment Manufacturing	7,812	88.36	41%		24%	12%	4%	1%
337	Furniture and Related Product Manufacturing	5,292	87.83	38%		27%	9%	2%	0%
339	Miscellaneous Manufacturing	2,770	86.78	35%		24%	8%	3%	0%

2. *Historically Affected Jobs in General Industry*

Noise is a potential hazard for most jobs that involve abrasive or high-power machinery, impact of rapidly moving parts (product or machinery), or power tools. According to IMIS noise measurements, workers in certain occupations within specific industries are exposed to excessive noise more frequently than others. While many jobs have noise exposure, historically, some of the occupations with the most extreme exposures (listed by Standard Industrial Classification, or SIC) have included:

- ***SIC 20 and 21* (food, beverages, and tobacco industry):** slaughterers and meat packers.
- ***SIC 22, 23, and 31* (textile, apparel, and leather industry):** textile winders, shoe and leather workers and repairers, textile knitting and weaving machine operators.
- ***SIC 24* (lumber and wood products industry, including logging and lumber mill operations):** most occupations (except cabinetmakers).

- ***SIC 25* (furniture and fixtures industry):** machine feeders.
- ***SIC 26* (paper and paper industry):** paper goods machine operators.
- ***SIC 28 through 30* (printing and publishing, chemicals and petroleum, and plastics and rubber industries):** chemical equipment operators (SIC 28 and 29), laborers and freight movers (SIC 28 and 29), grinding machine operators (SIC 30), and helpers (SIC 30).
- ***SIC 32* (nonmetallic minerals industry):** inspectors, testers, and sorters; extruding, forming, and pressing machine operators; hoist and winch operators; unspecified “operators.”
- ***SIC 33 and 34* (primary metal and fabricated metal products industries):** forging machine operators, grinding and lapping machine operators, and welders.
- ***SIC 35 through 39* (various equipment manufacturers):** milling and planing machine operators, coil winders and tapers, forging machine operators, grinding and lapping machine operators, and abrasive blasters.

3. <u>Summary of Construction Industry Noise Exposure by Trade and Activity</u>

Table II–6. Summary of Average TWA Construction Noise Exposure from University of Washington Noise Monitoring Research

Trades Monitored	Number of Measurements	OSHA TWA Mean dBA	OSHA TWA Percent >90 dBA
Brick/Tile Worker	28	75.2	8
Bricklayer	15	83.8	4
Carpenter	82	82.3	11
Cement Mason	26	78.9	10
Electrician	208	80.0	4
Insulation Worker	22	74.5	5
Iron Worker	59	82.1	10
Laborer	58	83.3	14
Operating Engineer	44	83.5	14
Sheet Metal Worker	38	80.4	0

Source: Adapted from Seixas and Neitzel, 2002. (Submittal to OSHA’s Advance Notice of Proposed Rulemaking Docket H-011G).

Table II–7. Task-Specific Average Noise Levels by Construction Trade

TRADE (Tasks)	Average dBA for Each Task Event		TRADE (Tasks)	Average dBA for Each Task Event
CARPENTER				
Operating work vehicle	80.1		Wood framing	91.0
Break, rest, lunch, cleanup	87.8		Building forms	92.9
Shop work	88.8		Stripping forms	94.8
Interior finish	89.4		Welding	94.9
Manual material handling	89.4		“Other” tasks	95.3
Layout	90.5			

Table II–7. Task-Specific Average Noise Levels by Construction Trade

TRADE (Tasks)	Average dBA for Each Task Event		TRADE (Tasks)	Average dBA for Each Task Event
CEMENT MASONS				
Floor leveling	70.4		Placing concrete	87.8
Break, rest, lunch, cleanup	83.3		Repairing concrete	88.9
Finishing concrete	84.4		Patching concrete	92.6
Setting forms	86.5		“Other” tasks	93.1
Manual material handling	86.5		Grinding	95.2
ELECTRICIANS				
Operating work vehicle	79.2		Installing slab conduit	91.0
Sheet metal work	81.6		Installing wall conduit	91.1
Manual material handling	86.5		Installing cable tray	91.8
Panel wiring, installing fixtures	87.0		Pulling wire	95.6
Break, rest, lunch, cleanup	87.0		Installing trench conduit	95.8
“Other” tasks	90.5			
INSULATION WORKERS				
Sheet metal work	77.8		“Other” tasks	83.4
Applying insulation by hand	83.0		Manual material handling	84.6
Break, rest, lunch, cleanup	83.3			
IRONWORKERS				
Operating forklift	87.1		Manual materials handling	94.3
Setting forms	87.9		“Other” tasks	94.7
Operating work vehicle	88.5		Tying and placing rebar	95.5
Erecting iron	91.8		Break, rest, lunch, cleanup	95.6
Grinding	91.9		Welding and burning	98.4
Rigging	93.6		Laying metal deck	99.6
Bolt up	93.7			
LABORERS				
Layout	80.1		Placing concrete	91.5
Manual material handling	82.7		Stripping forms	91.7
Interior finish	85.2		Building forms	92.1
Operating forklift	85.3		Break, rest, lunch, cleanup	92.3
Finishing concrete	85.3		Rigging	92.6
Grouting	86.1		“Other” tasks	95.4
Wood framing	86.5		Demolition	99.3
Floor leveling	87.5		Chipping concrete	102.9
MASONRY TRADES				

Table II–7. Task-Specific Average Noise Levels by Construction Trade

TRADE (Tasks)	Average dBA for Each Task Event	TRADE (Tasks)	Average dBA for Each Task Event
Bricking, blocking, tiling	90.2	Manual material handling	88.4
Break, rest, lunch, cleanup	86.4	"Other" tasks	94.4
Forklift operation	88.5	Pointing, cleaning, caulking	91.6
Grinding	97.0	Weatherproofing	84.2
Grouting, tending, mortaring	91.4	Work vehicle operation	96.3
OPERATING ENGINEERS			
Break, rest, lunch, cleanup	85.7	Layout	89.3
Rigging	86.6	Grade checking	89.6
"Other" tasks	86.9	Welding	91.2

Source: Adapted from Seixas and Neitzel, 2004.

I. Regulations and Standards

1. *Brief History of Occupational Noise Standards*

The Occupational Safety and Health Act (OSH Act) of 1970 built upon earlier attempts in the United States to regulate noise hazards associated with occupational hearing loss. In 1969, the Walsh-Healey Public Contract Act added the Occupational Noise Exposure Standard as an amendment, basing it on the American Conference of Governmental Industrial Hygienists (ACGIH) noise threshold limit value (TLV) in effect at that time. This set an 8-hour TWA of 90 dBA and a 5-dBA exchange rate for any company with a federal contract worth more than $10,000. This effort to reduce occupational noise hazards was not far-reaching but was a first attempt to regulate noise hazards. Adopted into the OSH Act in 1970, it served as the basis for OSHA's Noise standard. The same 8-hour TWA and exchange rate are still used by OSHA today.

Also in 1969, the Bureau of Labor Standards promulgated an occupational construction noise standard under the Construction Safety Act, which was later adopted by OSHA in 1971. Soon after, in 1972, NIOSH published recommendations for an OSHA occupational noise standard, which included a recommended 8-hour TWA exposure limit of 85 dBA and a 5-dBA exchange rate. However, in 1973, OSHA's Standards Advisory Committee maintained the 90-dBA 8-hour TWA with a 5-dBA exchange rate. Even though noise energy exposure doubles every 3 dB, OSHA thought it important to account for the time during the workday that a worker was not exposed to noise hazards. At the time, using a 5-dB exchange rate was viewed as a sufficient way to account for this.

In 1974, OSHA published a proposed occupational noise standard, which included a requirement for employers to provide a hearing conservation program for workers exposed to an 8-hour TWA of 85 dBA or more. This provision was adopted as part of the amendments of 1981 and 1983. The 8-hour TWA for OSHA's noise standard remained at 90 dBA with a 5-dBA exchange rate and included a requirement for a hearing conservation program for workers exposed to an 8-hour TWA of at least 85 dBA. While OSHA provided requirements for hearing conservation programs in general industry, the construction industry standard remained less specific in that regard. More recently, in the 2002 recordkeeping standard (29 CFR Part 1904), OSHA clarified the criteria for reporting cases involving occupational hearing loss.

In 1979, the U.S. Environmental Protection Agency (EPA) developed labeling requirements for hearing protectors, which required hearing protector manufacturers to measure the ability of their products to reduce noise exposure—called the noise reduction rating (NRR). OSHA adopted the NRR but later recognized that the NRR listed on hearing protectors often did not reflect the actual level of protection, which likely was lower than indicated on the label because most workers were not provided with fit-testing, and donning methods in a controlled laboratory setting were not representative of the donning methods that workers used in the field. EPA is considering options for updating this rule. See Appendix E for current information on NRRs and hearing protection labeling requirements. In special cases, noise exposure originates from noise-generating headsets. See Appendix F for a discussion of the techniques used to evaluate the noise exposure levels of these workers.

2. *OSHA Noise Standards*

General Industry: 29 CFR 1910.95, "Occupational Noise Exposure." This standard is designed to protect general industry workers, such as those working in the manufacturing, utilities, and service sectors. The General Industry standard establishes permissible noise exposures, requires the use of engineering and administrative controls, and sets out the requirements of a hearing conservation program. Paragraphs (c) through (n) of the General Industry standard do not apply to the oil and gas well-drilling and servicing operations; however, paragraphs (a) and (b) do apply.

The general industry noise standard contains two noise exposure limit tables. Each table serves a different purpose:

- ***Table G-16:*** This table applies to the engineering and administrative controls section, which provides a 90-dBA criterion for an 8-hour TWA PEL and is measured using a 90-dBA threshold (i.e., noise below 90 dBA is not integrated into the TWA). This table limits short-term noise exposure to a level not greater than 115 dBA (for up to 15 minutes).

- ***Table G-16A:*** This table, presented in Appendix A of 29 CFR 1910.95, provides information (e.g., reference durations) useful for calculating TWA exposures when the workshift noise exposure is composed of two or more periods of noise at different levels. Although this table lists noise levels exceeding 115 dBA, these listings are only intended as aids in calculating TWA exposure levels; the listings for higher noise exposure levels do not imply that these noise levels are acceptable.

Additional information (Links to App II:A of the Noise eTool) on the general industry standard is also available.

Construction Industry: Noise in construction is covered under 29 CFR 1926.52, "Occupational Noise Exposure," and 29 CFR 1926.101, "Hearing Protection." Under 29 CFR 1926.52, employers are required to use feasible engineering or workplace controls when workers are exposed to noise at or above permissible noise exposures, which are listed in Table D-2 [1926.52(d)(1)]. The PEL of 90 dBA for an 8-hour TWA is measured using a 90-dBA threshold (this is the only threshold used for the construction industry noise standards). 29 CFR 1926.101 requires employers to provide hearing protectors that have been individually fitted (or determined to fit) by a competent person if it is not feasible to reduce noise exposure below permissible levels using engineering or workplace controls.

The requirements for permissible noise exposures and controls under the Construction standard are the same as those under the general industry standard (1910.95), though other requirements differ. Continuing effective hearing conservation programs are required in all cases where the sound levels exceed the values shown in Table D-2 (1926.52(d)(1)). When a hearing conservation program is required, employers must incorporate as many elements listed in the Standard Interpretation titled "Effective Hearing Conservation Program Elements for Construction Industry" (08/04/1992) into their program as feasible.

Agricultural Worksites: Although there is no standard for occupational noise exposure in agriculture, the evaluation and control methods discussed in this chapter are still valid. For any potential citations, CSHOs must use the guidance in the *Field Operations Manual*.

Maritime Worksites: Marine terminals and longshoring operations fall under the requirements of the general industry noise standard; therefore, employers in such operations must meet the elements of the general industry Hearing Conservation Amendment, 29 CFR 1910.95(c) through (o).

J. Noise Exposure Controls—Overview

Noise controls should minimize or eliminate sources of noise; prevent the propagation, amplification, and reverberation of noise; and protect workers from excessive noise exposure. Ideally, the use of engineering controls should reduce noise exposure to the point where the risk to hearing is significantly reduced or eliminated.

Engineering and administrative controls are essential to an effective hearing loss prevention program. They are technologically feasible for most noise sources, but their economic feasibility must be determined on an individual basis. In some instances the application of a relatively simple noise-control solution reduces the hazard to the extent that the other elements of the program, such as audiometric testing and the use of hearing protection devices, are no longer necessary. In other cases, the noise reduction process may be more complex and must be accomplished in stages over a period of time. Even so, with each reduction of a few decibels, the risk of hearing loss is reduced, communication is improved, and noise-related annoyance is reduced.

The first step in noise control is to identify the noise sources and their relative importance. This can be difficult in an industrial setting with many noise sources. It can be accomplished through several methods used together: obtain a frequency spectrum from an octave band analyzer, turn various components in the factory on and off or use temporary mufflers or enclosures to isolate noise sources, and probe areas close to equipment with a sound level meter to pinpoint areas where sound is dominant. These measures will aid in identifying the sound sources that affect workers the most and should be prioritized when implementing noise controls. Once the noise sources have been identified, it is possible to proceed in choosing an engineering control, administrative control, or a form of personal protective equipment to reduce the noise level if noise exposure is too high (Driscoll, Principles of Noise Control).

1. Hierarchy of Controls for Noise

The hierarchy of controls for noise can be summarized as: 1) prevent or contain the escape of the hazardous workplace agent at its source (engineering controls), 2) control exposure by changing work schedules to reduce the amount of time any one worker spends in the hazard area (administrative controls), and 3) control the exposure with barriers between the worker and the hazard (personal protective equipment). This hierarchy highlights the principle that the best prevention strategy is to eliminate exposure to hazards that can lead to hearing loss. Corporations that have started buy-quiet programs are moving toward workplaces where no harmful noise will exist. Many companies are automating equipment or setting up procedures that can be managed by workers from a quiet control room free from harmful noise. When it is not possible to eliminate the noise hazard or relocate the worker to a safe area, the worker must be protected with personal protective equipment.

[Note: See CPL 02-00-150 - Field Operations Manual (FOM) for current citation policy when addressing engineering/administrative controls versus hearing conservation program.]

2. *Noise-Control Engineering—Concepts and Options*

The rest of this section, until the discussion of administrative controls, presents information adapted from material developed under contract for the Noise eTool by Dennis Driscoll in 2002.

Much industrial noise can be controlled through simple solutions. It is important, however, that all individuals administering abatement projects have a good understanding of the principles of noise control and proper use of acoustical materials. Industrial hygienists, safety professionals, facility engineers, and others can make significant progress in reducing equipment noise levels and worker noise exposures by combining their knowledge of acoustics with an understanding of the manufacturing equipment and/or processes.

Reducing excessive equipment noise can be accomplished by treating the source, the sound transmission path, the receiver, or any combination of these options. Descriptions of these control measures follow.

i) Source Treatment

The best long-term solution to noise control is to treat the root cause of the noise problem. For source treatment to be effective, however, a comprehensive noise-control survey usually needs to be conducted to clearly identify the source and determine its relative contribution to the area noise level and worker noise exposure. At least four methods exist for treating the source: modification, retrofit, substitution, and relocation.

Modification

For the most part, industrial noise is caused by mechanical impacts, high-velocity fluid flow, high-velocity air flow, vibrating surface areas of a machine, and vibrations of the product being manufactured.

Mechanical Impacts

To reduce noise caused by mechanical impacts, the modifications outlined below should be considered. For any of these options to be practical, however, they must not adversely affect production:

- Reduce excessive driving forces.
- Reduce or optimize speed.
- Minimize distance between impacting parts.
- Dynamically balance rotating equipment.
- Maintain equipment in good working order.
- Use vibration isolation when applicable.

High-Velocity Fluid Flow

High-velocity fluid flow can often create excessive noise as the transported medium passes through control valves or simply passes through the piping. Frequently, noise is carried downstream by the fluid, and/or vibratory energy is transferred to the pipe wall. A comprehensive acoustical survey can isolate the actual noise source so that the appropriate noise-control measures can be identified. When deemed practical, some effective modifications for high-velocity fluid-flow noise include:

- Locate control valves in straight runs of pipe.
- Locate all L's and T's at least 10 pipe diameters downstream of a valve.
- Ensure that all pipe cross-section reducers and expanders are at an included angle of 15 to 20 degrees.
- Eliminate sudden changes of direction and influx of one stream into another.
- Limit the fluid-flow velocity to a maximum of 30 feet per second for liquids.
- Maintain laminar flow for liquids (keep the Reynolds Number less than 2,000).
- When vibratory energy is transferred to the pipe wall, use flex connectors and/or vibration isolation for the piping system and/or acoustical insulation.
- When excessive noise in the fluid cannot be controlled by any of the options above, install an in-line silencer.

High-Velocity Air Flow (Pneumatic or Compressed Air Systems)

One of the most common noise sources within manufacturing equipment is pneumatic- or compressed-air-driven devices such as air valves, cylinders, and solenoid valves. High-velocity air is also a major contributor to worker noise exposure where hand-held air wands or guns are used to remove debris from work areas. Finally, compressed air nozzles are often used to eject parts from a machine or conveyor line. All these forms of pneumatic systems generate undesirable noise as the high-velocity air mixes with the atmospheric air, creating excessive turbulence and particle separation. It is important to note that the intensity of sound is proportional to the air flow velocity raised to the 8th power. Therefore, as a source modification, it is recommended that the air-pressure setting for all pneumatic devices be reduced or optimized to as low a value as practical. As a general guideline, the sound level can be reduced by approximately 6 dBA for each 30% reduction in air velocity. Additional noise controls for high-velocity air are presented in the retrofit and relocation sections below.

Surface- or Panel-Radiated Noise

Machine casings or panels can be a source of noise when sufficient vibratory energy is transferred into the metal structure and the panel is an efficient radiator of sound. Typically, machine casings or large metal surface areas have the potential to radiate sound when at least one dimension of the panel is longer than one-quarter of the sound's wavelength. Conducting a thorough noise-control survey will help in identifying the source of vibration and in determining the existence of any surface-radiated sound. When a machine casing or panel is a primary noise source, the most effective modification is to reduce its radiation efficiency. The following noise-control measures should be considered:

- Divide vibrating surface areas into smaller sections.
- Add stiffeners to large unsupported metal panels such as rectangular ducts or large machine casing sections.
- Add small openings or perforations to large, solid surfaces.
- Use expanded metal, when practical, in place of thin metal panels.

- Add vibration damping material.

Retrofit Products and Applications

A variety of commercially available acoustical products and applications can be applied on or relatively close to noise sources to minimize noise. The *Noise and Vibration Control Product Manufacturer Guide* should be consulted for a partial list of the manufacturers of these products and applications. Specific retrofit materials and/or applications include the following:

Vibration Damping

Vibration damping materials are an effective retrofit for controlling resonant tones radiated by vibrating metal panels or surface areas. In addition, this application can minimize the transfer of high-frequency sound energy through a panel. The two basic damping applications are free-layer and constrained-layer damping. Free-layer damping, also known as extensional damping, consists of attaching an energy-dissipating material on one or both sides of a relatively thin metal panel. As a guide, free-layer damping works best on panels less than ¼-inch thick. For thicker machine casings or structures, the best application is constrained-layer damping, which consists of damping material bonded to the metal surface covered by an outer metal constraining layer, forming a laminated construction. Each application can provide up to 30 dB of noise reduction.

It is important to note that the noise reduction capabilities of the damping application are essentially equal, regardless of which side it is applied to on a panel or structure. Also, for practical purposes, it is not necessary to cover 100% of a panel to achieve a significant noise reduction. For example, 50% coverage of a surface area will provide a noise reduction that is roughly 3 dB less than 100% coverage. In other words, assuming that 100% coverage results in 26 dB of attenuation, 50% coverage would provide approximately 23 dB of reduction, 25% coverage would produce a 20-dB decrease, and so on. Next, for free-layer damping treatments, it is recommended that the application material be at least as thick as the panel or base layer to which it is applied. For constrained-layer damping, the damping material again should be the same thickness as the panel; however, the outer metal constraining layer may be half the thickness of the base layer.

Finally, just because a surface area vibrates, it is not safe to assume it is radiating significant noise. If fact, probably less than 5% of all vibrating panels produce sufficient airborne noise to be of concern in an occupational setting. For damping materials to be successful, at a minimum, the two following conditions must be satisfied (determine by a comprehensive noise-control survey):

1) The panel being treated must be capable of creating high noise levels in the first place.

2) The structure must be vibrating at one of its natural frequencies or normal modes of vibration.

When selecting the right type of damping material, it is recommended that the person making the decision refer to the expertise of the product manufacturer or their designated representative(s). Typically, the supplier will need to obtain specific information from the buyer, such as the temperature and size of the surface area to be treated and the substrate thickness. The supplier will then use the input data to select the most effective product for the particular application. The vendor can also provide the buyer with estimates of noise reduction and costs for procuring the material.

Some common applications for vibration damping include:

- Hopper bins and product chutes

- Resin pellet transfer lines (provided they are metal pipe)
- Thin metal machine casings or panels that radiate resonant tones
- Metal panels being impacted by production parts (e.g., drop bins)
- Metal enclosure walls
- Fan and blower housings
- Gear box casings (constrained-layer damping required for thick substrates)

Vibration Isolation

Most industrial equipment vibrates to some extent. Determining whether or not the vibrating forces are severe enough to cause a problem is accomplished through a comprehensive noise and/or vibration survey. As machines operate, they produce either harmonic forces associated with unbalanced rotating components or impulsive forces attributed to impacts such as punch presses, forging hammers, and shearing actions. Excessive noise can be one result of the vibratory energy produced; however, potential damage to the equipment itself, the building, and/or the product being manufactured is more likely. Quite often, vibration problems are clearly identified by predictive-maintenance programs that exist within most industrial plants.

Assuming that the root cause or source cannot be effectively modified, the next option for controlling undesirable vibration is to install vibration isolation. Isolators come in the form of metal springs, elastomeric mounts, and resilient pads. These devices serve to decouple the relatively “solid” connection between the source and the recipient of the vibration. As a result, instead of the vibratory forces being transmitted to other machine components or the building, they are readily absorbed and dissipated by the isolators.

When selecting the appropriate isolation device(s), the person making the decision should consider the expertise of trained professionals. It is critical to note that improper selection and installation of isolators can actually make a noise and vibration problem worse. Many manufacturers of vibration isolation equipment have useful websites for troubleshooting problems and finding solutions (see the *Noise and Vibration Control Product Manufacturer Guide* for a partial list of manufacturers).

Some common applications for vibration isolation are:

- Pipe hangers
- Heating, ventilation, and air conditioning (HVAC) equipment
- Flex connectors for piping systems
- Rotating machinery mounts and bases for electric motors, compressors, turbines, fans, pumps, and other similar equipment
- Impact equipment such as punch presses, forging hammers or hammer mills, and shearing presses
- Enclosure isolation

Silencers

Silencers are devices inserted in the path of a flowing medium, such as a pipeline or duct, to reduce the downstream sound level. For industrial applications, the medium typically is air. There are basically four types of silencers: dissipative (absorptive), reactive (reflective), combination of dissipative and reactive, and pneumatic or compressed air devices. This section will address the absorptive and reflective type; a separate section will discuss the pneumatic or compressed air silencers. The type of silencer required will depend on the spectral content of the noise source and operational conditions of the source itself.

Dissipative silencers use sound-absorbing materials to surround or encompass the primary airflow passage. These silencers' principal method of sound attenuation is by absorption. The advantages and disadvantages of dissipative silencers include:

Advantages:

- Very good medium-frequency (500–2,000 Hz) to high-frequency (>2,000 Hz) attenuation.
- Low-to-medium pressure loss.
- They are a standard design.

Disadvantages:

- Poor low-frequency (<500 Hz) attenuation.
- Very sensitive to moisture and particulates in the air stream.
- They can be a difficult retrofit.

Reactive silencers use sound reflections and large impedance changes (area variations) to reduce noise in the airflow. The principal method of attenuation is through sound reflection, which cancels and interferes with the oncoming sound waves. The advantages and disadvantages of reactive silencers include:

Advantages:

- Good low-frequency attenuation.
- Can be designed to minimize pure tones.
- Can be used in high-temperature and corrosive environments.

Disadvantages:

- Usually there is a high cost when fabricated from corrosion-resistant materials.
- Sensitive to particulate and moisture contamination.
- Relatively narrow range of attenuation.
- High-to-medium pressure loss.
- They can be a difficult retrofit.
- They can be expensive because they are typically a custom design.

The combination dissipative and reactive silencer is essentially a reactive silencer with sound-absorption added to provide high-frequency attenuation capabilities. The advantages and disadvantages are similar to those listed for each type.

To determine which type of silencer is best for a particular application, a trained professional should be consulted. The manufacturer or a designated representative will need to work closely with the facility engineering representative(s) to clearly identify all operational and physical constraints. The *Noise and Vibration Control Product Manufacturer Guide* contains a partial list of silencer manufacturers and their websites.

Typical applications for silencers include:

- High-pressure gas pressure regulators, air vents, and blow downs
- Internal combustion engines
- Reciprocating compressors
- Centrifugal compressors
- Rotary positive displacement blowers
- Rotary vacuum pumps and separators
- Industrial fans
- HVAC systems
- Totally enclosed, fan-cooled electric motors
- Gas turbines

Pneumatic or Compressed Air Silencers

In the earlier High-Velocity Air Flow section, it was mentioned that pneumatic or compressed air is a very common noise source in manufacturing plants. Assuming sufficient noise reduction cannot be achieved by optimizing the air-pressure setting, the second step for controlling this class of noise source is to use commercially available silencers.

For retrofitting pneumatic devices, selecting the appropriate silencer type is critical for this control measure to succeed over time. If the source is a solenoid valve, air cylinder, air motor, or some other device that simply exhausts compressed air to the atmosphere, then a simple diffuser-type silencer will suffice. The disadvantage of these types of devices is that they can cause unacceptable back pressure. Therefore, when selecting a diffuser silencer, it is important that the pressure-loss constraints for the particular application be satisfied. All diffuser silencers can provide 15 to 30 dB of noise reduction.

For compressed air systems that perform a service or specific task, such as ejecting parts or blowing off debris, a number of devices are available for retrofit at the point of discharge. Another typical application for compressed air is in blow-off guns or air wands. These tools come in a variety of sizes and shapes and can generate noise levels of 90 dBA to 115 dBA, depending on the velocity of the air and the surface area they contact. It is recommended that the *Noise and Vibration Control Product Manufacturer Guide* be consulted for a list of available suppliers. Usually, the manufacturer websites provide sufficient information and self-help guidance to enable selection of the most appropriate device for retrofit.

It should be noted that silencers for pneumatic or compressed air systems normally require routine inspection, maintenance, and/or replacement, as these silencers will plug up with debris, be removed by operators, or occasionally become damaged over time. If these devices are kept in good working order, however, excessive high-velocity air noise in manufacturing facilities technically should not be an issue.

The major problem with air guns is that, like other pneumatic or compressed air systems used to drive and motivate machinery, equipment operators will often increase the air pressure in an attempt to create more blow-off power. Earlier, in the High-Velocity Air Flow section, it was noted that the intensity of noise is proportional to the 8th power of the air velocity. Consequently, a higher pressure setting will significantly increase the noise level. In addition, when a compressed air silencer is installed on machines, many operators will remove or suppress this device to maintain the perception of having the higher level of power to which they are accustomed, which is based on their subjective assessment of the sound level. To prevent unnecessary or unauthorized air adjustments by the process or equipment operators, air-pressure regulators should be set and locked to ensure that they cannot be modified without a supervisor's consent, and operators should be educated and trained in determining whether the power is adequate.

Substitute for the Source

Another source treatment involves using alternative equipment or materials that are inherently quieter yet still meet the production needs. This option is called substitution for the source. Often, equipment manufacturers have alternative devices that perform the same function at lower noise levels. These quieter devices typically cost more, however, as they require tighter tolerances and more precision as they are manufactured. Therefore, when applicable, it will be necessary for the user to determine if the noise reduction benefit justifies the additional cost. The supplier's or the manufacturer's website should be consulted to learn if quieter equipment is available and at what additional cost. Examples where alternative and quieter equipment may exist include:

- Gears
- Bearings
- Fans or blowers
- Control valves
- Air compressors
- Conveyors
- Electric motors
- Pumps

There might also be opportunities to replace equipment with different devices or materials. Here, the user should investigate whether alternative and quieter ways exist to accomplish the task or intended service. Where practical, examples of source substitution include:

- Using belt drives over gears.
- Using belt conveyors instead of rollers.
- Employing mechanical parts ejectors or pickups over compressed air.
- Substituting quiet air nozzles for open-ended pipe or air lines.
- Replacing omnidirectional fans on electric motors with unidirectional aerodynamic fans.
- Substituting metal or steel parts with materials having high internal-damping properties, such as wood, nylon, or stiff plastic components.
- Using perforated or mesh panels in place of solid panels.

Relocation of the Source

Controlling noise by locating or relocating the source should be considered for the design and equipment layout of new plant areas and for reconfiguring existing production areas. A simple rule to follow is to keep machines, processes, and work areas of approximately equal noise level together, and separate particularly noisy and quiet areas by buffer zones having intermediate noise levels. In addition, a single noisy machine should not be placed in a relatively quiet, populated area. Reasonable attention to equipment layout from an acoustical standpoint will not eliminate all noise problems, but it will help minimize the overall background noise level and provide more favorable working conditions.

Here are some examples of source relocation:

- Rerouting all pneumatic or compressed air discharge ports from outside to the inside of machine cabinets.
- Using pipe extensions to relocate pneumatic exhausts away from the immediate area and into unoccupied spaces.
- Locating blowers (e.g., dust collectors, vacuum pumps) on the building roof or in routinely unoccupied areas, and using extended ductwork to service the process or equipment of concern.
- Conducting reclaim or material scrap grinding in routinely unoccupied areas.

ii) Path Treatment

Assuming that all available options for controlling noise at the source have been exhausted, the next step in the noise-control hierarchy is to determine ways to treat the sound transmission path. Typical path treatments include adding sound-absorption materials to the room or equipment surfaces, installing sound transmission loss materials between the source and receiver(s), using acoustical enclosures or barriers, or any combination of these treatments. A description of each treatment option follows.

Sound-Absorption Materials

Sound-absorption materials are used to reduce the buildup of sound in the reverberant field. The reverberant field exists at all locations where sound waves reflect off relatively hard surfaces, such as walls, ceilings, or inside enclosures, and then combine with the sound waves propagating directly from the noise source. The added effect produces a higher noise level than the level that would have existed in the absence of any reflecting surfaces.

A user must understand and apply the principles of room acoustics when adding sound-absorbing materials to the walls and ceiling to reduce the noise levels throughout the room. If a user installs sound absorption in a room without putting any science behind the decision, then the likelihood of success will be tenuous at best.

Using sound absorption on a room’s surfaces has both advantages and disadvantages:

Advantages:

- Provides a significant reduction in the reverberant sound buildup, especially in pre-existing hard surface spaces.
- Works best in relatively small volume rooms or spaces (<10,000 ft^2).
- Requires minimal maintenance after initial installation.
- Can be purchased and installed at a reasonable cost.
- Works best on middle- to high-frequency noise.

Disadvantages:

- Room treatment does nothing to address the root cause of the noise problem.
- Does not reduce noise resulting from direct sound propagation.
- The absorption can deteriorate over several years and may need periodic replacement (perhaps every 7 to 10 years).
- Rarely does this form of treatment eliminate the need for hearing protection.

Keep in mind that adding sound absorption to decrease the reflected or reverberant noise in a room will do nothing to reduce the acoustical energy propagating by direct line of sight from the source. Therefore, it is helpful for the user to estimate what portion of a worker's noise exposure comes from the direct sound field and what percentage results from reverberant sound. When reverberant noise is a major contributor to a worker's daily noise exposure, then adding sound-absorbing materials may be beneficial.

Sound Transmission Loss (TL) Materials

Sound TL materials are used to block or attenuate noise propagating through a structure, such as the walls of an enclosure or room. These materials are typically heavy and dense, with poor sound transmission properties. Common applications include barriers, enclosure panels, windows, doors, and building materials for room construction.

All products sold for noise control should have a TL rating that is determined by ASTM standard. It is important to note that TL rating varies with frequency. TL values generally range from 20 to 60 dB, with the higher number indicating superior attenuation properties. For TL values of common building materials, consult Table 9.12 in *The Noise Manual* (AIHA, 2003, or latest edition).

Acoustical Enclosures

The acoustical enclosure is probably the most common path of treatment. Quite often enclosures are used to address multiple noise sources all at once or when there are no feasible control measures for the source. However, there are a number of advantages and disadvantages associated with solid enclosures (no acoustical leaks) that must be considered by the user.

Advantages:

- Can provide 20 to 40 dB of noise reduction.
- Can be installed in a relatively short time frame.
- Can be purchased and installed at a reasonable cost.

- Provides significant noise reduction across a wide range of frequencies.

Disadvantages:

- Worker visual and physical access to equipment is restricted.
- Repeated disassembly and reassembly of the enclosure often results in the creation of significant sound-flanking paths via small gaps and openings along the panel joints.
- Heat buildup inside the enclosure can be problematic.
- Internal lighting and fire suppression may need to be incorporated into the design.
- The long-term potential for internal surface contamination from oil mist or other airborne particulates is high.
- The panels become damaged or the internal absorption material simply deteriorates over time.
- Enclosures require periodic maintenance, such as replacement of seals and gasket material, to keep the acoustical integrity at a high attenuation value.

Enclosures, both off-the-shelf and custom-design, are available from a number of manufacturers listed in the *Noise and Vibration Control Product Manufacturer Guide*. It can also be more cost-effective to build enclosures in-house by following the *Guidelines for Building Enclosures*.

Acoustical Barriers

An acoustical barrier is a partial partition inserted between the noise source and receiver, which helps block or shield the receiver from the direct sound transmission path. For a partial barrier to be effective, it is critical that the receiver be in the direct field, not the reverberant field. Should the worker's location be primarily in the reverberant field, then the benefit of the barrier will be negligible.

The noise reduction provided by a barrier is a direct function of its relative location to the source and receiver, its effective dimensions, and the frequency spectrum of the noise source. The practical limits of barrier attenuation will range from 15 to 20 dB. For additional details on calculating barrier insertion loss or attenuation, the user should review some of the references, particularly The Noise Manual (AIHA, 2003; or latest edition). Recommendations for acoustical barrier design and location to maximize noise reduction capabilities include:

- The barrier should be located as close as practical to either or both the source and receiver.
- The width of the barrier on either side of the noise source should be at least twice its height (the wider the better).
- The height should be as tall as practical.
- The sound transmission loss of the panel should be at least 10 dB greater than the estimated noise reduction of the barrier.
- The barrier should be solid and not contain any gaps or openings.
- The worker(s) being protected by the barrier should work primarily in the direct sound field.

iii) Receiver Treatment

The final control option involves reducing noise at the receiver. When deemed practical, personnel shelters can be installed or the receiver can be relocated to a relatively quiet area. It is important to keep in mind that worker noise exposure is a function of both the magnitude of noise and duration of exposure. Therefore, receiver treatment works best in areas with high noise for those job activities that are fairly stationary or confined to a relatively small area, and where significant time is spent throughout the workday.

Worker Enclosures

Enclosures, or personnel shelters, can provide a cost-effective means for lowering worker noise exposure instead of lowering equipment noise levels. Control booths or rooms are commercially available from a number of manufacturers, many of which are listed in the *Noise and Vibration Control Product Manufacturer Guide* (see Section VII—Resources). The cost for these units typically ranges from $5,000 to $35,000 depending on the size and sophistication of their design and their need for electronic controls, video monitoring, number of observation windows, and other features. Any of the vendors listed in the manufacturer's guide can provide a cost estimate upon request. As a minimum requirement, all control rooms should maintain an interior sound level lower than 80 dBA, which will minimize worker noise exposure. Should there be a need to communicate with workers inside a control room, however, then a better design criterion would be to limit sound levels to 60 dBA or less.

As mentioned above, for a personnel enclosure to work well, it is critical that worker(s) spend a significant portion of their workshift in the shelter. The amount of time needed inside the enclosure will depend on the magnitude of the existing noise exposure. Appendix A: Noise Exposure Computation of the OSHA Occupational Noise Exposure standard, 29 CFR 1910.95, can be used to help determine the amount of time needed inside an enclosure to reduce noise exposures below select target levels, such as a TWA of 90 dBA or 85 dBA.

Relocation

Finally, if it is not essential for the worker to spend significant time in the immediate vicinity of noisy equipment, then another option for reducing noise exposure would be to relocate the worker to a quieter area, when practical. Quite often, equipment operators will spend most of their time up close to the production or process equipment, when in fact, they could stand back 5 to 7 feet, where the sound level might be a few decibels less. For relocation to work, however, it is critical that the worker still be able to perform the same job function.

To help identify areas or zones where lower noise levels exist, a comprehensive sound survey of the production area is recommended. It is also valuable to plot the sound level data on an equipment layout or floor plan, then add or draw contour lines of equal sound levels. This results in a noise contour map, which is often useful because it provides a simple representation of the sound field over a large area. Besides identifying regions of lower noise levels, these maps may also be used to visually educate and train workers regarding where hearing protection is mandatory, and as a tool for identifying hot spots for potential noise controls.

3. <u>Administrative Controls</u>

Administrative controls, defined as "management involvement, training of workers, and changes in the work schedule or operations that reduce noise exposure," may also effectively reduce noise exposure for workers. Examples include operating a noisy machine on the second or third shift when fewer people are exposed, or shifting a worker to a less noisy job once a hazardous daily noise dose has been reached.

Generally, administrative controls have limited use in industry because workers are rarely permitted to shift from one job to another. Be aware that if noise levels are high enough, rotation could increase the chances of hearing loss in more workers. If there is a regular noise level of 90 dB, for example, a healthy worker in the area can rotate into an area with a 50-dB noise level without a substantial increase in risk of hearing loss.

Another administrative control involves redesigning workers' work schedules to reduce the amount of time that any one worker is located in the hazard area. To increase the effectiveness of this control, employers can also ensure that noise exposure is kept to a minimum in nonproduction areas frequented by workers. Select quiet areas to use as lunch rooms and work break rooms. If these areas must be near the production line, they should be acoustically treated (as describe elsewhere in this section) to minimize background noise levels. Employers can also increase the distance between workers and the noise source. This can be accomplished in many ways. For example, television monitors allow the worker to monitor a job or process at a safe distance from the noise-producing area; a boom-mounted drill increases the distance from the noise source to the worker. Additionally, noisy jobs on construction sites might be scheduled when other trades will not be affected.

Another administrative control involves creating policies that result in regularly scheduled equipment maintenance. Maintenance should be scheduled frequently enough to minimize the noise produced by equipment with parts that are loose or not lubricated. Regular maintenance should allow a piece of equipment to operate within 2 dBA of its lowest potential operating noise level. Maintenance workers can also be trained to observe and listen for noise sources in equipment. This might involve providing training on using sound level meters to perform surveys in work areas to identify areas with high noise levels.

4. Personal Protective Equipment (Hearing Protection)

Hearing protection devices (HPDs) are considered the last option for controlling noise exposures. HPDs are generally used during the time it takes to implement engineering or administrative controls, or when such controls are not feasible. Unless great care is taken in establishing a hearing conservation program, workers will often receive very little benefit from HPDs. The best hearing protector, when fitted correctly, is one that is accepted by the worker and worn properly. If the worker exposure is above 85 dBA (8-hour TWA), hearing protection must be made available, along with the other requirements in the hearing protection program.

Earplugs come in a variety of sizes, shapes, and materials and can be reusable and/or disposable (Figure 10). Earplugs are designed to occlude the ear canal when worn. All hearing protectors are provided with an NRR. Although earplugs can offer protection against the harmful effects of impulse noise, and some earplugs are designed specifically to reduce this type of noise, the NRR is based on the attenuation of continuous noise and may not be an accurate indicator of the protection attainable against impulse noise. Earplugs are better suited for warm and/or humid environments, such as foundries, smelters, glass works, and outside construction in the summer.

Figure 10. Earplugs

Earmuffs are another type of hearing protector (Figure 11). They come in a variety of sizes, shapes, and materials and are relatively easy to dispense, as they are one-size devices designed to fit nearly all adult users. Earmuffs are designed to cover the external ear and thus reduce the amount of sound reaching the inner ear. Care must be taken to ensure that the seal of the earmuff is not broken by safety glasses, facial hair, respirators, or other equipment, as even a very small leak in the seal can destroy the effectiveness of the earmuff. Earmuffs should be chosen based on the frequency that needs to be reduced. Refer to the EPA label on the manufacturer's product. Earmuffs are a good choice for intermittent exposure, given how easy they are to put on and take off. Additionally, in cold environments, their warming effect is appreciated (OTM/Driscoll).

Hearing bands are a third type of HPD (Figure 11) and are similar to earplugs, but with a stiff band that connects the portions that insert into a worker’s ears. The band typically wraps around the back of the wearer’s neck, though variations are available. Hearing bands come in a variety of sizes, shapes, and materials and are popular for their convenience. Hearing bands may not provide the same noise attenuation as properly fitting earplugs, as the portions that fit into the ears are stationary and cannot be twisted into place like earplugs.

Earplugs, earmuffs, or hearing bands alone might not provide sufficient protection from significantly high noise levels. In this case, workers should wear double hearing protection—earmuffs with earplugs. Avoid corded earplugs, as the cord would interfere with the muff seal. Additionally, hearing bands cannot be worn with earplugs or earmuffs, as the connected band would interfere with the muff seal, and there is no room to insert earplugs at the same time.

Figure 11. Earmuffs and Hearing Bands

HPDs are rated to indicate the extent to which they reduce worker noise exposure. New technologies are being developed to test the effectiveness of earplugs and could eventually change the way hearing protection is rated. See Appendix E for current information on NRR methods, ratings, and requirements.

III. MEASUREMENTS

A. Equipment

Several sound-measuring instruments are available to CSHOs. These include sound level meters, noise dosimeters, and octave band analyzers. This section describes general equipment care, followed by the uses and limitations of each kind of instrument.

1. Noise Evaluation Instrument Care and Calibration

Instruments that measure noise contain delicate electronics and require practical care. Store and transport the equipment in its custom case. Be aware of the instrument manufacturer's recommendations for proper storage (for example, some manufacturers recommend removing all batteries from stored equipment, while others require a primary battery to remain in the instrument). Make sure batteries will last the anticipated sampling period. A battery tester can be useful. CSHOs may need to install fresh batteries or recharge reusable batteries with a battery charger.

> *All instruments must be calibrated (according to the manufacturer's instructions) to ensure measurement accuracy. [29 CFR 1910.95(d)(2)(ii)]*

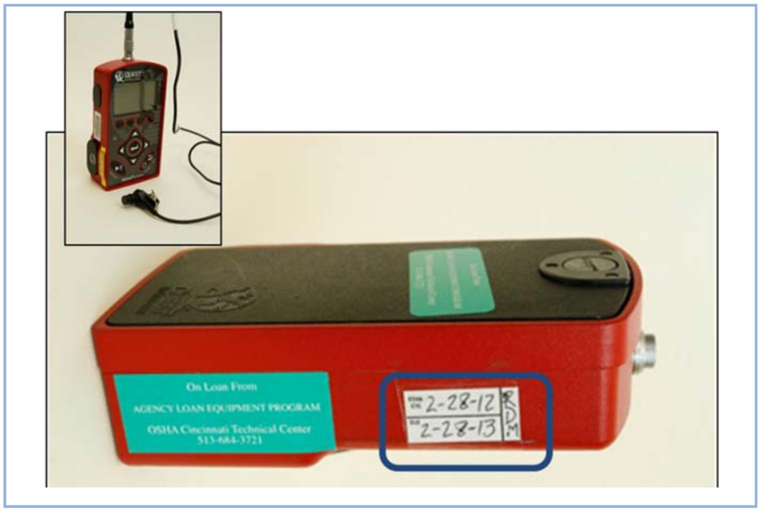
All noise-measuring instruments used by CSHOs require two types of calibration:

- Periodic factory-level calibration (e.g., annual)
- Pre- and post-use calibration

Both pre- and post-inspection calibrations are required for any noise instruments used by CSHOs. It is important to understand the difference between these two types of calibrations. Calibrators must also be calibrated on an annual basis.

Equipment manufacturers typically recommend ***periodic calibration*** on an annual basis. These rigorous testing protocols ensure that the electronic components are in good working order and detect shifts in performance that indicate gradual deterioration. Periodic calibration results in a calibration certificate documenting the standard of performance. Typically, the instrument will also receive a sticker indicating its last calibration date and when the next periodic calibration is due (Figure 12). An instrument owned by OSHA that is past its calibration due date must be returned to OSHA's Cincinnati Technical Center (CTC) to have its calibration renewed. Do not continue to use it past the calibration date.

Figure 12. Noise Dosimeter Calibration Sticker



During periodic calibration, the CTC also performs preventive maintenance to ensure that the equipment remains fully functional over its life expectancy. If the calibration team detects a problem, it services the instrument as necessary. When returning equipment to CTC for periodic calibration, be sure to include a note about any problems or concerns with equipment function so they can be evaluated as part of the maintenance process. If equipment is not functioning well, CTC requests that the instrument be returned for inspection, even if it is not yet due for calibration.

OSHA's CTC is qualified to perform periodic (annual) calibration for the noise-monitoring instruments commonly issued to CSHOs. CTC also coordinates periodic factory calibration of any OSHA-owned noise-monitoring instruments that it does not service directly.

Employers that lease or own Type I or Type II noise-measuring instruments can arrange annual calibration of the equipment through the equipment supplier or manufacturer.

Octave band analyzers that are integrated into a sound level meter will be calibrated as part of the sound level meter. However, detachable octave band analyzers must be returned to CTC for periodic calibration with the meter with which they are intended to be used

Pre- and post-calibration procedures confirm that the instrument is functioning properly on the day that it is used and prove that it is still registering sound levels correctly at the end of the day. Pre- and post-calibrations also confirm that changes in temperature or humidity have not affected the instrument's accuracy. If practical, spot check the instrument with a calibrator after the stabilization period.

When unpacking a cold instrument in a warm environment, or moving from one temperature zone to another, allow the instrument at least 5 minutes to stabilize for each 18˚F (10˚C) of change.

Each instrument model is calibrated in a slightly different manner, but the general process follows basic standard steps. Typical daily ***pre-use calibration*** involves (1) setting up the instrument for use, (2) turning on both the electronic "calibrator" and the noise-measuring instruments to allow them to "warm up," (3) checking the calibrator and instrument battery charge, (4) testing the instruments with a standard tone of known pitch and intensity produced by the calibrator (e.g., 114 dB at 1,000 Hz), (5) checking the instrument reading during the test and making minor adjustments to the instrument if necessary, and (6) documenting the calibration results. For the ***post-use calibration check,*** the process is repeated, without step 5, after the instrument has been used. Both the pre- and post-use calibration must be documented (If it isn't properly documented, it didn't happen). See Figures 13 and 14 for illustrations of this process for dosimeters and sound level meters, respectively.

Figure 13. Noise Dosimeter Calibration

Figure 14. Sound Level Meter Calibration

Confirm that you understand the procedures for calibrating each of the instruments you use. If in doubt, review instructions in each instrument's user's manual and consult CTC if questions arise. In general, as long as the sound level readout is within 0.2 dB of the known source (the calibrator output), it is suggested that no calibration adjustments be made. If large fluctuations (greater than 1 dB) in the level occur, then either the calibrator or the instrument may have a problem.

Review your noise instrument calibration procedure and check whether your process:

1. *Confirms that both the calibrator and the instrument have not exceeded the periodic calibration due date.*
2. *Uses the correct calibrator for the instrument.*
3. *Uses the correct adaptor between the calibrator and the instrument microphone.*
4. *Confirms the battery charge.*
5. *Adjusts the instrument calibration when the tolerance is within the manufacturer's published limits (e.g., ±0.2 to 1 dB) but rejects the equipment if the calibration reading is outside the limits (e.g., ±1 dB or more).*
6. *Prevents use of equipment that is outside its periodic calibration due date or fails pre-use calibration.*
7. *Creates a record of pre-use calibration.*

Additionally, confirm that you know how to change the battery in both the calibrator and the instruments. If in doubt, review instructions in each instrument's user's manual. A low battery is the number-one cause of equipment failing pre- and post-use calibration. Changing the battery will often bring the equipment back into an acceptable calibration range immediately, but a little practice is needed to change the battery quickly on some equipment. Be prepared, so that a low battery doesn't slow you down during an early morning calibration session (Figure 15).

Figure 15. Changing Equipment Batteries

Noise measurements collected by CSHOs cannot be used as a basis for citations unless they are obtained using equipment that has a current (within the past 12 months) periodic calibration certificate on file and that has received ***documented*** calibration before and after the measurements were made using accepted practices for documentation, as outlined in the OSHA *Field Operations Manual*.

2. Sound Level Meters

Sound level meters provide instantaneous noise measurements for screening purposes (Figure 16). During an initial walkaround, a sound level meter helps identify areas with elevated noise levels where full-shift noise dosimetry should be performed. Sound level meters are useful for:

- Spot-checking noise dosimeter performance.
- Determining a worker's noise dose whenever a noise dosimeter is unavailable or inappropriate.
- Identifying and evaluating individual noise sources for abatement purposes.
- Aiding in engineering control feasibility analysis for individual noise sources being considered for abatement.
- Evaluating the suitability of HPDs for the actual noise level in an area.

Figure 16. Sound Level Meter

i) Sound Level Meter Types and Performance

Sound level meters used by OSHA meet American National Standards Institute (ANSI) Standard S1.4-1971 (R1976) or S1.4-1983, "Specifications for Sound Level Meters." These ANSI standards set performance and accuracy tolerances according to three levels of precision: Types 0, 1, and 2.

- Type 0 is used in laboratories.
- Type 1 is used for precision measurements in the field.
- Type 2 is used for general purpose measurements.

The most widely used sound level meter for workplace evaluations, the ***Type 2 meter,*** performs with the minimum level of precision required by OSHA for noise measurements. These meters are usually sufficient for general purpose noise surveys. For compliance purposes, readings obtained with a Type 2 sound level meter are considered to have an accuracy of ±2 dBA.

One model of sound level meter typically used by CSHOs, the Quest SoundPro, is designed to operate in temperatures of 14˚ to 122˚F (-10˚C to 50˚C).

Over this range, temperature has a modest effect on the accuracy of measurements (less than ±0.5 dB). Likewise, the sound level meter can be expected to operate effectively between 10% and 90% relative humidity.

In contrast, a ***Type 1 meter*** has an accuracy of ±1 dBA. The Type 1 meter accuracy, precision, and additional features make it the preferred model for obtaining readings that will be used to help design cost-effective noise controls.

For unusual measurement situations, refer to the manufacturer's instructions and appropriate ANSI standards for guidance in interpreting instrument accuracy.

Other types of sound level meters also exist but do not meet ANSI requirements for the Type 2 or Type 1 designation. These meters, which are often modestly priced, can be useful pre-screening tools for employers seeking to identify noisy locations and track improvements during noise reduction efforts. They cannot, however, be used to document compliance with OSHA standards; only properly calibrated Type 2 or Type 1 meters can serve that purpose. For example, sound level meter applications are available for some smartphones. Such an application can give a rough estimate of the noise level in a particular location but may not be used to document compliance with OSHA standards.

All sound level meters are affected by temperature and humidity; however, these instruments are intended to provide reliable readings within the normal range of workplace temperatures. During extreme weather, temperatures might be considerably outside that range in untempered storage (e.g., the trunk of a parked car). Avoid storing noise measurement equipment where the temperature could be lower than -13˚F (-25˚C) or higher than 158˚F (70˚C). Avoid carrying cold equipment into a very humid environment, which could permit moisture to condense on the instrument. To prevent this situation, do not keep noise equipment in the trunk of a cold car; instead, carry it in the passenger compartment and store it indoors at the destination. For equipment that must be carried for a brief time into a very cold area to collect a measurement, one strategy is to keep the equipment under a coat (or otherwise wrapped/insulated), if possible, to keep it from getting cold.

Sound level meters should be calibrated using the steps outlined in Section 1, above, and according to the manufacturer's instructions.

ii) <u>Using a Sound Level Meter</u>

Different work environments and different sound level meter microphones might require variations in measurement procedures. For practical purposes, however, certain basic steps apply in most circumstances.

Confirm that the sound level meter is properly calibrated and temperature-stabilized. Then, position the microphone in the monitored worker's hearing zone. OSHA defines the hearing zone as a 2-foot-wide sphere surrounding the head. Considerations of practicality and safety will dictate the actual microphone placement at each survey location. Note that when noise levels at a worker's two ears are different, the higher level must be sampled for compliance determinations.

Figure 17. Sound Level Meter Positioning

Keep in mind that your body or surrounding equipment can influence the noise level, acting as a barrier between the noise source and the microphone. Hold the sound level meter away from your body to minimize this effect (Figure 17).

Consult the manufacturer for any specific instructions for positioning the model of sound level meter you plan to use. This may be particularly important when measuring in unusual settings. For example, the manufacturer may have specific instructions for sound level readings in a non-reverberant environment.

Use a wind screen to reduce measurement errors caused by wind turbulence over the microphone. Typical wind screens are made of soft foam rubber and are designed to fit over the microphone (Figure 18). Although not necessarily needed indoors if air movement is minimal, a wind screen can be left in place for all measurements. Collected measurements can be affected by anything that comes across the face of the sound level meter microphone, such as hair, shirt collars, scarves, or other objects. The use of a wind screen reduces the effects of this incidental contact. Wind screens have the added advantage of protecting the microphone, at least somewhat, from damage resulting from impact, dust, paint overspray, and moisture.

Figure 18. Wind Screen

Most Type 1 and Type 2 sound level meters can be set to respond with either a “slow response” or a “fast response”. The meter dynamics are such that the meter will reach 63% of the final steady-state reading within one time constant:

- ***Fast response*** corresponds to a 125-millisecond (ms) time constant.
- ***Slow response*** corresponds to a 1-second time constant.

The meter screen shows the average sound pressure level measured by the meter during the period selected. In most industrial settings, the meter fluctuates less (and therefore is easier to read) when measurements are made with the slow response rather than the fast response. A rapidly fluctuating sound generally yields higher maximum sound pressure levels when measured with a fast response. The choice of meter response depends on the type of noise being measured, the intended use of the measurements, and the specifications of any applicable standards. For typical occupational noise measurements, including extremely elevated short-term noise (e.g., noise that will be compared to the 115 dBA maximum for a 15-minute period), the meter response on a sound level meter should be set at slow. For more information on OSHA’s standard for extremely elevated short-term noise exposures see Section II.I.2— OSHA Noise Standards.

Many sound level meters also have “peak” and “impulse” response settings for measuring transient sounds (sounds that decay or pass with time). These settings are not interchangeable; the true peak value is the maximum value of the noise waveform, while the impulse measurement is an integrated measurement. It is appropriate to use the true peak reading only when determining compliance with OSHA's 140-dB peak (instantaneous) sound pressure level [29 CFR 1910.95(b)(1) or 29 CFR 1926.52(e)]. Avoid using the impulse response setting when measuring true peak sound pressure levels.

Note that noise dosimeters and sound level meters that are set to integrate or average sound over a period of time do not use either the fast or slow time constant; they will sample many times per second.

3. *Octave Band Analyzer*

Most sounds are not a pure tone but rather a mix of several frequencies. The frequency of a sound influences the extent to which different materials attenuate that sound. Knowing the component frequencies of the sound can help determine the materials and designs that will provide the greatest noise reduction. Therefore, octave band analyzers can be used to help determine the feasibility of controls for individual noise sources for abatement purposes and to evaluate whether hearing protectors provide adequate protection.

i) Octave Band Analyzer Types and Performance

Octave band analyzers segment noise into its component parts. The standard octave band filter set provides filters with the following center frequencies: 16; 31.5; 63; 125; 250; 500; 1,000; 2,000; 4,000; 8,000; and 16,000 Hz. The special signature of a given noise can be obtained by taking sound level meter readings at each of these settings (assuming that the noise is fairly constant over time). The results may identify the octave bands that contain the majority of the total radiated sound power (Figure 19).

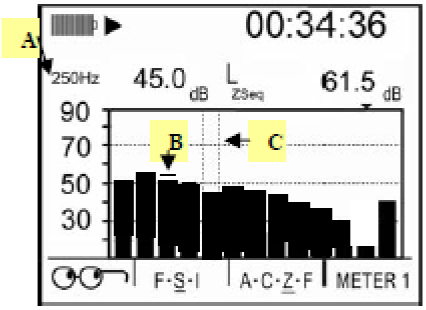
Question: *I've heard that some sound level meters should be pointed at the noise source, while others should be held at an angle (e.g., 70 degrees, 90 degrees).*

Answer: *In many cases, orientation makes no significant difference, but it is always best to follow any recommendation from the manufacturer. Such a recommendation would be based on microphone type. Typical recommendations include:*

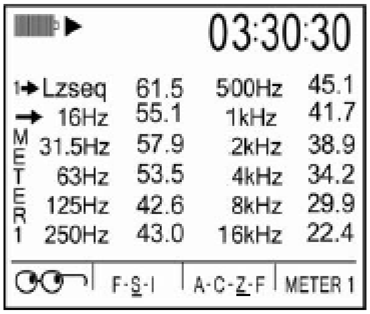
- *Free-field microphones—point directly toward the noise source (a 0-degree angle).*
- *Random incidence microphones—hold at a 70-degree angle to the source.*
- *Pressure microphones—hold at a 90-degree angle to the source.*

CSHOs should consult with CTC regarding the microphone models provided with their sound level meters.

Figure 19. Octave Band Analyzer Settings and Center Frequencies



(a) Sample bar chart with curves



03:30:30

1→Lzseq	61.5	500Hz	45.1
→ 16Hz	55.1	1kHz	41.7
31.5Hz	57.9	2kHz	38.9
63Hz	53.5	4kHz	34.2
125Hz	42.6	8kHz	29.9
250Hz	43.0	16kHz	22.4

(b) Tabulation screen

Press “Enter” (center arrow) key to switch screens.

Sample bar chart screen: (A) selected frequency band (250 Hz in example), (B) selected frequency in curve, (C) amplitude (dB) in band.

Tabulation screen: lists amplitude in dB for each frequency band.

For octave band analysis, the ideal sound level meter network (weighting) scale setting is one that provides no weighting at all, such as the Z-weighted scale, which has an unweighted flat response across the entire frequency spectrum from 10 Hz to 20,000 Hz. The C-weighted scale is also an acceptable option for octave band analysis because, in the range of most workplace noise level measurements, unweighted sound level measurements are less than 1 dB higher than the corresponding C-scale measurements. The A-weighted scale, however, is not an appropriate setting for octave band analysis because, by definition, it influences the meter response differently at various frequencies in the range of normal human hearing.

For a more detailed analysis, the spectrum is sometimes measured in one-third octave bands. Although one-third octave bands can be useful for noise engineers concerned with precise frequency measurements, the standard single octave bands are sufficient for most evaluations performed by OSHA.

Whether detachable or integrated into a sound level meter, an octave band analyzer receives its daily calibration in conjunction with the sound level meter with which it will be used. This might involve activating an additional setting during the daily meter calibration. Consult the user's manual for the equipment you will be using.

ii) Using the Octave Band Analyzer

The Type 1 sound level meters used by OSHA (such as the Quest SoundPro) have built-in octave band analysis capability. Some other models of sound level meter are designed to work with a separate octave band analyzer that is physically attached to the meter (Figure 20). In either case, the sound level meter microphone operates normally, but the noise signal detected by the microphone is separated into its component frequencies. When the octave band analyzer is activated and a particular frequency band selected, the meter readout provides the decibel level associated with that frequency. By sequentially switching the meter to each frequency band and taking a reading, the CSHO can determine which octave bands are most represented in the noise.

For example, an octave band analysis providing the following results indicated that the frequencies around 500 Hz and 1,000 Hz were most prominent (Table III–1):

Table III–1. Octave Band Analysis (Noise A)

Hz	31.5	63	125	250	**500**	**1,000**	2,000	4,000	8,000	16,000
dB	68	69	72	76	**89**	**92**	74	77	71	71

In contrast, the following octave band analysis (Table III–2) obtained during concrete demolition (multiple noise sources) indicated that nearly all frequencies contributed to the noise level at that position—a distance of 60 feet from the demolition point. At that point, the overall sound level was 91 dB, demonstrating a standard principle of sound: the sum of all octave bands is greater than any single octave band reading, but the logarithmic values cannot be summed by simple arithmetic addition. See Appendix B for more information on determining the sum of two or more sound levels.

Table III–2. Octave Band Analysis (Noise B)

Hz	31.5	63	125	250	500	1,000	2,000	4,000	8,000	16,000
dB	81	87	83	83	83	86	86	87	82	68

Figure 20. Octave Band Analyzer Graph

Some octave band analyzers can be set to automatic function (i.e., the instrument automatically checks the sound level of each frequency band and stores the results). Other instruments require the user to manually switch between the different frequency bands, recording each reading in sequence.

Variable frequency sounds and sounds that constantly vary in intensity present a challenge to frequency analysis. Unless the sound is relatively constant throughout the process of evaluating all frequency bands, it might not be possible to obtain an accurate reading. The CSHO should attempt to determine whether cyclic sounds have a stable period during which readings would be more accurate.

4. Noise Dosimeter

Like a sound level meter, a noise dosimeter can measure sound levels. However, the dosimeter is actually worn by the worker to determine the personal noise dose during the workshift or sampling period (Figure 21). Noise dosimetry is a form of personal sampling, averaging noise exposure over time and reporting results such as a TWA exposure or a percentage of the PEL.

Dosimeters can be used to:

- Make compliance measurements according to OSHA's Noise standard.
- Measure the worker's exposure to noise over a period of time (e.g., a task or an entire workshift) and automatically compute the necessary noise dose calculations.

Increasingly, some sound level meters can function as noise dosimeters (although they are larger than typical dosimeters), while many noise dosimeters provide instantaneous sound level readings in decibels and therefore can be used as Type 2 sound level meters.

Figure 21. Noise Dosimeter

i) <u>Noise Dosimeter Types and Performance</u>

Most noise dosimeters operate with the precision and accuracy of a Type 2 sound level meter. Therefore, the variations in dosimeter types are primarily a function of either the physical form or the analytical features of each model. Historically, the typical noise dosimeter has included a small positionable microphone connected to the dosimeter by a thin cable. The microphone sits in the worker's hearing zone (e.g., shoulder or lapel near the ear), while the dosimeter clips to the worker's belt. Advances in miniature electronics and wireless technology, however, have permitted manufacturers to offer similar capabilities in a wider range of physical forms (e.g., wireless microphones that clip to the worker's shoulder and transmit information back to a base station, miniature microphones that measure sound levels in the worker's ear).

Function also varies. Simple dosimeters record a single channel and report basic dosimetry results. More complex models can record as if they were three or four separate dosimeters, each integrating the sound level over time using different criteria (e.g., 3 dB and 5 dB exchange rates, different threshold settings).

Noise dosimeters are subject to the same sensitivity to temperature and humidity as sound level meters. Although some have water-resistant housings, they should still be treated as sensitive electronic instruments and be protected from moisture and physical impact. The dosimeter calibration process is nearly identical to that for sound level meters. Frequently, for a given brand of instruments, the same calibrator can be used for a manufacturer's sound level meters and noise dosimeters (Figure 22).

Figure 22. Calibrator Adapter

Always consider the accuracy of noise-measuring equipment when using readings for compliance purposes.

Like Type 2 sound level meters, Type 2 noise dosimeters have an implied accuracy of ±2 dBA. To prove an overexposure, the 8-hour TWA sound level (L-TWA), must be 2 dBA over the PEL.

In practice, the workers are overexposed to noise with an 8-hour TWA of 92 dBA (a dose of 132% as measured at the 90-dBA threshold setting of the dosimeter) and an average sound level of 92 dBA.

Workers must be included in a hearing conservation program when measured noise levels are 87 dBA as an 8-hour TWA (a dose of 66% of the PEL as measured at the 80-dBA threshold setting).

Noise dosimeters routinely must run for 8 to 10 hours per day. This means battery function is particularly important. Some models might require new batteries each day of use. Just as for sound level meters, each dosimeter must receive periodic calibration every 12 months and a daily calibration and battery check before each use. They also require a post-use calibration check. The documentation procedures are the same as those for sound level meters.

ii) Using Noise Dosimeters

According to OSHA's Noise standard (29 CFR 1910.95), the noise dosimeter is the primary instrument for making compliance measurements. Before use, the dosimeter must be set up to record noise exposure using the following criteria:

- Exchange rate: 5 dB
- Frequency weighting: A
- Response: slow
- Criterion level: 85 dBA (Hearing Conservation) or 90 dBA (Administrative and Engineering Controls).
- Threshold: 80 dBA (Hearing Conservation) or 90 dBA (Administrative and Engineering Controls).

As noted above, some dosimeters can simultaneously record exposure using two sets of criteria. With these instruments, the CSHO can obtain separate noise exposure levels based on both the 80 dBA and the 90 dBA threshold. Other noise dosimeters that lack this feature must be set to record using one of these thresholds or the other.

In addition to the 8-hour TWAs, OSHA's noise standards list a short-term level of 115 dBA for a 15 minute period, which is not to be exceeded; this is for steady state sounds measured on the slow response setting. Although sound this loud is unusual, some dosimeter models indicate when the maximum allowable sound level of 115 dBA has been exceeded. This signal should not be used for compliance determination, however, because it might not take the duration of the exposure to this noise level into consideration. But noise that exceeds 115 dBA should be incorporated into the overall TWA noise exposure determination (see Section II.I.2—OSHA Noise Standards for more information). The standard for short-term noise levels is distinct from OSHA's instantaneous ceiling limit of 140 dBA for impact noises (occurring less frequently than one per second and typically measured using a sound level meter set to the fast response setting.

You will need to make other decisions regarding dosimeter setup. For example, the typical noise dosimeter offers several options for the frequency with which noise is sampled and data logged. The more frequently the data are logged, the more data points are stored (and the larger the file eventually will be).

The calibrated noise dosimeter fastens to the worker's belt, while the microphone clips to the shoulder or lapel. Orient the microphone so it points straight up—you might need to adjust the clip to find a functional position. Avoid positioning the microphone where it could become enfolded in clothing or rub against cloth or other materials, both of which could influence the results.

If appropriate, run the microphone cable under the worker's outer layer of clothing to keep it out of the way and prevent it from snagging on objects in the work area. The dosimeter can hang inside the outer layer of clothes as well (an advantage in wet weather), but the microphone must remain in the open air without contacting other surfaces (except the base on which it clips).

Some dosimeter models are capable of taking separate measurements (studies) for different job tasks or processes within the same workshift. The dosimeter can isolate the loudest job task the worker performs. This data can be reviewed later by the CSHO to determine which job tasks contributed most to a worker's overall 8-hour TWA. This feature is useful for assessing engineering controls.

The dosimeter microphone must be protected from wind and harsh materials. Wind screens are optional indoors if air currents are minimal. Always use a windscreen in areas with air motion, outdoors, and in dusty locations or during jobs when the microphone might get dirty (Figure 23). The foam rubber wind screen will help protect the microphone. Additional precautions are required to protect the microphone under the particularly harsh conditions that occur during abrasive blasting, when the microphone should be clipped inside the abrasive blasting helmet.

Workers are understandably curious about the noise dosimeter, and particularly the microphone. Take time to explain that it only collects information on how loud the sounds are—it does not record speech. Activate the dosimeter and replace its screen cover, or lock out the controls before the worker begins working. As a good practice, take sound level measurements frequently during the course of the noise dosimetry. The sound level measurements document the noise in the area at specific points in time and from specific sources. These values both validate the dosimeter reading and provide insight into how and when exposure is occurring. Some noise dosimeters log data that can be downloaded to a computer and later graphed against time to show how the worker's noise exposure varies over the course of a shift. This is a useful feature, but is not a substitute for good notes on the workplace and the sources of noise in specific times and places.

Figure 23. Microphone Positioning and Wind Screen Use

OSHA's Health Response Team (HRT) maintains the following specialized noise analysis equipment, which can be used for noise exposure and engineering control evaluations:

Sound Level Meter and Octave Band Analyzer

The HRT maintains multipurpose Type I sound level meters and octave band analyzers, which can also be operated as sound intensity analyzers for identifying noise sources and determining engineering controls. In addition, this equipment includes a building acoustics system for measuring noise decay and determining the reverberation characteristics for a given room. Based on the noise decay data, calculations can be performed to estimate potential noise reduction if absorptive materials are applied to room surfaces, such as the walls and ceiling.

Specialized Noise Dosimeters

The HRT maintains super-duty noise dosimeters that are contained in a sealed, waterproof, intrinsically safe metal housing. The dosimeters have no controls or displays, which eliminates the possibility of tampering or damage by the individual wearing the monitor. The dosimeters are programmed and controlled using a remote control unit or personal computer. The remote control unit can also be operated as an additional dosimeter. Data is transferred from the dosimeter via an infrared port on the dosimeter housing.

IV. INVESTIGATION GUIDELINES

A workplace noise investigation typically involves:

- Advance planning, including determining whether sound levels at the site might be hazardous.
- Reviewing employer records.
    - Reviewing the Hearing Conservation Program and audiograms.
    - Reviewing the OSHA 300 Log for hearing loss cases.
    - Determining if workers have hearing loss.
- Conducting the walkaround evaluation.
    - Identifying the sources of noise.
    - Documenting noise levels.
    - Conducting follow-up monitoring.
    - Determining the noise's potential effect on workers.
- Evaluating the employer's efforts to protect workers' hearing (hazard abatement and control).

In some workplaces your visit will be the first time a thorough investigation has been performed; frequently, however, at least some aspects of noise investigations will have been completed previously through the employer's workplace health and safety measures or sometimes as part of seemingly unrelated activities, such as expanding operations or upgrading equipment. To conduct an investigation, you will need to determine what information is already available through employer or industry records, and then confirm it and fill in the gaps. To ensure that the investigation is efficient, however, you must be prepared to accomplish both these steps simultaneously, which requires some advance planning.

A. Planning the Investigation

An effective noise investigation begins before you arrive on site. First, conduct a little research to determine whether noise hazards are likely. If so, plan to conduct noise measurements and monitoring. Confirm that the instruments' annual calibrations are current (i.e., have not expired), ensure that the batteries are fresh, and calibrate the sound level meter and noise dosimeters before the opening conference. This will permit you to begin obtaining sound level measurements during your initial walkaround at the site. After these preparations, you will also be ready to start obtaining personal noise dosimetry samples early in the visit, while you have an opportunity to collect samples of significant duration. The resulting noise dosimetry might not be full shift, but it will provide valuable information regarding worker noise exposure that first day on site.

Sources of information about whether you are likely to encounter noise hazards at an establishment include:

- Previous inspection records for the establishment, employer, or other facilities in the same or similar industries.
- BLS information summarizing state or national data from the "hearing loss" column of employers' OSHA 300 Logs.
- OSHA IMIS records on noise-related citations from inspections conducted across the nation.
- NIOSH reports on the industry, including Health Hazard Evaluations (HHEs).

- Your own knowledge of or experience with the industry and its processes.

1. *Searching Online for Industry Noise Statistics*

i) BLS Report on Hearing Loss in an Industry

Reports of hearing loss by industry are summarized in BLS's "Table SNR08: Incidence Rates of Nonfatal Occupational Illness, by Industry and Category of Illness." This extensive table lists, by industry, the incidence of reported illnesses per 10,000 full-time workers, as shown on OSHA 300 Logs that employers are required to submit. The table includes a column for hearing loss. Comparing the hearing loss reporting rates in various industries will give you an estimate of the impact that noise has on the industry you are inspecting compared with other industries. Note that variations in hearing loss reporting rates can influence the apparent incidence rate.

BLS publishes this information annually each fall, covering the previous year's data. Check for the latest edition of Table SNR08, or for previous years' tables, at http://www.bls.gov/search/?cx=011405714443654768953:btgxl8qv780&cof=FORID:10;NB:1&ie=ISO-8859-1&prefix=&query=table+SNR08&submit.x=28&submit.y=5&filter=0&sa=Search.

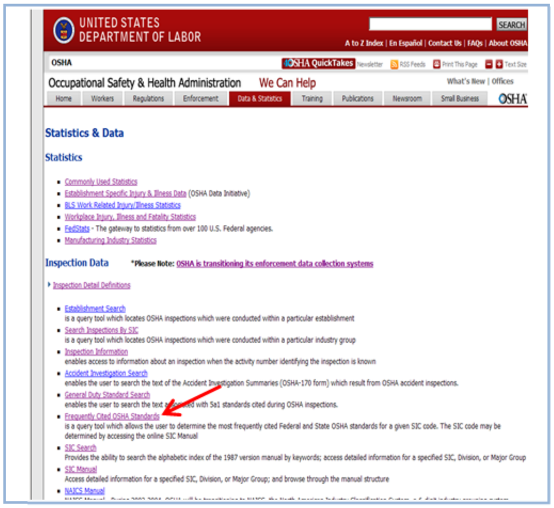
Table IV–1 shows an example from BLS Table SNR08 for NAICS 311111 (Dog and Cat Food Manufacturing); 12.8% of the 2009 reported occupational illnesses were related to hearing loss.

Table IV–1. Example Incidence Rates of Nonfatal Occupational Illness

Industry	NAICS Code	2009 Annual Average Employment (Thousands)	Incidence rates per 10,000 full-time workers					
			Total Cases	Skin Diseases or Disorders	Respiratory Conditions	Poisonings	Hearing Loss	All Other Illnesses
Animal food manufacturing	3111	52.0	30.7	—	—	—	9.4	18.2
Dog and cat food manufacturing	**311111**	**19.7**	**20.8**	—	—	—	**12.8**	—

Extracted from BLS Table SNR08, published in 2010. Available at http://www.bls.gov/iif/oshwc/osh/os/ostb2430.pdf.

Figure 24. Navigating to IMIS Noise Citations



Statistics & Data

Statistics

- Commonly Used Statistics
- Establishment Specific Injury & Illness Data (OSHA Data Initiative)
- BLS Work Related Injury/Illness Statistics
- Workplace Injury, Illness and Fatality Statistics
- FedStats - The gateway to statistics from over 100 U.S. Federal agencies.
- Manufacturing Industry Statistics

Inspection Data *Please Note: OSHA is transitioning its enforcement data collection systems

Inspection Detail Definitions

- Establishment Search
  is a query tool which locates OSHA inspections which were conducted within a particular establishment
- Search Inspections By SIC
  is a query tool which locates OSHA inspections which were conducted within a particular industry group
- Inspection Information
  enables access to information about an inspection when the activity number identifying the inspection is known
- Accident Investigation Search
  enables the user to search the text of the Accident Investigation Summaries (OSHA-170 form) which result from OSHA accident inspections.
- General Duty Standard Search
  enables the user to search the text associated with 5a1 standards cited during OSHA inspections.
- Frequently Cited OSHA Standards
  is a query tool which allows the user to determine the most frequently cited Federal and State OSHA standards for a given SIC code. The SIC code may be determined by accessing the online SIC Manual
- SIC Search
  Provides the ability to search the alphabetic index of the 1987 version manual by keywords; access detailed information for a specified SIC, Division, or Major Group
- SIC Manual
  Access detailed information for a specified SIC, Division, or Major Group; and browse through the manual structure
- NAICS Manual

ii) IMIS Noise Citations by Industry

If the establishment has not been inspected previously, OSHA's online records can show you whether the noise and hearing conservation standards are among those frequently cited in this industry, or whether the industry is listed as one that receives a lot of noise citations.

The CSHO can easily search the inspection information database to determine whether previous inspections of that industry, or a similar industry, resulted in citations under OSHA's noise standards. To access inspection records, start at OSHA's website home page and choose the "Data & Statistics" tab near the top of the page. Select "Frequently Cited OSHA Standards" from the options presented and enter the SIC or NAICS (Figure 24).

When the search page opens, enter the SIC of the industry of interest and click "Submit." If the SIC is not available, use the SIC lookup link on that page to select an appropriate code. The search provides a table of results—a ranked list of the standards cited in that industry for the previous fiscal year.

Using SIC 2047 (Dog and Cat Food Manufacturing) as an example again, the search showed that 1910.95 was the 10th most frequently cited standard in this industry that year. The search returns the information as a data table, shown below as Table IV–2.

Table IV–2. Inspection Statistics for SIC 2047 – Dog and Cat Food Manufacturing in FY 2011 (Organized by Most Frequently Cited Standard)

Standard	#Cited	#Insp	$Penalty	Description
Total	53	9	74774	
19100147	8	4	14345	The control of hazardous energy (lockout/tagout).
19100212	6	5	25466	General requirements for all machines.
19100027	5	1	3570	Fixed ladders.
19040029	4	1	2000	Forms.
19100305	4	3	1250	Wiring methods, components, and equipment for general use.
19100023	3	1	4641	Guarding floor and wall openings and holes.
19100120	3	1	2860	Hazardous waste operations and emergency response.
19101200	3	2	1250	Hazard communication.
19100022	2	2	3035	General requirements.
19100095	**2**	**2**	**1428**	**Occupational noise exposure.**
19100134	2	2	0	Respiratory protection.
19100303	2	2	3035	General requirements.
19100132	1	1	1250	General requirements.
19100242	1	1	1250	Hand and portable powered tools and equipment, general.

Notes: Standards are presented as eight-character part/section levels consisting of the part number followed by the standard number. Standard numbers less than 1000 require leading zeros: 1910.95 becomes 19100095.

For the row labeled "Total," the value in the "#Insp" column represents the number of inspections in which one or more citations were issued. Note that the total is not the sum of the number of inspections associated with each standard cited: multiple standards may be cited in one inspection.

Interpreting the table: Citations were issued during nine inspections conducted in SIC 2047 between October 2010 and September 2011 (FY 2011).[3] OSHA's noise standard, 1910.95, was cited during two (22%) of those nine inspections (see column #Insp). Overall, the noise standard was cited twice, putting it among the 10 most frequently cited standards in this industry for that year. The dollar penalties for noise standard violations accounted for 2% of the total $74,774 in penalties associated with citations issued in SIC 2047 in FY 2011.

Few inspections likely occurred in a small industry during a single year. For this reason, for smaller industries, the CSHO might obtain additional useful information by searching a wider range of dates (e.g., several years). Select "Search Inspections By SIC" and enter the SIC or NAICS and the date range desired. The resulting data table shows all the inspections conducted in that industry within the

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[3] *OSHA might also have conducted other inspections in that SIC that did not result in citations. Inspections that did not include citations are not counted in this table.*

requested time period. The table indicates the number of violations for each inspection but does not list them individually. Clicking on the inspection number, however, will open the inspection's information screen, showing which standards were violated.

iii) NIOSH HHEs by Industry

To access NIOSH HHEs that mention noise exposure levels or dosimetry data, go to http://www.cdc.gov/niosh/hhe and select "Find an HHE Report." In the search screen that appears, search by keyword "noise," choose an industry category, and limit the dates, if desired. Between 2000 and the end of 2011, NIOSH reported on 62 HHEs that included an evaluation of occupational noise exposure.

2. Equipment Needed for Worksite Noise Evaluations

You will need a sound level meter (Type 2 or Type 1) and, depending on the extent of the evaluation, an octave band analyzer that is compatible with your sound level meter and noise dosimeters. A noise instrument calibrator also will be required.

Additional equipment includes spare batteries for all instruments. Check that you have the correct batteries. Calibrators often require a different size battery than sound level meters or noise dosimeters.

Pack so that you have the following readily accessible: tape measure, preferably a 100-foot length; pens and paper for sketching the worksite layout; and standard noise measurement forms.

While conducting noise evaluations, you should wear protective equipment appropriate for the site, including hearing protection. Keep earplugs or muffs with you at all times and wear them whenever you are in an area that the employer has designated as a noise-hazardous zone (e.g., by posting signs or if your escort tells you hearing protection is required), when you find that measured noise levels approach 85 dBA, and any other time that you suspect that noise levels are elevated. Use hearing protection anywhere it is noisy enough that you would have to raise your voice to carry on a conversation with someone 3 feet away. In some situations, double hearing protection might be necessary (see ADM 04-00-001, OSHA Safety and Health Management System).

B. Reviewing Employer Records

Review employer records to determine whether hazardous noise levels have been found in the past and to evaluate the employer's hearing conservation and recordkeeping programs. The records can also indicate what steps the employer has taken to reduce any excessive noise exposure and whether there is evidence that workers are experiencing noise-induced hearing loss. Also, ask the employer for noise questionnaires that may be in use. Refer to CPL 02-02-072, Rules of Agency Practice and Procedure Concerning OSHA Access to Employee Medical Records (8/22/07), for guidance on appropriately requesting, reviewing, documenting, and retaining worker audiogram records.

If you can conduct the walkaround inspection before the records review, review the employer's records while noise dosimeters are operating. (Periodically return to the work area to confirm that the equipment is still operating properly and to collect sound level measurements to compare with the dosimeter data.)

Request copies of previous noise surveys or evaluations that included sound level measurements. Note noise levels that exceed the AL, along with the associated location, equipment, and activities. Inquire about the duration of exposure and determine which workers might be exposed to the noise by using the equation for calculating the TWA for the percent dose (see Appendix B). Look at noise dosimetry data to determine whether workers were exposed over the AL or the PEL. If the measurements are being used to show compliance, check that the equipment used to make the measurements was at least a Type 2 sound level meter (or dosimeter) with periodic and daily calibration fully documented.

1. Reviewing Audiograms

Look at the results of any audiometric evaluations. Determine whether the audiometry was performed by a qualified individual using calibrated equipment and whether results of audiometric testing are compared to the worker's previous audiometric test results. If a worker exhibited a temporary threshold shift, consider whether facility managers took appropriate action. Check the OSHA 300 Logs to determine whether the employer has reported cases of hearing loss. The employer should be asked how the determination was made to re-establish baselines and about any apparent hearing loss cases recorded (or those cases not recorded) on the OSHA 300 Logs.

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 following audiogram 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: 2,000, 3,000, and 4,000 Hz. Compare each audiogram to the baseline and take the average of the difference in the threshold at the three required frequencies. If the average is less than 10 dB, no STS has occurred. If the average is 10 dB or more, 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 10 dB or higher, an STS has occurred. See Appendix J for more information about adjusting audiograms for age.

2. Extended Workshifts

For workers working longer than an 8-hour shift, the AL for hearing conservation is reduced proportionately from 85 dBA. For the reduction equation, see Appendix B. Table IV–3 shows the AL (50% dose) based on shift duration:

Table IV–3. Extended Workshifts and Action Level Reduction

Exposure Time (hours)	Action Level (dBA)
8	85
9	84.2
10	83.4

12	82.1
16	80

It is preferable to determine compliance with the reduced AL by performing dosimetry for as much of the shift as possible. Perform full-shift dosimetry whenever possible. Use a dosimeter set to a 90-dBA PEL, 80-dBA threshold, 5-dB exchange rate, and slow response.

CSHOs who use representative sound level meter readings instead of dosimetry to document exposures should ensure that such readings are taken as close to the hearing zone of the worker as possible, and that the period of time represented by each segment of exposure is documented.

Table G-16A in Appendix A of 1910.95 lists the reference duration for various sound levels. The reference duration in Table G-16A is the exposure duration for a specified TWA sound level at which a dose of 100% will occur. Also, the PEL is not reduced for extended workshifts. PEL compliance is measured using a dosimeter set with a threshold of 90 dBA; any noise below 90 dBA is not integrated into the dose measurement.

Extended Workshifts

Another Sample Calculation

Given:

- *9.5 hour workshift*
- *Employee noise dose was 53% during a 460 minute sample*

$$AL_{9.5} = 16.61 \log_{10}\left[\frac{50}{(12.5)(9.5)}\right] + 90 = 83.8\ dBA$$

$$Adjusted\ AL = 83.8 + 2\ (meter\ accuracy) = 85.8\ dBA$$

Employee Exposure:

$$TWA = 16.61 \log_{10}\left[\frac{53}{100}\right] + 90 = 85.4\ dBA$$

If a

TWA, there is no violation. This is because the measured noise exposure does not exceed the adjusted AL of 87 dBA (85 dBA +2 dBA allowed for Type 2 meter accuracy).

For more information about extended workshift sampling, see Appendix H.

3. *Hearing Conservation Program*

If the walkaround has not yet been completed, follow through by investigating noisy locations in person. If the walkaround has already been conducted, review your noise measurements taken at high-noise-level operations.

Where workers are exposed to noise at the AL or higher, examine the employer's hearing conservation program. Check that the program includes the basic elements of a hearing conservation program (e.g., monitoring, training, noise exposure reduction measures, audiometric evaluation) and that noise-exposed workers are enrolled in the program. Look for evidence that noise-exposed workers are receiving hearing conservation training and have been fitted with and taught to use their HPDs correctly. Confirm that the employer provided a choice of hearing protectors and that this personal protective equipment provided an appropriate level of protection for the workplace noise level. For more information about determining whether the attenuation of a HPD is sufficient, see Appendix E.

C. Conducting the Walkaround Evaluation

The walkaround inspection is a chance for you to see the workers' working conditions first hand and to measure noise levels using the sound level meter or noise dosimeter (set to operate as a sound level meter). Use your senses to identify areas that might have hazardous noise, and then use the sound level meter to document the noise levels.

For each noise level, include a description of the noise source (including a photograph), record the distance from the source at which the measurement was made, and note how many and which workers are potentially exposed. Also note that if a noise is intermittent, the frequency and duration of the noise, as well as both A- and C-weighted noise levels, must be identified unless octave band analyzer readings are possible.

Interview workers and supervisors to inquire about which areas they think are most noisy at the site. Also, ask which are the noisiest areas in which they work. As you visit these areas, identify the sources of noise, and use the noise sound level meter to determine whether sound levels could be hazardous.

Select workers for noise dosimetry and carefully explain the process, including the fact that the microphone only measures how loud or quiet the noise is; it does not record speech. Follow the dosimeter manufacturer's instructions to set up and use the instrument, being careful to record the time the instrument is turned on and off. Throughout the day, use the sound level meter to corroborate the noise dosimeter readings. Readings taken at times when significant noise events occur can be particularly useful, as are series of sound level readings obtained at regular intervals (e.g., once or twice per hour, or 10 times per shift).

1. Create a Noise Diagram (Noise Mapping)

The noise diagram or schematic is a useful strategy for recording noise levels in context. The diagram can help determine which workers have noise exposure, and it is useful for communicating with workers and the employer. Use a plant schematic or sketch the general floor plan. Mark and identify noisy processes. Use the sound level meter to determine the noise level adjacent to the noisy equipment or process and at various distances from the noise source. Specifically, measure noise at the ear position of workers in the vicinity.

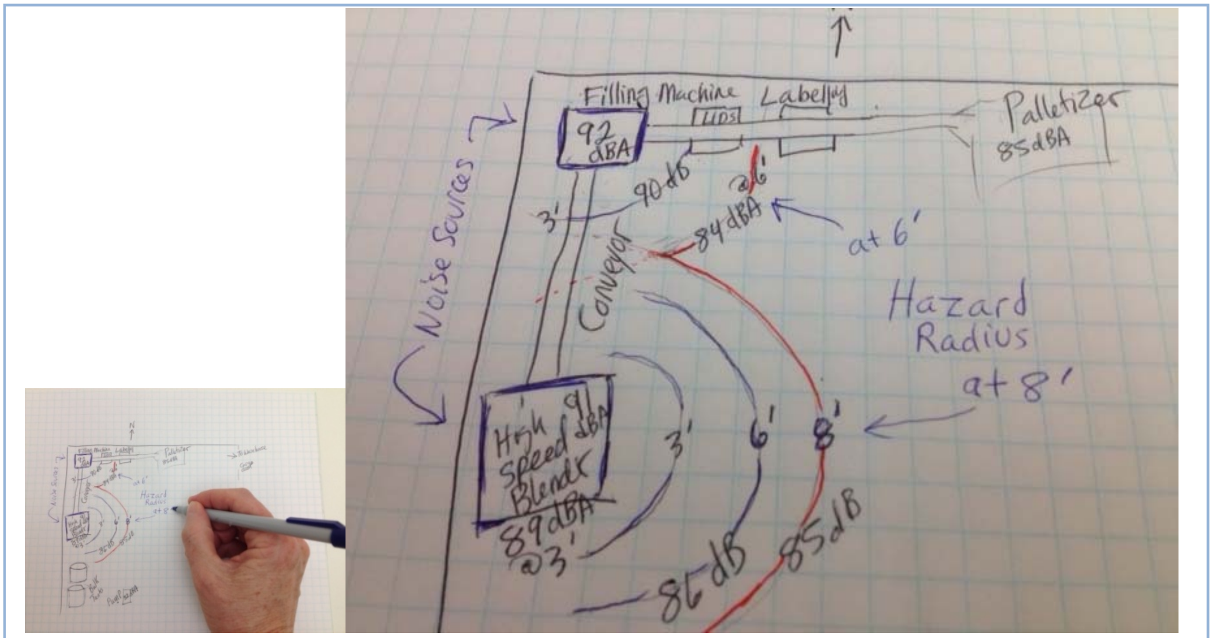
Next move away from the noise source, making sequential measurements to determine the "hazard

radius"—the distances from the noise source at which the noise level drops to the PEL and below the AL (Figure 25). Mark the distances in the sketch. Also, the dimensions of the work area and the materials that were used to construct the room should be identified.

Figure 25. Taking Measurements for a Noise Diagram

Your completed sketch will show a series of contours around the noise source(s) (Figure 26). Expect the contours for adjacent noise sources to overlap. Workers operating entirely outside the contour are not exposed to noise in excess of the AL. Workers whose tasks take them closer to the equipment might experience exposures between the AL and the PEL, or even in excess of the PEL. Take photographs to document the type of equipment or process.

Figure 26. Drawing a Noise Diagram



Where noise levels exceed the PEL, an octave band analyzer can help you determine the frequency profile of the sound. This information can aid in pinpointing the cause of the sound (e.g., slipping belt, vibrating supports) and will be useful for planning control measures.

The sound level meter is also useful for confirming the extent to which the employer's-noise reduction measures have reduced workers' noise exposure. In this case, octave band analysis can help confirm that the materials used are appropriate for controlling the particular noise.

When monitoring is complete at the end of the day, follow standard procedures for recording results from the instruments. If necessary, consult the instrument user's manual or contact CTC for assistance. Dosimeter output usually includes the TWA (normalized to 8 hours), the L_{AVG} or L_{EQ} representing the average dose for the period monitored, the percent dose, and the maximum or peak reading. Do not neglect to perform the post-use calibration check on each instrument.

D. Follow-Up Monitoring

If noise levels documented by sound level meter or dosimetry on the first day indicate that additional sampling is required, you will need to return to conduct follow-up monitoring. The additional monitoring could be necessary to confirm that workers are adequately protected or that an overexposure exists, or you might need to monitor another operation not being performed on the first day. Since the follow-up monitoring will focus on noise dosimetry, prepare to arrive in time to start monitoring with calibrated equipment just as the shift begins. The goal is to sample for a full 8 hours (or 8 hours plus the lunch break period if the break is not included in the dosimetry).

See Appendix H for extensive information on conducting noise inspections. The appendix addresses (by section):

- Pre-inspection activities.
- The opening conference (including a list of documents to request).
- Suggestions for the walkaround portion of the investigation, including sample questions for workers.
- Advice on using noise dosimeters to collect full-shift samples when the workday is not exactly 8 hours long.
- Considerations for post-inspection activities, including a list of items to discuss at the closing conference.
- Follow-up inspections.
- A list of example questions to ask the employer about hearing conservation and noise.

V. HAZARD ABATEMENT AND CONTROL

A. Engineering Controls

Engineering controls meant to reduce noise levels can take many forms. They can reduce noise at the source by replacing or modifying equipment, or they can reflect or absorb noise along the transmission path before it reaches the receiver. HPDs worn by a worker also block noise before it reaches the receiver's (i.e., the worker's) ears, but because they are worn by the worker, HPDs are considered personal protective equipment rather than engineering controls.

For hearing loss prevention purposes, engineering controls are defined as any modification or replacement of equipment, or related physical change at the noise source or along the transmission path (with the exception of HPDs), that reduces the noise level at the worker's ear. Engineering controls should be effective, efficient, and economical. According to CPL 2-2.35A Appendix A, *effective* controls reduce noise levels by at least 3 dB. *Efficient* controls should not cause extra hazards, production problems, or maintenance or sanitation issues. *Economical* controls are cost-effective for the employer (discussed in Section B of this section).

This section describes several types of engineering noise controls, focusing on the different ways various materials can be used to reduce a receiver's noise exposure. Noise is typically generated either by the surface motion of a vibrating solid material or by turbulence in a fluid, including air. All engineering control options either reduce the amount of noise generated by these events or interfere with the path between the noise source and the receiver.

A number of references on engineering controls are listed in Section VII—Resources. Some have been in use many years; however, many of the principles of noise control are as relevant now as they were decades ago. Additionally, considerable information is available in:

Pneumatic or compressed air systems (e.g., air valves, cylinders, solenoids, compressed air nozzles) used in manufacturing are a major contributor to noise. This type of noise is relatively easy to reduce with controls.

In this chapter

Appendix K—Three Ways to Jump Start a Noise-Control Program

Section VII—Resources (Subsections A and E)

On the Internet

Washington State Department of Labor and Industries' Noise Reduction Ideas Bank

NIOSH's Industrial Noise Control Manual (document number 79-117a)

World Health Organization's Engineering Noise Control, available online at: http://www.who.int/occupational_health/publications/noise10.pdf

1. Source Treatment

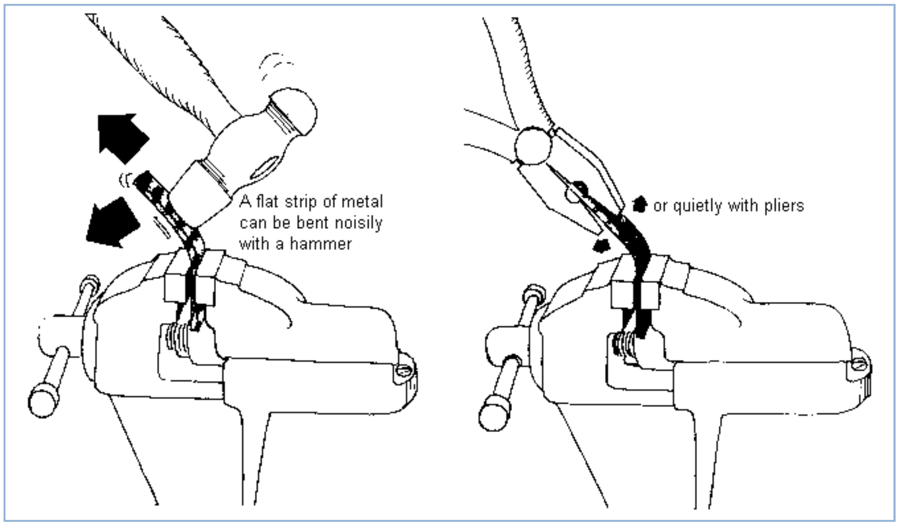
i) Mechanical Impacts

The driving force in a piece of equipment with a rotating part typically produces noise when the rotating part is out of balance or when the bearings are worn. The sound typically increases as the speed of the rotation increases. One simple, cost-effective way to reduce this noise is through preventive maintenance, which includes properly lubricating and aligning moving parts. For more information on controlling noise through preventive maintenance, see Appendix K—Three Ways to Jump Start a Noise-Control Program.

Another way to reduce the noise generated by the driving force of a piece of equipment is to decrease the speed of the equipment. The tradeoff with this approach is that in some processes there may be an associated loss in productive capacity.

In processes that involve impacts, increasing the duration of impact while reducing the force can reduce the driving force as well. This concept is illustrated in Figure 27. A worker can bend a piece of metal by hitting it with a hammer and applying a large amount of force over a short period of time or by applying the same force with the pliers over a longer time period, thereby reducing the noise.

Figure 27. Reducing Driving Force

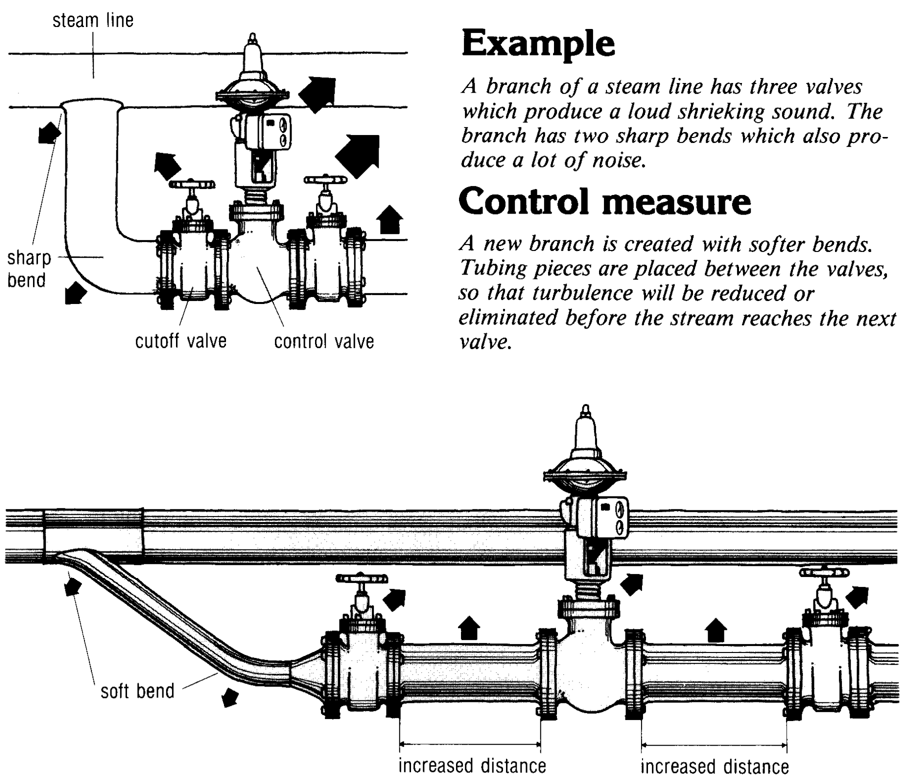


ii) Reduce High Velocity of Fluid Flow

Fluid (whether air or liquid) that moves through vents, valves, and piping at high velocities can generate noise due to turbulence.

Figure 28 shows that installing softer bends in the pipe and increasing the distance between the valves will reduce the turbulence in the line and, consequently, reduce the noise generated. This solution takes up more space and is often not possible in a process. However, it is sometimes possible in air ejection processes to reduce the required velocity of the air flowing from the nozzle by increasing the accuracy of the aim of the nozzle. Often, large pressure drops across valves, which cause noise, can be prevented with in-line diffuser silencers, which reduce the pressure upstream of the valve. Installing a muffler on the end of the nozzle is another option. All these methods can help reduce noise from compressed air sources. For additional information see Appendix K—Three Ways to Jump Start a Noise-Control Program.

Figure 28. Reducing Turbulence in a Steam Pipeline



Example

A branch of a steam line has three valves which produce a loud shrieking sound. The branch has two sharp bends which also produce a lot of noise.

Control measure

A new branch is created with softer bends. Tubing pieces are placed between the valves, so that turbulence will be reduced or eliminated before the stream reaches the next valve.

(Driscoll, Principles of Noise Control)

iii) Mufflers and Silencers

Mufflers (also called silencers) can be used on noisy, pressurized air equipment to reduce noise at the source. A muffler is a device that reduces the noise level from a moving air or gas stream, such as one found in a pneumatic tool (Figure 29). Like the muffler on an automobile, it absorbs some noise before it can reach the receiver (in this case, the ears of the worker who is exposed to the noise). Mufflers come in several configurations, some more sensitive to dust and moisture than others. In general, mufflers must be cleaned on a regular basis to be effective at reducing noise; if they are not cleaned, they actually can increase noise levels. Consult the muffler manufacturer for recommended cleaning procedures and frequency.

Figure 29 Schematic of Muffler Interior

iv) Reduce Pneumatic and Compressed Air Systems

A special case of high-velocity fluid flow is compressed air, which is used widely for many purposes, such as:

- Blowing debris off parts and surfaces
- Moving products on assembly lines
- Spraying paint and other substances
- Driving pneumatic tools

Compressed air causes noise exposure in most major industry sectors. Because compressed air is so common (and loud), it accounts for a large percentage of all workplace noise exposure.

Fortunately, noise from compressed air sources is easy and relatively inexpensive to abate. Examples of options for reducing noise from compressed air include:

- Adjusting the pressure regulator to reduce the air pressure in the air line coming from the compressor to the minimum pressure needed to accomplish the task. Lower pressure is not only quieter, but it saves energy and is safer. (To reduce serious injuries, OSHA requires that air pressure be held to 30 pounds per square inch or less when it could potentially contact skin).
- Replacing noisy air nozzles, guns, and wands with quieter models that have built-in noise-control features. Some models produce strong air thrust while reducing noise, using less compressed air, and saving energy (Figure 30).
- Installing additional air pressure control valves so air lines can be controlled individually to their effective minimum.
- Retrofitting pneumatic tools, compressors, and machinery by adding pneumatic mufflers or inline diffuser silencers and expansion chamber silencers. These function by providing the escaping exhaust air stream a larger area through which to expand and exit—so the air is released at a lower speed and pressure. This control option can cut noise by 20 dB or more.
- Purchasing equipment that comes with these features and replacing the noise control (nozzle or silencer) if function deteriorates.
- Adjusting the angle of air jets so that lower air pressure is needed to move products. In some cases, a more precise nozzle will permit further reductions.
- Updating workplace policies to reduce reliance on compressed air where it is unnecessary. For example, vacuuming instead of using compressed air for cleaning. This method also reduces air contaminants (such as spilled or settled dust containing a hazardous substance) that would become airborne when blown with compressed air.

For more information on controlling noise from pneumatic and compressed air systems, see Appendix K—Three Ways to Jump Start a Noise-Control Program.

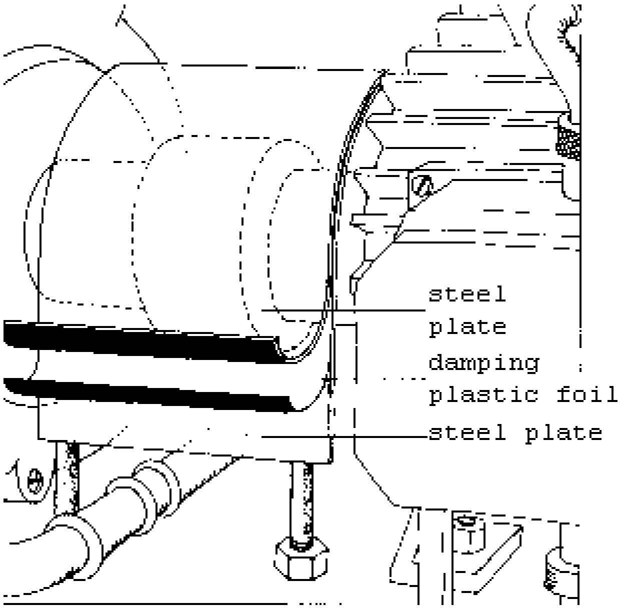
Figure 30. Noise-Reducing Compressed Air Nozzles

v) Retrofit Applications

Reduce Response of Vibrating Surfaces by Vibration Damping

Damping is another means of noise reduction. It dissipates energy associated with vibration, often using a coating applied to the surfaces of the noise source. For example, in parts manufacturing, metal parts are transferred via metal chutes, causing excessive noise from the impact of metal on metal. When the chute is coated with a damping material (e.g., mastic, asphalted felt), the noise level is reduced. Figure 31 shows a steel plate covering a moving part on a piece of equipment. A sheet of plastic foil is placed between the two steel plates, providing a damping effect.

Figure 31. Damping Effect



Damping is typically used to dissipate energy associated with large, thin, vibrating panels on pieces of equipment. For low-frequency noise, significant reductions in noise levels can occur when only 50% of the surface area of the vibrating panels is treated with damping material. It is necessary to treat the entire panel with damping material in order to achieve similar reductions in high-frequency noise.

Damping materials fall into three major categories: free-layer, constrained-layer, and constrained-layer laminates.

Simple ***free-layer*** damping materials consist of rubbery “viscoelastic” materials that can be painted, sprayed, troweled, or adhered (i.e., with adhesive or magnetism) onto the noisy surface. Typically, on sheet metal, a layer of damping material half the thickness of the metal (or 10% by weight) will eliminate the “ringing” from impact. A much thicker layer of damping material, two to three times the thickness of the metal, will increase the sound-absorption coefficient of the metal to approximately 0.3 to 0.6.

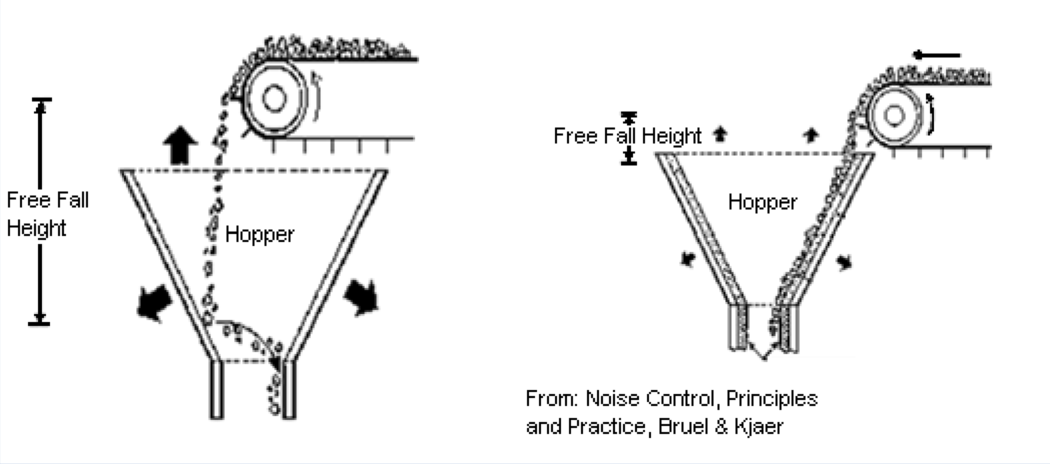
Constrained-layer damping materials add a rigid second layer adhered firmly over the viscoelastic layer. This effectively increases the damping effect, even with a very thin layer of the viscoelastic material. The rigid second layer must be inelastic (i.e., it must not stretch in any direction), but it can be quite thin—even a thin metal sheet or foil will work. This combination of materials is popular because it reduces noise efficiently but takes up little space. This concept is demonstrated in the previous figure, in which two steel plates are separated by a layer of plastic foil. Commercial vendors have developed numerous versions of these materials, including metal tapes; the tape provides the inelastic properties, while the adhesive provides the viscoelastic layer.

Constrained-layer laminates follow the same principle but laminate additional layers and thicknesses of rigid material (metal or wood). These laminates offer both good noise reduction properties and strength, to the extent that some typically noisy mechanical parts (e.g., covers for moving/mechanical parts, conveyer chutes) can be made of the laminate. The transmission loss of plywood and other composite materials is improved when a viscoelastic layer is sandwiched between layers. One drawback is that special techniques are required to bend, cut, or weld these laminated materials.

When determining which damping materials to use, one should consider the typical temperature and frequencies present in the equipment and consult the damping material manufacturers to identify optimal materials.

Keep in mind that the machine, the product being manufactured, and the process itself can all create and radiate noise. Consider the illustration in Figure 32 (conveying rocks into a hopper). In the example on the left side, the rocks impacting the metal-paneled walls of the hopper cause it to ring like a bell. As shown on the right side, reducing the free-fall height (by backing up the conveyor) such that there is only a short drop significantly reduces the potential energy, which reduces the resultant noise. Additionally, a durable rubber-like material is added to damp the hopper and minimize the ability of the metal panel to flex and vibrate, which eliminates this noise at the source. Damping material can be added to either side of the metal surface (Driscoll, Principles of Noise Control).

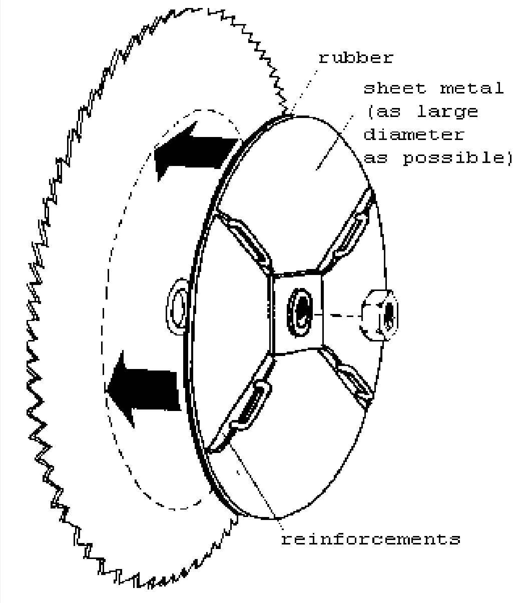
Figure 32. Reducing Free Fall Height



(Driscoll, Principles of Noise Control)

Damping materials are often used to reduce the response of a vibrating surface. They work by dissipating the mechanical energy of a vibrating panel in a way that does not allow the energy to re-radiate into the air as noise. The mechanical energy from a vibrating surface is typically converted into heat in the damping material, though the change in temperature is usually too small to be noticeable by touch. Large, flat surfaces that vibrate are likely to radiate more noise than smaller, stiffer surfaces. It is often not cost-effective, especially for large machines, to treat the entire machine with damping materials. Damping material attached to the center of a vibrating plate is more effective than the same amount of material attached on the sides of the same plate. This concept is displayed in Figure 33, in which a circular blade is outfitted with a sheet metal disc with a rubber buffer layer between the sheet metal and the blade.

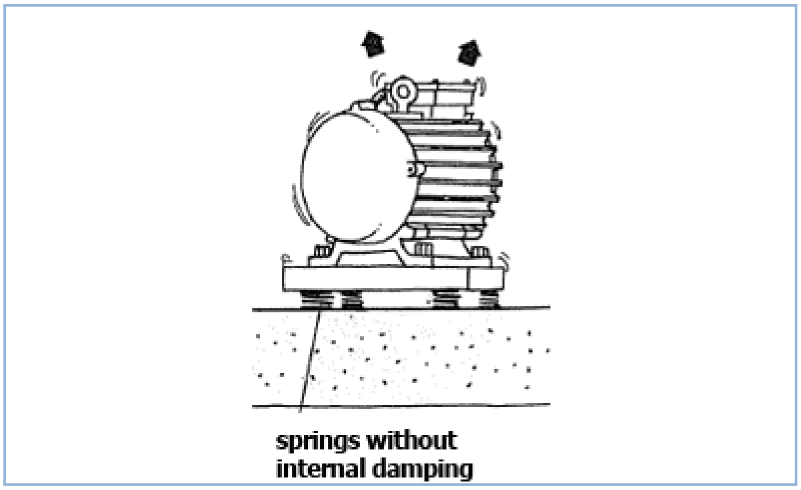
Figure 33. Adding Damping Material to a Saw Blade



Reducing Structure-Borne Noise by Vibration Isolation

When a machine rotates, cycles, and indexes, it often transfers some vibratory energy in the casing, pipes, and metal structure. Even though these parts of the machine may not be an efficient radiator of airborne sound, the vibrations can be carried (via solid connections) to a surface area that can convert this energy into airborne sound or noise. When structure-borne vibration is identified as a primary source, isolation of the exiting force from the structure is the most desirable and effective control. Figure 34 represents a vibrating piece of equipment that has been isolated using spring isolators to prevent noise transfer into the concrete floor (Driscoll, Principles of Noise Control).

Figure 34. Isolated Structure-Borne Noise



(Driscoll, Principles of Noise Control)

Noise control by reducing structure-borne vibration involves installing vibration mounts and providing proper lubrication and maintenance for equipment. Regular maintenance ensures proper operation of equipment and is less expensive than other engineering controls; this maintenance can include tightening belts and lubricating moving parts. Structure-borne vibration can also be reduced by isolating a vibrating piece of equipment—if identified as the primary source of noise—using vibration mountings or shock absorbers (Figure 35). The picture on the left shows neoprene isolators, while the picture on the right shows spring isolators. Vibration isolation mounts are effective for reducing low-frequency noise.

Figure 35. Neoprene and Spring Vibration Isolators

(Driscoll, Principles of Noise Control)

vi) Substitute for the Source

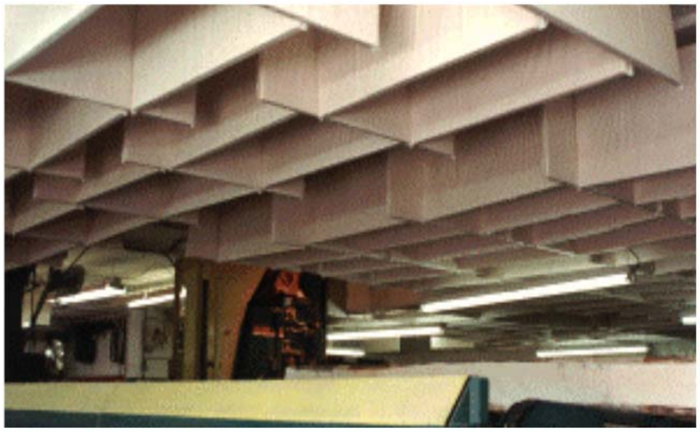
One way to reduce noise at the source is to replace noisy equipment with a quieter alternative. Manufacturers are aware of noise issues on equipment and often offer quieter models. When it comes time to replace equipment, employers are increasingly considering noise level as one of the selection criteria. Some employers develop "buy-quiet" programs as part of purchasing policies to ensure that noise levels are taken into consideration.

2. Path Treatment

i) Sound Absorption

Reflected sound (sound reverberating from the walls, ceiling, and floor) will add to the sound wave propagating directly from the source to the receiver, thus increasing the overall noise level within a room. Acoustical absorptive materials are used to reduce this reflected sound; installed on the walls or ceiling (Figure 36), they absorb and dissipate the sound before it can be reflected. Materials used for sound absorption are usually porous or fibrous (e.g., fiberglass, mineral wool, felt, polyurethane foams).

Figure 36. Sound-Absorption Paneling



(Driscoll, Principles of Noise Control)

The room shown in the figure has been treated with absorption panels in the ceiling space. Note that adding this material to reduce the reverberant sound does not reduce the direct sound coming from the equipment: that sound will always exist, even if the equipment is placed outside, where little to no reflection exists. When treating a ceiling with absorptive material, a useful guideline is that the noise level will not be significantly reduced for workers at ground level when acoustical panels are installed at ceiling heights greater than 15 feet. In this situation, workers are most likely affected primarily by the direct sound wave. Vertically hung panels can create new problems, such as interference with ventilation, lighting, and sprinkler patterns. Also, for this form of treatment to provide a measurable noise reduction, the original room must be acoustically "hard." In other words, the room surfaces must be made of highly reflective materials, such as concrete or painted cinder block.

As well as the sound material used to absorb sound in a room or enclosure, it is common to use sound-isolating material (also known as sound transmission loss material) to block sound from propagating from one room to another, or from inside an enclosure to outside. Often, as with enclosures and pipe insulation, one desires a combination of absorptive and sound isolation qualities. Unlike damping materials, however, it is critical for the sound-absorption material to be directly exposed to the source or noise. Attaching acoustical foam on the outside of a metal enclosure does not reduce noise; the material needs to be on the inside surface areas. This may sound simple, but it is not uncommon to find materials improperly used in this manner. Keep the function of each material in mind.

For the purpose of designing noise controls, it is useful to be able to compare the characteristics of different materials. The tendency of a material to *absorb* or reflect a sound is numerically represented by its *absorption coefficient*: the ratio of sound energy absorbed by the material to the sound energy incident to (striking) the material's surface. This coefficient is a decimal value between 0 (all sound reflected and none absorbed) and 1 (all sound absorbed). In simple terms, a material that reflects 66% of the sound energy that reaches it will absorb the remaining 34% and have an absorption coefficient of 0.34. Materials that absorb sound particularly well, such as fiberglass acoustical panels, have absorption coefficients approaching 1. An absorption coefficient reported as greater than 1 is an artifact of the test conditions.

Table V–1 displays the sound-absorption coefficients for three common sound-absorbant materials. The amount of noise absorbed by these materials depends on the density and thickness of the material and the frequency of the sound (Driscoll, Principles of Noise Control).

Table V–1. Effect of Thickness on Sound-Absorption Coefficients

Material	Range of Volume Density (lb/ft^3)	Range of Thickness (Inches)	Random-Incident Sound-Absorption Coefficient with Solid Backing (#4 Mounting)							
			Thickness (Inches)	Density (lb/ft^3)	*Octave-Band Center Frequency (Hz)*					
					125	*250*	*500*	*1,000*	*2,000*	*4,000*
Resilient fiberglass with resinous binder	1 to 3	1/2 to 6	1.0	1.5	0.12	0.28	0.73	0.89	0.92	0.93
			2.0	1.5	0.24	0.77	0.99	0.99	0.99	0.99
			2.0	3.0	0.22	0.82	0.99	0.99	0.99	0.99
Rigid fiberglass board	3 to 6	1/2 to 2	1.0	6.0	0.08	0.25	0.74	0.95	0.97	0.99
Open-cell acoustical foam	1.8 to 2.5	1/4 to 2	1.0	1.8	0.22	0.35	0.61	0.98	0.94	0.99

(Driscoll, Room Acoustics V2)

Frequency also influences sound absorption by materials. Table V–2 shows the absorption coefficient for common building materials at different frequencies. Note that dense materials, such as rough concrete, absorb lower frequencies better than other materials, while high frequencies are better absorbed by less dense materials, such as carpet and fiberglass. Painting concrete creates a smooth surface that greatly increases the percentage of sound that is reflected at all frequencies.

Table V–2. Absorption Coefficients of Common Surface Materials and Finishes

Material	125 Hz	250 Hz	500 Hz	1,000 Hz	2,000 Hz	4,000 Hz
Brick, unglazed	0.03	0.03	0.03	0.04	0.05	0.07
Brick, unglazed, painted	0.01	0.01	0.02	0.02	0.02	0.03
Carpet, heavy, on concrete	0.02	0.06	0.14	0.37	0.60	0.65
Carpet, heavy, on 40 oz hairfelt or foam rubber pad	0.08	0.24	0.57	0.69	0.71	0.73

Table V–2. Absorption Coefficients of Common Surface Materials and Finishes

Material	125 Hz	250 Hz	500 Hz	1,000 Hz	2,000 Hz	4,000 Hz
Carpet, 40 oz per square yard, with latex backing, over felt or foam rubber pad of same density (on concrete)	0.08	0.27	0.36	0.34	0.48	0.63
Concrete block, coarse	0.36	0.44	0.31	0.29	0.36	0.25
Concrete block, painted	0.1	0.05	0.06	0.07	0.09	0.08
Fabric, light velour, 10 oz/square yard, hung straight in contact with wall	0.03	0.04	0.11	0.17	0.24	0.35
Fabric, medium velour, 14 oz/square yard, draped in half	0.07	0.31	0.49	0.75	0.72	0.60
Fabric, heavy velour, 18 oz per square yard, draped in half	0.14	0.35	0.55	0.72	0.72	0.65
Plywood paneling, 3/8 inch thick (1 cm)	0.28	0.22	0.17	0.09	0.10	0.11
Floors, concrete or terrazzo	0.01	0.01	0.015	0.02	0.02	0.02
Floors, linoleum, asphalt (vinyl), rubber, or cork tile on concrete	0.02	0.03	0.03	0.03	0.03	0.02
Floors, wood	0.15	0.11	0.10	0.07	0.06	0.07
Floors, wood parquet in asphalt on concrete	0.04	0.04	0.07	0.06	0.06	0.07
Glass, large panes of heavy plate glass	0.18	0.06	0.04	0.03	0.02	0.02
Glass, ordinary window glass	0.35	0.25	0.18	0.12	0.07	0.04
Gypsum board, ½ inch, nailed to 2x4 wood frame 16 inches on center	0.29	0.10	0.05	0.04	0.07	0.09
Marble or glazed tile	0.01	0.01	0.01	0.02	0.02	0.02
Opening, covered by grill (e.g., ventilating)	0.25–0.75					
Plaster, gypsum or lime, smooth finish on tile or brick	0.013	0.015	0.02	0.03	0.04	0.05
Plaster, gypsum or lime, rough finish on lath	0.14	0.10	0.06	0.05	0.04	0.03
Plywood paneling, 3/8 inch thick	0.28	0.22	0.17	0.09	0.10	0.11
Water surface (pond or swimming pool)	0.008	0.008	0.013	0.015	0.020	0.025
Fiberglass boards and blankets, 2 inches thick, 1.5 to 3 pounds per square foot	0.17	0.55	0.80	0.90	0.85	0.8

Sources: NIOSH, 1979; Cox and D’Antonio, 2004.

Dense, heavy materials typically have low absorption coefficients (i.e., they reflect a high percentage of the sound energy). Because they do not absorb much sound energy, they do not transmit much sound and little sound penetrates through them.

ii) Reducing Noise Transfer Across Barriers—Using Sound Transmission Loss Materials

Table V–3 and V–4 show various transmission loss values for common building materials at specific frequencies and material thicknesses. Note that the values in these tables are measured under ideal laboratory conditions as a resource for comparing different materials. In the workplace, the noise exposure experienced by the receiver would not actually be reduced by the reported transmission loss value, because imperfections in enclosures, barriers, or other noise controls made of these materials permit sound to go around the material, leak through cracks or utility paths, or pass through other materials with lower transmission loss values (e.g., a door jamb, window glass) that were also used in construction.

Table V-3 demonstrates how the thickness of two materials (plywood and steel) influences the transmission loss values for the materials, and Table V–4 compares the relative transmission loss values for common building materials.

Table V–3. Effect of Thickness on Transmission Loss Values for Plywood and Steel (dB)

Material	125 Hz	250 Hz	500 Hz	1,000 Hz	2,000 Hz	4,000 Hz
Plywood, 1/4 in., 0.7 lb/ft²	17	15	20	24	28	27
Plywood, 3/4 in., 2 lb/ft²	24	22	27	28	25	27
Steel, 18 gauge, 2 lb/ft²	15	19	31	32	35	48
Steel, 16 gauge, 2.5 lb/ft²	21	30	34	37	40	47

Table V–4. Relative Transmission Loss for Example Materials (dB)

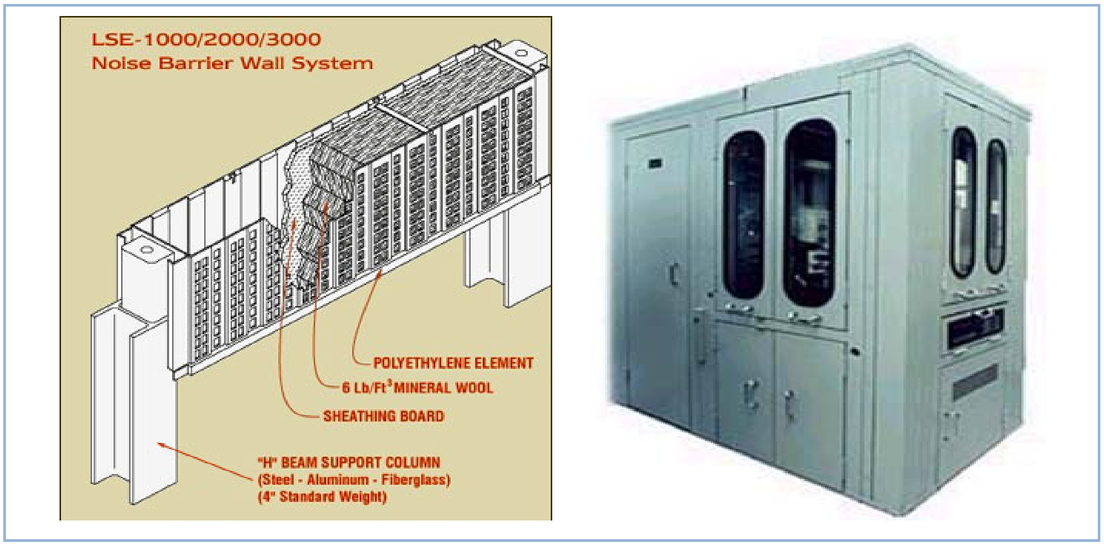
Material	125 Hz	250 Hz	500 Hz	1,000 Hz	2,000 Hz	4,000 Hz
Brick, 4 in.	30	36	37	37	37	43
Cinder block, 7⅝ in., hollow	33	33	33	39	45	51
Concrete block, 6 in., lightweight, painted	38	36	40	45	50	56
Curtains, lead vinyl, 1½ lb/ft²	22	23	25	31	35	42
Door, hardwood, 2⅝ in.	26	33	40	43	48	51
Fiber tile, filled mineral, 5/8 in.	30	32	39	43	53	60
Glass, plate, 1/4 in.	25	29	33	36	26	35
Glass, laminated, 1/2 in.	23	31	38	40	47	52
Panels, perforated metal with mineral fiber insulator, 4 in. thick	28	34	40	48	56	62
Plywood, 1/4 in., 0.7 lb/ft²	17	15	20	24	28	27
Plywood, 3/4 in., 2 lb/ft²	24	22	27	28	25	27
Steel, 18 gauge, 2 lb/ft²	15	19	31	32	35	48
Steel, 16 gauge, 2.5 lb/ft²	21	30	34	37	40	47
Sheet metal laminate, 2 lb/ft², viscoelastic core	15	25	28	32	39	42

Source: Lord et al., 1980.

Sound-absorbing materials are a valuable addition to acoustic enclosures and barriers, which can interrupt a noise path. Acoustic enclosures can be either full or partial and can surround either the noise source or the worker. A personnel enclosure works best if it is lined with sound-absorbing material. An alternative is an enclosure that surrounds a piece of equipment (a noise source), as pictured in Figure 37. Employers and workers should consider the risk of equipment overheating when surrounded by an acoustic enclosure.

Partitions or barriers can be constructed when a total enclosure is not possible. Barriers block mid and high frequencies better than low frequencies due to the greater diffraction of low-frequency sounds. Low frequencies can travel around corners and through holes, whereas high frequency sounds are more likely to be blocked (OTM/Driscoll).

Figure 37. Noise Barriers and Enclosures



(OTM/Driscoll)

Sound-absorption and reflection properties of different materials means that certain materials are better at interrupting noise than others. Additionally, the way they interrupt noise varies with the frequency of the sound and the physical characteristics of the material. The ability of a material to interrupt sound can be described by its ability to absorb sound and, separately, by the extent to which it does (or does not) transmit the portion of the sound it absorbs.

Generally, soft, thick, fuzzy, and porous materials absorb sound well, permitting only a modest amount of the sound to reflect off the surface back into the space. In contrast, hard, smooth surfaces tend to reflect a high percentage of the sound.

Heavy, dense materials absorb low-frequency sounds better than high-frequency sounds. Protective barriers made of these materials are better at reflecting high-frequency sounds but absorb the low-frequency sounds.

A barrier's ability to *attenuate* sound that it absorbs is described by its *transmission loss*. Transmission loss, measured in decibels in laboratory tests, represents a sample of a barrier material's ability to prevent sound energy from propagating through the material to produce sound on the other side. A sample of material with an excellent transmission loss may reduce the sound level through a test panel of that material by up to 60 dB. Both the material and the thickness of the sample influence its transmittal loss.

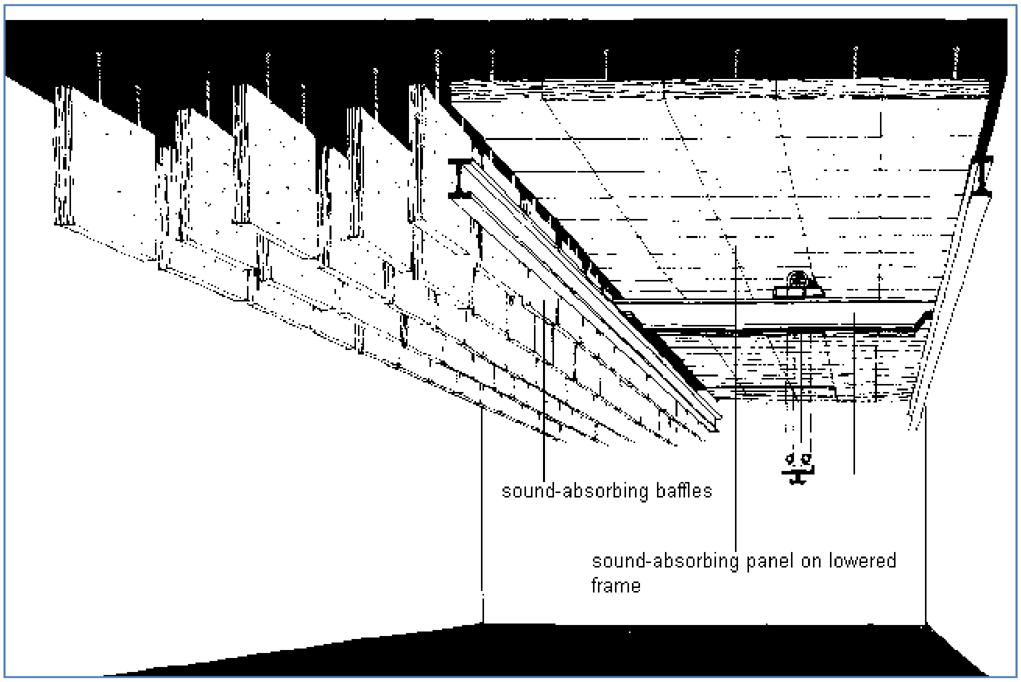
When constructing a partial barrier, it is important to consider factors other than the barrier material. For example, for a barrier to be effective, a receiver (worker) should be located in the direct field as opposed to the reverberant field. A barrier's effectiveness in attenuating noise is maximized in a non-reverberant environment. Therefore, if a receiver's noise exposure is predominantly from reverberation, the effectiveness of the barrier will be limited. The barrier should be placed as close as possible to the receiver or the noise source to minimize the angles from which sound is reflected to the receiver.

The dimensions of the barrier are also important. In general, the width of a barrier on either side of the noise source should be twice the height of the barrier. Additionally, any cracks or gaps in the barrier can significantly diminish the transmission loss value. Any gap through which air can pass will allow a significant amount of noise to pass as well.

iii) Reducing Reverberation

A common way to reduce reverberation in a room is to install sound-absorbing materials, such as acoustic tiles, in strategic places on the walls and ceiling surrounding the noise source. Reverberation can be greater when the room surfaces are hard (e.g., concrete, cinder block, corrugated metal); in these environments, sound-absorbing materials can be beneficial. This is a common treatment in theaters, broadcast studios, and sound-recording booths. Figure 38 shows a large, open room in which sound-absorbing baffles and acoustic tiles are hanging from the ceiling. This engineering control will do nothing to reduce the noise level from the noise source but will reduce the reflection of noise back into the room. As was mentioned previously, this type of control works best in a small room (less than 10,000 square feet) with low ceilings (less than 15 feet). In a room with high ceilings, the main source of noise to which workers are exposed is most likely direct noise from the source. Sound-absorbing materials should never be painted, as this would cover the pores in the material, thereby preventing noise from being absorbed.

Figure 38. Sound-Absorbing Baffles



Reflective and absorptive materials are able to reduce noise levels in different ways. Engineered noise-control laminates combine two or more layers of diverse materials with different properties, often with an air space between them. These layered materials absorb a high percentage of sound and then attenuate the sound to maximize the transmission loss. The sound is effectively captured with minimal reflection and transmission.

An alternate method of interrupting the noise path is to relocate the noise source. For example, air expansion at valves can cause significant noise; these valves can be routed to an area away from the worker by extending the piping, which would remove the noise source from the worker, thereby reducing the worker’s noise exposure.

iv) Acoustical Enclosures

Acoustical enclosures are the most popular path treatment used in industry. Such an enclosure is composed of a dense outer casing, often with a sound-absorptive material on the interior surfaces to help dissipate the acoustical energy.

Enclosures can present difficulties for the production process. Using them can involve many challenges, such as interior heat buildup, limited physical and visual access to the equipment, difficulty getting the product in and out of the enclosure without sacrificing some noise reduction, and maintenance personnel needing to disassemble the enclosure when repairing equipment. It is not unusual for a reassembled enclosure to lose much of its effectiveness due to poor fittings and small gaps or openings in the enclosure.

Despite the challenges associated with enclosures, they are often the most effective way to control noise hazards. A well-designed and relatively airtight enclosure can provide as much as 30 dB to 40 dB of noise reduction. For example, Figure 39 shows an enclosure with large retractable doors, large observation windows, internal lighting, and ventilation, among other features (Driscoll, Principles of Noise Control).

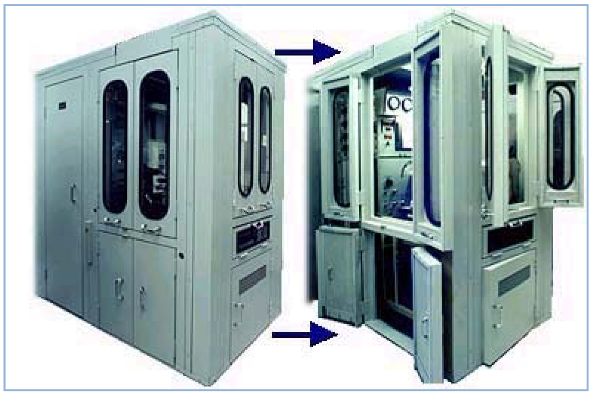


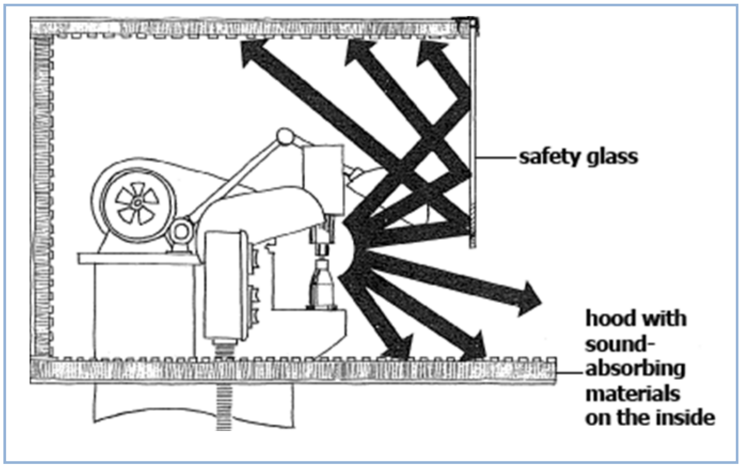
Figure 39. Large Equipment Enclosure with Retracting Doors

(Driscoll, Principles of Noise Control)

Complete enclosures around noise sources are not always possible due to requirements to access maintenance panels and equipment controls, provide ventilation, or keep the process flowing. In these cases, a partial enclosure may still substantially reduce noise. Like full enclosures, partial enclosures should have effective barrier materials on the outside and should be lined with absorptive materials on the inside. Because noise will escape through the opening, the noise path should be treated with sound-absorbing materials if possible. Also, the number of openings should be limited and should be directed away from workers, if possible. Figure 40 shows a partial enclosure that allows access while affording the operator some protection from the noise source.

Where possible, it is beneficial to combine noise control with machine guarding requirements to protect workers from other physical hazards (e.g., pinch points, crushing hazards). For more information on integrating noise control with machine guarding, see Appendix K—Three Ways to Jump Start a Noise-Control Program.

Figure 40. Partial Enclosure



(Driscoll, Principles of Noise Control)

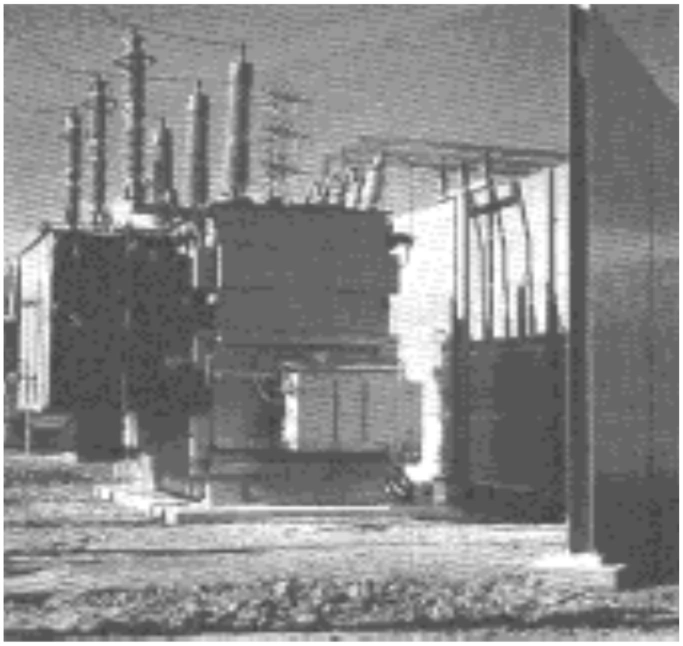
Enclosing a noise source is often impractical if there is not enough space or if workers need to access the noise source for maintenance or operational reasons. In these cases, lagging could be a more practical solution. Lagging, essentially a localized form of enclosure, can be wrapped around pipes or ducts that generate noise. The lagging should be designed following the same principles outlined for enclosures: with effective barrier materials on the outside and sound-absorptive materials on the inside.

Lagging is generally installed from the inside out, by first encircling the pipe or duct with the absorptive inner material, then applying an airtight limp barrier material as a protective covering. The airtight outside barrier of the lagging can be composed of asphalt paper, linoleum, neoprene sheeting, lead, loaded vinyl, or other materials with similar qualities. Placed against the pipe or duct, the lagging's inner absorptive material provides isolation between the outer layer and the noise source and also helps absorb noise from the source.

v) <u>Shields or Barriers</u>

A barrier is a partial wall, or partition, between the noise source and the receiver. It is made of a solid, dense material with high sound transmission loss. Sound barriers create a sound shadow at the location of the receiver, thus attenuating noise exposure.

Figure 41. Large Partition Wall



(Driscoll, Principles of Noise Control)

Note the large partition wall on the right side of the photograph in Figure 41. A barrier should be as tall as possible and be as close to the worker or the noise source (in between the two) as feasible in order to maximize the reduction in noise exposure. Of course, if a receiver is inside a room, reverberations from the ceilings and walls can diminish the effectiveness of a barrier. For this reason, indoor barriers are most effective when workers are in the direct field of sound from the noise source, as opposed to the reverberant field. Even outdoors, it is possible for noise to reflect from nearby buildings and contribute to the noise exposure of the receiver.

A noise barrier is most effective when its transmission loss is at least 10 dB greater than the insertion loss expected (see text box for definitions of transmission loss and insertion loss). If it is not, sound transmitted through the barrier may contribute significantly to the noise exposure of the receiver. One effective strategy for further reducing noise levels with barriers is to create barriers with multiple layers, sandwiching a material of different density (such as air) between the layers. Two 5-inch masonry walls spaced a few inches apart will have a greater transmission loss from one side to the other than a solid masonry wall that is 10 inches thick.

Insertion Loss vs. Transmission Loss

Insertion loss is the difference in sound pressure level (dB) measured at a fixed point before and after the noise control is installed. This common measure of acoustic performance represents the change in sound pressure level (dB) for the surroundings due to the "insertion" of noise reduction materials.

Transmission loss is the difference in sound power level across the noise reduction material. It is the difference between measurements made on either side of the material.

3. <u>Receiver Treatment</u>

i) <u>Enclosures (Cabs, Control Rooms, Isolation Booths)</u>

The receiver (again, the worker) can be protected from noise by an isolation booth. In the construction industry, a common example of a personnel enclosure is the cab on heavy equipment, such as a dozer. Figure 42 shows another type of personnel enclosure (in this case, a multi-person control room).

The design concepts for personnel enclosures are similar to those for equipment enclosures, but because they are used to enclose people, safe access and egress, fresh air supply, and thermal comfort are critical considerations. For any personnel enclosure, the room or booth's ability to exclude noise is impaired while the door is open. Workers are more likely to keep the door closed if they perceive that the atmosphere inside the booth is at least as comfortable as it is outside the booth. Workers generally use a personnel enclosure most effectively—keeping the door closed to exclude noise—when the enclosure provides tempered air (seasonally heated or air conditioned) and a sense of air movement inside.

Figure 42. Personnel Enclosure

(Driscoll, Principles of Noise Control)

B. Engineering Controls and Economic Feasibility

1. Overview

The cost of achieving acceptable noise levels varies greatly, depending on the industry. Even within specific industries, noise levels can vary widely with different processes, practices, and equipment. When a facility does make changes that include engineering control measures in a noisy area, it rarely follows up with a detailed noise evaluation that documents the changes, costs, and extent to which noise decreased. As a result, published literature contains relatively few specific examples comparing the costs and benefits of engineering controls.

The economic feasibility of lowering noise levels with engineering controls is an important factor in deciding whether to implement specific controls. In addition to the direct costs of design, materials, construction or installation, and maintenance of engineering controls, these controls can have indirect costs and benefits, such as decreasing worker absenteeism, increasing or decreasing worker productivity, and increasing or decreasing the life of process equipment. Furthermore, if an engineering control reduces worker TWAs below 85 dBA, the need for a hearing conservation program is eliminated, along with the associated costs. These costs include expenses for audiometry, training, HPDs, recordkeeping, and program administration.

As a general rule, engineering controls increase in cost as their implementation moves further from the design stage. It is typically cheaper to control noise by "designing it out" (i.e., modifying equipment or facility design plans to reduce the sound level associated with the finished product) than to purchase new production equipment. Purchasing new production equipment is also typically cheaper than retrofitting existing equipment with noise controls. Each facility must be responsible for evaluating which noise reduction options are most appropriate for it. Facilities will have different options for significantly reducing noise levels at the lowest possible cost.

The following case studies provide a sample of engineering control options that have been effective and economically feasible for other facilities. The studies are categorized by the engineering control technique involved. Cost information is included when available.

2. *Engineering Control Case Studies*

i) Acoustic Absorption

Case study: A fixed-base router initially produced a noise level of 84.8 dBA in testing. Workers placed 3M Thinsulate foam over the motor intake and exhaust vents. After the foam was installed, the router produced a noise level of 77.4 dBA, approximately 8 dBA less than the original noise level. The authors of this study estimated that it cost less than $1 per router to implement (Koning et al., 2003).

Case study: A company manufactures cement blocks in 8”,10", and 12" sizes according to orders. Cement, fly ash, and other raw materials are brought in on railcars and stored in silos. The ingredients are then mixed and sent to the block machine, which initially generated noise levels of 95 dBA. The employer installed acoustical panels around the block machine, lowering the noise generated by the machine to 88 dBA. The employer stated that the eight acoustical panels cost $45 each, for a total cost of $400.

Case study: A company manufactures mattresses and foundation products. The mattresses are assembled on a steel table. The nail gun operator (who assembles the mattresses) was previously exposed to noise levels of 93 dBA. The employer implemented the following changes: replaced the steel tables with wooden tables; reduced the nail gun from 110 psi to 85 psi; placed acoustical insulation on the top, bottom, and around the wooden tables; and wrapped foam around the table legs to absorb the vibration to the concrete floor. These measures lowered the noise generated to 87 dBA. The total cost was $500.

ii) Damping

Case study: A high-speed, strip-fed punch press was used in a manufacturing process to stamp electrical components. The equipment generated noise levels of 101 dBA when operating at an average of 271 strokes per minute. To reduce the noise level, the manufacturer installed anti-vibration mounts and applied a self-adhesive damping sheet to the sheet metal surfaces of the equipment. These measures lowered the noise generated by the equipment by 9 dB to 92 dBA.

Case study: A feeder bowl was used to sort aluminum disks and produced 101 dBA. The best way to reduce this noise level was to apply a damping compound to the feeder bowl. The damping compound reduced the noise level 12 dBA to 89 dBA. Five gallons of the compound cost $180 to $250, plus the approximate labor cost of $27 per hour and 1 hour per bowl.

iii) Design

Case study: A company used a tungsten-carbide-tipped blade to cut aluminum. The blade produced an average noise level of 97 dBA; the company reduced this noise level to 91 dBA by replacing it. The original blade was 350 mm in diameter, with 84 teeth and a thickness of 3.5 mm; the new blade was also 350 mm in diameter but had 108 teeth and a thickness of 3.2 mm. The former blade cost between $10 and $40, whereas the blade with more teeth cost between $60 and $400 (Government of Western Australia, 2009).

Case study: A company designed a bulldozer whose engine ran at a rated speed 5% lower than a typical bulldozer. The bulldozer also included other noise reduction measures, such as a cab damper mount. At 15 meters from the newly designed bulldozer, the noise level is 10 dB lower than a typical bulldozer (60 dB vs. 70 dB). The bulldozer operator's exposure was 7 dB lower than with the previous design. The costs of the old and new designs are difficult to compare but range from $70,000 for a 1990 version of the old design to $235,000 for the new design.

Case study: A U.S. government agency recognized that it had been spending money on retrofit noise controls while still buying new loud equipment. The agency determined that a two-prong approach was needed: buying new quiet equipment while continuing to retrofit old noisy equipment. By implementing a "Buy Quiet and Quiet by Design" requirement, the agency compelled noise emissions to be considered equally with other factors when buying equipment near an 80-dBA threshold. Among other tools in a "Buy Quiet Process Roadmap" created to help procurement officers identify and purchase quieter equipment, the agency developed a process for quantifying the long-term costs of noise exposure for the candidate products being considered for purchase. Both these costs and the equipment noise level are considered in the final purchase decision.

Case study: A standard pneumatic production rock drill was compared to a prototype pneumatic rock drill incorporating engineering noise-control measures (varying thrust pressure and water flow rate at the bit). By using the manufacturer's recommended operating pressure of 496 kPa (72 psi), the prototype's sound power was 10 dBA less than that of the standard drill. The drills' penetration rates were within 6 percent of each other, indicating that the noise control was effective without sacrificing performance. (NIOSH, 2009)

iv) <u>Isolation</u>

Case study: A bench grinder and finish grinder in an electrical contractor's workshop were resting on a metal cabinet against the wall. The equipment generated noise levels of 95 dBA. The equipment was removed from the cabinet and placed on pedestals, which were mounted to the floor with rubber mounts. As a result, the noise level dropped to 91 dBA. This control cost approximately $150. (HSE, 2005a)

v) <u>Insulation (Enclosure/Barrier)</u>

Case study: A company manufactured folding cartons. The cartons were produced in stacks, which were held together by uncut portions of the carton material. The cartons were separated using an air chisel powered by compressed air. This chisel generated noise levels of up to 95 dBA. A simple barrier wall of ¼-inch plywood was constructed, consisting of a frame with plywood attached to either side. The sound level of the receiver was reduced to 85 dBA.

vi) <u>Maintenance</u>

Case study: A 20-ton press was used in a manufacturing process to pierce aluminum plates. By replacing the bearings and providing proper lubrication when needed, the noise levels were reduced between 7 dBA and 16 dBA. These maintenance measures also increased the tonnage of the equipment to its original rating.

Case study: NIOSH evaluated the noise exposure of heavy equipment operators using new and older models of bulldozers. The newest bulldozer studied had noise controls consisting of acoustic foam on the ceiling of the rollover and falling object protection system, an exhaust muffler, and an enclosed engine compartment, all missing on the older bulldozers. Even with no cab, the newest bulldozer had the lowest recorded operator's noise dose of all the bulldozers (139% OSHA PEL). The operator of the new bulldozer with intact noise controls (except cab) had noise exposures 1/4 to 1/10 that of workers operating dozers lacking noise controls but otherwise in good condition (up to 1,397% OSHA PEL). (NIOSH, 1979)

vii) Silencing (Pneumatic)

Case study: A manufacturing process involved the use of a hoist motor for materials handling. The motor's air exhaust exposed the operator to 115 dBA. The manufacturer installed a muffler on the exhaust, reducing the noise level to 81 dBA. Off-the-shelf mufflers cost anywhere from $1 to $150 each, plus the cost of maintenance labor, which can be assumed to be $27 per hour (in 2009 dollars) for 1 hour per month.

Case study: A powder mill dropped ground product by gravity into a large orbital sifter. This process generated a noise hazard for the equipment operators, but the powder would destroy a traditional silencer. The facility manufactured a flexible connector between the pipe and the sifter that allowed the sifter to move and stay connected to the pipe above, while not allowing the sifter to direct noise energy through the inlet. An oversized silencer was then fitted over the flexible connector to catch the noise that leaked from the connector, reducing the noise level by 8 dB to 82 dB. The cost was £750 (equivalent to $1,309.34 at the time [2005]).

Case study: A pneumatic nail gun generated a noise level of 94.5 dBA at its muffler. A team of student researchers developed a way to construct an additional muffler to reduce the noise level to 75.5 dBA using common materials that cost less than $5 in total. These materials included a Viton O-ring, PVC housing, an 8-mm bolt, and a hose plug.

C. Economic Feasibility of Noise-Control Engineering

1. *Background*

This section suggests methods that CSHOs can use to evaluate the economic feasibility of noise engineering controls relative to current enforcement policy (see CPL 2-2.35A Appendix A and OSHA's *Field Operations Manual*) and for pre-citation documentation purposes. These methods are useful whenever the daily noise exposure exceeds the levels listed in 29 CFR 1910.95 and 20 CFR 1926.52.

The economic feasibility of noise engineering controls has been calculated using several different methods over the past decade. The primary difference between the methods involves how the costs of noise exposure are calculated (i.e., to what extent calculations include potential disability claims, workers' compensation insurance rates, purchase of hearing aids, purchase of HPDs, and the various costs of administering a hearing conservation program). Differences in how inflation is adjusted also create notable variations in both the costs of noise exposure and expenses related to purchasing, installing, and maintaining engineering controls.

In 2001, OSHA Region III produced an instruction on conducting economic feasibility evaluations for noise-control engineering. This instruction was based in part on information published in the Regulatory Impact and Regulatory Flexibility Analysis of the Hearing Conservation Amendment, OSHA Office of Regulatory Analysis, February 1983.

Note on Costs

Dollar amounts quoted in this section are relative estimates, used as examples to demonstrate methods for determining whether implementing a hearing conservation program or engineering controls is more economical. Actual costs will vary based on factors such as location, availability of supplies, and varying cost inflation. The CSHO should investigate local costs in situations where the relative cost differential is close, as determined following this procedure.

More recently, several sources have offered more detailed methods for evaluating the costs of noise and benefits of noise control (described in Appendix G).

The rest of this section presents information adapted from the Region III (2001) instruction mentioned above (Directive Number STD 1-4.1A).

The assumptions and tables in this section contain examples of approximate costs and other related information. This information is used here to demonstrate (through examples) some simple methods that CSHOs can use when considering economic feasibility of engineering controls compared to a hearing conservation program. The numbers used in these assumptions, tables, and examples should be refined as appropriate for each inspection and locality.

2. Assumptions for an Economic Analysis

To perform an economic analysis efficiently and realistically, several assumptions need to be made:

Assumption 1: If actual life expectancy of equipment is known to the CSHO, then it should be used. If unknown, assume the life expectancy of durable-equipment engineering noise control is 10 years. Regardless of the source of the life expectancy figure, use it to determine the average cost per year (i.e., total lump sum upfront costs for equipment divided by years of life expectancy).

Assumption 2: If actual costs for an engineering control are known to the CSHO, then they should be used. If costs for an item listed in Table V–6 are unknown, the *average* cost in Table V–6 shall be used for cost estimating.

Assumption 3: The maintenance cost for an engineering control shall not exceed 5% of the initial cost per year over a 10-year time span (based on guidance from the Office of the President of the United States, OMB).

Assumption 4: If actual maintenance costs for an engineering control are known to the CSHO, then they should be used. If unknown, then the percentage given in Table V–6 shall be used for cost estimating.

Assumption 5: The least expensive control option or group of controls that will achieve a reduction of 3 dBA or more in worker exposure shall be used for determining economic feasibility.

Assumption 6: An engineering or administrative control is economically feasible if its total cost is less than or equal to the cost of a continuing effective hearing conservation program for all the workers who would benefit from the control's implementation (i.e., have a reduction in their noise exposure).

Assumption 7: If actual costs of administrative controls are known to the CSHO, then they should be used. Where administrative controls are feasible but the costs are unknown, no additional costs will be assumed for cost estimation purposes.

Assumption 8: If the actual cost of a production penalty for a control option is known to the CSHO, then it should be used. If unknown, no production penalty will be assumed for cost estimation purposes.

Assumption 9: If a proposed noise control would also address another hazard (e.g., machine guarding, ventilation hood), then the cost of the noise control shall be deemed feasible because these other controls do not require an economic feasibility analysis.

Assumption 10: If actual hearing conservation program costs are known to the CSHO, then they should be used. If unknown, use an assumed figure of $375/worker/year (the average of the range provided in Appendix G.1.2 of this chapter). If applicable, use Table V–5 to adjust this unit cost based on the number of workers in the hearing conservation program at this worksite.

Assumption 11: Maintenance problems (e.g., bad bearings, steam leaks) that result in excessive workplace noise levels are cited under the engineering/administrative control paragraph; however, these are deemed economically feasible regardless of the cost.

Assumption 12: If engineering design for noise controls is done by the employer's engineering or industrial hygiene staff, then there will be no additional engineering costs applied to the control. In this case, the Table V–6 values will determine the costs of an engineering control.

Assumption 13: If outside or consulting engineering services are required to design and fine tune the control, then these costs must be estimated and added to Table V–6 values. For cost estimation, the hourly rate for a consulting acoustical engineer is assumed to be $150 (2010 dollars). The daily rate is assumed to be $1,000. Assume that the consulting engineer is local, and therefore, no travel or per diem costs need be considered. For each day in the field, it is customary for a consulting engineer to charge one additional day for report/plan preparation.

Note on Noise Evaluation Threshold

This example (Dusty Foundry) can also be used to demonstrate another topic: when different noise measurement thresholds are appropriate,

In this example the noise evaluations that determined the employees' exposure were intended to identify employees who needed to be included in the hearing conservation program. Therefore, the measurements would have been made with the 80-dBA threshold (and if a citation were to be issued, the daily dose would have to be greater than or equal to 66% of the PEL).

In contrast, if the evaluation had been intended to demonstrate compliance with the PEL or the need for engineering controls, the 90-dBA threshold would have been appropriate (and if a citation were to be issued, the daily dose would have had to be greater than or equal to132 percent of the PEL).

3. *General Principles*

An engineering control is any physical alteration in the workplace that will reduce occupational noise exposure. An administrative control is any manipulation of the worker's work schedule, procedure, or practice that will result in a reduction in the daily noise dose.

4. *Examples*

The following examples will serve to illustrate how and when economic feasibility determination is necessary.

i) Dusty Foundry

There are 100 production workers exposed in excess of 50% of the PEL.

1. What is the cost of a hearing conservation program per worker for this foundry? From Assumption 10 and Table V–5, we have:

$375 x .05 + $375 = $19 + $375 = $394

Therefore, the cost of a hearing conservation program per worker at this foundry is $394.

2. In the ***cleaning department,*** five workers polish small castings using hand-held pneumatic polishing tools. Seven additional workers at other tasks along the same wall in the cleaning department are similarly exposed to noise from the polishing tools. There are no engineering controls. The daily noise dose is 89 dBA to 93 dBA on the sampled workers. There are two shifts in this department. The polishers are side-by-side and place

the castings on wooden work tables. The background noise when no one is using the pneumatic tools is 79 dBA. You determine that retrofit mufflers, barriers between adjacent polishers, and absorptive treatment to the cement block wall in front of the polishing tables will result in a noise reduction of 9 dBA to 11 dBA at the worker's ear. In this case, the retrofit mufflers and sound absorbers and barriers are expendable and replaced every year. Are these controls economically feasible, given that the 8-hour TWA is less than 100 dBA?

a. Determine the cost of the pneumatic mufflers (i.e., small air exhaust muffler for a pneumatic hand tool). From Table V–6, the unit cost of such a muffler is $16.00 (average of high and low cost) with no maintenance or production penalty involved. In this case, the retrofit mufflers and sound absorbers and barriers are expendable and replaced every year. Therefore:

   $16.00 x 5 grinders = $80

b. Determine the cost of the absorbers and barriers. Five 4 x 4 foot areas of acoustical absorption are needed as well as three 8 x 8 foot barriers. Two workers will require 1.5 days (12 hours) to perform the installation. There would be no production penalty, and maintenance costs can be considered to be negligible. Therefore:

   80 sq. ft. absorption x $6 = $480

   192 sq. ft. barriers x $15 = $2,880

   Installation labor: 2 workers x 12 hours x $27/hour = $648.

c. Determine the total cost of engineering controls:

   Add the cost of the mufflers, acoustic absorbers, barriers, and installation.

   80 + 480 + 2,880 + 648 = $4,088

d. Determine the cost of hearing conservation for all workers who would benefit from these controls:

   Adjust the hearing conservation cost per worker (Table V–5) and multiply that cost by the number of workers (12).

   12 workers x 2 shifts x $394 = $9,456

   Given that the cost of engineering controls ($4,088) is less than the cost of hearing conservation ($9,456), these controls are both technically and economically feasible.

3. In the ***shakeout area,*** full-shift noise levels are 98 dBA to 100 dBA. Four workers are employed here for each of two shifts. Silica exposures for these workers are 3 to 4 times the PEL, given that there is no local exhaust ventilation provided. We propose a total enclosure of the shakeout that will be locally exhausted, mechanically isolated from the shaker table, and lined with some acoustically absorptive material. This control approach, if properly implemented, will reduce the noise exposures to 90 dBA and the silica exposures to one-quarter of the PEL. Given that the daily noise levels do not exceed 100 dBA, is enclosure of the shakeout economically feasible?

Because this engineering control will abate both silica and noise overexposures at the same time, an economic analysis is not necessary. This control, therefore, is both economically and technically feasible.

4. In the ***finishing department,*** two pedestal grinders were sampled for noise. Although both grinders were identical models finishing the same type of castings, one operator's exposure was 89 dBA while the other one's was 98 dBA. Further investigation revealed that the noisy grinder had defective idler bearings. Would bearing replacement be an economically feasible engineering control?

   From Assumption 11, we do not need to do an economic analysis for bearing replacement on this pedestal grinder because the noise is from the defective idle bearings, which need to be replaced to keep the equipment in good working order. Therefore, this control is economically feasible and should be cited as a violation of (b)(1).

5. To abate engineering violations, Dusty Foundry must ***engage a consulting engineer***. Consider problem 2.b and 2.c above. Dusty Foundry will need one day with the engineer on site to evaluate and prepare an abatement report. The cost for engineering will be:

   $1,000 x 1 days = $1,000
   $1,000 + $4,088 (cost of controls) = $5,088

   Therefore, the total cost for these controls with consulting engineering assistance is $5,088, which is still less than the cost of hearing conservation ($9,456). The engineering controls are still economically feasible.

ii) <u>Rocking Chair Furniture Company</u>

The company has 100 production workers exposed to daily noise exposures in excess of 50% of the PEL. (Note: If a citation will be issued, the daily dose must be greater than or equal to 66% of the PEL).

1. A large wood planer is situated in the middle of the production area. A loader and off-bearer operate the machine. It has no noise controls. The sound levels vary from 98 dBA to 118 dBA depending on the type of wood (hard versus soft) and the surface area of the wood being finished. All production workers are exposed to the noise from the machine. Administrative controls limit everybody's daily dose to less than 400%, or 100 dBA. Are engineering controls economically feasible?

a. The equipment manufacturer, contacted by phone, indicates that one engineering option is to rebuild the drive mechanism and replace the cutters with those of a helical design. According to the manufacturer's technical representative, this will greatly improve the quality of the planed finish and reduce the noise level to about 90 dBA. With the existing administrative controls, everybody's daily exposure level would be reduced to less than 84 dBA. A call to the regional service technician produced a cost figure of $10,000 per planer to retrofit, with no maintenance or production penalty involved.

   Per Assumption 7, the administrative controls contribute no additional cost. The total cost is $10,000 for major modifications to one planer. Per Assumption 1, this engineering control has a life expectancy of 10 years, so the average cost per year is $1,000.

b. A second engineering option is to enclose the existing planer with a plywood shop-built structure lined with sound-absorbing fiberglass (this design has no production penalty and a life expectancy of 10 years). Three workers will work together for 10 hours to install the enclosure, for a total of 30 hours. This option reduces the workers' exposure to a similar extent as would modifying the planer as described above. From Table V–6, we select the lower cost of $4,000, as the enclosure can be fabricated in-plant. Table V–6 also indicates that the enclosure will have a 5% maintenance cost. Table V-6 indicates that the labor rate is $27 per hour, so the total cost will be the cost of control + maintenance at 5% over 10 years + installation labor, thus:

   $4,000 + $ 2,000 + $810 = $6,810 total assumed cost.

   Per Assumption 1, this engineering control has a life expectancy of 10 years, so the average cost per year is $6,810 ÷ 10 = $681.

   Considering that all 100 workers will benefit from the implementation of this engineering control, the assumed cost for hearing conservation is calculated from Table V–5 with a 5% increase in the cost of the hearing conservation program, based on 100 workers participating:

   ($375 x .05) + $375 = $394 per worker per year
   $394 x 100 workers= $39,400 per year for all 100 workers

   Given that the engineering option cost per year is less than the cost per year of a hearing conservation program, the engineering option is economically feasible.

2. Consider the situation where the planer has been relocated to a room by itself. The room is treated with acoustical material to prevent reflected or reverberant noise. Both workers who operate the planer are administratively controlled to prevent their noise doses from exceeding 100 dBA. The planer is operated on the second shift only. The employer's records indicate that the hearing conservation program costs a little more than the initial estimate: an average of $419 per year per worker. Are either of the two engineering control options for the planer described in the previous paragraphs economically feasible?

   The per-worker cost of hearing conservation is:

   $419 x 2 = $938 per year for hearing conservation.

   This cost for hearing conservation is compared to the per-year cost of the two engineering options: rebuild and upgrade the planer at an average cost per year of $1,000, or construct an enclosure around the planer within the room at an average cost per year of $681.

   Since the $681 cost per year of constructing an enclosure is less than the $938 cost per year of the hearing conservation program, this engineering option is economically feasible.

iii) Tables for Economic Analysis Examples

Tables V–5 and V–6 provide background information used in the examples for economic feasibility determinations.

Table V–5. Hearing Conservation Program Costs and Corrections Based on Worker Geography

Costs per worker are sometimes lower for a large-scale hearing conservation program with many workers than for a small program covering just a few people. This "economy of scale" may reduce the per-worker cost under some circumstances, such as when a fixed daily-rate service can serve many workers in one day versus serving just a few workers for the same daily fee. Worker geography is a primary reason an employer might encounter this situation.

Assume that the estimated cost per worker for a larger hearing conservation program will be $375. For smaller hearing conservation programs with workers spread over a wide geographic area, adjustments to this cost are made as follows:

Total Number of Workers at the Same Geographic Location	Percent Increase per Worker per Year Over the Unit Cost	Resulting Calculation per Worker per Year (With Unit Cost at $375)
250+	0	($375 x 0) + $375 = $375
100–249	5	($375 x .05) + $375 = $394
50–99	8	($375 x .08) + $375 = $405
20–49	75	($375 x .75) + $375 = $656
0–19	125	($375 x 1.25) + $375 = $844

References for Table V–5 data were adapted from Table 7 in *Regulatory Impact and Regulatory Flexibility Analysis of the Hearing Conservation Amendment,* USDOL-OSHA, Office of Regulatory Analysis, February 1983. The example unit cost ($375/worker) for a hearing conservation program in 2010 dollars is the midpoint in the cost range of $350 to $400 described in Appendix G.1.2 of this OTM chapter.

Table V–6. Noise-Control Engineering Cost Assumptions

This table provides examples of some common noise-control equipment and materials, along with unit costs. The cost for noise-control equipment varies greatly, including costs for different models of the same type of control. If the actual cost is available for the control under consideration, use the actual cost. Otherwise, in accord with the assumptions listed at the beginning of this section, use the *average* cost in Table V–6 for cost estimating.

Control Option	dBA Reduction	Cost (in 2010 $)	Percent Production Penalty	Maintenance Cost per Year
Absorption	3–5	2–10/ft^2	None	2%
Damping materials	2–20	2–6/ft^2	None	None
Damping pad	2–20	10–20/ft^2	None	None
Damping compound	2–20	180–250/5 gallon pail	None	None
Acoustic barriers	3–15	5–25/ft^2	None	2%
Mufflers, air exhaust (small)	5–25	2–30/unit	None	None

Mufflers, air exhaust (large)	5-25	10–600/unit	None	5%
Mufflers, engine (average)	5–25	300/unit	None	None
Mufflers, engine (very large)	5–25	10,000/unit	None	None
Silencers, small fan	5–25	300/unit	None	None
Silencers, large fan	5–25	3,000–25,000/unit	None	None
Vibration mounts	5–25	100–1,000/unit	None	1%
Quiet valves	5–25	500–5,000/unit	None	None
Cab enclosure (for heavy equipment)	5–20	15,000/unit	None	5%
Enclosure for multiple workers	5–20	5,000–35,000/unit	None	5%
Enclosure for process (partial)	3–10	500–3,500/unit	0–20	5%
Enclosure for process (total)	3–10	4,000–35,000/unit	0–20	5%
Duct wrap/lagging	3–5	5–300/100 ft	None	None
Ceiling baffles	Rated in Sabens: NRC of 0.4–0.5	2–15/ft^2	None	None

Note 1: Costs presented here were updated by contacting manufacturers for pricing over the period from May 2010 to April 2012.
Note 2: Installation costs are not included. According to data from the BLS, an average labor rate of $27/hour (2010 rate) could be assumed when considering installation costs (regional rates could be more or less).
Sources: BLS, 2009a,b.

When additional information is on hand, the CSHO may also make an informed decision about using the low or high end of the cost range (instead of the average). Select the high end of the cost range for larger sizes of equipment, materials with extra thickness, situations that require high-precision or specialty parts, locations with higher costs of living, or when other factors tip the selection toward the more costly option.

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VII. RESOURCES

A. Reference Books and Articles

1. *Comprehensive Review—Noise, Hearing Loss, Noise Control*

American Industrial Hygiene Association. 2003. *The Noise Manual*. 5th edition. Edited by E.H. Berger et al. Fairfax, VA: American Industrial Hygiene Association.

> *A comprehensive manual on noise hazard and control for industrial hygienists and safety professionals. A revised edition is anticipated in 2013.*

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> *Detailed information regarding occupational hearing loss.*

Suter, A.H. 2002. Construction Noise: Exposure, Effects, and the Potential for Remediation; a Review and Analysis. *AIHA Journal* 63:768-789. November/December.

2. *Noise Control and Engineering*

> *Investigators develop new products and applications for noise control; however, the principles and basic materials of noise control remain unchanged. Some earlier titles remain useful. Books can be obtained through new or used book sellers and through interlibrary loan programs.*

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NIOSH. 1978. *Industrial Noise Control Manual.* DHHS (NIOSH) Publication No. 79-117. http://www.cdc.gov/niosh/docs/1970/79-117pd.html.

> *This manual includes 61 case histories on noise-control modifications for industrial processes and equipment. It displays decibel and octave band analysis of noise levels before and after control methods were applied. It also presents relative costs of many control methods (in 1978 dollars).*

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B. Noise Physics

M^{C} Squared System Design Group, Inc. No date. Wavelength of sound – calculator. http://www.mcsquared.com/wavelength.htm.

> *This tool calculates the wavelength of any airborne noise frequency in inches, feet, and meters.*

C. Hearing Loss

1. *Hearing Loss—Reporting*

Council for Accreditation in Occupational Hearing Conservation. 2005. Determining When Hearing Loss Is Work Related. http://www.caohc.org/professional_supervisor/workrelatedloss.pdf.

2. *Hearing Loss—Incident Rates*

Bureau of Labor Statistics. 2011. TABLE SNR08: Incidence Rates of Nonfatal Occupational Illness, by Industry and Category of Illness, 2010. http://www.bls.gov/iif/oshwc/osh/os/ostb2808.pdf.

> *This extensive table lists, by industry, the incidence of reported illnesses per 10,000 full-time workers. The table includes a column for hearing loss. BLS publishes this information annually each fall, covering the previous year's data. Check for the latest edition and previous years at http://www.bls.gov/search/?cx=011405714443654768953:btgxl8qv780&cof=FORID:10;NB:1&ie=ISO-8859-1&prefix=&query=table+SNR08&submit.x=28&submit.y=5&filter=0&sa=Search.*

3. *Hearing Loss Prevention*

American National Standards Institute/American Society of Safety Engineers. 2007. *Hearing Loss Prevention for Construction and Demolition Workers.* ANSI/ASSE A10.46-2007.

> *This ANSI document recommends standards for hearing conservation programs for construction and demolition workers. Recommendations cover hazard identification, hazard control, hearing protection devices, audiometry, training, recordkeeping, and program evaluations. An appendix lists noise levels (in decibels) that are likely to be exceeded by several dozen different construction activities and cites a source for each listed level.*

D. Sound Levels of Equipment, Occupations, and Activities

> *See also ANSI/ASSE A10.46-2007 under the "Hearing Loss Prevention" heading.*

Noise Navigator® Sound Level Database. 2008. http://www.e-a-r.com/pdf/hearingcons/Noise_Nav_1_35.xls.

> *An extensive database of over 1,700 sound level measurements reported by various references for a wide range of equipment and activities (occupational, recreational, and military noise sources). A reference for each source is provided. The "Intro" tab of this Excel spreadsheet introduces the spreadsheets in which the sound level measurements are organized. This*

> *database is compiled by E-A-R/Aero Company and the University of Washington; as of spring 2012, the current version (1.4) is dated 2008.*

Noise Database for Prediction of Noise on Construction and Open Sites. 2005. http://archive.defra.gov.uk/environment/quality/noise/research/construct-noise/constructnoise-database.pdf.

> *Eight tables reporting average measurements for noise from equipment used on construction and open sites in the United Kingdom (UK). Organized by construction phase and type; noise level information includes both unweighted octave band L_{eq} levels and overall A-weighted L_{eq} values (in decibels). This document was commissioned by the UK government and published in 2005.*

Noise Emissions for Outdoor Equipment. http://ec.europa.eu/enterprise/mechan_equipment/noise/citizen/app.

> *This European Commission database lists operating noise levels for several dozen categories of outdoor equipment. The European Commission requires equipment manufacturers to accompany their equipment with a declaration of conformity, stating that the equipment conforms to the provisions of noise-limiting directives issued by the European Community governing organizations (e.g., Directive 2000/14/EC of the European Parliament and Council, May 8, 2000). Equipment manufacturers continue to add new information to this database in a standard format.*

E. Noise Control

1. *Engineering Controls and Noise-Control Programs*

Colgate-Palmolive. 2012. *Excellence Award Corporate-Wide: Colgate-Palmolive Company.* http://www.safeinsound.us/swf/colgate/index.html.

> *Colgate-Palmolive won the 2012 Safe-in-Sound award through an extensive international effort to reduce noise exposure in its facilities around the world. This online presentation outlines the company's efforts and successes and presents a summary of numerous adopted engineering modifications (with photos, notes on the changes made, and examples of noise reductions achieved).*

National Aeronautics and Space Administration. Approximate Sound Power-Pressure Conversion Worksheet. http://buyquietroadmap.com/buy-quiet-purchasing/buy-quiet-process-roadmap/forms-worksheets/convert-sound-power-tofrom-sound-pressure/approximate-sound-pressurepower-conversion-worksheet.

> *A simplified conversion method for sound pressure/power conversion; part of the NASA Buy-Quiet Roadmap.*

2. *Noise-Control Products*

Sound and Vibration Magazine. 2011. Buyer's Guide to Products for Sound and Vibration Control. http://www.sandv.com/downloads/1107bgnv.pdf.

> *This guide is published annually. Check http://www.sandv.com/home.htm for the latest edition.*

3. *Buy-Quiet and Quiet by Design Programs*

National Aeronautics and Space Administration. 2012. *Buy-Quiet Process Roadmap.* http://buyquietroadmap.com/buy-quiet-purchasing/buy-quiet-process-roadmap.

> *This is an online tool for navigating the procurement of low-noise equipment. Part of the NASA EARLAB Auditory Demonstration Laboratory website, the Roadmap can be accessed from the "Buy-Quiet Purchasing" tab in the top navigation menu. Other NASA hearing conservation resources, such as the "Auditory Demonstrations" series and "TWA Calculator," are also part of this website. All are available as free, publicly accessible digital downloadable files. This site is hosted and maintained by Nelson Acoustics as a service to the noise-control and hearing conservation technical community and was updated in 2012.*
>
> *The website describes itself as follows: "The Roadmap guides users through a stepwise process that includes project planning, researching the marketplace, selecting an achievable noise emission criterion, and developing a specification document. The Roadmap also includes guidelines for identifying the appropriate government procurement strategy for each purchase, based on an assessment of the purchase-specific long-term financial and noise exposure risk. The Roadmap is applicable to both public and private sector organizations, and the downloadable forms and worksheets can be customized to each organization. There is a very brief tutorial PowerPoint presentation here: http://buyquietroadmap.com/buy-quiet-purchasing/buy-quiet-process-roadmap/about-the-nasa-buy-quiet-process-roadmap/roadmap-tutorials."*

F. Cost of Hearing Loss/Cost of Hearing Conservation Programs

Nelson, D.A. 2012. White Paper: The Long-Term Cost of Noise Exposure. http://buyquietroadmap.com/wp-content/uploads/2010/02/Long-Term-Cost-of-Noise-Exposure.pdf.

> *NASA's Roadmap (see entry in the previous section) includes this paper, which provides one alternative methodology for calculating the cost of long-term exposure to the noise emission of various products being considered for a particular purchase. This allows the comparison of the true cost of candidate products that may differ in noise emission and price. Users may input their own experience; for example, as discussed in Appendix G of this chapter, hearing conservation costs vary widely due to factors such as economies of scale, geography, and what elements are included in the calculation). NASA seeks feedback on this methodology in order to continue to improve and update the Roadmap.*

Driscoll, D.P. and L.H. Royster. 2003. Chapter 9: Noise Control Engineering. In American Industrial Hygiene Association. *The Noise Manual*. 5th edition. Edited by E.H. Berger et al. Fairfax, VA: American Industrial Hygiene Association.

> *See "Benefits and Costs of Noise Control" on pages 281–289.*

G. Acoustical Consultants

National Council of Acoustical Consultants. 2012. What Sets an Expert Apart? http://www.ncac.com/howto.php.

> *This site also includes an online directory of consultants.*

National Aeronautics and Space Administration. No date. When to Hire an Acoustical Consultant: Get Help Before You Get in Over Your Head. http://buyquietroadmap.com/buy-quiet-purchasing/buy-quiet-process-roadmap/procurement-planning/when-to-hire-an-acoustical-consultant.

This Web page (part of NASA's Roadmap) lists examples of situations where an acoustical engineer can provide valuable expertise and when a product representative can be useful. The site also describes credentials that acoustical professionals might have.

American Industrial Hygiene Association. Search for a Consultant. https://webportal.aiha.org/Custom/ConsultantsSearch.aspx.

Industrial hygiene professionals develop hearing conservation programs, conduct noise evaluations, measure sound levels, and perform noise dosimetry. In the box for "Specialty," select "Hearing Conservation/Noise Reduction."

H. Associations, Education, and Conferences

Institute of Noise Control Engineering. http://www.inceusa.org.

Sponsor of the annual conference "Inter-Noise, International Congress and Exposition on Noise Control Engineering." Offers continuing education.

National Council of Acoustical Consultants. http://www.ncac.com.

"The acoustician seeks to understand and quantify the production, control, transmission and effects of sound." Offers continuing education.

Acoustical Society of America. http://acousticalsociety.org.

International scientific society in acoustics dedicated to increasing and diffusing the knowledge of acoustics and its practical applications. Offers continuing education.

Council for Accreditation in Occupational Hearing Conservation. http://www.caohc.org/index.php.

Offers continuing education.

Acoustical Solutions, Inc. ASI University. http://www.acousticalsolutions.com/asi-university.

This noise-control materials manufacturer's website offers general background information on understanding noise-control principles and terminology. Offers continuing education related to noise through the American Institute of Architects.

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:

$$\text{Total } L = 10 \times \log_{10}\left(\sum_{1}^{n} 10^{\mathrm{Ln}/10}\right)$$

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.

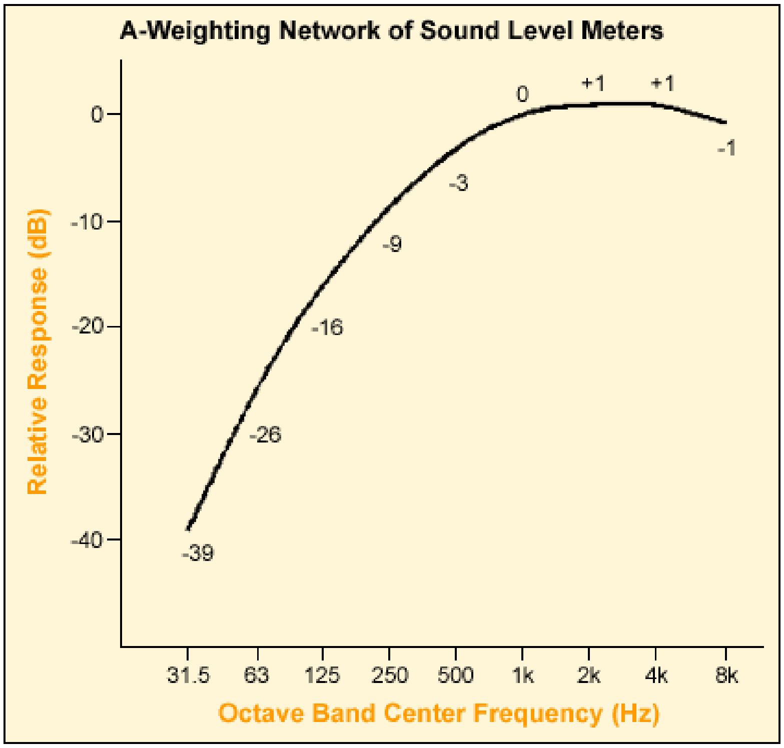
Example: A worker in a machine shop is exposed to 95 dBA for 2 hours, 69 to 78 dBA for 4 hours (including a 15-minute break and 45-minute lunch), and 90 dBA for 3 additional hours.

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.

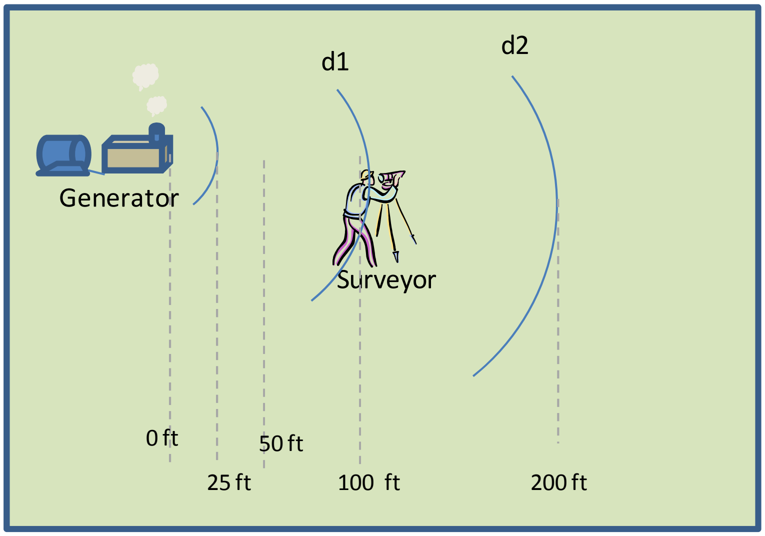
The A-weighted sound level is calculated by combining the corrected band levels:

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

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 Converting a Single Dose Measurement to an 8-hour TWA Sound Level

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)

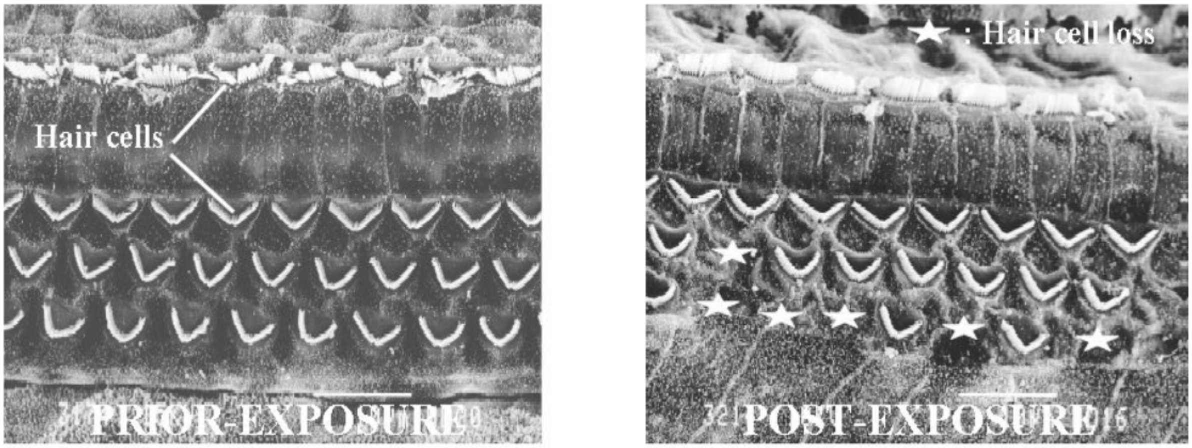
Carbon monoxide (Lacerda et al., 2005)

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.

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.

To set priorities, AIHA suggests that important 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?

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.

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

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.

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.

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

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.

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.

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.

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.

<u>Collect Data</u>:

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.

<u>End Study</u>:

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).

<u>Review Data</u>:

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.

Example #3: 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.

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