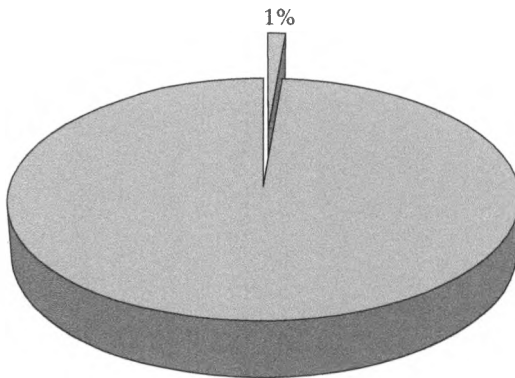


## CHAPTER 10

# Environmental Control and Noise



*Percentage of OSHA General Industry citations addressing this subject*

In Chapter 9, we explored the important task of measuring and evaluating air contaminants to determine the degree of exposure to health hazards. Once having found that an air contaminant does exist, there are a variety of strategies available for dealing with it. In Chapter 3, it was stated that from the profession, there has emerged a definite hierarchy of strategies that have come to be known as the “three lines of defense.” These strategies are engineering controls, work-practice controls, and personal protective equipment, in that order. In this chapter, we will examine methods to provide engineering solutions to the air-contaminant problem, chiefly through ventilation. Noise hazards will also be examined, along with both engineering and work-practice controls to control these hazards.

### VENTILATION

Ventilation may be the most obvious engineering solution to an air-contaminant problem, but before acceding to this solution, it should be recognized that other ways to deal with the problem may be even better. In Chapter 3, a series of approaches was

enumerated as "engineering design principles." In this chapter, some applications of these engineering principles will be seen.

The most desirable way to deal with an air contaminant is to change the process so that the contaminant is no longer produced. This is so obvious that it is sometimes overlooked. It may be that the process cannot be changed, but if it can, there may be tremendous gains in store, not only in health and safety, but in production cost and efficiency as well. For instance, it may be found that machined parts can be machined dry, avoiding cutting oil exposures to the machinist's skin as well as solvent contamination of the air as the parts are later cleaned. Forging, die casting, or powdered metal technology may eliminate several machining processes, changing the process in beneficial ways. Some of these ideas may generate more disadvantages than advantages in given situations, but each application should be checked for potential benefit. There is no better way for the safety and health manager to win recognition from top management than by generating a clever idea that cuts costs or increases production while it also enhances safety or health.

For more ideas, consider the hazards of toxic air contaminants from welding operations. Sometimes the principal source of the contaminant is the surface coating on the metal to be welded. Perhaps as a process change, this surface coating can be removed prior to the commencement of welding. Better yet, perhaps the material does not require welding at all. Possibly a crimping operation could produce an effective joint, eliminating the need for welding or soldering.

Chemical processes are classified as batch or continuous. The choice between the two usually involves many considerations, including investment cost, length of production run expected, volumes to be produced, and the important factor of air contamination. Continuous processes generally reduce the exposure of materials to the air because open handling is reduced, and batches of materials are not sitting idle awaiting processing. However, the mechanical handling equipment used for continuous processes may increase the contamination levels. Each situation must be studied to determine the best solution, keeping in mind safety and health aspects.

One way a process can be changed is to isolate or enclose it. If a particularly contaminating process is in the plant, perhaps it should be located in a separate building so that it does not contribute to the overall ventilation problem.

A slight variation to changing the process is to change the materials used. Carbon tetrachloride has been found to be a health hazard, so other solvents have been substituted. The chlorinated hydrocarbon solvents substituted, such as trichloroethylene and perchloroethylene, are also being found to be hazardous, but fortunately not as hazardous as carbon tetrachloride. New solvents may be found to reduce hazards even further. Labar (Labar, 1993) classifies many dangerous hydrocarbon solvents as "volatile organic compounds" (VOCs) and suggests substituting water-based solvents for VOCs. An extra benefit of water-based solvents is that sometimes they are not as slippery as VOCs if spilled on the floor. They may be expensive and usually take longer to dry than VOCs. Another problem can be corrosion. Everyone knows that water causes rust, and if water-based solvents are used for washdowns, stainless steel nozzles may be required. Finally, water-based solvents may themselves be health hazards, such as causing urinary tract infections.

Substitution of materials may be a good idea, but all of the pros and cons should be identified and evaluated.

Another possible substitution is in sand blasting. Silica sand is often used for blasting to improve surface characteristics. But airborne silica causes the lung disease called *silicosis*. Perhaps the silica sand could be replaced by steel shot, removing the silica contamination.

A classic example of changing materials to reduce hazards is the switch from hazardous lead-based paints to substitute materials such as iron oxide pigments. Another classic was the switch from Freon to propane as a propellant for aerosol cans. In this case, the materials switch was intended to protect the environment (the ozone layer), but the solution may be more hazardous to the individual because propane is a flammable gas.

## Design Principles

If the process cannot be changed or materials substituted, a well-designed ventilation system may be the best solution to the problem. OSHA has a standard that deals with this subject, but it must be emphasized that ventilation is a very technical subject, and the safety and health manager may want to turn to a professional engineer to design an adequate ventilation solution to an air-contamination problem. Exhaust ventilation is not the same as ordinary heating and air conditioning, and design errors can be made if this difference is not considered. An example is shown in Figure 10.1. Most heating and air-conditioning ducts have right-angle bends, which may be fine for gases, but greatly impair the ability of the ducts to transport particulates.

Another questionable ventilation system is an ordinary household fan used to blow away smoke from a contaminant source. It is true that a fan can dilute the concentration of a contaminant in a given place, and dilution ventilation is a recognized method of reducing concentrations to levels lower than the PEL. But the question is "Where is the fan blowing the contamination to?" It is adding to the overall background level of air contamination in the plant and may later have to be dealt with if other processes are also producing contaminations.

A basic objective of exhaust ventilation is to isolate and remove harmful contaminants from the air. The more these contaminants are concentrated into limited

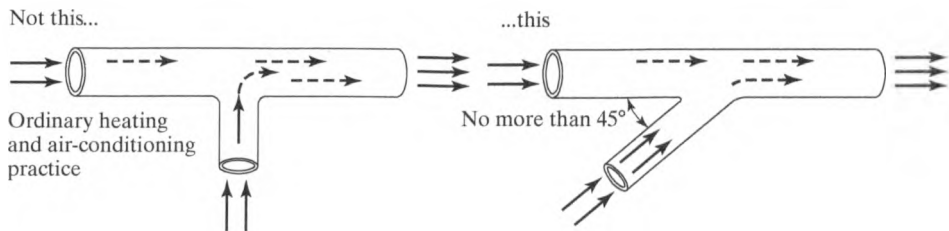


FIGURE 10.1

Avoid sharp angles at duct entry.

plant areas, the easier they are to separate from the air. Dilution ventilation, although expedient in some cases, is counterproductive to the goal of removing the contaminant. Dilution ventilation can be likened to “sweeping the dirt under the rug.”

Focus is an important consideration for ventilation systems. Sheer volume or flow velocity is not enough. Ventilation technology is producing some very fine local exhaust systems that focus the intake right on the contaminant, much as a vacuum cleaner is designed to do. Even if sufficient flow could be achieved with a general ventilation system, the flow could be a nuisance because such a wind might blow away papers and other materials, making the job awkward and inefficient.

The earlier mention of a vacuum cleaner might give some safety and health managers the wrong idea. Particle size for fumes or other contaminants will usually be too small to be effectively trapped in the bag of an ordinary vacuum cleaner. If the process does not trap the contaminant, it is merely blowing it around, perhaps increasing exposure.

The best exhaust ventilation systems are the “pull” types, not the “push” types. Even within the exhaust duct, the fan should be placed at the end of the duct if possible, as shown in Figure 10.2. Leaks in the duct then merely draw in more air rather than pump contaminated air back into the plant environment.

## Makeup Air

With an exhaust ventilation system or systems, some source of *makeup air* is essential. The traditional way to supply makeup air was simply to open windows and doors. Today, however, it has become increasingly attractive to recirculate the exhaust air after filtration and decontamination. Not only does such a solution save energy but it also reduces external atmospheric pollution, a very important point considering regulations of the Environmental Protection Agency (EPA) and the general environmental concerns of the public.

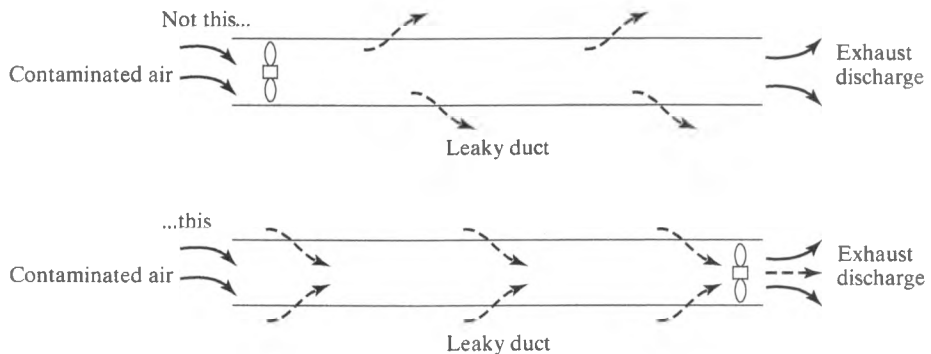


FIGURE 10.2

Fan location—keep negative pressure within the duct.

A recirculating system can be used to remove dust by means of a high-efficiency filter. It is essential to recognize the importance of the condition of the filter to the overall effectiveness of the system. The filter will clog up over time if it is doing its job, and thus it must be serviced, cleaned, or changed. A bypass damper can be employed to permit selective proportioning of the system from full recirculating to full exhaust. This bypass can save energy when weather conditions are mild and recirculation is unnecessary. A manometer can be used to detect a pressure differential across the filter as well as an alarm to sound if this differential becomes too great. Both are intended to provide indication or warning to the operator that the filter is in need of service.

Safety and health managers are warned to monitor recirculation systems closely. Frequently in industry, a sophisticated ventilation system is installed for a process, and then it is ignored. Some filter alarms are merely red lights, which operators often ignore. Even audible alarms such as buzzers and horns are sometimes disabled by disconnecting electrical leads. Both operations and maintenance personnel have been found guilty of disabling these devices, which are designed to protect the workers' health.

Besides using recirculating systems, there are some other ways around the problem of energy losses due to the introduction of makeup air into the building. One method is to introduce the makeup air right at the point at which the contamination is taking place. With this strategy, the makeup air may need no air conditioning—no cooling in summer and no heating in winter. The exhaust system will merely suck up the unconditioned makeup air together with the contaminants, and workers will have little exposure to either.

Another solution to the problem is to use a heat exchanger to recapture the energy of the exhaust air and transfer it to the incoming makeup air. It is difficult to make this solution practical, however, because the heat differential between makeup air and exhaust air is usually too low to make the heat exchanger effective. In addition, the heat exchanger approach necessitates positioning the makeup air duct close to the exhaust air duct, which introduces the possibility of cross-contamination. Finally, heat exchanger systems can be expensive, both to install and to maintain effectively—too expensive in many cases to amortize by means of energy cost savings over the life of the system.

Besides the energy problem, another problem with supplying makeup air is the presence of contaminated air from the outside. This is an unusual problem, but it has presented itself on occasion. At one plant, the makeup air inlet was adjacent to a major freeway, which caused carbon monoxide and other automobile exhaust emissions to be drawn into the building. In another poor design, the makeup air inlet was so close to the exhaust system discharge that contaminants were being drawn back in and recirculated around the plant. That way, if workers managed to escape breathing the contaminated air the first time through, they got another chance to become exposed!

A quick check to determine whether there is a sufficient makeup air supply is to check atmospheric pressure both inside and outside the plant. The pressure inside should be only slightly lower than the pressure outside. If the pressure inside is substantially lower, then the makeup air supply is insufficient. The basic relationship between makeup and exhaust is illustrated in Figure 10.3. The cross-sectional area of makeup openings

multiplied by the velocity of flow through those openings must equal the cross-sectional area of the exhaust openings multiplied by the velocity of flow through the exhaust.

The provision for adequate makeup air and a sufficient volume of general exhaust ventilation is sometimes the only practical solution to the problem of reducing air-contaminant exposures to specified levels. Case Study 10.1 will illustrate the principle of this solution to the problem.

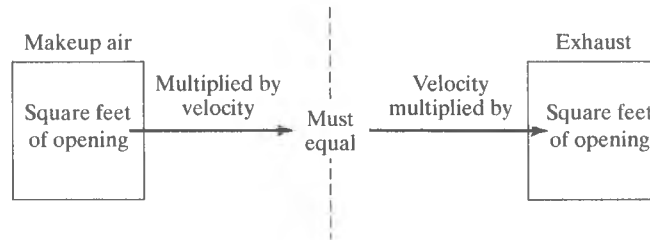


FIGURE 10.3

Balancing makeup and exhaust air.

### CASE STUDY 10.1

An industrial process liberates 2 cubic feet of chlorobenzene per hour into a room that measures 20 feet by 40 feet and has a ceiling height of 12 feet. What minimum general exhaust ventilation in cubic feet per minute is necessary to prevent a general health hazard in this room?

#### **Solution**

A subtle facet of this problem is that for a continuously operating process, the dimensions of the room are really irrelevant to the solution. It is true that for a short-duration exposure, the size of the room will affect the dilution of the chlorobenzene within the confines of the room. But to deal with a continuous process, one must provide sufficient ventilation to yield an ample supply of makeup air to continuously dilute the chlorobenzene to levels within limits, *regardless of room size*.

The PEL for chlorobenzene is 75 ppm. Let  $X$  = the total ventilation necessary to dilute the chlorobenzene. Then,

$$\begin{aligned} \frac{2}{X} &= \frac{75}{1,000,000} \\ X &= \frac{2 \times 1,000,000}{75} = 26,667 \text{ ft}^3/\text{hour} \\ &= \frac{26,667 \text{ ft}^3/\text{hour}}{60 \text{ minutes/hour}} \\ &= 444 \text{ ft}^3/\text{minute}. \end{aligned}$$

## Purification Devices

If the exhaust air is clean enough to meet external standards, no filtration or purification may be necessary once the air gets outside the plant. But often some type of purification device is necessary on the outside as is required indoors for recirculating systems, particularly for the removal of particulates. The paragraphs that follow describe some of the basic types of particulate removal devices.

*Centrifugal* devices, often called *cyclones*, take advantage of the mass of the contaminant particles, causing them to collect on the sides of the cyclone in the swirling air and then slide to the bottom and settle in the neck of the funnel, where they can be periodically emptied. Another type of centrifugal device causes the dirty air to strike louvers, whereupon particles separate from the air. A typical application for cyclones is grain dust removal for grain elevators and mills. Cyclones are also used for woodworking sawdust, plastic, dusts, and some chemical dry particulates.

*Electrostatic precipitators* place a very high (e.g., 50,000-volt) electrical charge on the particles, causing them to be attracted to an electrode of opposite electrical charge. The collecting electrode can consist of plates, rods, or wires, all of which can be agitated to shake off the collected dust and cause it to settle at the bottom of the chamber. Electrostatic precipitators are used in the steel, cement, mining, and chemical industries. Electrostatic precipitators are also used in smokestacks to reduce fly ash.

*Wet scrubbers* include a wide variety of devices that employ water or chemical solution to wash the air of particulates or other contaminants. Some types pass the dirty air through standing water or solution. Another type forces dirty air to rise in a tower packed with a filler media through which water falls. The cleanest water is at the top of the tower, where the exiting air is at its cleanest. The bottom of the tower is the dirtiest, where the water vehicle is exiting the packing and is contacting the dirtiest, untreated exhaust air. Wet centrifugal types, like dry centrifugal types, take advantage of the mass of the particles by causing them to impinge on blades, plates, or baffles. Wet scrubbers are seen in the chemical industries, where they are able to remove gases and vapors in addition to particulates. Other industries that use wet scrubbers are the rubber, ceramics, foundries, and metal-cutting industries.

*Fabric, or bag-type, filters* are essentially like a vacuum cleaner bag. Some are huge and are located in separate buildings called baghouses. Fabric filters are used in the refining of toxic metals such as lead and in the woodworking, metal cutting, rubber, plastics, ceramics, and chemical industries.

## ASHRAE STANDARDS AND INDOOR AIR QUALITY

So far this chapter has focused on exhaust ventilation to remove known contaminants, especially particulates. However, heating and air-conditioning engineers in the twenty-first century have been concentrating on improving the overall quality of indoor air, not just the removal of specific contaminants. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has issued a general

standard: ASHRAE Standard 62-2001 – Ventilation for Acceptable Indoor Air Quality (IAQ). The reader may recall that the subject of Indoor Air Quality was introduced in Chapter 2 of this book, but the emphasis was on smoking in the workplace, not indoor air quality in general.

Engineers in the twenty-first century are looking at a particular air contaminant, carbon dioxide, as a benchmark indicator for indoor air quality in general. Carbon dioxide is discharged by humans in exhaled breath. If indoor ventilation is inadequate for the general load of human occupation of the space, carbon dioxide levels will build up. Table A.1 in this textbook lists the PEL for carbon dioxide at 5000 ppm. This is a rather high level of carbon dioxide, not one that would normally occur due to exhaled human breath. However, air-conditioning engineers are focusing on ventilation systems that refresh the air at much lower levels of carbon dioxide concentration. When air in the workplace truly becomes stale, body odors can become a problem. Sometimes workers complain of feeling drowsy or lethargic. While research is still necessary to verify and quantify these effects, increased attention is being given to the possible effects of stale air on productivity and achievement.

The control of general ventilation systems has become more sophisticated as the technology of measuring air parameters has advanced. Heating, ventilating, and air-conditioning (HVAC) systems are frequently capable of controlling not only the on-off flow of ventilation air, but also the rate of flow by adjusting the speed of the ventilation fans powering the system. This development has been further advanced by recent developments in variable speed drives for the fan motors. Air-conditioning systems that control the rate of air flow are identified as “Variable Air Volume” (VAV) systems. Safety and health managers who are familiar with VAV can offer advantages to their companies that go beyond the objective of worker safety and health. VAV systems also save energy by reducing the energy requirement of the fans. Saving energy is increasingly welcome in today’s environment of emphasis on energy consumption, global warming, and green engineering. Another advantage is more effective dehumidification. A final point to be recognized is that humidity and moisture from condensation are principal factors in mold and fungal growth, which can be detrimental not only to worker health but to the preservation of materials and processes within the facility as well. The recent advances by ASHRAE and the HVAC industry ensure that higher standards for indoor air quality will naturally follow. Although it was stated in Chapter 2 that OSHA abandoned its attempt to promulgate a new standard on indoor air quality, that issue may be revisited in light of new advancements in the field.

## INDUSTRIAL NOISE

Noise exposure is another classic health problem because chronic exposures are the ones that typically do the damage. A single acute exposure can do permanent damage, and in this sense, noise is a safety problem, but noise exposures of this type

are extremely rare. As with other health hazards, noise has a threshold limit value, and exposures are measured in terms of time-weighted averages. To understand the units of these measures, some background is needed in the physical characteristics of sound.

### Characteristics of Sound Waves

Noise can be defined as unwanted sound. In the industrial sense, noise usually means excessive sound or harmful sound. Sound is generally understood as a pressure wave in the atmosphere. In liquids, sound is also a pressure wave; in rigid solids, sound takes the form of a vibration.

Two basic characteristics of sound waves important to the subject of noise control are

1. the amplitude, or pressure peak intensity, of the wave;
2. the frequency in which the pressure peaks occur.

Our sense of hearing can detect both of these characteristics. Pressure intensity is sensed as loudness, whereas pressure frequency is sensed as pitch. Figure 10.4

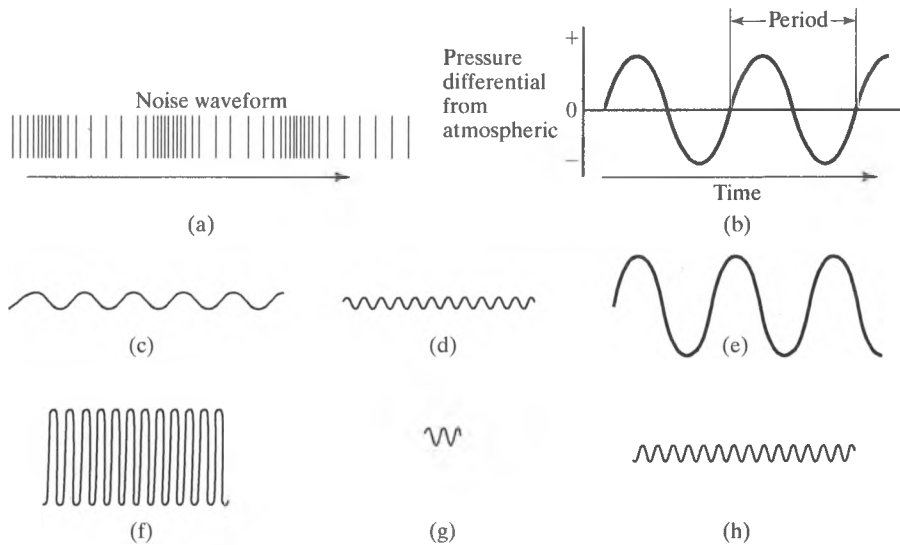


FIGURE 10.4

Characteristics of sound waves: (a) pressure wave is longitudinal (in the direction of travel of the sound); (b) relationship between pressure and time at a given point of sound exposure; (c) low pitch, soft sound; (d) high pitch, soft sound; (e) low pitch, loud sound; (f) high pitch, loud sound; (g) short-duration sound; (h) sustained sound.

illustrates the wave form of sound and also graphs the relationship between pressure and time. Note in Figure 10.4(b) that the *period* is the length of time required for the wave to complete its cycle. In the graph, it is measured at the point at which the pressure differential becomes zero and is starting to become negative. However, it could have been measured from peak to peak, valley to valley, or at any other convenient reference point in the cycle. These periods are always short, too short to count their occurrences while listening to the sound. If we could count the occurrences of these wave cycles, the resulting count per unit time would be the *frequency*, usually measured in numbers of cycles per second (*hertz*). A typical sound is at a frequency of 1000 cycles per second—that is, 1000 hertz (Hz). Obviously, we could never count 1000 pulses of pressure in a single second, but our ears have surprising sensitivity to variations in this frequency count. The sensation is known as *pitch*, and skilled musicians have trained their ears to hear very slight variations in sound-wave frequency. Frequency is important in analyzing the sources of occupational noise exposure.

Even more important than pitch in industrial settings is the pressure intensity of the sound wave. High peaks of pressure in the waves can do permanent damage to the delicate mechanisms in the human ear, causing permanent hearing loss. The mechanism of hearing damage is better understood by examining the diagram in Figure 10.5.

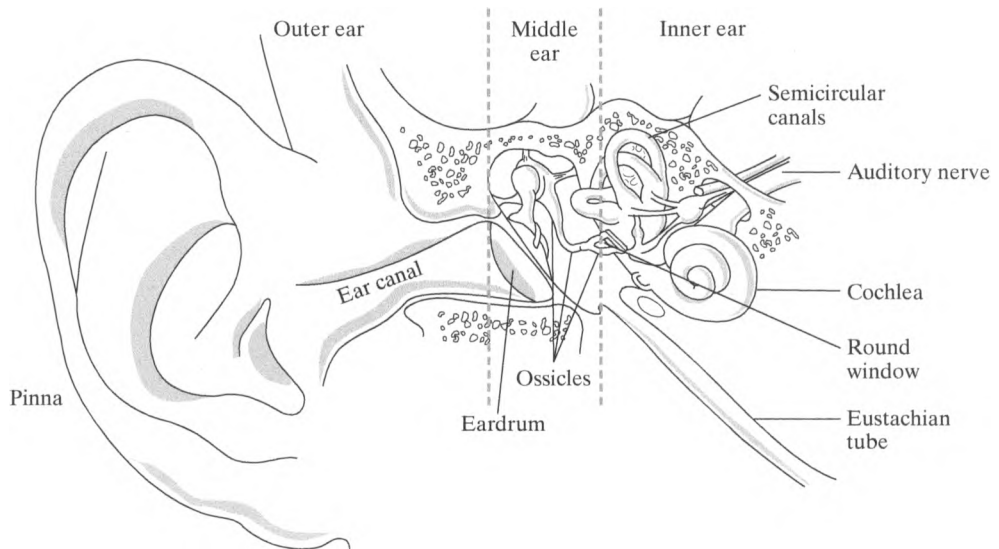


FIGURE 10.5

Diagram of the human ear. Note the snail-shaped organ in the inner ear. This organ is named the cochlea. The hairs inside the cochlea can become damaged by noise exposure and lose their ability to transmit noise signals to the brain via the auditory nerve.

The human ear has three regions: the outer ear, the middle ear, and the inner ear. Note in the diagram of the inner ear the snail-shaped organ called the cochlea. Tiny hairs inside this snail-shaped organ vibrate and transmit the vibrations to the brain via the auditory (cochlear) nerve. Continued exposure to high noise levels causes these tiny hairs to become damaged and lose their ability to transmit the noise to the brain. If the exposure is not too severe, the damage can be overcome by allowing the ear to rest from exposure for a few days.

The ear is delicate enough to pick up the tiny pressures of the faintest audible sounds and also is able to withstand an incredibly large range of pressures. The human ear can withstand, *without damage*, a sound pressure 10,000,000 times as great as the faintest sound it can hear! A necessary result of this incredible range of pressures is that the ear is not very sensitive to shades of differences in these pressures, especially as the pressures get into the upper part of the range. In other words, as sounds get fairly loud, the human ear cannot readily detect a large increase in the intensity, even a doubling or tripling of the intensity.

## Decibels

It is difficult to talk sensibly about such a large range of audible pressures, and it is especially difficult to set standards. Imagine a noise meter reading in the millions. The situation is further complicated by the lessening of the ability of the human ear to detect pressure differences as sounds get louder. To deal with these problems, a unit of measure called the *decibel* (dB) has been devised to measure sound-pressure intensity. The decibel has a logarithmic relation to the actual pressure intensity, and thus the scale becomes compressed as the sound becomes louder, until in the upper ranges, the decibel is only a gross measure of actual pressure intensity. But this is appropriate because, as was mentioned before, the human ear only hears gross differences anyway when the sound becomes very loud. Figure 10.6 relates the decibel to familiar sound levels.

The logarithmic decibel scale is convenient, but it does give rise to some problems. If a machine in the plant is very loud, putting a second machine just like it right beside it will not make the sound twice as loud. Remember that the range of sound pressures is tremendous and that the human ear hears only a slight increase in loudness, when the actual sound pressure may have doubled due to the addition of the extra machine. The decibel scale recognizes the addition of the new machine as an increase in noise level of only 3 decibels. Conversely, if the noise level in the plant exceeds allowable standards by very much, shutting off half the machines in the plant, an obviously drastic measure, may have very little effect in bringing down the total noise level on the decibel scale. Table 10.1 provides a scale for combining decibels to arrive at a total noise level from two sources. If there are three or more sources, two sources are combined and then treated as one source to be combined with a third, and so on, until all sources have been combined into a single total. An example is helpful in illustrating the method.

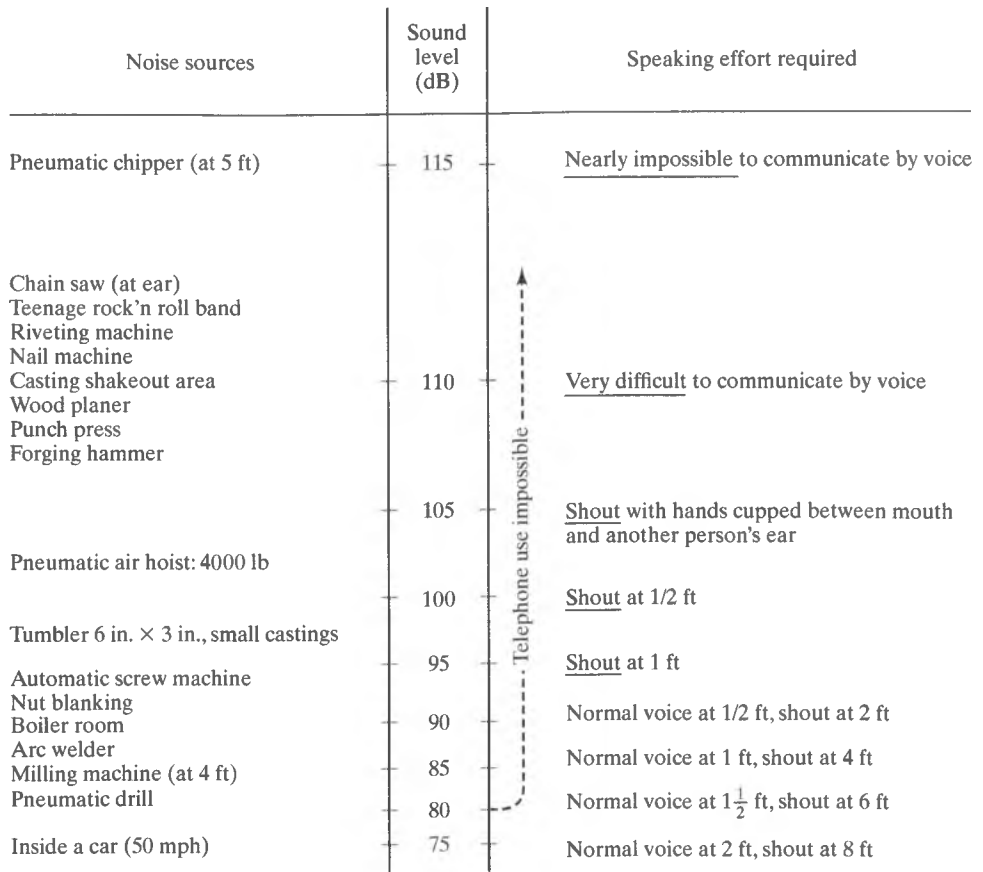


FIGURE 10.6

Decibel noise levels of familiar sounds (Source: NIOSH, Industrial Noise Control Manual (NIOSH 79-117), 1978).

Difference between two decibel levels to be added (dB)	Amount to be added to larger level to obtain decibel sum (dB)
0	3.0
1	2.6
2	2.1
3	1.8
4	1.4
5	1.2

(continued)

TABLE 10.1 (Continued)

Difference between two decibel levels to be added (dB)	Amount to be added to larger level to obtain decibel sum (dB)
6	1.0
7	0.8
8	0.6
9	0.5
10	0.4
11	0.3
12	0.2

Source: NIOSH (Industrial Noise Control Manual (NIOSH 79-117), 1978).

### CASE STUDY 10.2

Suppose that noise exposure at a workstation is essentially due to four sources, as follows:

Machine A	86 dB
Machine B (identical to machine A)	86 dB
Machine C	82 dB
Machine D	78 dB

First, the two identical noise sources, Machines A and B, are combined to produce a noise level of 89 dB. Then Machine C is added as follows:

$$\text{dB difference} = 89 \text{ dB} - 82 \text{ dB} = 7 \text{ dB.}$$

From Table 10.1, a difference of 7 dB between two sources results in the addition of 0.8 dB to the larger source. Therefore, the combined sound of machines A, B, and C is

$$\text{combined sound (A, B, C)} = 89 \text{ dB} + 0.8 \text{ dB} = 89.8 \text{ dB.}$$

Adding Machine D, we have

$$\text{dB difference} = 89.8 \text{ dB} - 78 \text{ dB} = 11.8 \text{ dB} = 12 \text{ dB.}$$

Returning to Table 10.1, a difference of 12 dB between two sources results in the addition of 0.2 dB to the larger source. Therefore, the combined sound of all machines is

$$\text{combined sound (A, B, C, D)} = 89.8 \text{ dB} + 0.2 \text{ dB} = 90.0 \text{ dB.}$$

Figure 10.7 diagrams the computation of Case Study 10.2. It should be noted that the measurement of both the total combined sound and the individual machine contributions toward that total are made from the position of the operator. Otherwise, distance factors would affect the results. The computation of combined noise levels is useful in considering the potential benefits of removing machines, enclosing machines, or changing the process.

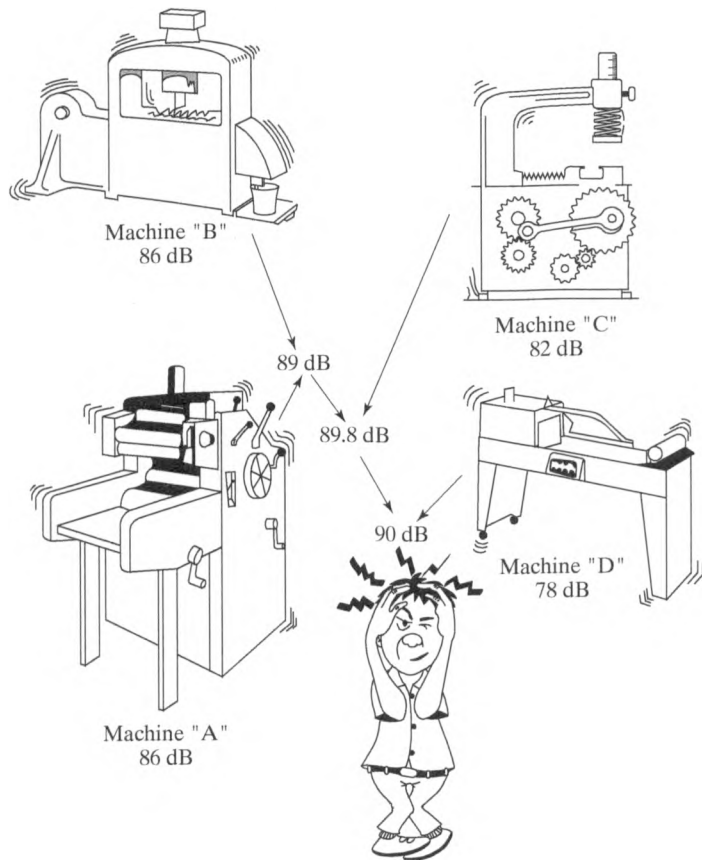


FIGURE 10.7

Combining noise from several sources.

We have been emphasizing sound intensity measured in decibels, but frequency (or pitch) also plays a role in noise control. Industrial noise is typically a combination of sound frequencies from each of several sources. The total range of sound frequencies audible to the human ear is from about 20 to about 20,000 Hz. The ear is more sensitive to some of these frequencies than others, particularly the upper middle range from about 1000 to about 6000 Hz. Thus, sound-level meters have been devised to bias the decibel reading slightly to emphasize the frequencies from 1000 to 6000 Hz. This biased reading is called the *A-weighted scale*,<sup>1</sup> and resulting readings are abbreviated dBA instead of simply dB. OSHA recognizes the A-scale, and OSHA PELs are expressed in dBAs.

<sup>1</sup>There are also a B-scale and C-scale, but these scales are seldom used.

### OSHA Noise Standards

Noise is unusual in that it is a hazard for which OSHA has set both a PEL and an AL. The best known is the PEL, which is set at 90 dBA for an 8-hour TWA. The action level (AL) was established in the early 1980s at 85 dBA for an 8-hour TWA, about 10 years after the 90-dBA PEL was established. It is widely recognized that workers can tolerate short periods of noise higher than the 8-hour TWA without damage, so OSHA specifies a range of decibel exposure levels for various exposure periods. The range of OSHA PELs for noise exposure is given in Table 10.2.

The range of permissible exposures in Table 10.2 makes possible a computation of a time-weighted-average exposure, relating each exposure time to the limit permitted for that sound level. The procedure is very similar to the calculation used earlier when multiple contaminants are present in the atmosphere. The formula used is

$$D = 100 \sum_{i=1}^n \frac{C_i}{T_i} = 100 \left( \frac{C_1}{T_1} + \frac{C_2}{T_2} + \dots + \frac{C_n}{T_n} \right), \quad (10.1)$$

where  $D$  = total shift noise exposure (“dose”) as a percent of PEL

$C_i$  = time of exposure at noise level  $i$

$T_i$  = maximum permissible exposure time at noise level  $i$  (from Table 10.2)

$n$  = number of different noise levels observed

Case Study 10.3 illustrates the computations in an example scenario.

TABLE 10.2 OSHA’s Table of PELs for Noise

A-weighted sound level	Reference duration time (hours)
80	32
81	27.9
82	24.3
83	21.1
84	18.4
85	16
86	13.9
87	12.1
88	10.6
89	9.2
90	8
91	7.0
92	6.2
93	5.3
94	4.6

A-weighted sound level	Reference duration time (hours)
95	4
96	3.5
97	3.0
98	2.6
99	2.3
100	2
101	1.7
102	1.5
103	1.4
104	1.3
105	1
106	0.87
107	0.76
108	0.66
109	0.57
110	0.50
111	0.44
112	0.38
113	0.33
114	0.29
115	0.25
116	0.22
117	0.19
118	0.16
119	0.14
120	0.125
121	0.110
122	0.095
123	0.082
124	0.072
125	0.063
126	0.054
127	0.047
128	0.041
129	0.036
130	0.031

Source: Code of Federal Regulations 29 CFR 1910.95.

An interesting computation is for total shift exposure exactly at the AL of 85 dBA. By using Equation (10.1), the computation is as follows:

$$D = 100 \sum_{i=1}^n \frac{C_i}{T_i} = 100 \left( \frac{8}{16} \right) = 50\%.$$

Thus, the AL is computed to be 50% of the maximum permissible PEL. However, the reader should note from the earlier discussion of sound intensity that 85 dBA represents less than one-half of the absolute sound intensity of noise at 90 dB.

**CASE STUDY 10.3**

Noise-level readings show that a worker exposure to noise in a given plant is as follows:

8:00 A.M.–10:00 A.M.	90 dBA
10:00 A.M.–11:00 A.M.	95 dBA
11:00 A.M.–12:30 P.M.	75 dBA
12:30 P.M.–1:30 P.M.	85 dBA
1:30 P.M.–2:00 P.M.	95 dBA
2:00 P.M.–4:00 P.M.	90 dBA

Adding up the noise durations for each level, we obtain the following:

At noise level 90 dBA	2 + 2 = 4	hours
At noise level 95 dBA	1 + 1/2 = 1½	hours
At noise level 75 dBA	1½	hours (ignore)
At noise level 85 dBA	1	hours
Total	8	hours

The reason that the 1½-hour exposure at 75 dBA was ignored is that 75 dBA is below the range of Table 10.2. In other words, workers may be exposed to noise levels of 75 dBA for as long as desired with no adverse effects, at least as far as safety standards are concerned.

Computing the ratios at each level and summing, in accordance with Equation (10.1), yields

$$\begin{aligned} D &= 100 \sum_{i=1}^n \frac{C_i}{T_i} = 100 \left( \frac{4}{8} + \frac{1\frac{1}{2}}{4} + \frac{1}{16} \right) \\ &= 100(0.5 + 0.375 + 0.0625) \\ &= 93.75\%. \end{aligned}$$

Since 93.75% is less than 100%, the PEL is not exceeded. However, since 93.75% is greater than 50%, the AL of 85 dBA (8-hour TWA) is exceeded.

Sometimes noise is percussive or intermittent so that, technically speaking, there are tiny intervals of silence between sharp reports. Some employers have followed the scheme that these tiny intervals of silence can be counted toward the quiet time, reducing the observed duration of noise in excess of 90 dBA, but this interpretation is incorrect. Any variations in noise levels that have maxima less than 1 second apart are to be considered continuous. The slow response scale of modern noise-level meters tends to ignore such tiny interval variations, and thus "slow response" is specified in noise-level metering.

The standards do have a specification for peak impulse or impact noise at 140 dBA, but this, of course, is much higher than the PELs for continuous noise. Thus, the 140-dB OSHA specification can be considered a ceiling, or C, value. The 140-dB ceiling should be considered a limit for acute exposure and is accordingly a safety hazard. However, such exposures are so rare and difficult to measure after the fact that ceiling violations are virtually never cited. Ordinary sound-level meters are not very effective in measuring impact noise. Even for continuous exposures, measurement can be a problem that will now be addressed.

## Noise Measurement

As a first check for potential noise problems, the safety and health manager should take a walk through the plant and listen. As a rule of *thumb*, if you can reach out and touch someone with your *thumb* but still cannot hear and understand that person's conversation (without his or her shouting), either your hearing is already damaged or deficient or there is excessive noise in the area. If the noise is continuous throughout the working shift but is no louder than a continuously running vacuum cleaner, there is probably no violation of standards. But if the noise is as loud as a subway passing through a station continuously throughout the full shift, a violation probably exists. If subways are unfamiliar to you, imagine a fast-moving freight train passing within 20 feet; such a noise level would easily constitute a violation if the exposure were continuous for a full 8-hour shift. Some exposures louder than the train might be permissible if they are of short duration, as was obvious in the calculation of average exposures in the preceding section. Anything between the vacuum cleaner and the train in sound level would be a gray area that ought to be measured with accurate meters.

Accurate measurement of sound levels requires instruments such as the sound-level meter (SLM) illustrated in Figure 10.8. The meter registers the sound intensity in decibels. Sound-level meters are delicate instruments and must be handled carefully. Accuracy is a problem, and the safety and health manager should not expect performance better than  $\pm 1$  dB. Calibration is extremely important, and no sound-level meter is complete without a calibration device (known sound source) nearby. Variations in battery level must be compensated for, and humidity and temperature conditions can cause distortions.

Some skill is required in using the sound-level meter to obtain reliable readings. Naturally, the microphone receiver of the instrument must be held in the vicinity of the subject's ear in order to be representative of the exposure. However, the instrument should not be held too close, as the subject's body may affect the reading. The

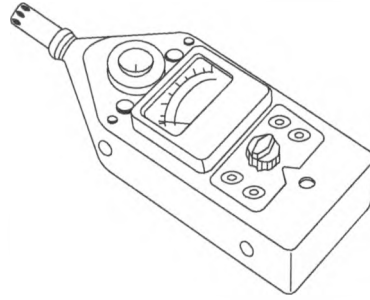


FIGURE 10.8  
Example of a sound-level meter.

instrument's microphone receiver should be shielded from wind currents, and the instrument itself should not be subjected to direct vibrations. The safety and health manager may find the sound-level meter most useful in comparing sound levels in various locations in the plant and in comparing different machines and operating modes.

Determining the full-shift, time-weighted-average exposure with a sound-level meter is tedious and requires a great number of samples. A convenient substitute is a cumulative device called a *dosimeter*, which is worn on the person of the subject under study. Dosimeters may seem to be a panacea, but they have their drawbacks. The wearer can easily bias the dosimeter by holding it close to a loud mechanism, or by simply rubbing, tapping, or blowing on the microphone. They are useful survey devices, however, and are used to monitor exposures if the firm's noise levels have exceeded the AL of 85 dBA for an 8-hour TWA.

Once it is determined that a problem exists, a more sophisticated measurement of noise level may be necessary to isolate the sources of the undesirable noise. An octave-band analyzer permits decibel readings to be taken at various frequencies over the audible range, as shown in the example in Figure 10.9. Various noise-reduction media have characteristic frequencies at which they are most effective. The octave-band analysis will help to delineate the problem frequencies as well as provide evidence to identify the problem sources. Finally, octave-band analysis is useful in determining the frequency characteristics of a particular industry's noise sources so that damage from these sources can be distinguished from damage from noise exposures that have occurred off the job.

## Engineering Controls

Once the instruments have proven that a problem exists, the safety and health manager needs physical solutions to the problems. If noise levels exceed the PEL, federal standards require that feasible engineering or administrative controls be used. If these measures fail to reduce noise exposures to within the PEL, personal protective equipment must be provided and used to reduce sound levels to within the PEL. Engineering controls should be considered a more thorough and permanent solution to the problem.

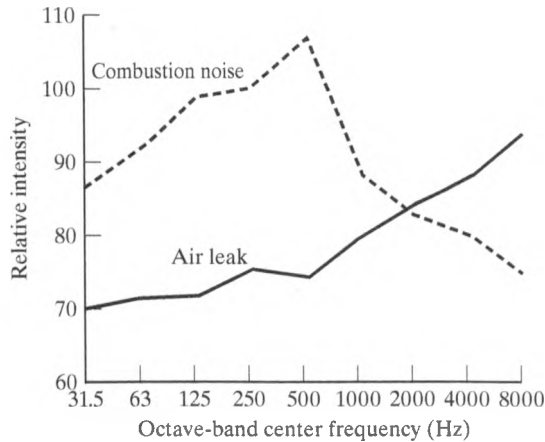


FIGURE 10.9

Example of octave-band analysis

(Source: NIOSH, Industrial Noise Control Manual (NIOSH 79-117), 1978).

As with the control of toxic substances, the simplest solutions may be so obvious that they are overlooked. Process modification or elimination should always receive consideration. Another very simple solution, if feasible, is merely to move the operator away from the primary source of the noise. This idea has more merit than it would intuitively appear because the noise intensity from a given source goes down as the square of the distance, in the absence of reflective walls and other distorting factors. The reason for this relationship can be seen in Figure 10.10.

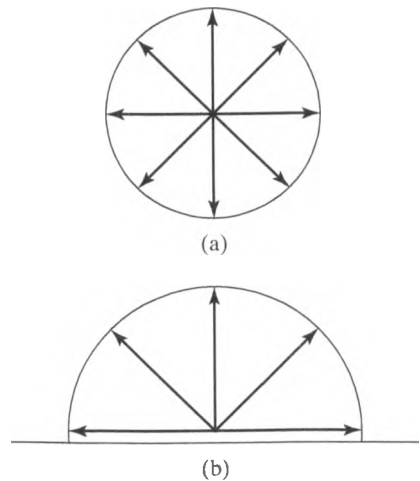


FIGURE 10.10

Distribution of sound intensity over the surface of a sphere as it radiates from a single source. (a) Sound emanates from a point source in all directions distributing over the surface of a sphere, the area of which is calculated by the formula  $4\pi r^2$ . Thus, the sound intensity is reduced as the square of the radial distance from the source. (b) Sound emanates from a point source located on the floor or other surface. The floor either absorbs or reflects the sound, but the resultant sound is still distributed over a hemisphere, the area of which is  $2\pi r^2$ . The squared-distance relationship still holds approximately.

It must be remembered that it is absolute sound intensity, not decibels, that varies inversely with the square of the distance from the source. The logarithmic decibel scale results in a 3-dB change whenever the sound intensity is changed by a factor of 2 (doubled or halved). This leads to a rule of thumb for distance. Since sound intensity varies as the square of the distance from the source, a doubling of distance results in a *fourfold* reduction in sound intensity, which in turn reduces the decibel level by 6 dB. The effect is shown in Case Study 10.4.

#### CASE STUDY 10.4

A worker's machine is located at a distance of 2 feet from the operator and produces a noise exposure of 95 dB to the operator. How much is to be gained by moving the operator to a position 4 feet from the machine? How much reduction could be achieved by a move to 8 feet?

#### **Solution**

A move from 2 to 4 feet is a doubling of distance and results in a 6-dB reduction in sound level. The resultant level would be

$$95 \text{ dB} - 6 \text{ dB} = 89 \text{ dB}$$

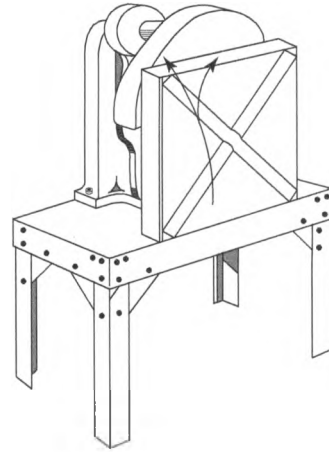
which would probably be within the 8-hour PEL of 90 dB even after considering reflections and other sources, if these sources are not very significant.

A move to 8 feet would be a second doubling, resulting in a reduction of another 6 dB to a resultant 83 dB, ignoring reflections and other sound sources. This would reduce noise exposures to less than the AL of 85 dBA for an 8-hour TWA.

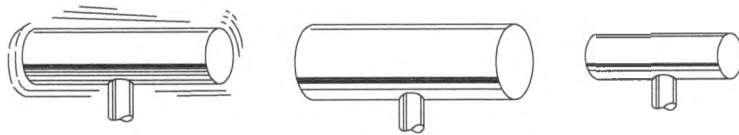
It is not likely to be feasible to move operators away from their own machines, and even if it is, to move away from one machine may place the operator close to a neighboring machine. Distance factors work best in separating operators from noise arising from adjacent machines or other processes in the area. A general spreading out of the plant layout can be beneficial in this regard.

If spreading out the plant layout is infeasible or too costly, the installation of sound-absorbing barriers between stations can increase their virtual separation as far as noise is concerned. The gain to be achieved by such barriers is variable and complicated to estimate in advance. An acoustics expert is recommended for advice in this area, and even the expert is likely to experiment with various temporary barriers, measuring the "before" and "after" sound levels with each. Heavy materials absorb sound vibrations, a fact that makes curtains or shields containing lead a popular choice.

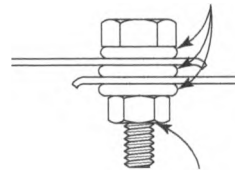
Sheet metal surfaces on machines are susceptible to mechanical vibrations and may act as sound-amplifying surfaces. Metal gear contact in the drive mechanism can sometimes be eliminated by substitution of nylon gear wheels for metal gears or by the use of belt drives instead of gears. Simpler still would be a stepped-up preventive maintenance schedule to lubricate the gears more often, perhaps reducing noise levels. Useful principles for engineering controls to reduce noise are illustrated in Figures 10.11 to 10.16.



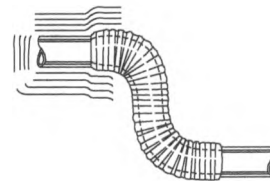
**FIGURE 10.11**  
Application of welded stiffeners to reduce vibrations in a sheet metal component  
(Source: Arkansas Department of Labor, Lovett, 1976).



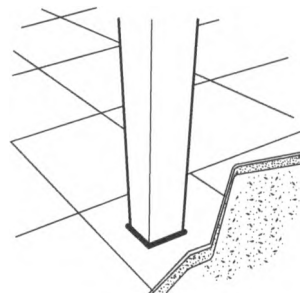
**FIGURE 10.12**  
Enlarge or reduce size of a part to eliminate vibration resonance  
(Source: Arkansas Department of Labor, Lovett, 1976).



**FIGURE 10.13**  
Rubber cushions on both sides of vibrating sheet metal surfaces where they are joined  
(Source: Arkansas Department of Labor, Lovett, 1976).



**FIGURE 10.14**  
Flexible section in rigid pipe isolates vibrations  
(Source: Arkansas Department of Labor, Lovett, 1976).



**FIGURE 10.15**  
Resilient floor (Source: Arkansas Department of Labor, Lovett, 1976).

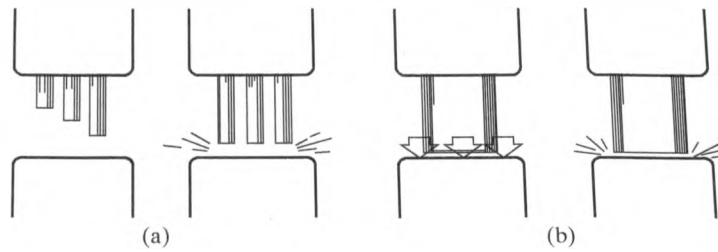


FIGURE 10.16

Power press improvements to reduce noise levels: (a) design die to result in a dull, crunching sound instead of a sharp bang; (b) replace the sharp impact action of a mechanical press with the relatively quiet pressure action of a hydraulic press. Note that the hydraulic press ram does not travel as far as the mechanical one does. The mechanical press bangs down on the work piece, but the hydraulic press is able to achieve great power with a squeezing action at the bottom of the ram travel.

Perhaps more expensive than any of the engineering control approaches discussed so far would be the isolation of the offending machine by means of an enclosure. The effectiveness depends on the type of material used to construct the enclosure and also depends to a surprising degree on the number and extent of openings or leaks in the enclosure. Figure 10.17 shows the relationship between opening size and loss of effectiveness for an example noise enclosure that has a capability of a 50-dB reduction if there are no leaks. Note that most of the effectiveness of the enclosure is lost if there is a hole in the enclosure wall of less than one-half of 1% of the total area of the enclosure.

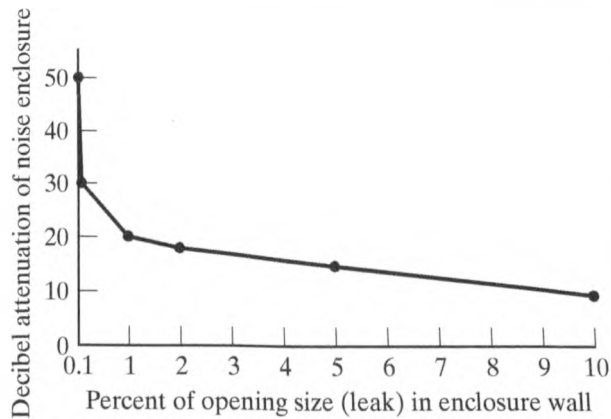


FIGURE 10.17

Loss in effectiveness of a noise enclosure due to leaks. For a sample enclosure that has an ideal (airtight) noise-reduction (attenuation) capability of 50 dB, leaks in the walls reduce the decibel attenuation by remarkable amounts, as shown.

## Administrative Controls

It was stated earlier that either engineering or administrative controls are specified where feasible for excessive noise levels and that engineering controls are preferable. However, the administrative controls alternative was left unexplained. Administratively, management can schedule production runs so that noise levels are split between shifts and individual workers are not subjected to full-shift exposures. Other tricks are to interrupt production runs with preventive maintenance to give workers some quiet time. During normal shift breaks, workers can be removed to a quiet rest area. Sometimes workers can share a loud job and a more quiet one by trading jobs at midshift. All of these practices can be used to bring down noise-exposure levels to within the PEL for the given time of exposure as determined from Table 10.2. Since the term *administrative control* is somewhat vague, the term *work-practices control* has become preferable to refer to the various methods of shifting employee exposures to comply with Table 10.2.

## Hearing Protection and Conservation

Personal protective equipment is required when engineering and administrative controls both fail to reduce noise to legal levels. Specifically, hearing protection is to be provided to all employees exposed to the 85-dBA TWA AL. In addition to providing protection, employers must permit employees to select protectors from a variety of suitable types and must train employees in the proper use and care of the protectors. One aspect of proper use is fit, and employers must ensure proper fit. These actions are mandatory when ALs are exceeded, but the reader may have noted that the actual wearing of the protectors by the workers is not among the mandatory steps to be taken if ALs are exceeded. However, there are conditions under which workers must actually wear the protectors. These are as follows:

1. Whenever worker exposures are greater than the PELs (see Table 10.2)
2. Whenever worker exposures are greater than the AL of 85 dBA (TWA) *and* the worker has experienced a *permanent significant threshold shift*

When testing shows a threshold shift in a worker's hearing, the implication is that the worker's hearing has been damaged and needs special protection. In these cases, the noise levels are required to be reduced by the protectors to 85 dBA (TWA), not 90 dBA (TWA).

Personal protective equipment should not be considered a final solution, because elimination of the source of the noise provides a more satisfactory work environment. Sometimes workers are lax in the wearing of personal protective equipment, and injurious exposures result. The careful selection and fitting of various types of personal hearing protective equipment is discussed in Chapter 12.

Whenever the AL of 85 dBA (8-hour TWA) is exceeded, a "continuing, effective hearing conservation program" should be administered, including audiometric testing, noise monitoring, calibration of equipment, training, warning signs for noisy areas, and recordkeeping of audiometric tests and equipment calibration.

Audiometric testing involves a small, perhaps portable, listening station in which a subject listens to recorded sounds and an audiologist measures the subject's hearing acuity at various frequencies. Audiometric testing can be very useful in determining sources of hearing loss, or more particularly in providing data to determine whether hearing loss is due to occupational or off-the-job exposure. If plant noise levels are high, it is foolhardy to hire new employees without first testing their *baseline* hearing acuity. Without any evidence of hearing deficiency at the time of employment, any hearing deficiencies that show up after employment appear strongly to be work related.

When observing the frequency profile of a worker's hearing acuity, the audiologist often looks for a *4000-Hz shift* for evidence of occupational exposure. Experience has shown that much industrial noise occurs in the 4000-Hz frequency range, which causes audiologists to suspect occupational exposure when hearing acuity becomes deficient in this range.

## RADIATION

A natural progression from the subject of noise is to the subject of radiation. Noise is, in fact, a form of radiant (wave) energy, but the term *radiation* is generally considered to mean electromagnetic radiation such as X rays and gamma rays, or high-speed particles such as alpha particles, protons, and electrons. Federal standards separate radiation into the categories *ionizing* and *nonionizing*.

Ionizing radiation is the more dangerous of the two types and is the type most associated with atomic energy. By far the most important category of ionizing radiation, from the occupational exposure standpoint, is the X ray. X rays are no longer the exclusive domain of the medical and dental professions. X rays are being widely used in manufacturing operations, especially in inspection systems.

Nonionizing radiation is somewhat of a misnomer, but applies to a more benign type of radiation in the electromagnetic spectrum. Included are radio and microwave frequencies. These phenomena are also increasingly important in industrial applications. Some workers are concerned about radiation exposure from the constant use of computer terminals. Computer terminals are of concern, but their principal hazard is musculoskeletal disorders, not radiation. Musculoskeletal disorders are considered an ergonomics hazard, and were covered in Chapter 8.

## SUMMARY

To achieve a safe and healthful workplace and to comply with federal standards, the employer must devise engineering or administrative control solutions to air-contaminant and noise problems, if feasible. For air contaminants, the employer should first seek to eliminate the source of the toxic substances or find more benign substitutes for such process materials. If these attempts fail, ventilation is usually the answer. Ordinary heating and air-conditioning systems are designed for a different purpose and are generally not acceptable for eliminating air contaminants, especially particulates. A basic

principle is to attempt to focus the ventilation in the form of local exhaust ventilation. The supply of makeup air also is an important consideration. A variety of filtering or particle removal mechanisms is available for purifying the air and either returning it to the plant atmosphere or exhausting it into the outside environment.

Industrial noise is a phenomenon that requires an understanding of the physics of sound-wave energy, the way in which noise is heard, and how noise affects human hearing. Human hearing is capable of sensing an incredible range of amplitudes (loudness) of wave energy while employing a very fine degree of discrimination among frequencies (pitch). So great is the range of amplitudes that a logarithmic scale is used to measure the absolute sound pressures and describe the levels of sound that humans actually hear. Computations of noise levels can be done by logarithmic manipulations or by using formulas and tables provided by OSHA standards. The basic OSHA noise standard (PEL) is 90 dB as an 8-hour time-weighted average (TWA). The action level is 85 dB, a level that is actually less than half the PEL in absolute sound intensity, due to the logarithmic nature of the decibel scale. A rule of thumb is that a doubling of absolute sound intensity results in an increase of 3 decibels on the decibel scale.

Radiation is another physical phenomenon that has similarities to noise. Two categories of radiation are recognized: ionizing radiation and nonionizing radiation. Ionizing radiation is the more dangerous of the two. The most widely encountered form of ionizing radiation in industry is the X ray.

Chapters 9 and 10 have shown that the subjects of occupational health and environmental control can be quite technical. The safety and health manager probably will find it beneficial to employ experts to take time-weighted averages with appropriate meters and sampling instruments. Subsequent control measures, such as ventilation systems for toxic substances and acoustic panels for noise control, may require the design capabilities of experts in their respective fields. Dealing with these experts demands a degree of understanding of their methods and terminology, but does not require the safety and health manager to duplicate the experts' capability in each field. Such an understanding of methods, terminology, and basic principles of occupational health and environmental control are what these chapters have attempted to provide.

## EXERCISES AND STUDY QUESTIONS

- 10.1 Identify the comparative hazards of batch versus continuous processes for chemicals.
- 10.2 Explain the benefits and disadvantages of using an ordinary household fan for ventilation in the presence of toxic substances.
- 10.3 What are the comparative advantages and disadvantages of using a vacuum cleaner to exhaust toxic air contaminants by placing the hose intake close to the source of the contaminant?
- 10.4 Why should toxic air contaminant ventilation systems "pull" instead of "push"?
- 10.5 What is the purpose of a "manometer" in exhaust ventilation systems?
- 10.6 Explain three solutions to the problem of energy losses in the supply of makeup air for exhaust ventilation systems.

- 10.7** Identify four different types of devices for the purification of exhaust air before releasing to the outside air.
- 10.8** What two basic characteristics of sound are easily detected by human hearing? Which of these two is more dangerous?
- 10.9** Identify the two principal types of hazardous radiation. To which class do X rays belong?
- 10.10** What is the principal, recognized hazard from working at computer terminals?
- 10.11** A plant has two identical standby generator units for emergency use. In the area of the generators, the normal noise level registers 81 dBA on the sound-level meter with the generators turned off. When one generator switches on, the SLM needle jumps to 83.6 dBA.
- Perform calculations to determine what the dBA reading will be when the second generator also turns on (so that both generators are on).
  - If both generators are on for a full 8-hour shift, will OSHA's PEL be exceeded? Will the AL be exceeded? Explain.
  - If one generator is on for half the shift and both are on for the other half, will the PEL be exceeded? Will the AL be exceeded? Explain.
  - In the absence of any plant background noise, what would be the sound level contributed by a single generator? by both generators? Show calculations to explain.
- 10.12** Four machines contribute the following noise levels in dB to a worker's exposure:
- |           |        |
|-----------|--------|
| Machine 1 | 80 dBA |
| Machine 2 | 86 dBA |
| Machine 3 | 93 dBA |
| Machine 4 | 70 dBA |
- Calculate the combined noise-level exposure for this worker.
  - The offending machine is obviously Machine 3. Suppose that Machine 3 was at a distance of 5 feet away from the worker when the 93-dBA noise level was measured. Determine how far away would Machine 3 have to be moved to bring the worker's continuous 8-hour combined exposure from *all* machines down to the OSHA PEL?
- 10.13** What are some desirable alternatives to industrial ventilation to remove air contaminants?
- 10.14** What is makeup air?
- 10.15** Ten machines all contribute equally to the noise exposure of one worker, whose exposure level is 99 dB for a full 8-hour shift. When all the machines are turned off, the noise level is 65 dB. How many of the 10 machines must be turned off to achieve a full-shift noise-exposure level that would meet standards if the worker wears no personal protective equipment?
- 10.16** A worker stands on a factory floor and a sound-level meter shows a reading of 55 dB at that point. A machine 3 feet away is turned on, and the meter jumps to 90 dB. What will the SLM read if the machine is moved to a point 12 feet away?
- 10.17** A paper mill uses liquid chlorine, delivered in 90-ton railroad tank cars, as a pulp bleaching agent. One volume of liquid chlorine produces approximately 450 volumes of vapor under normal atmospheric temperature and pressure. The density of liquid chlorine is 103 pounds per cubic foot. In the event of rupture and vapor release of 20% of the tank car contents, how much vapor by volume would be released? If the release were in a closed building with a 30-foot ceiling height without ventilation, how large would the building have to be (in square *miles* of floor space) to contain the thoroughly mixed vapor-air ratio within the OSHA PEL? The logical conclusion to this exercise is that, with or without ventilation, it is more practical to unload chlorine tank cars outdoors.

- 10.18** A worker exposure to noise in a given plant is measured, resulting in the following readings for various time periods during the 8-hour shift:

8:00 A.M.–9:00 A.M.	86 dBA
9:00 A.M.–11:00 A.M.	84 dBA
11:00 A.M.–12 noon	81 dBA
12 noon–1:00 P.M.	101 dBA
1:00 P.M.–4:00 P.M.	75 dBA

- (a) Perform computations to determine whether maximum PELs have been exceeded.
- (b) Have ALs been exceeded?
- (c) Given the noise exposure just described, would the employer be required to furnish hearing protectors?
- (d) Would employees be required to use the hearing protectors?
- (e) Suppose that an engineering control could be devised that would cut the noise level (sound pressure level) in half either in the morning or in the afternoon, but not both. Which would you select? Why?
- 10.19** From the perspective used by the federal enforcement agency, rank the following solutions to a worker noise-exposure problem (from most effective, “1,” to least effective, “4”):
- *Solution A* Enclose the noise source with a barrier that reduces the noise level by 3 dBA.
  - *Solution B* Position the operator at a distance twice as far from the source of the noise.
  - *Solution C* Rotate personnel so that each worker is exposed to the noise source for only one-half shift.
  - *Solution D* Provide ear protection that cuts the absolute sound pressure in half. Justify your choices with calculations, analysis, and in light of established priorities.
- 10.20** A certain drying process produces 5 cubic feet of ethanol vapors per hour. If general exhaust ventilation is used, calculate the flow in cubic feet per hour needed to keep the ethanol vapors within OSHA limits. What is another name for ethanol?
- 10.21** For each of the following materials, suggest substitutes that are feasible for some operations and that prevent certain hazards:
- (a) Silica (for blasting)
- (b) Lead-based paint
- (c) Freon (as a propellant)
- (d) Acetylene (for welding)
- 10.22** What problem frequently develops with ventilation filter alarms that indicate pressure differential across the filter?
- 10.23** What is the purpose of using a heat exchanger for makeup air? What is the disadvantage of this approach?

- 10.24 If the air outside is at substantially higher pressure than the air inside the plant, what ventilation problem probably exists?
- 10.25 What form of ionizing radiation is most commonly encountered in industrial exposures?
- 10.26 Identify some candidates for process changes to eliminate hazards associated with metal machining processes and explain how they might help.
- 10.27 What type of ventilation system can be likened to “sweeping dirt under the rug?” Explain the logic behind this connection.
- 10.28 Identify the benefits of performing an octave-band analysis for a noise problem.
- 10.29 What is a VAV system? What advantages does it have over traditional HVAC systems?
- 10.30 Why has the air contaminant carbon dioxide taken on new importance in recent years?
- 10.31 Two identical machines are running in the presence of negligible, undetectable background noise at a workstation. The sound level meter registers 93 dB. What will the meter read if one of the machines is turned off?
- 10.32 It has been said that the permissible level (PEL) for noise is more than twice as loud as the action level (AL). Would you agree? What is the numerical difference in dBA?
- 10.33 Identify two conditions in each of which workers are required to wear hearing protectors.
- 10.34 Explain why personal protective equipment is not considered a satisfactory final solution to noise exposure in the workplace.
- 10.35 Identify essential elements of an effective “hearing conservation program.”
- 10.36 Identify two drawbacks to personal hearing protectors to deal with noise problems.
- 10.37 What is the significance of a “4000 Hz shift” in a worker’s hearing acuity?
- 10.38 Why is it especially important to test workers’ hearing at the beginning of employment?
- 10.39 Identify two primary strategies for employers to utilize to deal with air contaminants.
- 10.40 What type of air contaminant is especially difficult to eliminate using ordinary heating and air conditioning systems?
- 10.41 What type of air contaminant is the focus of “electrostatic precipitators?”
- 10.42 Identify three types of wet scrubbers.
- 10.43 What are two primary disadvantages of constructing an isolation enclosure for a noisy machine?
- 10.44 What is the advantage of rubber cushions between sheet metal surfaces bolted together?
- 10.45 What noise reduction advantage can be gained by changing the physical size of a vibrating machine part?
- 10.46 What advantage lies in using a flexible connection between sections of rigid pipe?
- 10.47 Why are hydraulic presses sometimes an improvement over mechanical presses in the control of noise?
- 10.48 Are industrial X rays considered “ionizing” or “nonionizing?”
- 10.49 **Design Case Study.** A particular welding process is found to be generating toxic phosgene gas. Identify some possible remedies.
- 10.50 **Design Case Study.** A glue-making process releases ethylene glycol that becomes generally diluted and interspersed throughout the plant atmosphere. The rate of release is 2.4 cubic feet per hour vapor volume at standard plant temperature and pressure. The plant ventilation system is of the general dilution type, with makeup air being supplied through windows and doors throughout the plant area. The plant area is 12,000 square feet and the average ceiling height is 16 feet. The problem is to specify the capacity of the general ventilation system required to maintain a steady-state condition throughout this process area that protects against both health and safety hazards due to ethylene glycol. For your information in performing calculations, the following data are provided:

Ethylene glycol ( $\text{CH}_2\text{OHCH}_2\text{OH}$ )  
Molecular weight 62.1

Boiling point: 197.5°C  
 LEL: 3.2%  
 Firepoint: -13°C Flashpoint: 232°F  
 Autoignition temperature: 752°F  
 Vapor pressure: 0.05 mm at 20°C  
 PEL: 50 ppm (ceiling)

- (a) How much exhaust ventilation (in cubic feet per hour, general dilution type) is required to maintain safety hazards below explosive levels?
- (b) How much exhaust ventilation (in cubic feet per hour, general dilution type) is required to maintain health hazards below OSHA-specified action levels?
- (c) How many plant area room changes per hour would the level of ventilation calculated in part (b) represent?

**10.51 Design Case Study.** A particularly noisy process is operated by a single operator working at a control console. The 8-hour TWA exposure level for this operator is 96 dBA. The company has initiated an engineering project to alleviate the problem and has two plans:

- *Plan A.* Move the operator's control console from its current position 5 feet from the source of the noise to a point 10 feet away.
- *Plan B.* Enclose the noise source in an enclosure that would be effective in reducing the *absolute* sound pressure by 75%.

Evaluate the effectiveness of each of these plans in reducing the noise-exposure level. Suppose that both plans were executed; calculate the combined effect of both plans on the noise-exposure level.

## RESEARCH EXERCISES

- 10.52** An employer is having difficulty meeting the OSHA asbestos standard using engineering controls and is considering using administrative (work-practice) controls. Study current OSHA standards for asbestos and prepare a professional recommendation to this employer, citing appropriate sections of the OSHA standard to justify your position.
- 10.53** While visiting an industrial site where asbestos is being removed, you observe that air hoses are being used to blow dust off work clothing. Comment on this procedure, citing specific portions of the OSHA standards to justify your position.
- 10.54** Sometimes industries voluntarily initiate actions to control exposures to levels even lower than those specified by OSHA standards. Examine a noteworthy example of this initiated by the Lead Industries Association, Inc. (LIA). What other industry association joined with LIA in this initiative? Specifically, what target improvement became the 5-year goal of this initiative?

## STANDARDS RESEARCH QUESTIONS

- 10.55** This chapter has dealt with noise. Search the General Industry OSHA standard and use the database on the Companion Website to determine how seriously OSHA takes the general hazard of noise exposure. Specifically, find the frequency of citation, the percentage of the citations designated as "serious," and the dollar level of proposed penalties for noise citations.

- 10.56** The effectiveness of exhaust ventilation systems depends on the design of the hood for enclosing the operation to be ventilated. Search the OSHA standards for provisions pertaining to exhaust hoods. Use the database tool on the Companion Website to determine whether OSHA ever writes citations for exhaust hoods. If any citations are found, what percentage of the citations are designated as “serious”?
- 10.57** Examine the OSHA standards for “audiometric testing” and “hearing conservation programs.” What is the action level trigger for these programs? Are the standards for these programs frequently cited? How does their citation frequency compare with the frequency of citation for ventilation hazards? How do these standards compare for “seriousness” (percentage of citations that are designated as “serious”)?