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

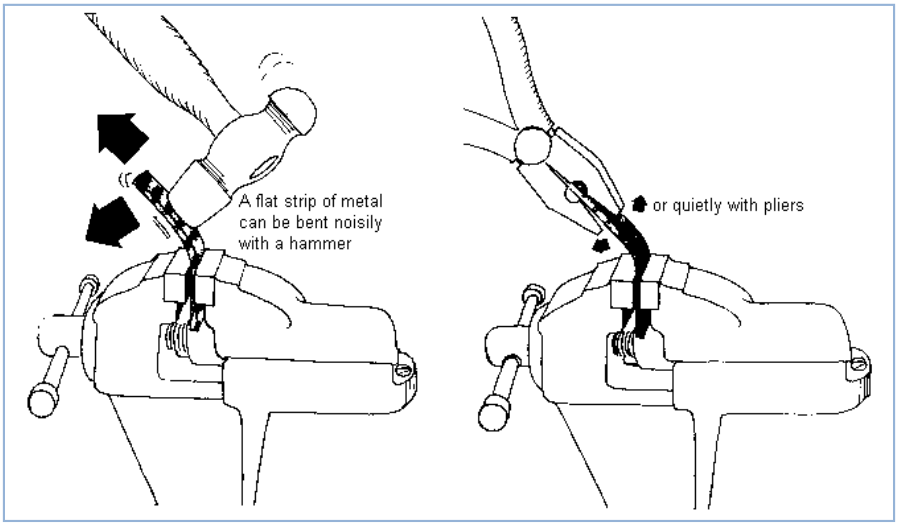
i) Mechanical Impacts

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

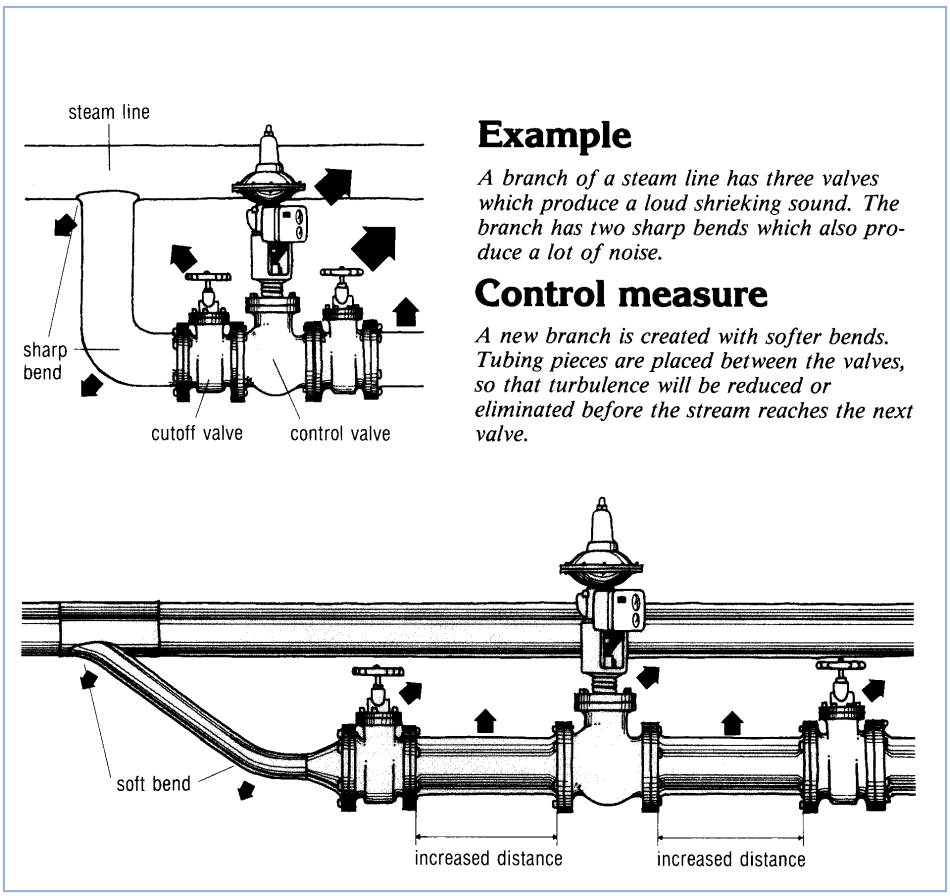


ii) <u>Reduce High Velocity of Fluid Flow</u>

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



(Driscoll, Principles of Noise Control)

iii) <u>Mufflers and Silencers</u>

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.

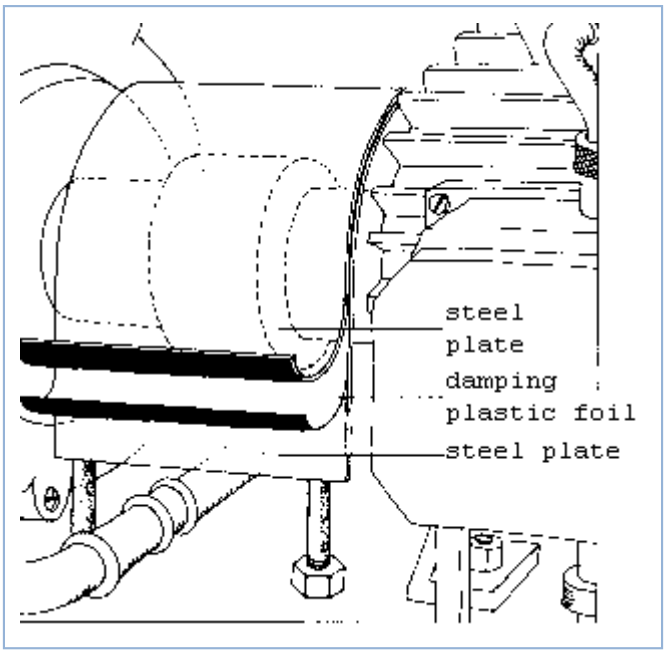
Figure 30. Noise-Reducing Compressed Air Nozzles

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.*

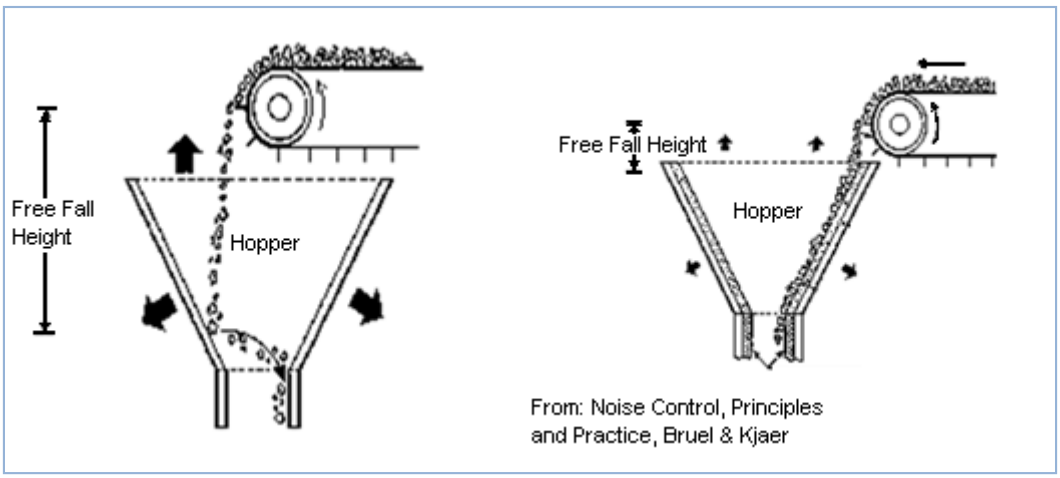
***Constrained-layer** damping materials add a rigid second layer adhered firmly over the viscoelastic layer. This effectively increases the damping effect, even with a very thin layer of the viscoelastic material. The rigid second layer must be inelastic (i.e., it must not stretch in any direction), 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).

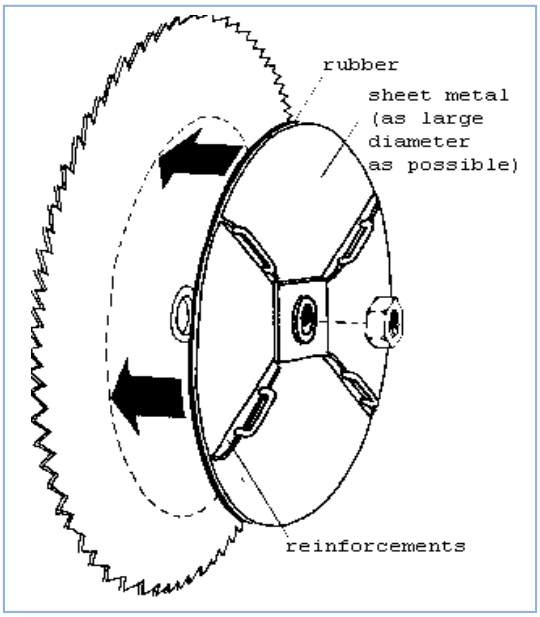
Figure 32. Reducing Free Fall Height



(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.

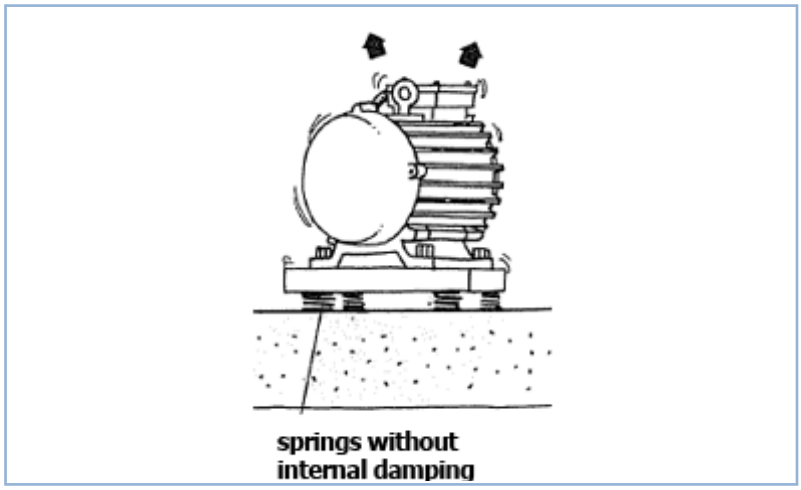
Figure 33. Adding Damping Material to a Saw Blade



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/ft³)	Range of Thickness (Inches)	Random-Incident Sound-Absorption Coefficient with Solid Backing (#4 Mounting)							
			Thickness (Inches)	Density (lb/ft³)	*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*
Carpet, 40 oz per square yard, with latex backing, over felt or	*0.08*	*0.27*	*0.36*	*0.34*	*0.48*	*0.63*

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
foam rubber pad of same density (on concrete)						
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) <u>Reducing Noise Transfer Across Barriers—Using Sound Transmission Loss Materials</u>

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)

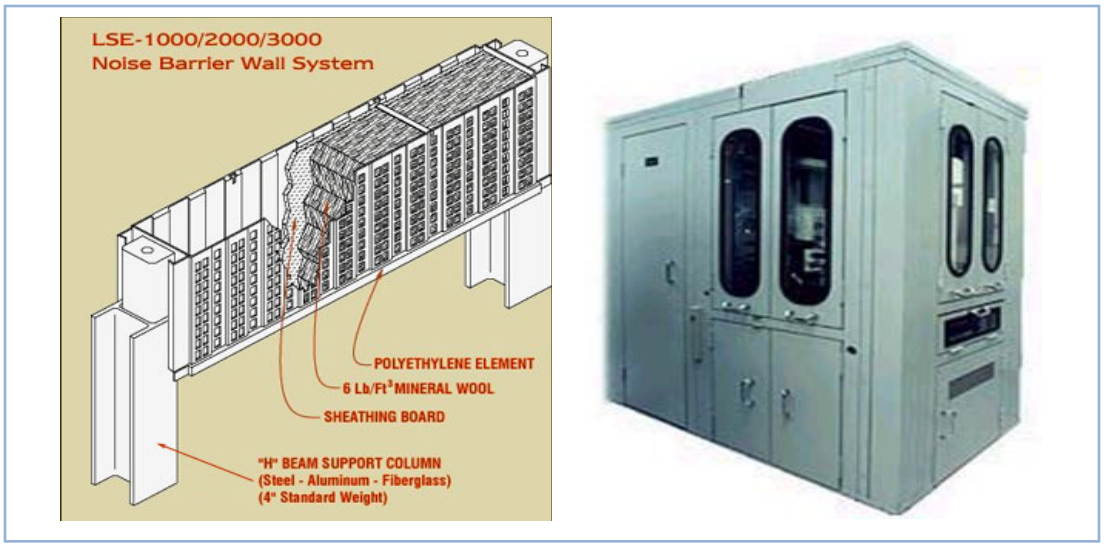
Material	125 Hz	250 Hz	500 Hz	1,000 Hz	2,000 Hz	4,000 Hz
Brick, 4 in.	*30*	*36*	*37*	*37*	*37*	*43*
Cinder block, 7⅝ in., hollow	*33*	*33*	*33*	*39*	*45*	*51*
Concrete block, 6 in., lightweight, painted	*38*	*36*	*40*	*45*	*50*	*56*
Curtains, lead vinyl, 1½ lb/ft²	*22*	*23*	*25*	*31*	*35*	*42*
Door, 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.

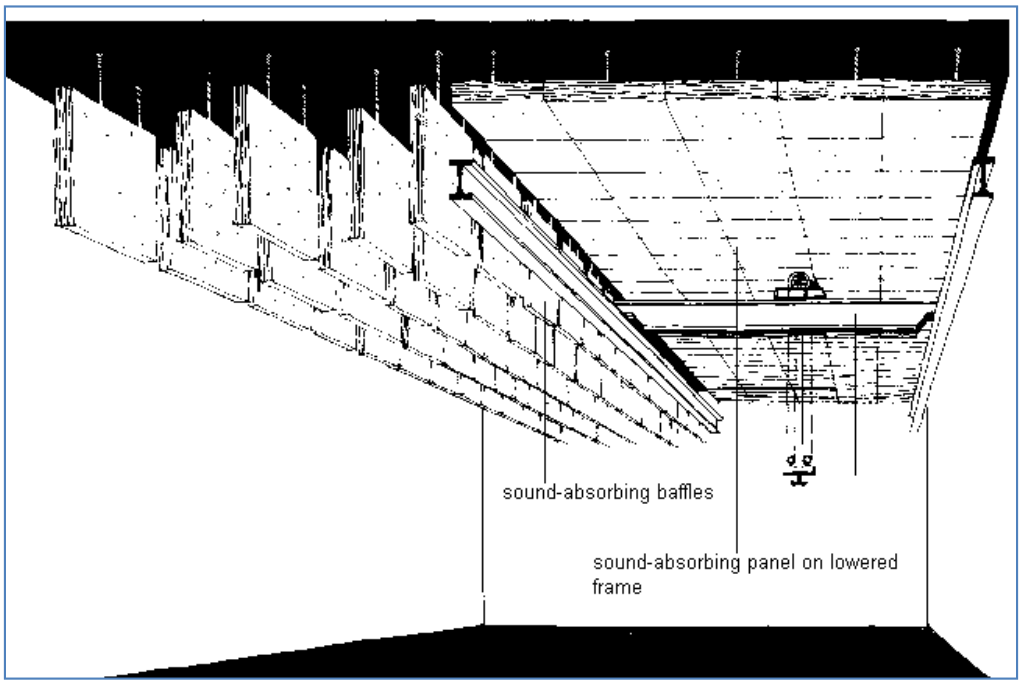
When constructing a partial barrier, it is important to consider factors other than the barrier material. For example, for a barrier to be effective, a receiver (worker) should be located in the direct field as opposed to the reverberant field. A barrier's effectiveness in attenuating noise is maximized 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) <u>Reducing Reverberation</u>

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.

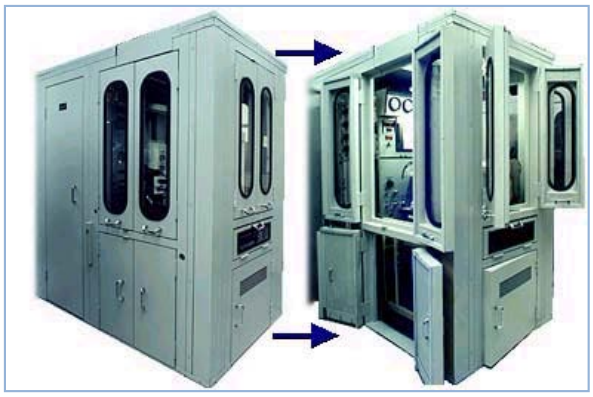
iv) <u>Acoustical Enclosures</u>

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

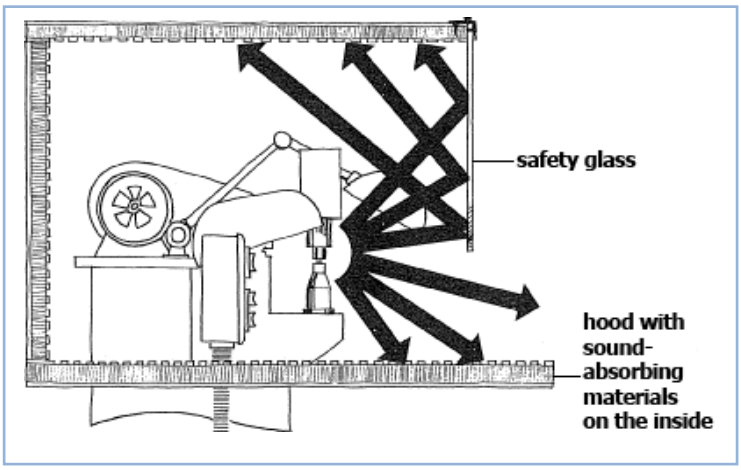


(Driscoll, Principles of Noise Control)

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)

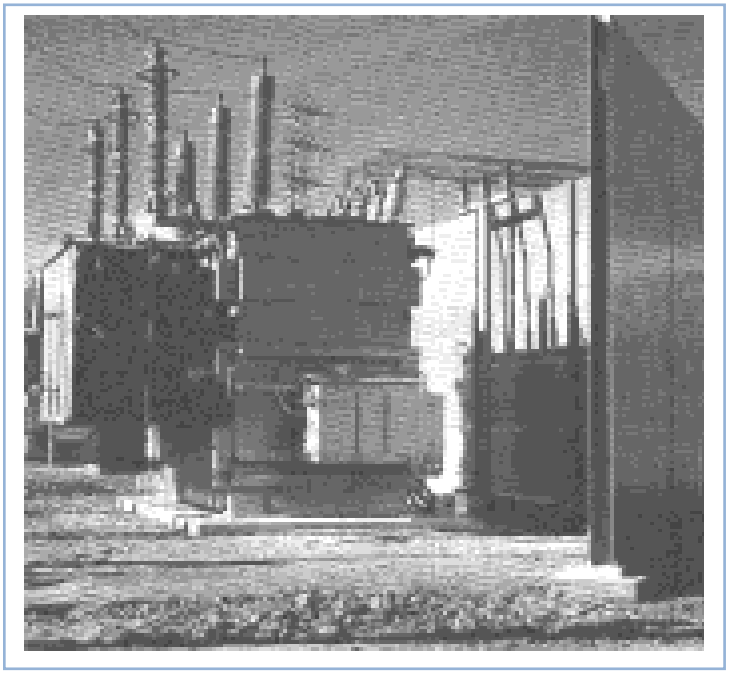
Enclosing a noise source is often impractical if there is not enough space or if workers need to access the noise source for maintenance or operational reasons. In these cases, lagging could be a more practical solution. Lagging, essentially a localized form of enclosure, can be wrapped around pipes 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.

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

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.

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. <u>Engineering Controls and Economic Feasibility</u>

1. <u>Overview</u>

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.

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

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.

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.

<u>Assumption 11:</u> 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.

<u>Assumption 12:</u> 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.

<u>Assumption 13:</u> 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.

3. <u>General Principles</u>

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. <u>Examples</u>

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

i) <u>Dusty Foundry</u>

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:*

$$\$375 \times .05 + \$375 = \$19 + \$375 = \$394$$

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*

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).

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.