COMMUNITY NOISE FUNDAMENTALS

A TRAINING MANUAL

ENVIRONMENTAL ACOUSTICS LABORATORY
E.A.L.
THE PENNSYLVANIA STATE UNIVERSITY

THE PENNSYLVANIA STATE UNIVERSITY
ENVIRONMENTAL ACOUSTICS LABORATORY
5 MOORE BUILDING
UNIVERSITY PARK, PENNSYLVANIA 16802

COMMUNITY NOISE FUNDAMENTALS: A TRAINING MANUAL

P.L. MICHAEL
W.T. ACHOR
G.R. BIENVENUE
D.M. DEJOY
R.L. KERLIN
A.H. KOHUT
J.H. PROUT

MARCH 1979

U.S. ENVIRONMENTAL PROTECTION AGENCY

Contract No. 68-01-4892
Office of Noise Abatement and Control
Washington, DC 20460

ACKNOWLEDGMENTS

This manual is the result of work undertaken by staff of the Environmental Acoustics Laboratory (EAL) of The Pennsylvania State University under contract with the U.S. Environmental Protection Agency (EPA), Office of Noise Abatement and Control (Contract No. 68-01-4892). It is a revision of the December 1977 manual produced by EAL as the Final Report for EPA Contract No. 68-01-3875. This revision includes various suggestions and comments for change that were presented at a workshop held at The Pennsylvania State University in early October 1978. Attendees at this workshop included twenty-three individuals representing various governmental and private agencies and organizations. The principal authors wish to express their indebtedness to this group for its collaborative help and encouragement towards the completion of this manual.

EXECUTIVE SUMMARY

Listen! What sounds do you hear right now? In your office you may hear the gentle whoosh of the ventilating system, the secretary's typewriter, a conversation nearby, a telephone and, if you listen closely, maybe you can hear the hum of the light fixtures. These are typical sounds of a quiet office -- there may be others. Listen again when you are at home - before you go inside. Now what do you hear? In quiet residential areas you may hear birds, insects, children at play, cars passing on the street, auto horns, dogs barking and maybe even the neighbor's lawn mower. How quiet is it where you are now?

Some sounds are pleasant, some are annoying, and they produce different reactions in different individuals. Although desirable sounds may be many decibels louder than undesirable sounds which we call noise, it is the control of the noise that is becoming a primary concern in growing communities.

Sound affects our daily lives from conception to death: at work, during recreational activities, and while we are trying to rest. Unwanted sound or noise may interfere with speech communication, warning signals, or sleep; it may cause annoyance or physical discomfort; it may present a safety problem; it may cause temporary or permanent hearing loss, or contribute to other stress-related health problems. Noise is the largest chronic health problem in contemporary society in terms of the number of persons affected. For these reasons, the abatement of noise is a concern at all levels of government: Federal, state and local.

Technically, sounds are rapid variations in air pressure. The largest variation in pressure commonly encountered is about 10,000,000 times greater than the smallest pressure variation our ears can detect. To simplify the measurements, this range of pressures has been mathematically compressed into a range of 0 to 140 using the decibel (dB). The decibel not only reduces the range of the measurement scale, it also makes possible accurate measurements over this very wide range of levels.

The level of sound received can be reduced simply by increasing the distance between the source and the receiver. Unfortunately, the noise reduction afforded by increased distance is too often counteracted; for example, when an airport or other noisy source is relocated away from communities in an attempt to reduce the noise exposures, housing developments tend to build up around the new locations. Informed community planning before and during city growth can help keep residential neighborhoods quiet. Help is available from the Federal government in the form of legislation setting limits on the level of transportation noise and guides for the development of municipal noise control ordinances.

Practical, enforceable noise ordinances often provide for enforcement under existing anti-nuisance legislation with the addition of numerical noise level limits. These limits are usually stated in terms of their L_A values in dB, which means they are measured with special instruments that give different emphasis to different audible frequencies (sounds of different pitch). The normal variation in sound level over a long period of time such as a day or a night can be smoothed out by determining L_{eq}, a single-number dB value that represents the noise environment for a period of time. Combining practical enforcement regulations that have noise level limits in terms of L_A and L_{eq} with informed planning will result in a quiet community.

This manual is designed as a reference to be used by persons involved in community noise programs. Basic information is provided on topics ranging from the basics of sound and hearing to noise measurement and control to rules and regulations. Guidelines are provided for the user to select sections related to particular community noise program tasks.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Figures | Page

Figures		Page

Chapter 1

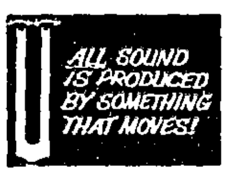
BASICS OF SOUND

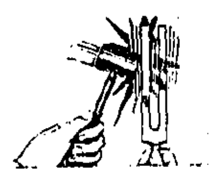
This chapter was written for those readers who are unfamiliar with the characteristics of sound and its propagation, and therefore presents this information on a descriptive rather than a mathematical basis. For those readers who require a more comprehensive treatment of this subject, a bibliography has been compiled and is presented at the end of the manual. A glossary, defining most of the terms that may be encountered in readings in this area, has also been included.

1.1 What is Sound?

The nature of sound is often debated with the following question: if a tree falls in the forest, and no one is near to hear it fall, is there a sound? In other words, does sound deal with a cause (a vibrating object such as the falling tree) or with an effect (the sensory experience of hearing)? The answer is that sound is both these things. It is both a physical event and a physiological sensation (1).

The sensation of sound is a result of oscillations in pressure, particle displacement, and particle velocity, in an elastic medium between the sound source and the ear. Sound is <u>caused</u> when an object is set into vibration by some force.





This vibration causes molecular movement of the medium in which the object is situated, thereby propagating a sound wave. Sound is "<u>heard</u>" when a sound wave impinges on the human ear and is recognized by the brain. Further, the characteristics of the sound wave must fall within the limitations of the human ear for the sound to be heard because the human ear cannot hear all sounds. Sound frequencies (pressure variation rates) can be too high (ultrasonic) or too low (infrasonic), or the sound amplitudes may be too soft to be heard by man.

1.2 How is Sound Propagated?

Sound is transmitted from the sound source to the ear by movement of molecules in the medium. This molecular movement is called a sound wave.

In air, sound waves are described in terms of propagated changes in pressure that alternate above and below atmospheric pressure. These pressure changes are produced when vibrating objects (sound sources) cause alternate regions of high and low pressure that propagate from the source. In the production of airborne sound waves, the vibrating sound source actually "bumps" into the adjacent air molecules forcing them to move (see Figure 1.1). These molecules, in turn, bump into others further away from the source, and so on.

Thus, the energy from the sound source is imparted to the air molecules and thereby is transmitted through the medium. Note that sound energy and <u>not</u> air particles travel from the source through the medium. A similar situation occurs when dropping a pebble into a pond. When the pebble hits the water, it causes a wave motion to emanate from it in all directions, moving outward in concentric spheres.

There are two aspects of a sound wave: compression and rarefaction. The compression phase occurs when the air molecules are forced closely together (causing an instantaneous increase in air pressure) and the rarefaction phase occurs when the air molecules are pulled apart from each other (causing an instantaneous decrease in pressure). This complete sequence of one compression and one rarefaction is called a <u>cycle</u>. The cycle of a simple sound wave and its component parts is illustrated in Figure 1.2. The ear is very sensitive to the variations of pressure above and below that of the atmosphere (sound pressure). Sound pressures 1/1000 of an atmosphere will be intolerably loud. The sound pressure for loud speech at about 1 meter is about one millionth of atmospheric pressure.

1.3 What are the Attributes of Sound?

Sound has several attributes by which it may be characterized. We describe sounds as varying in pitch, measured objectively as frequency, in loudness, measured objectively as amplitude. An additional attribute that helps to describe the distinct character of a sound is its time distribution.

1.3.1 Frequency

Frequency is defined as the number of complete pressure variations, or cycles, per second of a sound wave. As discussed earlier, one cycle is equal to one complete compression and rarefaction variation of a sound wave.

The unit for expressing frequency is cycles per second (abbreviated c.p.s., c/s, cps) or <u>hertz</u> (abbreviated Hz). The latter term is now in more general

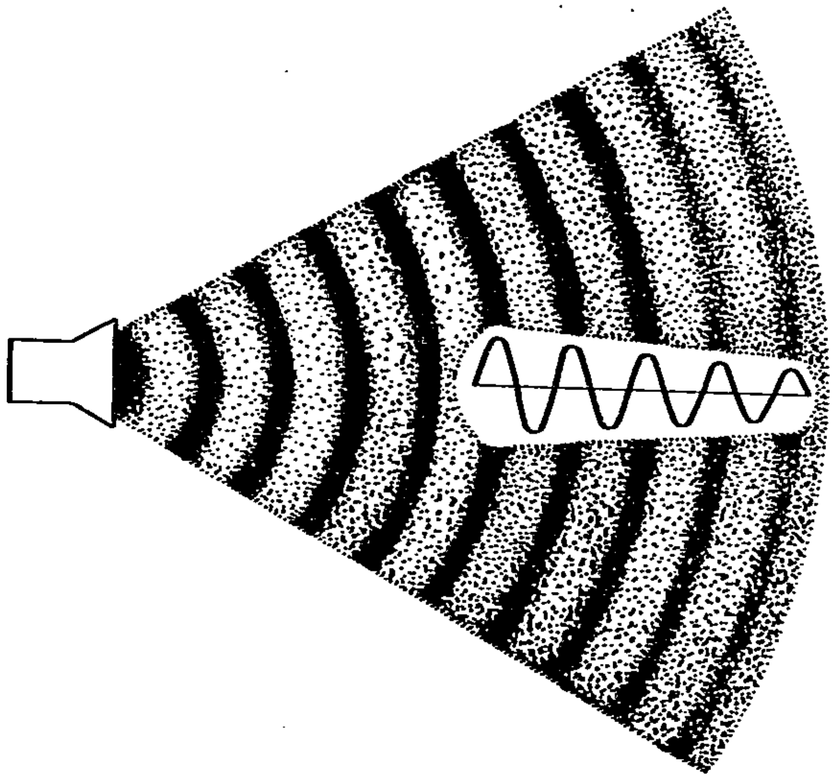


Figure 1.1. Propagation of a Sound Wave From a Small Source. The waves spread and decrease in amplitude as the distance from the source increases.

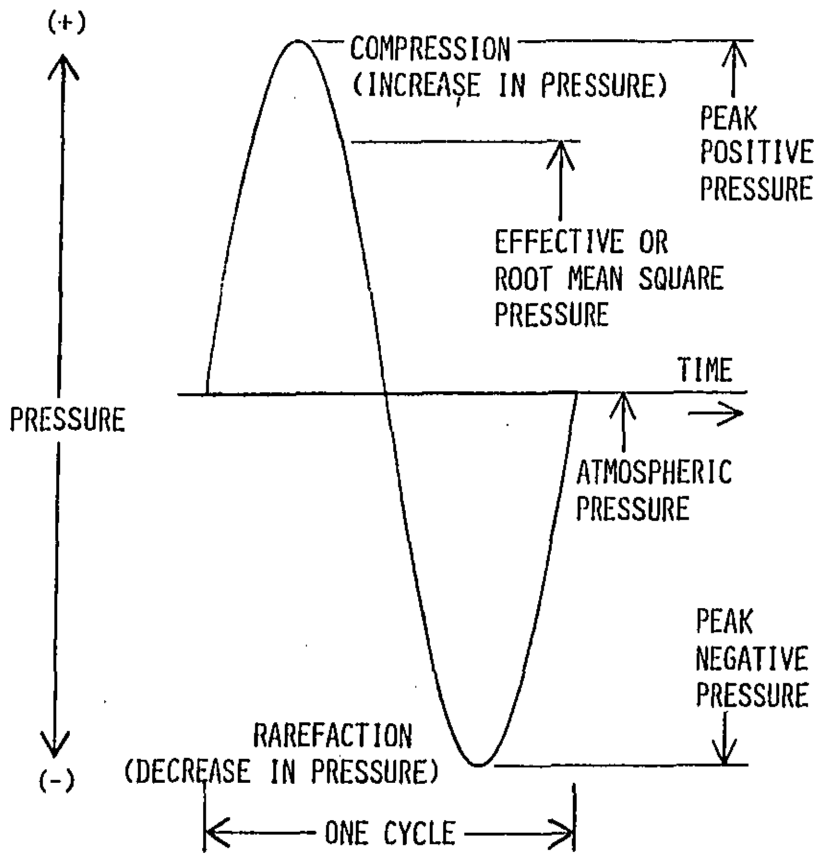


FIG. 1.2 A CYCLF OF A SOUND WAVE SHOWING PRESSURE VARIATION WITH TIME

use. Thus, if a sound source vibrates 500 times per second, it produces a sound with a frequency of 500 cps or 500 Hz. The term kilohertz (kHz) is also frequently used and means 1000 cycles per second or 1000 Hz. Thus, a 4000 Hz tone may be expressed as 4 kHz.

Frequency is related to the subjective sensation of pitch. The term pitch indicates that the human ear is involved in the evaluation of the sound. The lower the frequency of a sound, the lower we perceive its pitch. Therefore, a sound with a frequency of 250 Hz will sound much lower in pitch than a sound with a frequency of 2000 Hz.

Sound can consist of a single frequency (called a pure tone) or a combination of many frequencies (called a complex tone). Very few sound sources produce pure tones, although a tuning fork almost produces one. Most sounds in our environment are complex sounds--that is, they are actually a combination of many separate pure tones which exist simultaneously and vary in level. A distribution of the amount of sound at each frequency is called the spectrum of a sound.

Because the frequency range is so broad, it is frequently divided into numerous bands. Division into octave bands, for example, is convenient when measuring sound and will be discussed in Chapter 11. An octave band is a frequency bandwidth that has an upper band-edge frequency equal to twice its lower band-edge frequency. The most frequently used octave bands in sound measurement are geometrically centered at 31.5, 63, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. For example, all frequencies between 707 Hz (f_1) and 1414 Hz (f_2) comprise one octave band centered at 1000 Hz (fc), which is calculated geometrically by taking the square root of the product of 707 and 1414 Hz, i.e., $f_c = \sqrt{f_1 f_2}$. The next octave band includes all frequencies from 1414 Hz through 2828 Hz and is centered at 2000 Hz. It should be noted that as the octave band increases in center frequency, the width of the band increases also. For example, the 1000 Hz octave band has a width of 707 Hz, while the 2000 Hz octave band has a width of 1414 Hz.

The human ear operates within certain frequency limitations. A healthy young person can hear normal sound levels over a range of frequencies from about 20 to 20,000 Hz. However, sounds of the same amplitude but with different frequencies are not all perceived with equal loudness. The ear is most sensitive to sounds between 1000 and 4000 Hz. Generally, the ear's sensitivity falls off as frequencies increase above 4000 Hz and as they decrease below 1000 Hz.

Sounds outside the audible frequency range are sometimes termed ultrasonic or infrasonic. Ultrasonic sounds have frequencies above the normal upper limits of the audible frequency range--they are too high to be heard by most human ears. Examples of ultrasonic sounds are those which are produced by a dog whistle, ultrasonic cleaners, or welding devices. Infrasonic sounds, on the other hand, are those whose frequencies are below the normal lower limits of the audible frequency range--they are too low to be heard by most human ears. Infrasonic sounds are normally created by very large sound sources such as ventilating systems or wind tunnels.

Although ultrasonic and infrasonic sounds are not audible to many people, they can be heard or "felt" by a significant number of sensitive persons, and the stress of these exposures may be harmful to some (2). Maximum exposure limits have been proposed by an ANSI Writing Group (2).

1.3.2 Amplitude

The preceding section has shown that the frequency of a sound wave is dependent on the rate at which the sound source vibrates. The faster its rate of vibration, the higher the frequency of the sound generated. The amplitude of sound, however, depends on the amount of displacement of the vibrating source.

The subjective correlate of amplitude is loudness. Thus, the higher the amplitude or level of sound, the louder we perceive it, although there is not always a one-to-one relationship between the physical amplitude of sound and the sensation of loudness. Figure 1.3 illustrates simple sounds which have the same frequency but vary in level.

The ear is sensitive to a wide range of sound amplitudes and this creates many difficulties in working with absolute sound pressure units. For instance, the human ear is sensitive to a pressure range greater than 0.00002 to 20,000 newtons per square meter. This corresponds to a sound pressure range of about three-billionths to three pounds per square inch. The higher pressures usually occur only in explosions. Because of the awkwardness and difficulty of working with such a broad range of absolute units, the decibel has been adopted to compress this large range and more closely follow the response of the human ear. Figure 1.4 shows sound pressures (and corresponding sound levels in decibels) for a variety of common sounds.

Generally, sound pressures for simple impulsive-type sounds are described in terms of their peak values above or below atmospheric pressure. However, common sounds that are continuous for time periods greater than about one second are normally described in terms of the effective or root-mean-square (rms) values. The rms pressures are obtained by averaging the energy into several cycles of the sound. Sound level meter readings are based on rms pressures.

The Decibel: The decibel (abbreviated dB) is a convenient means for describing sound pressure level: the logarithmic level of sound pressure above an arbitrarily chosen reference, 0.00002 newtons per square meter (N/m^2). This reference pressure can also be expressed as 20 micropascals (μPa). In other words the decibel is based on a ratio comparing two sound pressures. One sound pressure is that which we wish to quantify and the other sound pressure is termed a reference. The reference represents approximately the minimum audible threshold of the normal ear. The decibel, then, is based on a ratio expressing how much greater a sound pressure is than the least sound pressure we can hear, and it is expressed as a level above the specified reference pressure.

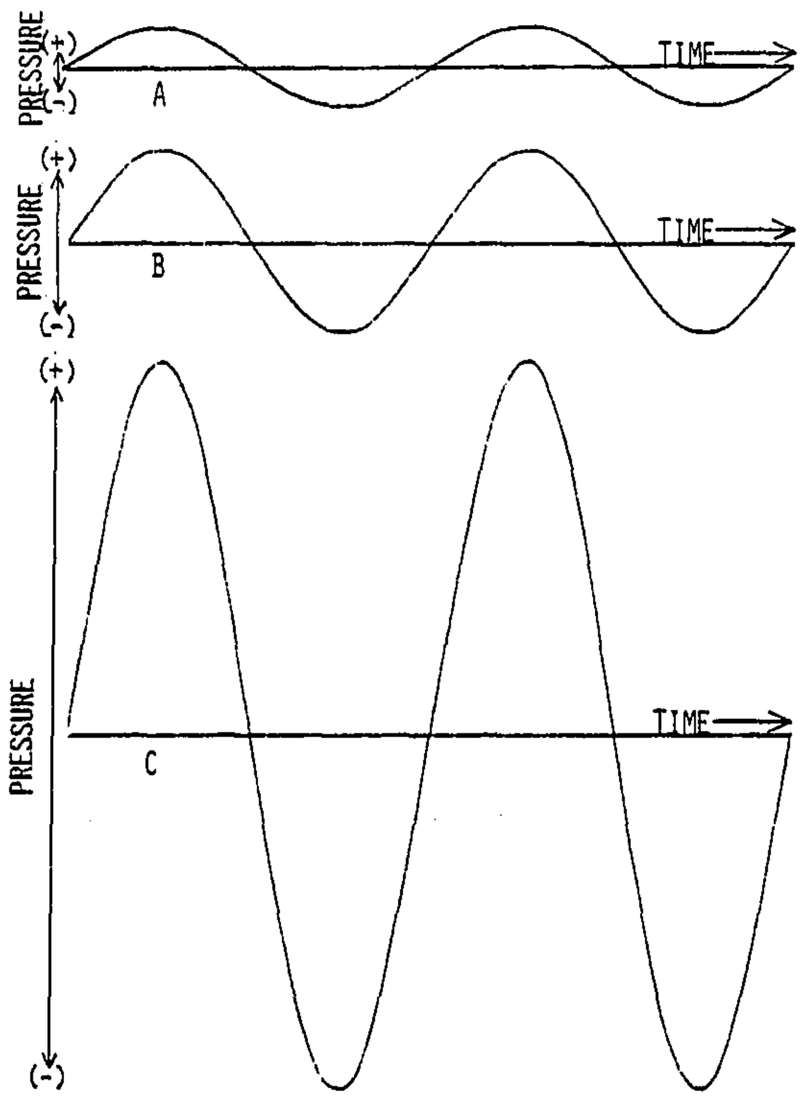


FIG. 1.3 SOUND WAVES WITH THE SAME FREQUENCY BUT DIFFERENT AMPLITUDES OF PRESSURE CHANGES WITH TIME

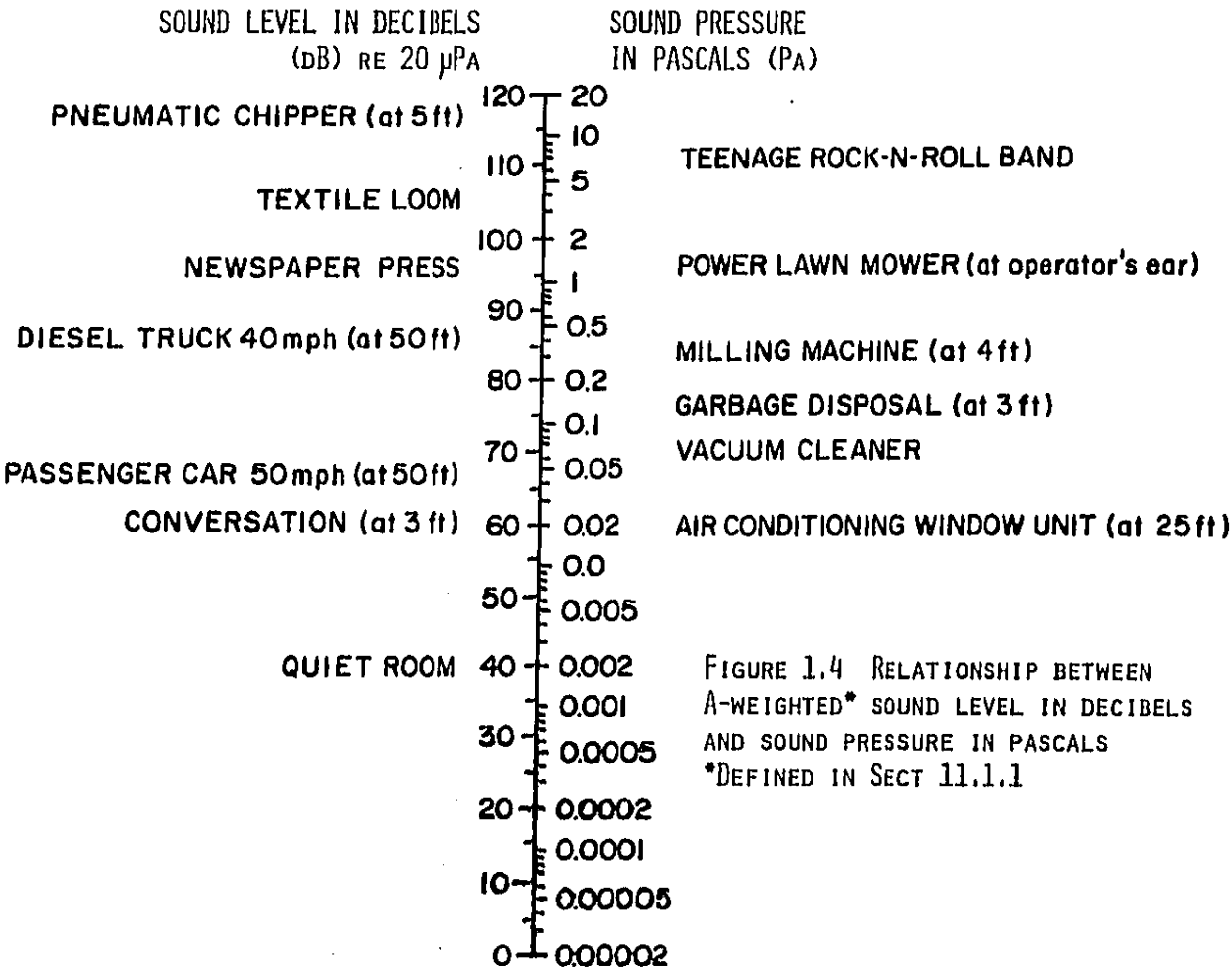


FIGURE 1.4 RELATIONSHIP BETWEEN A-WEIGHTED* SOUND LEVEL IN DECIBELS AND SOUND PRESSURE IN PASCALS
*DEFINED IN SECT 11.1.1

The formula for determining the sound pressure level is:

$$L_p = 20 \; \mathrm{Log}_{10} \frac{p_1}{p_0}$$

where p_1 is the sound pressure at the measurement location and p_0 is the reference pressure of 20 μPa. Figure 1.4 relates decibel values to sounds commonly heard in our environment.

As sound increases beyond normal exposure levels, it will first cause discomfort, then tickle, and finally, pain (in the region from 110 through 130 dB sound pressure level). Permanent and irreversible damage to hearing may result from extended exposures to sound levels well below those that cause tickle and pain sensations.

1.3.3 Time Distribution

The time distribution of sound may be classified broadly under three noise temporal patterns:

1) steady-state
2) time-varying / fluctuating
3) impulsive.

Both the steady-state and time-varying categories can be divided into continuous or intermittent patterns. That is, there can be continuous or intermittent steady-state noises as well as continuous or intermittent fluctuating noises. Details on the classification of these temporal patterns and measurement methodologies to be used for each of the patterns are provided in Section 10.3.

1.4 What is Noise?

Most of this chapter was devoted to defining sound and its attributes. But what about noise? What is it, and what are its attributes?

Noise is often defined as unwanted sound. Our perception of sound as noise is very individual and depends, to a large extent, on our emotional state and our activities during exposure to the sound. For example, music may be appreciated during moments of relaxation; however, for certain individuals it may be very distracting or annoying if they are concentrating on a particular task, listening carefully to a faint communication, or trying to sleep.

Many health effects of noise are being investigated. Studies have shown that the effects of sound on humans depend on the spectrum, amplitude, and temporal pattern of the noise. Further details on human response to sound exposures may be found in Chapter 5.

REFERENCES

1. Stevens, S.S. and Warshofsky, F., Sound and Hearing, Time-Life Books, Time Inc., N.Y., 1970.

2. Michael, P., Kerlin, R., Bienvenue, G. and Prout, J., "An Evaluation of Industrial Acoustic Radiation Above 10 kHz," Final Report on Contract No., HSM-99-72-125, U.S. Department of Health, Education, and Welfare, Public Health Service Center for Disease Control, National Institute for Occupational Safety and Health, Feb. 1974.

Chapter 2

AUDITION

> "It is hearing, with its offspring, speech, that gives man his superlative capacity to communicate: to pass along hard-won knowledge, to make use of that knowledge, and so to rule an entire planet" (1).

Audition is one of man's most complex and intriguing senses. Our ears have become essential to our survival. They alert us to danger; provide us the pleasure of music and sound; and, most importantly, allow us to communicate with each other through speech -- and speech is the basis of our society. The importance of hearing and speech to man's socialization is most dramatically seen in those who are hearing impaired. Unless help is provided, these people are often isolated from society, unable to function in a world that relies on speech, and incapable of expressing themselves fully in that world.

The normal healthy human ear is a remarkable and efficient sense organ. It is sensitive to very low sound pressures that produce a displacement of the eardrum no greater than the diameter of a hydrogen molecule, and yet it is capable of transducing sounds more than a million times louder than this. It also can detect a wide range of frequencies or pitches from very low to very high. The ear has always intrigued researchers, and although it has been studied for many years, it still holds many secrets.

What then is audition? What anatomical structures comprise the ear and how do they operate? And how can noise damage our hearing? These questions will be addressed in this chapter.

2.1 Anatomy of the Ear

The ear may be thought of as consisting of three sections: the outer ear, the middle ear, and the inner ear. These major divisions of the ear, as well as the various anatomical structures which comprise them, are shown in Figures 2.1 and 2.2.

2.1.1 The Outer Ear

The outer or external ear has two parts:

1) the pinna or auricle
2) the external auditory meatus or ear canal.

These structures are illustrated in Figure 2.3.

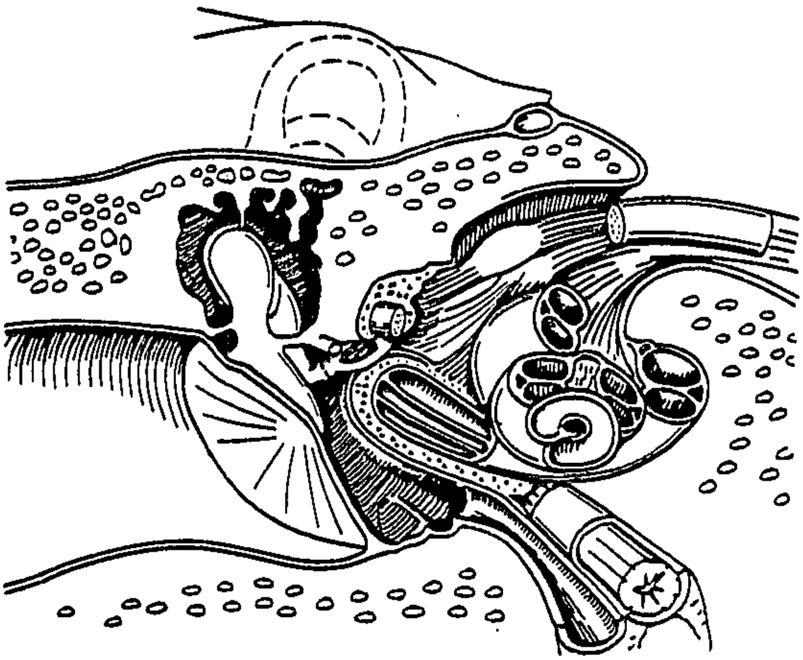


Figure 2.1 Anatomical cross-section of the human hearing mechanism.

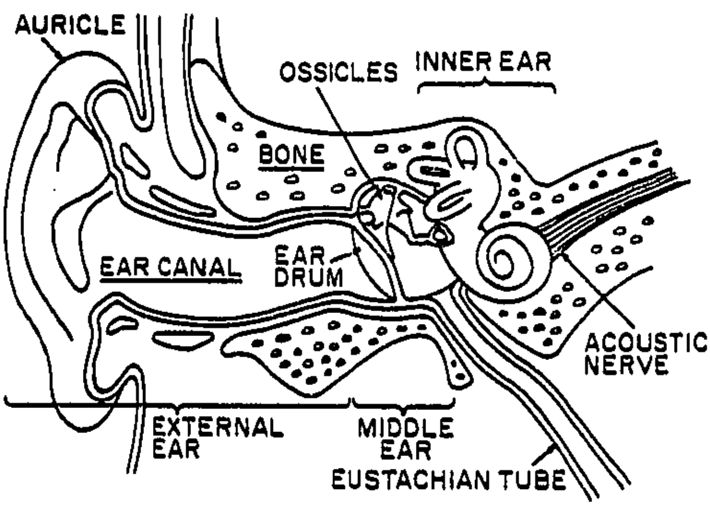


Figure 2.2 Schematic cross-section of the ear.

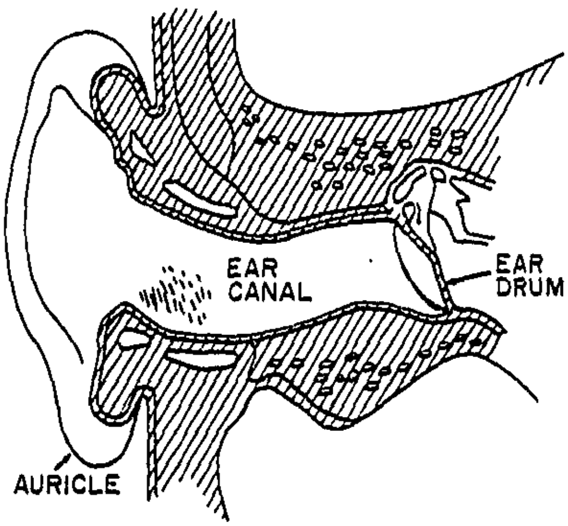


Figure 2.3 Schematic cross-section of the external ear.

Pinna or Auricle: The pinna, or auricle, is that structure which we commonly refer to as our "ear". It is a flap-like appendage fastened to the side of the head at an angle of 30 degrees (2). In relation to the contributions of other structures of the ear, the pinna plays only a minor role in the auditory process. However, it does serve as an aid in sound localization and also functions to channel very high frequency sounds into the ear canal.

The Ear Canal or External Auditory Meatus: The primary function of the ear canal, or external auditory meatus, is to conduct sound to the eardrum. The ear canal is a curved, irregularly shaped tube which is closed at one end by the eardrum. Although the size and shape of the ear canal differ significantly between individuals and even between ears of the same individual, the ear canal has certain acoustic properties which aid the auditory process. The average length of the ear canal is about 25 to 33 mm (1 to 1-1/3 inch). A tube of this length, when closed at one end by the eardrum, will produce a resonance at a frequency of about 3,000 to 4,000 hertz. This resonance acts to increase the response of the ear by about a factor of 3 (10 dB). In other words, the ear canal is structured in such a way that frequencies around 3,000 hertz will be made to sound around 10 dB louder by the time they have passed through the canal and have arrived at the eardrum. This acoustic phenomenon becomes important when one considers that these frequencies fall within the range of frequencies which comprise human speech.

The ear canal also serves a protective function. It contains both hairs and wax-secreting glands which prevent the intrusion of foreign bodies into the canal. Normally, ear wax flows toward the entrance of the ear canal, carrying with it the dust and dirt that accumulates in the canal. The normal flow of wax may be interrupted by changes in the body chemistry that can cause the wax to become hard and to build up within the ear. Too much cleaning or the prolonged use of ear plugs may caused increased production of wax, and when the wax builds up to the point where the canal is blocked, a loss of hearing will result. Any build-up of wax deep within the ear canal should be removed very carefully by a well-trained person to prevent damage to the eardrum and middle ear structures.

The surface of the external ear canal is extremely delicate and easily irritated. Cleaning or scratching with matchsticks, nails, hairpins, etc., can break the skin and cause a very painful and persistent infection. Infections can cause swelling of the canal walls, and occasionally, a loss of hearing when the canal swells shut. An infected ear should be given prompt attention by a physician.

2.1.2 The Middle Ear

The middle ear is an air-filled cavity that lies between the outer ear and the inner ear (Figure 2.4). While the outer ear functions primarily to direct sound into the canal, the middle ear acts as a transducer that changes this sound energy, which is in the form of air pressure variations, into mechanical energy. This transduction is accomplished through several structures -- the eardrum and three small bones within the middle ear (2).

The Eardrum or Tympanic Membrane: The eardrum separates the ear canal from the tympanic or middle ear cavity. The eardrum is a very thin and delicate membrane that is capable of responding to a wide variation of sound pressure levels. These changes in sound pressure level actually displace or move the eardrum very slightly. Although the eardrum is seldom damaged from displacements caused by common high-level noises, it may be damaged by a large displacement resulting from the force of an explosion or rapid change in air pressure. Thus, the often repeated statement -- "the noise was so loud it almost burst my eardrum" -- is rarely true as a result of exposure to common steady-state noise.

When an eardrum is ruptured, however, the attached middle ear bones may be dislocated; therefore, the eardrum should be carefully examined immediately after the injury occurs to determine if it is necessary to realign the middle ear bones. In a high percentage of cases, surgical procedures are successful in realigning dislocated ossicles, so that little or no significant loss in hearing acuity results from this injury.

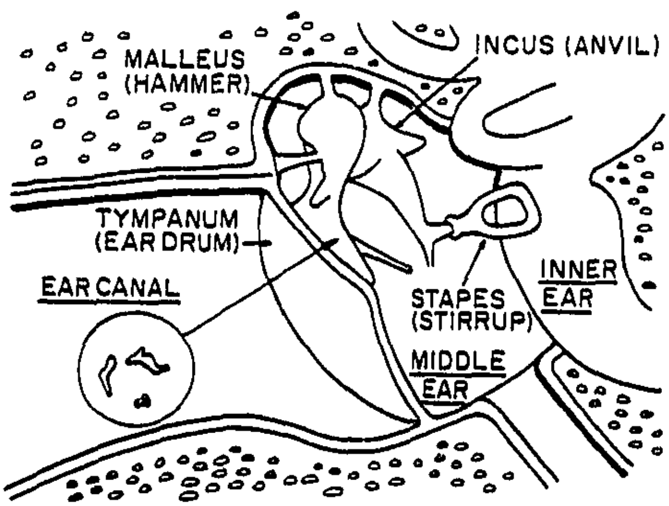


Figure 2.4 Schematic cross-section of the middle ear. Inset shows actual size of Ossicles.

The Middle Ear Bones or Ossicles: As shown in Figure 2.4, the middle ear contains three small bones -- the malleus (hammer), the incus (anvil), and the stapes (stirrup). These three bones, the smallest in the human body, serve a dual function:

1) they efficiently deliver sound vibrations to the inner ear, and

2) they protect the inner ear from receiving vibrations which could damage it (2).

The ossicles are suspended in the air-filled middle ear cavity connected to each other and to the walls of the middle ear cavity by ligaments and muscles. The largest and outermost ossicle, the malleus, is attached to the eardrum, while part of the stapes (the innermost ossicle) rests in a small hole in the bone which separates the air-filled middle ear from the delicate fluid-filled membranes of the inner ear. This small hole, called the oval window, exposes a portion of one of the fluid-filled inner ear membranes to the stapes. Thus, the ossicles form a mechanical link connecting the eardrum to the oval window of the inner ear. An inward displacement of the eardrum, then, will result in a similar displacement of the ossicles. Therefore, the stapes will move further into the oval window pushing in on the exposed inner ear membrane and ultimately displacing the fluid within it.

The middle ear mechanism (the ossicles and eardrum) is a mechanical impedance matching device -- that is, it allows pressure variations in air to be transmitted into pressure variations in fluid with very little loss of energy occurring between the two media.

The efficiency of this transmission system is due to the relative size difference between the eardrum and the oval window (the eardrum has an area about 20 times that of the oval window), and to the lever action of the ossicles (the movement of the malleus is greater than that of the stapes). Because of these conditions, the force per unit area becomes greater at the stapes than at the eardrum. An analogous situation occurs when hammering a nail into wood. Because the area of the point of the nail is much smaller than the area of the head of the hammer, the energy imparted into the nail from the hammer is concentrated into a smaller area, and thus the energy per unit area is increased, and the nail is easily driven into the wood.

This complex auditory system also acts in a protective capacity by mismatching impedances through the involuntary relaxation of coupling efficiency between the ossicles. In other words, the muscles of the middle ear can contract and exert tension on the ossicular chain which will decrease the efficiency of the transmission of energy to the inner ear -- thus protecting it from damage. It must be noted, however, that the amount of protection afforded is quite small and is not comparable to that provided by a carefully fitted hearing protective device.

The most common problem encountered in the middle ear is infection. This dark, damp, air-filled space is completely enclosed except for the small Eustachian tube that connects this space to the back of the throat; thus, it is very susceptible to infection, particularly in children. If the Eustachian tube is closed as a result of an infection or an allergy (see Figure 2.2) there is no way to equalize the pressure inside the middle ear with that of the surrounding atmosphere. In such an event, a significant change in atmospheric pressure, such as that encountered in an airplane or when driving in mountainous territory, may produce a loss of hearing sensitivity and extreme discomfort as a result of the displacement of the eardrum toward the low pressure side. Even in a healthy ear there may be a temporary loss of hearing sensitivity as the result of the Eustachian tube becoming blocked, but this loss of hearing can be restored simply by swallowing or chewing gum to momentarily open the Eustachian tube.

Another middle-ear problem may result from an abnormal bone growth (otosclerosis) around the middle ear bones, which restricts their normal movement. The cause of otosclerosis is not totally understood, but heredity is considered to be an important factor. The type of hearing loss that results from otosclerosis is generally observed first at low frequencies. As time passes, it extends to high frequencies, and eventually, may result in a severe overall loss in hearing sensitivity. Hearing aids may often restore hearing sensitivity lost as a result of otosclerosis, but effective surgical procedures have been refined to such a point that hearing aids are rarely necessary in these cases.

2.1.3 The Inner Ear

The inner ear is completely surrounded by bone that protects its delicate components. As shown in Figure 2.5, it contains both organs for hearing (the cochlea) and for balance (the semicircular canals). One end of the space inside the bony shell of the inner ear is shaped like a snail shell and contains the cochlea -- or end organ of hearing. The fluid-filled cochlea, which is only partially exposed through the oval window, serves to detect and analyze incoming sound signals and to translate them into nerve impulses that are transmitted to the brain. The other end of the inner ear is shaped like three semicircular loops. These bony loops house the membranous semicircular canals which contain the sensors for balance and orientation.

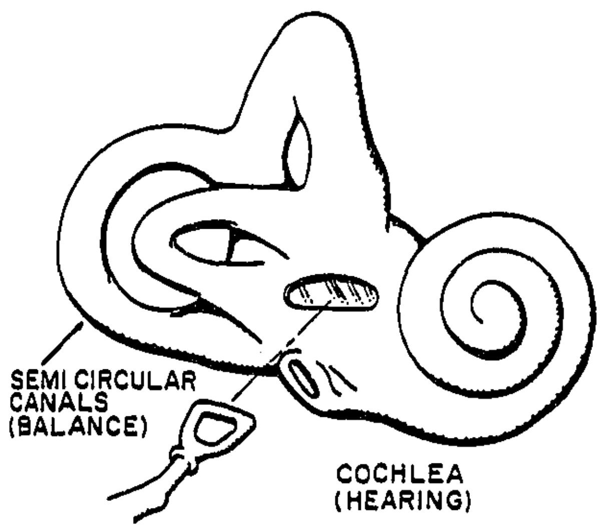


Figure 2.5 Schematic drawing of the inner ear.

In operation, sound energy is transmitted into the inner ear by the stapes, whose base, you will recall, is coupled to the oval window of the inner ear. Both the oval window, and the round window located below it are covered with a thin, elastic membrane which retains the few drops of fluid within the cochlea. As the stapes forces the oval window in and out with the dynamic characteristics of the incident sound, the round window membrane and the fluid of the cochlea are moved with these same characteristic motions. About thirty thousand hair cells located in the one-inch long cochlea detect and analyze these fluid motions and translate them into nerve impluses, which are transmitted to the brain for further analysis and interpretation.

The hair cells within the cochlea may be damaged by old age, disease, certain types of drugs, and exposure to high levels of noise. Unfortunately, the characteristics of the hearing losses resulting from these various causes are often very similar, and it is impossible to determine the etiology or cause in a particular case.

2.2 The Physiology of Hearing

The preceding section of this chapter discussed the structures and functions of each of the three parts of the ear separately. This section will endeavor to provide an overall view of the functioning of the auditory system.

The function of the auditory system is to change sound pressure variations in the air into neural impulses which are relayed to the brain where they are recognized as sound. This process requires a series of three energy transductions (changes of types of energy):

1) air pressure vibrations are converted into mechanical vibrations,
2) mechanical vibrations are converted into pressure variations in fluid, and
3) pressure variations in fluid are converted into neural impulses.

Each structure of the ear contributes to these transduction processes. Sound incident upon the ear travels through the ear canal to the eardrum. The combined alternating sound pressures that are incident upon the eardrum cause the eardrum to vibrate with the same relative characteristics as the sound source(s). The mechanical vibration of the eardrum is then coupled through the three bones of the middle ear to the oval window in the inner ear. The vibration of the stapes in the oval window is transmitted to the fluid contained in the inner ear. (Very high level sounds may also cause the fluid to be set into motion directly from vibration of the skull.) This fluid movement is detected by thousands of hair cells which act as transducers, changing physical energy into neural impulses which are, in turn, transmitted through the eighth cranial nerve to the brain for further analysis. It is only when the neural impulses have reached the brain that we "hear". Thus, audition is an intricate process requiring many structures -- all necessary contributors to our ability to hear.

The auditory system is somewhat analogous to a man-made communications system -- the radio. In much the same way the radio announcer's voice is transduced several times (from acoustical to electrical to radio to electrical and back to acoustical energy) before it is finally received by a listener, sound in the environment must also be transduced several times in the auditory system before it can be received by the brain.

To continue this analogy, if any part of the radio system is damaged, such as the microphone or antenna, the message cannot be clearly understood by the receiver, or, in some cases, may not be received at all. The same thing occurs in the auditory system. If damage occurs to any of the auditory structures they cannot efficiently transduce or transfer sound energy and a hearing loss will result. The final section of this chapter will discuss hearing loss caused by noise.

2.3 Noise-Induced Hearing Loss

The number of people who have noise-induced hearing impairment cannot be accurately assessed because of several factors, three of which are:

1) Hearing test results (the audiogram) are not available for a significant percentage of our population. Also, conventional hearing tests are not sensitive to small changes in hearing.
2) The audiogram can be used to determine total hearing impairment but it does not provide adequate information to differentiate among the causes of hearing loss. That is, the high frequency loss caused by an overexposure to noise is not significantly different from the losses caused by old age, ototoxic drugs, and childhood diseases.
3) The many different definitions for hearing loss that have been used by different investigators significantly affect the estimates proposed for the number of people with losses or the number of people who are exposed to noise that may be hazardous.

One of the most widely accepted estimates of the number of people exposed to noise that may be hazardous is 40 million, while approximately 80 million persons are in some way affected by noise (3).

2.3.1 How Noise Damages Hearing

Noise-induced hearing loss may be temporary or permanent depending upon the level and frequency characteristics of the noise, the duration of exposures, and the susceptibility of the individual.[1] Usually, temporary losses of hearing sensitivity will diminish so that the original sensitivities are restored within about sixteen hours (4-6). Permanent losses are irreversible and cannot be corrected by conventional surgical or therapeutic procedures.

Noise-induced damage with the inner ear generally occurs in hair cells located within the cochlea. Hearing acuity is generally first affected in the frequency range from 2000 to 6000 Hz with most affected persons showing a loss, or "dip:, at 4000 Hz. If high-level exposures are continued, the loss of hearing will further increase around 4000 Hz and spread to lower frequencies.

---

[1]The reader is referred to the Bibliography for sources dealing more fully with hearing loss.

2.3.2 The Problem at Work

Available research data indicate that workers in many industrial areas have sufficient noise exposures to cause significant hearing impairments (4-6). The best estimates of the number of persons who have significant hearing impairment as a result of overexposure to noise are based on a comparison of the number of those with hearing impairments found in high-noise work areas and the general population who have relatively low noise exposures (7). These studies show that significant hearing impairments for industrial populations are 10% to 30% greater for all ages than for general populations that have relatively low-level noise exposures. For example, at age 55, 22% of a group that has had low noise exposures may show significant hearing impairment, while in an industrial high-noise exposure group, the percentage is 46. Significant hearing loss is defined in many state compensation laws to be greater than 25 dB hearing level (referenced to the American National Standards Institute, ANSI S3.6 - 1969 Specifications) averaged at 500 Hz, 1000 Hz and 2000 Hz. Several groups are suggesting that the hearing level at 3000 and even 4000 Hz be added for this averaging.

Noise-induced hearing loss is a particularly difficult and insidious problem because a person does not usually know that his hearing is being affected, and the damage usually develops over a long period of time so that the loss of hearing may not be apparent until a considerable amount of damage has resulted. Even after incurring a significant amount of damage, a person with noise-induced hearing loss will be able to hear common, low frequency (vowel) sounds very well, but he will miss the high frequencies (consonants) so important in speech. He will hear people talking at loudness levels that are nearly normal, but he may not be able to understand what they are saying. A noise-induced hearing loss becomes particularly noticeable when speech communication is attempted in noisy places, such as in a room where many people are talking, or where a radio is playing loudly, or in a car moving at a high speed with the windows open.

2.3.3 The Problem Away from Work

An additional concern is that many individuals are exposed to harmful noises while away from work. Many people are often exposed to potentially hazardous noises that might come from guns, power tools, lawn mowers, airplanes, subways, race cars, loud music, or even from riding at high speed in a car with windows open. Of particular concern is the problem of the interaction of home and workplace noise exposures. If a worker has received a significant but "safe" noise dose at work, his daily noise exposure may become hazardous if he adds to it several hours of power tool noise or loud music in the evening. The total daily noise dose, including both workplace and recreational noise exposures, must be considered when evaluating the hazard of noise exposures.

REFERENCES

1. Stevens, S. S. and Warshofsky, F., Sound and Hearing, Time-Life Books, Time Inc., N.Y., 1970.

2. Zemlin, Willard A., Speech and Hearing Science, Prentice-Hall Inc., Englewood Cliffs, N.J., 1968.

3. "Report to the President and Congress on Noise" U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460. EPA Document No. NRC 500.1 December 31, 1971 (GPO Stock No. 5500-0040) (NTIS No. PB-206-716).

4. Occupational Safety and Health Standards (Williams-Steiger Occupational Safety and Health Act of 1970), U.S. Department of Labor, Federal Register, May 29, 1971.

5. "Occupational Exposure to Noise," U.S. Department of Health, Education and Welfare, National Institute for Occupational Safety and Health, 1972.

6. "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," U.S. Environmental Protection Agency, March, 1974, EPA 550/9-74-004.

7. "Noise as a Public Health Hazard," American Speech and Hearing Association, Report No. 4, pp. 105-109, Feb. 1969.

Chapter 3

COMMUNITY NOISE PROGRAMS

Noise has become a major detractor from the quality of life in both large and small communities, and it has become apparent that without some form of community intervention, noise pollution levels will only increase. Fortunately, communities are becoming aware of the need to develop and implement effective noise control programs. This chapter outlines the major elements that should be considered in developing a comprehensive community noise program. Recommendations for implementation of an effective community noise control program are also presented.

3.1 Major Elements in the Development of A Community Noise Control Program

The major elements in the development of a comprehensive noise control program are:

1) problem definition
2) problem solution: goal setting
3) problem solution: action plan

Each of these elements will be discussed below.

3.1.1 Problem Definition

Before a community takes positive steps to reduce noise, an analysis of the noise environment of the community should be carried out. Information concerning the sound levels and sound sources present in the area should be obtained, and this information should be supplemented by an assessment of the residents' reactions to these sounds. Sound measurements identify the major sound sources in the area. Social surveys provide information about the subjective reactions of citizens to these sounds and their attitudes toward the sources. Complaint activity, although it underestimates the actual annoyance of the population, provides additional information about reactions to noise. (A more comprehensive treatment of social surveys appears in Chapter 7.)

3.1.2 Problem Solution: Goal Setting

The next step is to determine what constitutes a desirable noise environment, and how such an environment can be achieved. Program goals must be formulated, and various ways of achieving these goals need to be carefully considered. Usually it is best to state program goals in quantitative terms: that is, specific noise level standards should be set for the situations of concern. The Federal EPA Levels and Criteria documents (2,3) provide information concerning these levels.

Each community faces unique noise pollution problems, however, and should carefully consider the costs and benefits to the community before adopting noise level standards. The community must determine those aspects of the noise problem that are the most serious, and these should receive priority consideration. It must be determined in each instance if control measures should be directed at the noise source, path, or receptor. Generally, it is most effective to control the source of the noise, but this is not always possible. Consideration must also be given to the control technology available and its attendant costs and personnel requirements. At this point, the community needs to develop an action plan.

3.1.3 Problem Solution: Action Plan

Next it is necessary to determine the steps to take to insure that the goals specified in the preceding phase of development are achieved. The action plan chosen must be legal, cost effective, and enforceable. An effective program must be enforceable; otherwise it is only a "paper program." The action plan should also include provisions for program evaluation.

3.2 Recommendations for Implementation of an Effective Community Noise Program

The preceding sections have outlined the major elements in the development of a community noise program. At this point it is appropriate to offer some specific recommendations concerning the means by which such a program might be implemented.

1) A community should adopt a comprehensive noise ordinance with realistic and beneficial objective noise criteria.

As of 1977 more than 900 municipalities in the U.S. had some form of noise ordinance. This represents a 300% increase since 1970. The provisions of noise ordinances can be stated in either qualitative or quantitative terms. Qualitative nuisance-type ordinances which define unlawful noise in subjective terms (such as "unnecessary" and "excessive") have proved difficult to enforce. When, however, qualitative regulations are expressed in objective terms (for example, forbidding the use of gas engine lawn mowers between the hours of 10 PM and 8 AM), enforcement is straightforward. The present trend is to state most regulations in objective quantitative terms. Such ordinances, which usually specify maximum allowable sound levels as measured with the A-weighted scale of a standard sound level meter, are easier to enforce.

The Federal EPA, in conjunction with the National Institute of Municipal Law Officers, has developed a model community noise ordinance (5). This ordinance contains provisions for quantitative regulations for land use and zoning, motor vehicles and other sources of community noise. In addition, a nuisance type provision for noise disturbances is included. The ordinance is flexible enough to be modified to the needs of both large and small communities. An ordinance of this type should constitute an integral part of a community noise program.

2) An efficient enforcement program should be established.

Once realistic objective standards have been specified, the community must develop and fund practical enforcement procedures. Typically a large proportion of the program's funds must be committed to staff training and equipment purchase. Unless adequate funding for both reliable noise measuring equipment and trained personnel is provided, the regulations will be unenforceable, and the community will be left with only a "paper regulation." As might be expected, it is the smaller communities that experience the greatest difficulty in funding their noise control efforts. Larger cities usually are able to hire environmental protection or noise control officers while smaller cities often rely on police officers. When police officers are used they should be specially trained and should be allowed sufficient relief from other duties to enforce the ordinance effectively. The EPA can often provide training and technical assistance.

Florida has initiated a program in which it utilizes its State University System to aid local noise control programs. Five universities, located in different regions of the state, are under contract to the state for the purposes of providing technical and training services to the local programs (6). This includes services ranging from providing basic noise information to city officials and conducting preliminary noise surveys, to the training of enforcement personnel.

3) A good community noise program should include a public awareness campaign.

The citizens of the community should be educated as to the need for noise abatement and each citizen's role in reducing community noise pollution. Much of the success of the Memphis, Tennessee noise control program has been attributed to its large scale education campaign (7). The cooperation of civic groups, newspapers, advertising media, youth groups, and schools should be sought in reaching the public.

4) A preventative noise control program should be established to identify and prevent future noise problems before they occur.

It is almost always easier to design a quiet community than to reduce the sound level of one that is already noisy. The community should establish some form of formal review process in which careful attention is given to the noise impact of proposed buildings, subdivisions, transportation facilities, etc. The developer should be required to prepare an analysis of noise impact for the proposed sites. Noise should be an element in the community's comprehensive planning activities and in its land use and zoning regulations (see Ch. 9). The community should also consider the noise emission characteristics of the equipment and machinery it purchases. This is especially so for sources such as air compressors, trucks, tractors, power tools, truck-mounted solid waste compactors, compost choppers, pavement breakers, etc.

5) The community should establish a continuing evaluation and monitoring program to determine the effectiveness of its effort to control noise.

An attempt should be made to determine that the noise program is achieving its stated goals. If the goals are stated in quantitative terms, regular monitoring of the sound levels at selected sites will permit assessment of the progress made. Another measure of progress would be a significant reduction in the complaint rate. If an attitude survey was made prior to implementing the program, a follow-up survey would provide another measure of community satisfaction. It is almost inevitable that experience will dictate that changes be made in goals or in noise control procedures; the effects of such changes also should be evaluated.

6) The successful community noise program requires adequate funding, staffing, and community support.

A noise control program without an adequate budget is virtually useless. As of 1973, a full 90% of community noise ordinances of all types had no fiscal support (8). Attempts must be made to obtain local support and to locate sources of state and Federal funding.

The level of staffing that a program can maintain is directly proportional to its budget. Large cities such as New York and Chicago have large full-time professional staffs. New York has a staff of over 40, while Chicago has more than 20 full-time professionals. Smaller cities such as Inglewood, California and Boulder, Colorado also have at least one full-time trained professional.

Communities of the same approximate population often differ greatly in the extent and severity of their noise problems. It is thus very difficult to specify staff requirements by population. It is possible that in some cities with populations of about 50,000 one full-time professional could do an adequate job of program management and enforcement provided he/she had some form of part-time assistance. However, in other cities of similar size this would be totally inadequate. But, in communities of any size, the success of the program depends on good management. The noise control activities of the community should be centralized in a single office, preferably with noise control as its sole responsibility. When control is fragmented "few, if any, of the responsible agencies view noise control as principal -- or even an important mission" (9, p.210). The noise control office should be able to deal effectively with other municipal agencies, and serve as the focal point of community noise activity. It is this need for management and coordination as much as the need for enforcement that makes it desirable that any program, regardless of size, have at least one full-time staff member.

In establishing the community noise program, consideration should also be given to the formation of a Noise Control Advisory Council. Such a body could provide recommendations for the development of the program, stimulate public interest in noise abatement, and participate in program evaluation. In some communities Hearing Boards have been utilized to hear cases regarding ordinance violations or requests for variances. This approach avoids overburdening existing courts.

REFERENCES

1. "Promoting Environmental Quality Through Urban Planning and Control", Environmental Protection Agency, Environmental Studies Division, 1973.

2. "Information on Levels of Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," U.S. Environmental Protection Agency, March, 1974. EPA Document Number EPA-550/9-74-004.

3. "Public Health and Welfare Criteria for Noise," U.S. Environmental Protection Agency, July, 1973. EPA Document Number EPA-550/9-73-002.

4. Bragdon, C.R., "Environmental Noise Control Programs in the United States." Sound and Vibration December 1977 pp 12-16.

5. "Model Community Noise Control Ordinance," U.S. Environmental Protection Agency, Sept., 1975. EPA Document Number EPA-550/9-76-003.

6. "Local Noise Programs in Florida," State of Florida Department of Pollution Control, 1975.

7. "Chicago Urban Noise Study," Chicago Department of Environmental Control, 1970.

8. Bragdon, C.R., "Municipal Noise Ordinances," Sound and Vibration, December, 1973. See also annually updated reviews, same magazine.

9. Council on Environmental Quality, "Environmental Quality Third Annual Report," Washington, D.C.: U.S. Government Printing Office, 1972.

Chapter 4

HISTORY OF NOISE CONTROL REGULATIONS

> "The essential problem in a legislative approach to the control of noise is that of weighing the rights of the individual versus the needs of the community. Each individual in a society is expected to suffer a certain amount of annoyance or interference. The amount to be borne depends on the society's weighing of the harm to the individual against the utility to other segments of society -- in this case, the producers of noise. The type of legislation of a particular political jurisdiction determines the balance between these two considerations". (1)

This statement provides a perspective from which to view the complexities inherent in the formulation of rules and regulations for the control of noise. Further, an additional factor that complicates the problem of noise legislation and enforcement is the problem of conflicts between government units arising from disputes over jurisdictional boundaries. For instance, a particularly noisy area such as a major airport facility may fall under the jurisdiction of several agencies. Also, certain aspects of legislative control can be pre-empted by a superior authority. For example, the Federal government pre-empts jurisdiction for noise control of jet aircraft and interstate tractor-trailer vehicles. Consequently, there is a continuing need for clarification and delegation of authority and responsibilities between Federal, state, and local units of government.

4.1 Historical Perspective

Regulation for the control of noise is not a recent societal concern. Reportedly, there was an ordinance enacted some 2500 years ago in ancient Sybaris, Greece, banning metal works and the keeping of roosters within the city in order to protect against noise exposures.

The concern over the increasing intrusion of noise in the United States follows that expressed by many European countries in the post World War II era. Noise problems became evident in many European countries during the period of reconstruction and economic expansion following the war. The continuing construction and transportation-related noise have made substantial impact in the lives of many Europeans.

In the United States the urbanization of our society, the increased mobility of our life style, and the technological advances of our industrialized society have been among those factors that have brought large numbers of people into close contact with sources of noise. Many new noise sources such as commercial aviation (the SST), recreational vehicles (the snowmobile and motorcycle), mechanized tools (the gasoline-engine-powered chain saw and lawn mower), and convenience devices (appliances), have entered our daily lives. The noise produced by these elements has combined with that already existing to produce an increased sense of dissatisfaction with the noisy conditions that pervade both our working and leisure environments.

The increasing popular pressure for noise abatement has resulted in a variety of activities in the public and private sectors. The Federal government has taken steps to control noise, and, in particular, has assumed responsibility for noise regulation of activities-affecting interstate commerce.

4.2 Legislation

The most promising means for the abatement and prevention of environmental noise is through the enactment of effective legislation. Thus, suitable ordinances may be enacted to deal with the major sources of noise found in the areas of industrial, aircraft, surface transportation, and neighborhood noise. Effective legislation must include objective rules, regulations, and/or standards; whenever practicable, these should be based on quantitative measures of noise. Generally, the use of quantitative measures allows for easier enforcement of noise abatement measures where viable limits of permissible noise levels are established. Further, such specified limits may be used to assess the existing quality of an environment and can be adjusted in time to lower values in order to provide the basis for a continuing improvement in the environment. The Federal government has taken action to set standards for the emission of noise from major sources under the provisions of various legislative acts and through actions by different regulatory agencies.

The Noise Control Act of 1972 (2) was adopted as U.S. public law to control the emission of noise that is detrimental to the human environment. It is based on findings of the U.S. Congress which state that the "inadequately controlled noise presents a growing danger to the health and welfare of the Nation's population, particularly in urban areas." Also, the Act serves to provide a national uniformity in the control of major sources of noise in commerce while at the same time recognizing that the primary responsibility for control of noise rests with state and local governments. The Act embodies a policy that calls for the promotion of an environment for all Americans that is free from noise that jeopardizes health or welfare.

To date, the Noise Control Act of 1972 remains as one of the primary motivating forces behind the national collective movement for quieting the environment. The Act was the culmination of efforts begun when the Office of Noise Abatement and Control (ONAC) was established within the U.S. Environmental Protection Agency (EPA) by authority of the Noise Pollution and Abatement Act of 1970. This Act required that the ONAC conduct a full and complete study of noise and its effects on the public health and welfare and report the results, together with EPA's recommendation for legislation, to the President and Congress. The report (3) was published in 1972, having been prepared on the basis of material collected and published in 15 technical information documents (4-19) and from testimony obtained at eight different public hearings held by the ONAC (19-26).

4.2.1 Industrial Noise

The Federal government has made a substantial effort to regulate and control exposure of people to industrial noise. In May of 1969, under provisions of the longstanding Walsh-Healy Public Contracts Act of 1942, the U.S. Secretary of Labor issued regulations (27) requiring the administration of a continuing, effective hearing conservation program. Noise exposure limits were established in terms of permissible level and duration of exposure. This established the now widely known permissible L_A limit of 90 dB for an eight hour duration in the work place which is estimated to protect about 85% of the working population from adverse hearing impairment during a normal working lifetime. The Walsh-Healy criteria, however, were applicable only to working conditions of employees of contractors supplying the Federal government with materials, supplies, articles, or equipment under contracts in excess of a total of $10,000.

The Williams-Steiger Occupational Safety and Health Act of 1970[1] (PL 91-596) (28) became effective April 28, 1971. On May 29, 1971 (29), under the provisions of this Act, the Secretary of Labor extended the Walsh-Healy standards of noise exposure to apply to all businesses affecting interstate commerce. This action provided a substantial increase in the number of employees protected from industrial noise exposure. Enforcement activity under this Act by the Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor has received considerable public attention. OSHA published a new set of proposed requirements and procedures for control of occupational noise exposure on October 24, 1974 (30). These standards have received wide-ranging comment and some criticism due, in part, to the fact that they would maintain the prevailing limits of exposure based on an L_A of 90 dB for eight hours. In general, most interested parties concur that limits lower than those proposed in new OSHA requirements are a desirable goal, but there are differences of opinion about the costs and practicality of lower limits, and about the noise control procedures to be used.

It should be pointed out that enabling legislation such as the Occupational Safety and Health Act of 1970 or the Noise Control Act of

[1]Sometimes referred to as the OSHAct (of 1970).

1972 generally provides the authority for setting criteria, and that subsequent regulations or standards are promulgated by the appropriate administrative body (OSHA or ONAC) in compliance with the general provisions of the legislation. It is in this context that, frequently, our courts and judicial system come into play in order to provide an interpretation of the legislative intent as regards its proper (and legal) administration.

4.2.2 Aircraft/Airport Noise

Aviation noise abatement has received more attention at the Federal level than any other form of environmental noise mainly because the rapid development of the technology of flight, especially the introduction of the jet airliner, has led to a major increase in environmental noise. The Federal government exercises a pre-emptive responsibility in controlling this segment of interstate commerce. It was in 1968 when Public Law 90-411 (31) added Section 1431 titled "Control and Abatement of Aircraft Noise and Sonic Boom" to the Federal Aviation Act of 1958 and the Department of Transportation Act of 1966. Under the legislative authority of this Act, the Federal Aviation Administration (FAA) of the U.S. Department of Transportation promulgated Federal Aviation Regulations (FAR) Part 36 (32) to put a stop on the escalation of aircraft noise. These regulations set noise emission standards to be used in type certification procedures that are applied to new aircraft types or existing types on which "acoustical changes" are to be made. Unfortunately, these regulations were adopted too late to be effective for the majority of types of airplanes that will be in our commercial fleet until well after 1980. However, the EPA and FAA have since developed other regulations that require a program of retrofit and replacement of existing commercial airplanes in order that they also meet existing Federal (FAR Part 36) noise standards (33). The institution of this retrofit program, scheduled for completion on January 1, 1985, clarifies the overall aims of a high-priority program for abatement of aircraft noise and assures a better measure of program success.

The FAA is also initiating noise control regulations and guidelines in such areas as the control of operational (flight) activities, and airport planning for development and/or improvements of facilities. The highest standards for aviation safety are included in all of these noise abatement activities since the FAA has the authority and responsibility for both of these problem areas.

The EPA has a special role in the area of aircraft/airport noise under the Noise Control Act of 1970, whereby the agency is required to make proposals to the FAA with regard to any regulations that may be required to protect the public health and welfare. The FAA must then respond by either agreeing to the proposal or explaining its disagreement. Thus, the FAA may choose to either promulgate or disregard EPA-suggested regulations.

4.2.3 Surface Transportation Noise (Highway and Railroad)

In 1966 the U.S. Congress passed the Department of Transportation Act creating the U.S. Department of Transportation (DOT). Activity in the area of noise abatement by DOT was mandated under this act. Standards for the abatement of noise from highways and highway construction were first issued in April 1972 by the Federal Highway Administration (FHWA) of the DOT as Policy and Procedure Memorandum (PPM) 90-2 (34). Later standards and procedures rules were issued and became effective May 24, 1976 (35). These newer noise standards set forth provisions for highway-traffic noise studies, noise abatement procedures, steps for coordination with local officials, and desired noise levels for use in planning and design of highways. The Office of Noise Abatement and Control (ONAC) of the EPA has also taken steps to regulate sources of highway noise. On October 29, 1974, the EPA issued regulations (36) setting specific maximum in-use noise emission standards applicable to vehicles over 4536 kg (10,000 lb) operated by interstate motor carriers. Rules prescribing procedures for inspection, surveillance, and measurement to determine compliance with these standards have been promulgated by the Bureau of Motor Carrier Safety (BMCS) of the DOT (37); BMCS is responsible for enforcing these regulations. The EPA also has promulgated noise emission standards for new medium and heavy duty trucks (38). These new product standards, more stringent than in-use regulations, are the result of EPA's earlier identification of trucks as a major source of transportation noise (39). In the case of in-use noise emission standards, several states and localities have joined with the BMCS in enforcing these regulations; this is a pertinent example of the type of cooperation that should be encouraged between different governmental jurisdictions for quieting the environment.

In the area of railroad noise, the EPA has promulgated railroad noise emission standards establishing specific maximum in-use noise level standards applicable to trains operated by interstate rail carriers (40). These standards, which became effective on December 31, 1976, are for measurements made at 100 feet perpendicular to the center line of the track and they include more restrictive levels for locomotives manufactured after December 31, 1976. The DOT through the Federal Railroad Administration (FRA) is responsible for the enforcement of this regulation and has issued compliance regulations for enforcement of the emission standards (41). Under a provision of these regulations, any state or local jurisdiction may arrange to enforce the emission standards.

4.2.4 Neighborhood Noise

Neighborhood noise is a broad classification, including various types of noise sources and control measures. There are several Federal requirements and standards that are applicable in this area. The Public Buildings Service of the General Services Administration (GSA) has issued noise control requirements for construction equipment. These requirements apply to work at sites of Federal government structures under contract with the GSA (42). In addition to specifying equipment noise emission limits, these rules require contractors to comply with all applicable state and local rules and regulations relative to noise control.

Of more importance and long range impact, however, are the standards for noise abatement and control issued by the U.S. Department of Housing and Urban Development (HUD) in August 1971 (43). HUD has adopted a program policy for noise abatement and control that includes consideration of housing site selection (external noise exposure standards), structural characteristics of buildings (interior noise exposure standards), and noise ratings for appliances and equipment where the use of quieter products might be encouraged through departmental policy. In particular, HUD support is prohibited for new construction on sites that have unacceptable noise exposures. The adoption of these standards means that buildings to be financed with HUD's support will be constructed with noise-exposure abatement as a primary consideration for the future occupants.

EPA is also directly involved in the abatement of neighborhood noise through its actions to identify major sources of noise and promulgate noise emission standards for products distributed in commerce. Regulatory action to set noise emission standards for new products is an effective way of addressing the neighborhood noise problem. Controlling noise at the source is the most cost-effective method of reducing noise and, by requiring all manufacturers to meet comparable standards, pressure is applied so that available technology will be incorporated into new products. Since it is sometimes possible for the ultimate owner to remove emission control devices (for example, by removing the muffler from a lawn mower), enforcement of local ordinances still will be important.

4.3 State and Local Government

The traditional means for controlling noise has been civil actions under the common law guarantee of protection from a nuisance. Although such actions are sometimes successful, they are more often ineffective. Since remedies must be decided on the merits of each case by appropriate judicial action, the time and costs involved discourage taking such action. Other factors also reduce the effectiveness of nuisance actions. For example, a favorable noise abatement solution may be difficult to achieve if the noise-creating activity is justifiable because of its service or benefits to a certain segment of society. Furthermore the officials assigned (often local police) to administer and enforce an ordinance may receive little encouragement to do so from their superiors and the community at large. These factors point to the need for carefully drawn ordinances and adequate means for their enforcement.

There has been an increase in state and local noise control programs over the past several years. In some states and communities, however, budget crises have either restricted their growth or led to their termination. The number of state and local noise control programs has been estimated to have increased from 288 in 1973 to 665 in 1976 (44). In December 1974, a report was given (45) that listed 440 municipalities with noise regulations as compared to only 288 listed in the previous year (46). These 440 ordinances in 1974 represented provisions for noise control that were applicable to a combined population in excess of 62 million people. However, the provisions were different among ordinances in that the legal categories considered varied from either nuisance, zoning, vehicle, aircraft, or building noise singly to some combination of the five categories being covered by ordinance.

Some local ordinances may seek to control specific noises such as lawn mower or construction-site noise by limiting the hours of the noisy activity. Other laws may seek to provide comprehensive regulation for noise in the community. Zoning ordinance requirements may be based in part upon the goal of separating noise sources from certain segments of the community. Building codes may be used to protect the public from indoor noise in multi-family dwellings or from outdoor noise in housing that is to be located in noisy areas. Incorporation of noise regulations in existing codes requires that enforcement rest with the existing code enforcement agency. In contrast, a more comprehensive noise abatement program would do better to place regulation and enforcement with a special agency and suitably trained personnel.

In many cases, legislation for noise abatement at the state level made its appearance along with other legislation related to the environment. Most of this legislation was limited to the establishment of state environmental agencies or commissions, or to the delegation of authority in the area of the environment to existing agencies. Responsibility was given to set standards and guidelines concerning the control and abatement of pollution in various forms. Such laws fall commonly into three categories: general environmental laws which specifically include noise as an environmental problem, laws dealing only with noise, or environmental laws which make no mention of noise but which could be used by the states to combat their noise problems. Recently, states as a group have become more sophisticated in the writing of noise laws. States are beginning to specify noise limits in terms of decibels instead of the subjective and inexact terms previously used, such as "unnecessary" and "unreasonable." A growing number of states are also setting standards for noise from new vehicles and equipment and forbidding the sale of any such products that fail to conform to the standards. However, a coordinated and consistent pattern of program development among states has not yet evolved. Established programs which are characterized by a high level of activity and appropriate personnel, funding, instrumentation and enforcement activities are in the minority. As of 1974, the majority of states had either no program or minimal activities in noise control. A more recent report (47) given in December 1977 states that there are now in excess of 900 local, county and state noise control laws, and that this represents nearly a 300% increase in legislative activity since 1970.

At the regional level, there are several examples of noise abatement regulatory agencies. The most notable one is perhaps the Port Authority of New York and New Jersey, a bi-state agency created by the States of New York and New Jersey. This Authority has established noise standards for the operation of the airports within its jurisdiction; these include Kennedy, LaGuardia, Newark, and Teterboro Airports in the vicinity of New York City. The Authority is exempt from municipal and state laws with the exception of bi-state amendment of its charter. It has set up regulations governing take-offs from its airfields using an objective set of criteria for noise measured at certain points in the communities surrounding the airports. However, the only way the Port Authority can enforce these regulations is to threaten to withhold permission for planes to land. Unfortunately, there are frequent jurisdictional conflicts when it comes to this type of regional noise regulation and enforcement. This is understandable when one considers that many (several dozen) Federal and state agencies are involved with an airport facility. Other examples of regional efforts in noise abatement are the Minneapolis-St. Paul regional zoning for airports as well as a similar scheme for the Dallas-Fort Worth Regional Airport.

4.4 Progress Resulting from the Noise Control Act of 1972

In March 1977, EPA reported (48) on the progress it had made in accomplishing the mandated requirements of the Noise Control Act of 1972. The goal of this act is the promotion of an environment for all Americans free from noise that jeopardizes their health and welfare. A summary of progress made follows.

The Act requires EPA to coordinate all Federal noise research and control programs. EPA's leadership in this area has achieved substantial progress in producing a convergent trend in the noise-related activities of Federal agencies.

EPA has published two major noise documents. "Public Health and Welfare Criteria for Noise" (49), published in 1973, appraises knowledge related to the effects of noise on public health and welfare; this publication is often called the "criteria document." "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety" (50), published in 1974, identifies levels of environmental noise which adequately protect public health and welfare; this publication is often called the "levels document."

EPA has reported to Congress a study (51) of the adequacy of aircraft noise controls and standards. In the area of air transportation EPA functions in an advisory capacity to the Federal Aviation Administration (FAA). The FAA can accept or reject EPA recommendations relating to aircraft noise.

EPA has promulgated emission standards for railroad and motor carrier noise. Enforcement of the rules adopted by EPA for surface transportation is the responsibility of the Department of Transportation.

EPA has identified ten types of products as major sources of noise; they are:

- portable air compressors
- medium and heavy trucks
- wheel and crawler tractors (loaders and dozers)
- truck refrigerator units
- truck-mounted solid waste compactors
- motorcycles
- buses
- power lawn mowers
- pavement breakers
- rock drills

Other products under pre-identification study may be added to this list in the future. The EPA so far has published noise emission standards for two products on the list, namely, portable air compressors and medium and heavy trucks: products of these two types built after 1977 must not exceed EPA's noise emission standards. Proposed standards have been worked out for other products on the list.

EPA has engaged in substantial activity in the following areas: (a) noise research, (b) training of noise control personnel, (c) technical assistance to state and local governments, (d) development of noise measurement and monitoring methods, (e) preparation of state and local noise control legislation, and (f) dissemination of information to the public. These activities are summarized in the 1977 progress report (48).

4.5 Roles and Authority - Toward a National Strategy for Noise Control

In April of 1977, EPA published the 62 page document "Toward a National Strategy for Noise Control" (44). This document was developed "to continue the dialogue on the overall goals of the noise program, the role of government, the role of consumers, and the role of industry in noise control, along with the selection of specific abatement and enforcement activities for EPA." To reach the Noise Control Act's primary objective of a noise-free environment, EPA has formulated five specific operational goals for the future. These goals are:

A) To take all practical steps to eliminate hearing loss resulting from noise exposure;

B) To reduce environmental noise exposure to an L_{dn} value of no more than 75 dB immediately[2];

---

[2] L_{dn} is a measure of daily noise exposure, in which nighttime (between 10 PM and 7 AM) sound levels are weighted by the addition of 10 dB.

C) To reduce noise exposure levels to L_{dn} 65 dB or lower by vigorous regulatory and planning actions;
D) To strive for an eventual reduction of noise to an L_{dn} of 55 dB; and
E) To encourage and assist other Federal, state and local agencies in the adoption and implementation of long range noise control policies.

These goals are intended to be part of the basis for a national program.

In assessing the existing status for developing a more unified and coordinated approach to a national program, EPA has established the following. In the first years of activity since passage of the Noise Control Act, EPA of necessity has been mostly concerned and occupied with meeting certain specified deadlines for mandatory documents such as the airport/aircraft report, and the criteria and environmental noise level documents (49-51). Secondly, EPA has placed top priority on attacking the most serious noise sources first and therefore has developed source standards and regulations in the surface transportation and construction areas. Where lower priority has previously prevailed --in the areas of technical assistance, Federal program coordination, and labeling -- EPA now finds itself in a position to increase its activity and provide support for a broader approach to national noise control. It has identified three specific components that will greatly influence the shape of a national program according to the emphasis used. These are: (a) Federal noise emission regulations for new products, (b) state and local controls, and (c) Federal regulations requiring the labeling of products. Accordingly, EPA has designed a plan for its own program of activities with the intention of maximizing the effectiveness of its authority and influence. This strategy recognizes the essentiality of (a) state and local programs, (b) other Federal programs, and (c) informed consumer choice (through product labeling), for the national noise control effort. A major area of emphasis will be in the expansion of assistance to state and local agencies. This is considered essential to provide more immediate relief from noise, to provide control of non-Federally regulated sources of noise which are either a "nuisance" or otherwise a component of neighborhood noise, and to assist in the enforcement of EPA standards.

The EPA has only a portion of the authority necessary to carry out a national noise abatement and control effort. However, the Noise Control Act of 1972 has given the Agency the responsibility to serve as the coordinator of all Federal government noise abatement activities and, to give technical assistance to state and local agencies and to the general public. Unlike other Federal environmental legislation, the Act places no specific requirements upon state and local governments. Rather, full discretion is left to these governments whether to become involved in noise control, and to what degree. In addition, there are no provisions for grants to help fund local programs. The permitted delivery of technical assistance by the Federal government will require extensive utilization of the limited manpower resources which EPA has to offer. With the increase in the number of communities initiating noise programs, and the need to solve the practical problems of actual implementation and enforcement, EPA has designed a new approach to the delivery of noise control technical assistance to state and local governments.

The new approach is composed of two related programs: the Quiet Communities Program (QCP) and the ECHO (Each Community Helps Others) Program. The QCP plans to select a number of communities around the country and establish an intensive and close working relationship between these communities and EPA's regional offices in the development of a noise control program. These community programs may be of various types, either comprehensive, or in some particular functional area such as construction site noise, motor vehicle noise, boundary line standards, or railroad noise. Evaluations of these test projects will serve as guides for the future efforts of other communities. Under the ECHO program, EPA will assist communities that have well developed and successful noise programs to provide direct, person-to-person technical assistance to other communities with similar problems.

In Appendix A on tools for noise control programs, additional background information on rules and regulations will be found. However, the interested individual is referred to the EPA's national strategy document of April 1977 (44) and news of its subsequent further development for additional details.

REFERENCES

Many of the following documents can be purchased through the U.S. Government Printing Office (GPO), Washington, D.C. 20402, Phone 202/783-3238 or the National Technical Information Service (NTIS), U.S. Department of Commerce, 425 13th St., N.W., Room 620, Washington, D.C. 20004, Phone 202/296-4348. A GPO or NTIS document number will be included with the reference in such cases.

1. Bugliarello, G., Alexandre, A., Barnes, J. and Wakstein, C., The Impact of Noise Pollution, A Socio-Technological Introduction, Pergamon Press Inc., Maxwell House, Fairview Park, Elmsford, NY 10523, 1976.

2. Noise Control Act of 1972, Public Law 92-574, 92nd Congress, H.R. 11021, October 27, 1972, 86 Stat. 1234.

3. "Report to the President and Congress on Noise," U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460, EPA Document No. NRC 500.1, December 31, 1971. (GPO Stock No. 5500-0040) (NTIS No. PB-206-716).

4. "Noise from Construction Equipment and Operations, Building Equipment, and Home Appliances " NTID 300.1, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Technical Document, December 1971. (GPO Stock No. 5500-0044) (NTIS No. PB-206-717).

5. "Noise from Industrial Plants," NTID 300.2, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Technical Document, December 1971. (GPO Stock No. 5500-0042) (NTIS No. PB-206-718).

6. "Community Noise," NTID 300.3, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Technical Document, December 1971. (GPO Stock No. 5500-0041) (NTIS No. PB-207-124).

7. "Laws and Regulatory Schemes for Noise Abatement," NTID 300.4, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Technical Document, December 1971. (GPO Stock No. 5500-0046) (NTIS No. PB-206-719).

8. "Effects of Noise on Wildlife and Other Animals," NTID 300.4, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Technical Document, December 1971. (GPO Stock No. 5500-0055) (NTIS No. PB-206-720).

9. "An Assessment of Noise Concern in Other Nations," (2 Vols.) NTID 300.6, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Technical Document, December 1971. (GPO Stock No. 5500-0043) (NTIS No. PB-206-721, Vol.1 and PB-206-722 Vol.2).

10. "Effects of Noise on People," NTID 300.7, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Technical Document, December 1971. (GPO Stock No. 5500-0050) (NTIS No. PB-206-723).

11. "State and Municipal Non-Occupational Noise Programs," NTID 300.7, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Technical Document, December 1971. (Available at NTIS only, NTIS No. PB-208-659).

12. "Noise Programs of Professional/Industrial Organizations, Universities and Colleges," NTID 300.9, U.S. Environmental Protection Agency, Office of Noise Abatement and Control Technical Document, December 1971. (GPO Stock No. 5500-0053) (NTIS No. PB-207-125).

13. "Summary of Noise Programs in the Federal Government," NTID 300.10, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Technical Document, December 1971. (GPO Stock No. 5500-0061).

14. "The Social Impact of Noise," NTID 300.11, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Technical Document, December 1971. (GPO Stock No. 5500-0047) (NTIS No. PB-206-724).

15. "The Effect of Sonic Boom and Similar Impulsive Noise on Structures," NTID 300.12, U.S. Environmental Protections Agency, Office of Noise Abatement and Control, Technical Document, December 1971. (GPO Stock No. 5500-0048) (NTIS No. PB-206-725).

16. "Transportation Noise and Noise from Equipment Powered by Internal Combustion Engines," NTID 300.13, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Technical Document, December 1971. (GPO Stock No. 5500-0045) (NTIS No. PB-208-660).

17. "Economic Impact of Noise," NTID 300.14, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Technical Document, December 1971. (GPO Stock No. 5500-0049) (NTIS No. PB-206-726).

18. "Fundamentals of Noise: Measurement, Rating Schemes, and Standards," NTID 300.15, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Technical Document, December 1971. (GPO Stock No. 5500-0054) (NTIS No. PB-206-727).

19. "Public Hearings on Noise Abatement and Control," Vol. I - Construction Noise - Atlanta, Georgia, July 8-9, 1971. (GPO Stock No. 5500-0037) (NTIS No. PB-230-064).

20. "Public Hearings on Noise Abatement and Control," Vol. II - Manufacturing and Transportation Noise (Highway and Air) - Chicago, Illinois, July 28-29, 1971. (GPO Stock No. 5500-0085).

21. "Public Hearings on Noise Abatement and Control," Vol. III - Urban Planning, Architectural Design; and Noise in the Home - Dallas, Texas, August 18-19, 1971. (GPO Stock No. 5500-0062) (NTIS No. PB-230-065).

22. "Public Hearings on Noise Abatement and Control," Vol. IV - Standards and Measurements Methods, Legislation and Enforcement Problems - San Francisco, California, September 27-29, 1971. (GPO Stock No. 5500-0036).

23. "Public Hearings on Noise Abatement and Control," Vol. V - Agricultural and Recreational Use Noise - Denver, Colorado, September 30 - October 1, 1971. (Available only at EPA).

24. "Public Hearings on Noise Abatement and Control," Vol. VI - Transportation Noise (rail and other); Urban Noise Problems and Social Behavior - New York, NY, October 21-22, 1971. (GPO Stock No. 5500-0038).

25. "Public Hearings on Noise Abatement and Control," Vol. VII - Physiological and Psychological Effects - Boston, Mass. October 28-29, 1971. (GPO Stock No. 5500-0056).

26. "Public Hearings on Noise Abatement and Control," Vol VIII - Technology and Economics of Noise Control; National Programs and their Relation with State and Local - Washington, D.C. November 9-12, 1971. (GPO Stock No. 5500-0095).

27. Safety and Health Standards for Federal Supply Contracts (Walsh-Healy Public Contracts Act), U.S. Department of Labor, Federal Register 34, 7948-49 (May 20, 1969).

28. Occupational Safety and Health Act of 1970, Public Law 91-596, 91st Congress, S. 2193, December 29, 1970, 84 Stat. 1590.

29. Occupational Safety and Health Standards (Williams-Steiger Occupational Safety and Health Act of 1970), U.S. Department of Labor, Federal Register, 36, 10518 (May 29, 1971).

30. Occupational Noise Exposure, Proposed Requirements and Procedures (Williams-Steiger Occupational Safety and Health Act of 1970), U.S. Department of Labor, Federal Register, 37773-37778 (October 24, 1974).

31. An Act to Require Aircraft Noise Abatement Regulation, Public Law 90-411, 90th Congress, H.R. 3400, July 21, 1968.

32. "Federal Aviation Administration Noise Standards," Title 14, Code of Federal Regulations, Chapter I, Part 36.

33. "Federal Aviation Administration Regulations," Title 14, Code of Federal Regulations, Chapter I, Subchapter F, Part 91.

34. "Federal Highway Administration Noise Standards and Procedures," Policy and Procedure Memorandum 90-2, February 8, 1973.

35. "Federal Highway Administration Highway Noise Control Standards and Procedures," Title 23, Code of Federal Regulations, Chapter I, Subchapter J, Part 772.

36. "Environmental Protection Agency Final Noise Emission Standards for Motor Carriers Engaged in Interstate Commerce," Title 40, Code of Federal Regulations, Chapter I, Part 202. (Federal Register 39, 38208, October 29, 1974).

37. "Bureau of Motor Carrier Safety Regulations for Enforcement of Motor Carrier Noise Emission Standards, Title 49, Code of Federal Regulations, Chapter II, Part 325.

38. "Environmental Protection Agency Noise Emission Standards for New Medium and Heavy Duty Trucks," Title 40, Code of Federal Regulations, Chapter I, Part 205.

39. "Identification of Products as Major Sources of Noise," Environmental Protection Agency, Publication of Report, Federal Register 39, 22297, June 21, 1974.

40. "Environmental Protection Agency Railroad Noise Emission Standards," Title 40, Code of Federal Regulations, Chapter I, Part 201. (Federal Register 41, 2184, January 14, 1976).

41. "Federal Railroad Administration Railroad Noise Emission Compliance Regulations," Title 49, Code of Federal Regulations, Chapter II, Part 210, (Federal Register 42, 42343, August 23, 1977).

42. General Services Administration, Public Buildings Service, Construction Equipment and Practices, Noise Control, (Par. 44.8 in Guide Specification PBS 4-01100, October 1973).

43. "Noise Abatement and Control; Departmental Policy, Implementation Responsibilities and Standards," August 4, 1971, Department of Housing and Urban Development Circular 1390.2.

44. "Toward a National Strategy for Noise Control," U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460, April 1977.

45. Bragdon, C.R., "Municipal Noise Ordinances: 1974", Sound and Vibration 8, 28-30 December, 1974.

46. Bragdon, C.R., "City Noise Ordinances - A Status Report," Sound and Vibration 7, 34-35, December, 1973.

47. Bragdon, C.R., "Environmental Control Programs in the United States," Sound and Vibration 11, 12-16, December, 1977.

48. "EPA Noise Control Program Progress to Date," U.S. Environmental Protection Agency, Office of Noise Abatement and Control (AW 471), Washington, D.C. 20460, March 1977.

49. "Public Health and Welfare Criteria for Noise," U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460, EPA Document No. 550/9-73-002, July 27, 1973. (GPO Stock No. 5500-00103) NTIS No. PB-241 000/AS).

50. "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460, EPA Document No. 550/9-74-004, March 1974. (NTIS No. PB-239 429/AS).

51. "Report on Aircraft-Airport Noise," U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460, EPA Document No. Senate 93-8, August, 1973. (GPO Stock No. 5270-01936).

Chapter 5

EFFECTS OF NOISE ON BEHAVIOR AND WELL-BEING

The most obvious physiological effect of noise on humans is the temporary and permanent noise-induced hearing losses that may result from high level exposures. However, the effects of noise on man are not confined to the auditory system. The more subtle effects of noise on behavior and well-being have traditionally been given less attention than the auditory effects but the annoyance and irritability caused by exposures to noise are striking indicators that noise is a highly potent environmental stressor. The interaction of noise and other environmental stressors has complicated the studies of both physiological and psychological health problems so that they are not precisely defined.

This chapter begins with a discussion of annoyance reactions to noise. It then discusses noise in relation to our general physical and mental health and finally considers the effects of noise in several specific areas such as task performance, sleep and speech communication. Due to the significance and the extensive amount of information on the auditory effects of noise, a discussion of noise-induced hearing loss has been reserved for a subsequent chapter.

5.1 Annoyance and Community Response

Annoyance reactions are perhaps the most widespread response to noise. Annoyance might best be conceptualized as a social response to noise exposure. Noise has often been defined as unwanted sound, and it is this quality that is most often associated with annoyance. Annoyance has been studied from two general perspectives: annoyance reactions of the individual and annoyance reactions of the community.

5.1.1 Individual Reactions

Individual annoyance reactions have usually been investigated in the laboratory (1). Many of these studies involve artificial sounds with well specified properties. This aids the investigator in determining relationships between the individual's reaction and particular attributes of the sounds. Participants in these experiments are typically asked to rate a set of sounds along a certain dimension such as unpleasantness or to make comparisons between pairs of sounds on the given dimension.

It is generally accepted that annoyance increases with sound level, and that higher frequency sounds are more annoying. Also, those sounds that are intermittent or varying over time are rated as more annoying than those that are continuous or unchanging. In addition, annoyance appears to be related to the information content of the sound and the extent to which the sound interferes with some ongoing activity of the individual.

5.1.2 Community Reaction

Information concerning community annoyance is usually obtained through social surveys. Most social survey work has concentrated on population exposed to either aircraft or surface transportation related noises. In general, the research appears to suggest that there are a number of personal, social, and situational factors that appear to intervene between noise exposure and response. Taking into account the physical characteristics of the noise, it is possible to predict with some precision the percentage of individuals in a given community that will express annoyance with the noise. However, such information will not result in accurate predictions concerning the response of a given individual in that community. Inclusion of certain personal and social factors, such as those given below, have been shown to improve the accuracy of these predictors (2).

The following is a representative list of factors which at one time or another have been found to be related to annoyance. Generally, individuals are more readily annoyed:

1) when they are indoors as opposed to outdoors,
2) more often at night than during the day,
3) when they live in suburban areas as compared to urban areas. This is, in part, related to higher background noise levels in the city.
4) if they perceive the noise level or the source, itself, to be unnecessary,
5) if they perceive the noise to be a threat to their personal health and safety,
6) if they perceive the noise to be a threat to their economic investment (property value),
7) if they are dissatisfied with other aspects of the environment,
8) if they feel that the noise is beyond their control,
9) if they feel that they were treated unfairly or ignored by the authorities.

To some extent, the socioeconomic status of the community and its previous experience with noise are also related to annoyance, but here the effect is very complicated.

5.1.3 Complaint Activity

Complaint activity in the community is a poor measure of annoyance level in that research has shown that complaints represent only a small fraction of those annoyed (2% - 20%) (2). Also, people who complain do not differ from their neighbors in any significant way, nor are they particularly sensitive to noise (3). Figure 5.1 contains a summary of day-night noise levels and their respective annoyance and complaint rates. It is apparent from this figure that any noise level, no matter how low, will result in some annoyance, but that at any level complaint activity underestimates annoyance. Complaint activity should not stand alone as a measure of annoyance.

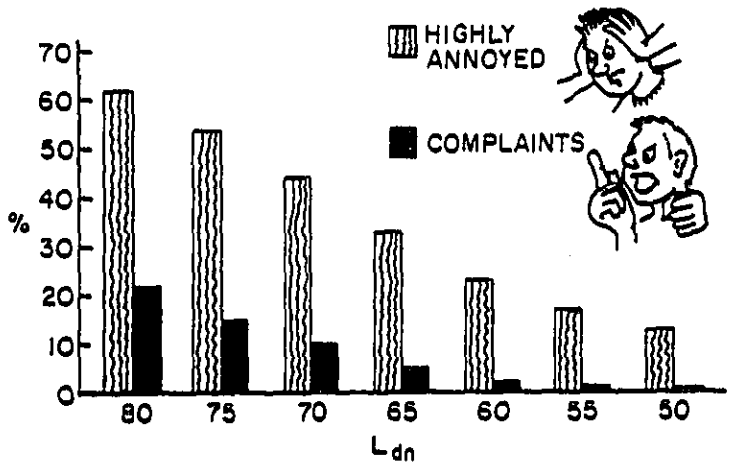


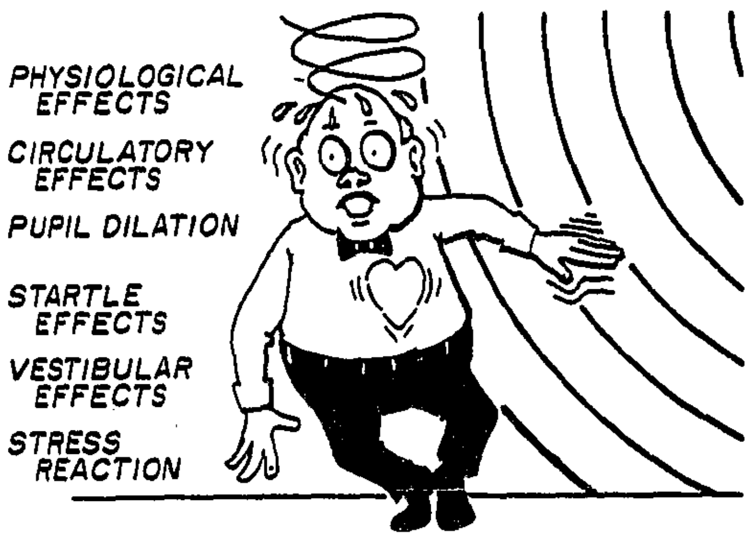
Figure 5.1. Percent of population responding to noise by annoyance and complaint activity as a function of L_{dn} (see Section 11.3.2).

5.1.4 Noise Ratings

Considerable interest has been directed at identifying the measure of noise that best correlates with annoyance. The A-frequency weighting on sound level meters has been, by far, the most widely used frequency weighting applied to community noise measurements. Both manual and automatic sampling procedures have been used with the A-frequency weighted measurement data. This simple A-weighted measure is normally used in such a way that sound magnitude, frequency distribution, and temporal characteristics are considered over a period of about 24 hours to describe community noise exposures. These A-weighted data may be presented as energy equivalents, L_{eq}, or average A-weighted sound levels that may have adjustments (penalties) for night time. They may also be presented as cumulative statistical values, L_x (see Chapter 11).

5.1.5 Implications of Annoyance and Community Response

Annoyance reactions are the most widespread type of reaction to noise, but these individual annoyance reactions are difficult to predict on the basis of noise exposure data per se. The addition of personal, social, and situational information improves the predictive power considerably. But it is generally necessary to go to large numbers of responses before annoyance levels (community annoyance levels) can be predicted with reasonable accuracy from noise data alone. Complaint level is almost always an under-estimation of annoyance in that only a small proportion of those annoyed actually complain. It is probably also safe to conclude that annoyance from noise can never be totally eliminated in any community setting. It should be kept in mind that noise which is loud enough to elicit irritability and annoyance responses is very likely to be a potential source of physiological effects that may be damaging to health.



5.2 Physiological Effects of Noise: Stress and Health

The purpose of this section is to present a summary of current knowledge on the non-auditory physiological and health effects of noise. A brief discussion of the general concept of systemic stress is also presented. The topics in this section include those that appear most relevant and those that have received the greatest amount of empirical attention. Noise-induced hearing loss is treated in Chapter 6.

5.2.1 The N-Response

The N-Response (4,5) is a group of physiological responses to sound. The response is characterized by:

1) a vasoconstriction of the peripheral blood vessels accompanied by minor changes in blood pressure and heart rate,
2) slow, deep breathing,
3) changes in electrodermal sensitivity (GSR-galvanic skin response),
4) a brief change in skeletal muscle tension.

These responses cannot be called fear, startle, or anxiety responses because some of them are associated with emotion arousing activities of the automatic nervous system, while others are associated with emotion suppressing activities (4). This pattern of responses begins to appear with noises below an L_A of 70 dB and the pattern appears to show adaptation in some cases with repeated stimulation (4).

5.2.2 Circulatory System Effects

Laboratory research provides some evidence that noise affects gross parameters of the circulatory system especially for noises above 100 dB. Measures used include blood pressure, pulse rate and heart rate (6). There is, however, some evidence that working in high noise environments does result in a greater incidence of circulatory problems than working in low noise environments (7). But, as is often the case with the field studies, it is extremely difficult to attribute these effects to noise per se and not to other stress-producing attributes of the work environment.

5.2.3 Pupillary Dilation

There is evidence, mostly from Europe, that noise affects eye pupil dilation. The magnitude of the effect appears to increase with the intensity of the stimulation, from an L_A of approximately 70 dB to at least approximately 110 dB (8). The significance of the response is not known at the present time, but there is an apparent neurological relationship between pupil dilation and the sense of balance (9).

5.2.4 Startle Effects

Startle is a primitive response that may be evoked by a wide variety of stimuli. The purpose of the response is to orient the organism to a potential source of danger. As would be expected, it is particularly susceptible to loud, unexpected noises. The physiological component of the response is essentially independent of the stimulus and includes increased pulse rate, increased blood pressure, and peripheral vasoconstriction. The behavioral component involves a complex pattern of body and facial responses as well as muscular movement. Although the N-response discussed above and the startle response share certain similarities, the patterns are different enough that physiologists consider them to be two different responses (4).

The startle response is normally present at low levels of sound energy, and does tend to show adaptation as a function of repeated stimulation in many, but not all, individuals (10). The significance of these effects is presently unclear.

5.2.5 Vestibular Effects

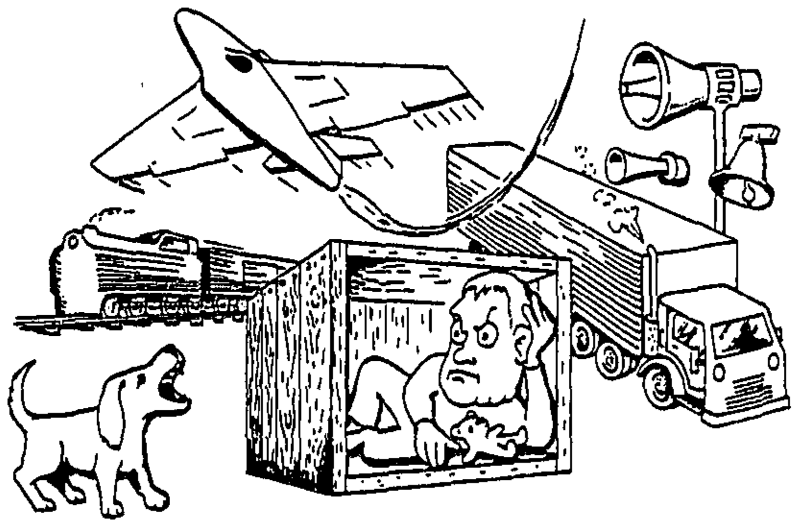
The vestibular organs of the inner ear (sacculus, utricle, and semicircular canals) are involved in maintaining body balance and orientation in space. The fact that organs important for both hearing and balance exist in such close proximity to each other suggests the possibility of an interrelationship between the two senses. Research has shown that noise can produce dizziness and nystagmus (rapid involuntary side-to-side eye movements). However, in order to obtain these effects, noise levels exceeding an L_A of 130 dB are usually required. Somewhat lower levels, of approximately 120 dB, appear to disturb balance, particularly if the stimulation is unequal at the two ears (11).

At present, there appears to be no evidence that long-term exposure to noise has any significant effect on the vestibular system (12). Further research, however, is warranted.

5.2.6 Stress Reactions

Attempts have been made to explain the effects of noise in terms of physiologic stress theory (13). The theory holds that a large variety of noxious agents are capable of producing a general stress reaction in the organism. Stress is largely non-specific in that different stressors do not each produce a specific set of responses. The organism's response to a stressor is called the General Adaptation Syndrome (GAS). The GAS has three stages: the alarm stage, in which the system prepares to fend off the stressor; the resistance stage, in which the body fights the stressor; and the exhaustion stage, which occurs if the body can no longer withstand the stressor. If the stressor is severe enough and present for a prolonged time, the stage of exhaustion is reached and the end result would be the death of the organism from its inability to defend itself against the stressor. In less severe instances, the price is paid in the resistance stage in terms of lowered resistance to infection and the development of the so-called diseases of adaptation - gastro-intestinal ulcers, elevated blood pressure, arthritis, etc.

It is fairly well established that noise of extremely high level can act as a stressor, and can, at least for some animals, lead to some of the reactions associated with the GAS (14). However, the implications for the human organism are, at present, very unclear. The theory is logically compelling, but the vast complexity and generality of theory make the determination of the effects of a single stressor such as noise a Herculean task. Consideration must be given to the interaction of various stressors, individual differences in susceptibility to stress, and the apparent adaptability of the human organism. Large scale epidemiological and psychophysiological research is needed.



5.3 Mental Health

Health as defined by the United Nations refers not only to the absence of disease, but physical, emotional and social well-being (15). Within the purview of this definition, all of the topics covered in this section have some direct or indirect relationship to health. Unfortunately, at the present time, most of these relationships remain undetermined. In fact, very little can be said definitively about the effects of noise on physical or mental health with the exception of its causing hearing loss.

A variety of subjective symptoms such as irritability, anxiety, nervousness, insomnia, loss of appetite, etc. have been associated with noise, but the subjective nature of these effects makes their verification difficult. Also, field research in noise is often impeded by the difficulty of separating those effects attributable to noise from the effects of other stress producing stimuli in the working and living environment.

The research reviewed in this section suggests that noise does affect a number of physiological systems of the individual but data are not available to determine if these effects are of a major consequence to health.

Noise has been accused of adversely affecting mental health. For example, recent data suggest a positive relationship between aircraft noise and mental hospital admissions (16). Unfortunately, the methodological criticism of the study was so intense that no valid conclusions concerning noise and mental health can be derived. There is a serious and immediate need for well controlled, large scale epidemiological research in this area.

5.4 Task Performance

Several comprehensive reviews of the effects of noise on task performance have been written (4,17,18). There seems to be general agreement among these reviewers that the research to date has failed to yield a consistent pattern of effects. Noise has been shown to improve task performance, to impair task performance, and, in some instances, to have no apparent effect. Overall, it is probably safe to conclude from these reviews that the effects of noise on short-term task performance are not severe in most cases, and that the detection of these decrements requires detailed performance assessment and the use of noise sensitive tasks.

In a literature review compiled by the EPA, the following conclusions pertaining to task performance were advanced (9).

-- Continuous noise without special meaning does not generally impair performance unless the sound exposure level L_A exceeds 90 dB. Even at this level the effects are not consistent.

-- Intermittent and impulsive noises are more disruptive than steady-state noises of the same level. Sometimes levels below 90 dB will produce effects, especially if the bursts come at irregular intervals.

-- High-frequency components of noise (above approximately 2000 Hz) usually produce more interference with performance than low frequency components of noise.

-- Noise usually does not affect the overall rate of work, but may increase the variability of the work rate.

-- Noise is more likely to increase error rates as opposed to rate of work.

-- Complex or demanding tasks are more subject to noise related impairments than simple tasks.

5.4.1 Characteristics of the Noise, Task, and Individual

The above conclusions suggest that the effects of noise on performance are related to the nature of the noise, the nature of the task, and the state of the individual.

Distracting or "attention demanding" noises, such as impulse or irregular intermittent noises or very intense noises, result in greater task interference.

Most performance decrements have been found on tasks that require 1) continuous performance, 2) prolonged vigilance, or 3) the performance of two tasks simultaneously. Tasks that require simple, repetitive operations are unaffected and sometimes enhanced by certain low level noises. Obviously, tasks that require the operator to attend to auditory cues for successful performance are almost always impaired in the presence of noise.

Noise sensitive tasks, such as those requiring continuous performance or prolonged vigilance, prevent the individual from pacing his performance and penalize the individual for momentary lapses of attention. On the other hand, simultaneous tasks bring about decrements because they overload the information processing capacity of the individual. The individual has a limited capacity information processing system and where noise is present less spare capacity exists for task information relative to quiet conditions (19-21). Consequently, noise-related impairments are often found in overloading or demanding task situations.

In the presence of an arousal-increasing stimulus such as noise, performance on simple or boring tasks might be improved because arousal level is increased toward an optimal level (22). Similarly, the presence of noise during the completion of a difficult or demanding task might result in a supra-optimal level of arousal and impaired performance. Tasks of moderate difficulty would remain unaffected by noise.

There appears to be a great amount of variation in the way in which different individuals respond to noise, and although this is a common observation, very little is known about the nature of these differences. There has, however, been an attempt to apply the theory of arousal to the problem of individual differences (23,24). The basic supposition of this approach is that individuals differ in their chronic levels of arousal. If one individual is chronically more aroused than another, no additional arousal afforded by the presence of noise would be more likely to lead to a condition of over-arousal for this individual than for a less chronically aroused individual. There is evidence linking the personality dimension of introversion-extroversion to autonomic indices of arousal and performance. It appears as if introverts are more chronically aroused than extroverts. Data are available which suggest that introverts perform better than extroverts in boring and monotonous task situations, and that introverts appear to be more adversely affected by noise than extroverts. These findings must only be considered as tentative, but this does appear to be a promising avenue for future research.

5.4.2 Cumulative and Post-Noise Effects

Research has been conducted which indicates that the adverse effects of noise tend to appear toward the end of task performance sessions (25). This effect appears to increase in magnitude as time spent in noise increases (26).

Recent studies have shown that, although noise may not affect performance during the actual exposure, it may produce impairments which occur after the noise has been terminated (27,28). These adverse behavioral after-effects have been noticed on tasks involving proofreading and frustration tolerance. Apparently noise exposure can cause some type of residual or depletion effects. Also, more severe after-effects were found with irregular-intermittent and intense ($L_A \geq 108$ dB) noises, with intermittency or unpredictability of the noise being more important variables than sound level.

These same researchers also found that when subjects were provided with the means to terminate the noise they were exposed to, the magnitude of the post-noise effect was reduced even when this control was not exercised.

5.4.3 Field Studies

Industrial and other work situations do not readily lend themselves to controlled experimentation. As a consequence, much of the previous field research has been subject to severe methodological deficiencies (4). It is usually difficult to separate the effects attributable to noise from those related to other physical stressors such as heat and air pollution, or to considerations of accident threat and job security. Evaluation of the positive effects of noise reduction efforts are often confounded by positive morale and motivation changes that also accompany the intervention in the work environment.

More recent work involving a five-year study of medical, attendance, and accident files for 1000 factory workers shows that workers in high noise settings ($L_A \geq 95$ dB) had more job-related accidents, sickness, and absenteeism than their counterparts in more quiet settings ($L_A \leq 80$ dB) (29). These results, too, are subject to criticism because it is quite possible that high noise levels are found in work situations that differ in some important respect such as accident hazard from those situations with lower noise levels.

5.4.4 Implications of Task Performance Effects

Assessment of the effects of noise on task performance requires consideration of the particular noise involved, the type of task in question, and the individuals performing the task. In general, overall rate of work is not affected, but variability is often increased. Demanding tasks or tasks that must be performed for relatively long periods of time are more subject to disruption by noise. Although, in some situations, performance during noise is unaffected, subsequent performance or behavior sometimes suffers as a result of previous noise exposure. Most of these conclusions are based on the results of short-term laboratory research. Valid field research is seriously lacking.

5.5 Sleep Disturbance

There are two aspects to the problem of sleep disturbance: one concerns actual arousal or waking due to noise, and the other concerns changes within the sleeping individual who does not awaken with the noise.

5.5.1 Stages of Sleep

During the course of sleep the individual typically goes through a progression of different stages of sleep. There are four principal stages, and these have been differentiated through the examination of brainwave activity. With relaxation, the rapid irregular waves change to a regular pattern. Stage 1 follows this period of relaxation, and it is characterized by a prolonged reduction in wave amplitude and frequency. Later, bursts of waves and large slow waves occur. This is stage 2. Approximately thirty to forty-five minutes later, bursts of high amplitude slow waves commence. This is stage 3. When these waves are present for 50% of the time, the deepest sleep stage, stage 4, is entered. After approximately sixty to ninety minutes, brain wave activity again resembles that found in stage 1. However, it is accompanied by rapid eye movement (REM). This is the REM stage, the stage where most dreaming takes place. It is usually thought that all stages of sleep are necessary for adequate functioning.

5.5.2 Variables Related to Sleep Disturbance

The major variables that appear related to response to noise during sleep are age, sex, stage, noise level, rate of noise occurrence, noise quality, and presleep activity (30,31).

Age: Middle-aged and older subjects are more affected than children and young persons at all stages of sleep.

Sex: Women are typically more sensitive to noise during sleep than men. Middle-aged women are especially sensitive to subsonic jet aircraft fly overs and simulated sonic booms.

Stage of Sleep: People tend to be most responsive to noise during sleep stage 1, next during 2, and then during REM and stage 3 and 4 sleep. Oftentimes, in the deeper sleep stages, noise does not produce behavioral awakening, but does result in shifts in stage. Usually, the shift is from a deep to a light sleep. The meaning of the stimulus is also important, in that more meaningful stimuli elicit greater response. In general, behavioral awakening is more likely to occur the longer someone has been sleeping.

Noise Level: As a general rule, the higher the noise level, the greater the probability of response, regardless of whether the response is defined as awakening or change in sleep stage (32).

Rate of Noise Occurrence: Research to date has yielded conflicting findings in this area. For example, low density traffic sounds have been shown to be more disruptive of sleep than high density sounds, while on the other hand, jet take-offs were found to be as disruptive at low rates as at higher rates (33). It is possible that the background noise levels, the uncertainty and the novelty of the sounds play important roles in sleep disturbance.

Noise Quality: Meaningful sounds awaken an individual at intensities lower than those required for meaningless or neutral sounds.

Presleep Activity: What research there is suggests that presleep activity such as exercise is not closely related to noise sensitivity during sleep. On the other hand, sleep deprivation does seem to increase the amount of time spent in stages 3 and 4 sleep and REM and consequently should affect noise sensitivity.

5.5.3 Implications of the Sleep Disturbance Effects

Sleeping in noisy environments appears to produce adverse effects either in the form of awakening the sleeper, or in the form of shifts in the stages of sleep. It should be pointed out that the existing data come almost exclusively from laboratory studies employing relatively few participants. There does appear to be a relationship between sleep disturbance and annoyance. Community noise surveys have shown sleep disturbance to be a major source of annoyance (34).

Overall, very little is known about the long term effects of sleep disturbance. The body needs sleep for normal functioning, and it is quite possible that sleep disturbance will yield adverse health effects. This is especially so for those individuals, such as the elderly, who are most sensitive to noise.

5.6 Speech Interference

Most people have experienced situations in which noise has prevented them from understanding someone's speech, or where they themselves were misunderstood. However, little scientific effort was directed to studying this problem until the advent of the telephone and the development of mechanized military systems. To date, a considerable amount of laboratory research has been done, and much is known about how a given speech sound will be masked by a particular noise (4,35,36). Speech interference is usually considered as one aspect of the general phenomemon of masking. Masking refers to the effect one sound has of making another sound more difficult to hear. One sound may alter the loudness, perceived quality, or apparent location of another sound.

This specialized laboratory research on masking has had limited applicability to the problem of ordinary speech. Ordinary speech is a complicated sequence of sounds with constantly varying level and spectral distributions. Also, for speech to be intelligible it is not necessary that all the sounds be heard. Speech is so redundant, and the typical listener so familiar with the language, that information can be missed and the speech will still be understood.

5.6.1 Variables Related to Degree of Speech Interference

There are a number of variables that influence the extent to which noise will interfere with speech. These are the characteristics of the speaker and listener, the characteristics of the message, and the characteristics of the masking noise.

Characteristics of the Speaker and the Listener: Noise will tend to interfere with speech reception to a greater extent if the speaker has poor articulation, or if the listener and speaker use different dialects. Also, lack of extensive knowledge of, and experience with, the language will render communication more difficult in noise. Both in terms of their poor articulation and lower degree of language familiarity, children appear to suffer more from background noise than do adults with normal hearing sensitivity. There is tentative evidence that suggests that noise in the home environment may be related to impaired auditory discrimination and reading achievement in children (37,38). Decrements in hearing acuity due to the aging process (presbycusis) also necessitate lower background noise levels for adequate speech communication (39).

Characteristics of the Message: Research has demonstrated that the intelligibility of speech in noise is related to the probability of occurrence of a given sound, word, or phrase (40). In other words, communications that contain simple and predictable information are less subject to interference from noise.

Characteristics of the Noise: As a general rule, the more intense the noise, the greater will be its interference with speech. The frequency spectrum of the noise is also very important in that the extent to which a given noise will interfere with speech depends in part on the sound pressure levels of the noise at the speech frequencies.

The effect of intermittent or impulse noise on speech intelligibility is difficult to assess. The severity of the effect depends on the frequency and duration of the bursts. As the frequency and duration increase, the level of speech intelligibility is reduced. Infrequent bursts of short duration usually do not interfere with speech in that some information can be missed without making the communication unintelligible.

5.6.2 Measures of Speech Interference

Various schemes have been developed to characterize noise in respect to its speech-masking abilities. The two best known are the Articulation Index (AI) and the Speech Interference Level (SIL) (42). These measures and their variants allow the user to predict the intelligibility of speech of a given level in a specific noise. The AI is the more complicated of the two measures because it takes into consideration the fact that certain frequencies in the noise are more effective in masking the other frequencies. The SIL provides only a measure of the averaged general masking capability of the noise with the lowest and highest frequencies ignored.

The simple A-weighted sound level L_A in dB is also a useful index of the masking ability of a noise. The A-weighting process emphasizes mid-range frequencies, as does the SIL. They differ in that the SIL ignores the lower frequencies, where the A-weighting includes them at a reduced level. The choice as to which measure to use depends on the level of accuracy required. The AI is the most accurate, but it is also the most complicated to use (43). In most instances, L_A or SIL measurements are adequate.

5.6.3 Noise Level, Vocal Effort, and Distance

Attempts have been made to graphically portray the dependence of intelligibility on distance between speaker and listener with respect to noise level (44). Figure 5.2 shows the distances over which speech can be understood for various noise levels. For example, at three feet a "raised" voice can be understood through an L_A of 71 dB. By "understood" it is meant that 95% of the key words in the group of sentences will be comprehended. It should be pointed out that these figures apply only to outdoor environments. Predictions for indoor environments would be more complex because consideration would have to be given to the reverberant qualities of indoor spaces.

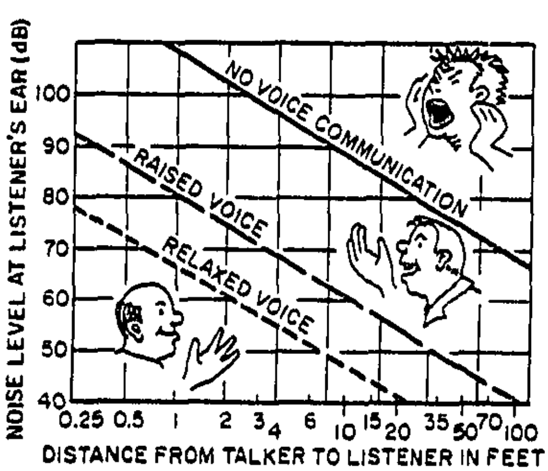


Figure 5.2. Relation between noise level and voice communication.

5.6.4 Implications of Speech Interference

Noise does interfere with speech. Research on community noise indicates that speech interference is a primary source of noise-related annoyance. In certain situations noise may mask signals that, if not heard, could lead to property damage, personal injury, or even death. Although people can adapt to even relatively high levels of background noise, there is evidence that they develop "noncommunicating" life styles (45), and this is undesirable in terms of the quality of life. There is also tentative evidence which suggests that noise in the home can adversely affect the language development of children.

Summary

Permanent noise-induced hearing loss is obviously the best documented and most significant effect of exposure to noise. In addition, however, noise has been shown to detract in many ways from the quality of life in our society. It has been demonstrated that, under certain circumstances, noise can produce annoyance, interference with speech communication, disturb sleep, and disrupt task performance. Noise is also capable of eliciting a variety of physiological responses.

REFERENCES

1. Galloway, W.J., Predicting Community Response to Noise from Laboratory Data, Transportation Noises: A Symposium on Acceptability Data, Chalupnik, J.D. (Ed), University of Washingtong Press, Seattle, 1970.

2. Tracor, "Community Response to Airport Noise," NASA Report CR-1961, 1971.

3. Alexandre, A., Decision Criteria Based on Spatio-temporal Comparisons of Surveys on Aircraft Noise, In Proceedings of the International Congress on Noise as a Public Health Problem, W.D. Ward Ed., pp 619-626 (U.S. EPA No. 550/9-73-008, 1973.

4. Kryter, K.D., The Effects of Noise on Man, Academic Press, New York, 1970.

5. Davis, R.C., Buchwald, A.M. and Frankman, R.W., Autonomic and Muscular Responses and Their Relation to Simple Stimuli, Psychological Monographs, 69, No. 405, 1955.

6. Etholm, B. and Egenberg, K.E., The Influence of Noise on Some Circulatory Functions, Acta Oto-Laryngol., 58, 208-213, 1966.

7. Jansen, G. Adverse Effects of Noise on Iron and Steel Workers, Stahl, Eisen., 81, 217-220, 1961.

8. Jansen, G., Relation Between Temporary Threshold Shift and Peripheral Circulatory Effects of Sound, In B.L. Welch and A.S. Welch (Eds.), Physiological Effects of Noise, New York: Plenum Press, 1970.

9. "Public Health and Welfare Criteria for Noise," U.S. Environmetnal Protection Agency, July, 1973. EPA Document Number EPA-550/9-73-002.

10. Landis, C. and Hunt, W.A., The Startle Pattern, New York: Farrar and Rinehart, Inc., 1968.

11. Nixon, C.W., "Some Effects of Noise on Man," Report No. AMRL-TR-71-53. U.S. Air Force, Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio, 1971.

12. Dieroff, H.G. and Scholtz, H.J., Zur Frage de Lambedingten Vestibularissqhaden bei begutachteten Larmarbeitern: Z. Larangol. Rhirol. Otol., 46, 746-757, 1967.

13. Selge, H., The Stress of Life, New York: McGraw-Hill Book Company, 1956.

14. Welch, B.L. and Welch, A.S. (Eds.), Physiological Effects of Noise, New York, Plenum Press, 1970.

15. The First Ten Years of the World Health Organization, Geneva: World Health Organization, 1958.

16. Abey-Wickrama, I., Albrook, M.F., Gattoni, F.E.G., and Herridge, C.F., Mental-Hospital Admissions and Aircraft Noise, Lancet, 297, 1275-1278, 1968.

17. Broadbent, D.E., Effects of Noise on Behavior, In C.M. Harris (Ed.), Handbook of Noise Control, New York: McGraw-Hill, 1957.

18. Gulian, E., Psychological Consequences of Exposure to Noise: Facts and Explanations. In W.D. Ward (Ed.) Proceedings of the International Congress on Noise as a Public Health Problem, pp. 363-378 (U.S. EPA No. 550/9-73-008, 1973).

19. Hockey, G.R.J., Effect of Loud Noise on Attentional Selectivity, Quarterly Journal of Experimental Psychology, 22, 28-36, 1970 a.

20. Hockey, G.R.J., Signal Probability and Spatial Location as Possible Basis for Increased Selectivity in Noise, Quarterly Journal of Experimental Psychology, 22, 37-42, 1970 b.

21. Kahnerman, D., Attention and Effort, Prentice-Hall, Englewood Cliffs, N.J., 1973.

22. Hebb, D.O., Drives and the C.N.S., Psychological Review 62, 243-254 1956.

23. Welford, A.T., Stress and Achievement, Australian Journal of Psychology, 17, 1-11, 1965.

24. Welford, A.T., Fundamentals of Skill, Methuen, London, 1968.

25. Broadbent, D.E., Decision and Stress, Academic Press, London, 1971.

26. Hartley, L.R., "Effects of Prior Noise or Prior Performance on Serial Reaction," Journal of Exp. Psych., 101, 255-261, 1973.

27. Glass, D.C. and Singer, J.E., Urban Stress: Experiments on Noise and Social Stressors, Academic Press, New York, 1972.

28. Wohlwill, J.F., Nasar, J.L., DeJoy, D.M. and Foruzani, H.H., Behavioral Effects of a Noisy Environment: Task Involvement vs. Passive Exposure, Journal of Applied Psychology, 61, 67-74, 1976.

29. Cohen. A., Industrial Noise and Medical Absence and Accident Record Data on Exposed Workers, In W.D. Ward (Ed.), Proceedings of the International Congress on Noise as a Public Health Problem, pp 441-454, (U.S. EPA No. 550/9-73-008, 1973).

30. Williams, H.L., Effects of Noise on Sleep: A Review., W.D. Ward (Ed.), Proceedings of the International Congress on Noise as a Public Health Problem, pp. 501-511, (U.S. EPA No. 550/9-73-008, 1973)

31. Lukas, J.S., Awakening Effects of Simulated Sonic Booms and Aircraft Noise on Men and Women, Journal of Sound and Vibration, 20, 457-466, 1972.

32. Thiessen, G.J., Effects of Noise from Passing Trucks on Sleep, Report Q1 presented at 77th Meeting Acoustical Society of America, Philadelphia, April, 1969.

33. Schieber, J.P., Etude analytique en laboratoire de l'influence du bruit sur le sommeil, Centre d/Etudes Bioclimatiques du CNRS, Strasbourg, France, April, 1968.

34. Lukas, J.S., Measures of Noise Level: Their Relative Accuracy in Predicting Objective and Subjective Responses to Noise During Sleep, (U.S. EPA No. 600/1-77-010, 1977).

35. Jeffress, L.A., Masking, In J.V. Tobias (Ed.) Foundations of Modern Auditory Theory, Vol. 1, Academic Press, New York, 1970

36. Webster, J.C., Effects of Noise on Speech Intelligibility, In W.D. Ward and J.E. Fricke (Eds.) Noise as a Public Health Hazard, ASHA Report No. 4, American Speech and Hearing Association, Washington, D.C., 1969.

37. Cohen, S., Glass, D.C., and Singer, J.E., Apartment Noise, Auditory Discrimination and Reading Ability in Children, Journal of Experimental Social Psychology, 9, 407-409, 1973.

38. Wachs, T.D., Uzgiris, I.C., and Hunt, J. McV., Cognitive Development in Infants of Different Age Levels and from Different Environmental Backgrounds: An Explanatory Investigation, Merrill-Palmer Quarterly, 17, 283-317, 1971.

39. Palva, A. and Jokinen, K., Presbyacusis: V. Filtered Speech Test, Acta Oto-Laryngol, 70, 232-241, 1970.

40. Miller, G.A., Heise, G.A. and Lichten, W., The Intelligibility of Speech as a Function of the Context of the Test Material, Journal of Experimental Psychology, 41, 329-335, 1951.

41. French, N.R., and Steinberg, J.C., Factors Governing the Intelligibility of Speech, Journal of the Acoustical Society of America, 19, 90-119, 1947.

42. Beranek, L.L., The Design of Speech Communication Systems, Proceedings Institute of Radio Engineers, 35, 880-890, 1947.

43. Klumpp, R.G. and Webster, J.C., Physical Measurements of Equally Speech-Interferring Navy Noises, Journal of the Acoustical Society of America, 35, 1328-1338, 1963.

44. Beranek, L.L., Noise Control in Office and Factory Spaces, 15th Annual Meeting Chem. Eng. Conf. Trans. Bull, 18, 26-33, 1950.

45. "Effects of Noise on People," U.S. Environmetnal Protection Agency, December 1971, (NTID 300.7).

Chapter 6

HIGH LEVEL NOISE EXPOSURE AND HEARING CONSERVATION

Noise-induced hearing loss is the most widely recognized and one of the most significant physiological effects of noise on people. It is now well established that individuals who are exposed to excessively noisy environments, without adequate hearing protection measures, will incur permanent and irreversible loss of hearing due to the noise exposure. However, many people do not understand the link between noise exposure and hearing loss. Individuals regularly expose themselves to high level noise and needlessly damage their hearing when the use of protective or preventive measures could have easily avoided this. This apparent lack of concern is attributable, to a great extent, to the insidious nature of noise-related hearing loss. The onset of this type of hearing loss is often very gradual, occurring over a period of years, and frequently not noticed until the loss of hearing is considerable. Further, the symptoms of noise-induced hearing loss, such as loss of auditory sensitivity and ringing in the ears, are often deceptive. These symptoms usually subside after the period of exposure, giving the misleading impression that no permanent damage has occurred.

This chapter will discuss the hazardous properties of high level noise, the effects of this noise on the auditory system, and protective measures which can be utilized to avoid noise-induced hearing loss.

6.1 Hazardous Properties of Noise

From prior research on the auditory effects of noise it is possible to list those characteristics of noise that contribute most directly to hearing loss. These characteristics are: overall noise level, frequency spectrum, exposure duration, and temporal pattern (1). Where possible, all of these factors should be considered when determining the hazard posed by a particular noise. Reliance should not be placed on a single characteristic of the noise. Also, the differences in individual susceptibility must be considered.

6.1.1 Overall Noise Level

Extended exposure to overall A-weighted sound levels of 70 to 80 dB will cause hearing impairment in only a few very susceptible individuals (2). It should be recognized that any specification of allowable exposure levels is a compromise based on assumptions concerning what percent of the population may realistically be protected, and concerning just what constitutes a significant hearing loss.

6.1.2 Frequency Spectrum

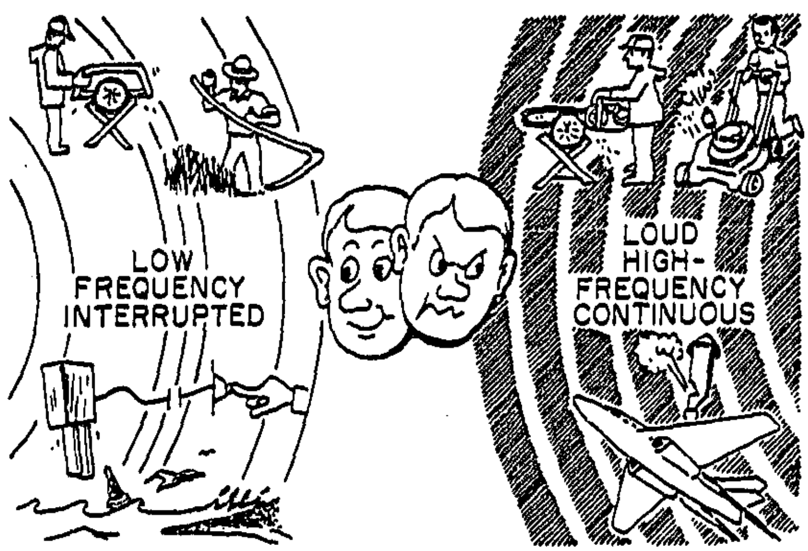
Research indicates that the ear is most sensitive to frequencies above 1000 Hz, and that hearing losses occur more readily at these higher frequencies. Also, noise containing a large percentage of energy below 4000 Hz is considered to be more hazardous to hearing than noise containing most of its energy above 4000 Hz (3).

6.1.3 Exposure Duration

Generally, as the length of exposure increases, so does the extent of the resultant hearing loss. Studies have suggested, however, that noise-induced hearing loss usually develops most rapidly during the first ten to fifteen years of exposure (4).

6.1.4 Temporal Pattern

The relationship between intermittent noise and hearing loss is not clearly defined. In general, however, intermittent noise has been shown to be less damaging than continuous noise, for the same total energy content. For example, four hours of continuous exposure to an L_A of 100 dB can be expected to be more hazardous than an exposure to the same sound energy one hour on and one hour off over an eight hour day.



6.1.5 Summary

In summary, then, the following general statements can be made concerning the hazardous properties of noise:

- -- the louder the noise, the more damaging it will be to hearing;
- -- the frequency components of noise between 1000 and 4000 Hz are more damaging than the low frequency components;
- -- generally, as the length of noise exposure increases, so does the extent of the resultant hearing loss; and
- -- continuous noise is generally more damaging than intermittent noise for the same energy content.

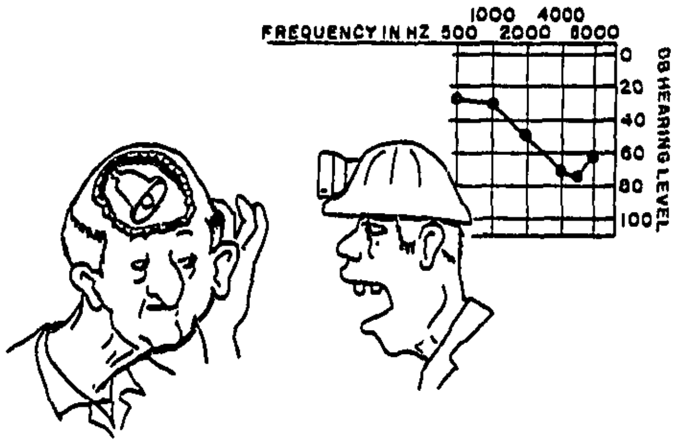
6.2 How Noise Damages Hearing

Observations in animals as well as in people show that noise reaching the inner ear directly affects the hair cells of the hearing organ (organ of Corti). These hair cells serve an important transducing function in audition. They convert the mechanical energy reaching the ear into neuroelectrical signals, which are carried by the auditory nerve to the brain. The outer ear, eardrum, and middle ear are almost never damaged by exposure to intense noise, although in some extreme situations, the eardrum can be ruptured by very intense impulsive noises. Blasts or other very loud impulse noises can also damage the organ of Corti by causing vibrations that simply tear apart some or all of the structure. Injuries resulting from single exposures to large pressure changes are called acoustic trauma. As the intensity of the noise and time for which the ear is exposed are increased, a greater proportion of the hair cells and their supporting structures are damaged or eventually destroyed.

Hearing acuity is generally affected first in the frequency range from 2000 to 6000 Hz with most affected persons showing a loss or "dip" at 4000 Hz. If high level exposures are continued, the loss of hearing will further increase around 4000 Hz and spread to lower frequencies. There is a great deal of individual variation in susceptibility to noise damage, so there is no single level of noise that separates safe and unsafe conditions for all ears. Furthermore, neither the subjective loudness of a noise, nor the extent to which the noise causes annoyance or interference with human activity, are reliable indicators of its potential danger to the hearing mechanism (5).

6.2.1 Indications of Noise-Induced Hearing Loss

Two noticeable indications of noise-induced damage to the auditory system are usually evident immediately following exposure to high level noise. They are:



1) a loss of auditory sensitivity
2) ringing in the ears (tinnitus).

A loss in auditory sensitivity can be determined by measuring the change in the absolute hearing threshold level. The absolute hearing threshold level is that at which a tone can just be detected. In other words, it represents the lower limit of our range of audibility. The greater the hearing threshold level, then, the greater the extent of hearing loss. An increase in the threshold level that results from noise exposure is called a noise-induced threshold shift. These threshold shifts can be either temporary or permanent. Temporary threshold shifts (TTS) decrease over a period of time until they disappear. Permanent threshold shifts (PTS) reflect changes in hearing which do not recover with time. As exposures are repeated, the ear may become less able to recover from the temporary threshold shifts and permanent hearing changes are observed.

6.2.2 Determination of a Hearing Handicap

The principal criterion of the extent to which hearing loss is a handicap is the ability to understand speech in quiet surroundings. However, much debate exists concerning the implications and significance of small amounts of hearing loss, and most guidelines for the assessment of the extent of handicap are based only on thresholds for tones in the region most important for the reception of speech (500, 1000, and 2000 Hz).

The Committee on Hearing of the American Academy of Ophthalmology and Otolaryngology (AAOO) has adopted guidelines stating that a handicap exists when the average hearing threshold level for 500, 1000, and 2000 Hz exceed 25 dB in the better ear (6). However, research shows that individuals with hearing losses above 2000 Hz may experience considerable difficulty in understanding speech in moderate levels of background noise (7), even though they don't come close to meeting the AAOO criterion. Hearing losses above 2000 Hz impair hearing so that it is difficult to distinguish the sounds of consonants that contain much of the information required to discriminate speech sounds. Because of this, several states have now included thresholds for 3000 Hz in the determination of "significant" hearing loss for their compensation laws.

6.2.3 Presbycusis and Other Factors Affecting Hearing

Presbycusis is the term given to hearing loss specifically ascribed to the effects of aging. Hearing becomes less sensitive with advancing age, even in the absence of damaging noise exposure. This effect is most pronounced at frequencies above 3000 Hz (8). At least in Western cultures, presbycusis appears to be more pronounced in males than in females, but this may be due to the noisy and more stressful activities that are more commonly engaged in by males.

The probability that a person will develop a hearing impairment due to noise depends on the pattern of exposure from all noises. It may be possible to control occupationally related noise exposure, but the control of non-work exposures poses a much more difficult problem. Recreational and other non-work exposures have been categorized as "sociocusis" factors (9). These factors complicate attempts at control of the acoustic environment and make it very difficult to determine the long term noise dose (over several years) that must be known in order to establish an accurate relationship between noise exposure and hearing loss.

6.3 Hearing Conservation Programs

Hearing conservation programs are designed to protect individuals from the hazardous effects of noise. Most hearing conservation programs are based on conditions at the work place; however, it is not unreasonable to extend these principles and practices to the community where damage to hearing also occurs.

In all cases, it should be kept in mind that the objective of a hearing conservation program is to prevent noise-induced hearing loss. Simple compliance with local, state, or Federal rules and regulations generally will not prevent all noise-induced hearing loss in susceptible individuals because the exposure limits selected for compliance purposes have, by necessity, been developed with consideration of the economic impact of control measures. Obviously, the lowest and safest economically feasible limits are desirable for the well-being of the individual.

An effective program should include three areas of concentration: noise assessment, noise reduction, and hearing assessment.

6.3.1 Assessment of Noise Dose

Noise hazard areas generally are identified by the duration and level of sound exposures. Noise dose, which depends on the product of these two factors, either can be measured using a sound level meter and a clock, or can be measured directly with a dosimeter. The resultant noise doses should be at least as low as those specified by the OSHA (see Section 6.4), but should be as low as is feasible for the particular noise exposure location.

6.3.2 Noise Reduction

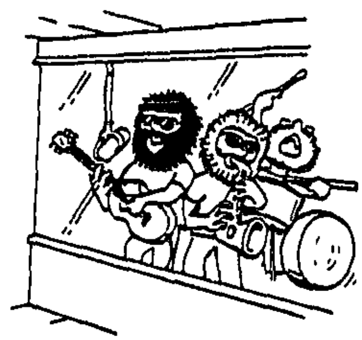
If the noise assessment indicates that hazardous conditions exist, several protective steps should be taken immediately. These include: hearing protection, source modification, and path modification.

SOURCE

RECEIVER

RECEIVER MODIFICATION

SOURCE MODIFICATION



PATH MODIFICATION

Hearing Protection: Primary consideration should be given to protecting the hearing mechanism. Once a hazard is detected, the initial steps taken should be aimed at hearing protection. Source modification and path modification often require implementation time, whereas steps to protect hearing can be taken immediately. In some instances, this can be accomplished by simply breaking up activity periods or by rotating persons in and out of the hazard area. These procedures increase the intermittency of the noise and thus decrease the threat of damage.

Another means of hearing protection involves the use of personal protective devices or ear protectors (10). These devices usually take the form of ear muffs worn over the external ear so as to provide an acoustical seal against the head, or ear plugs that provide an acoustical seal at the entrance to the external ear canal. The particular type of ear protector worn depends on such factors as the individual's ear anatomy and the environment of the person being protected. Hearing protectors will provide effective hearing protection only if there is an effective hearing conservation program to assure proper fitting, wearing, and motivation at and away from the work place. It should be pointed out that the only unequivocal means for evaluating the effectiveness of personal protectors is to measure the hearing thresholds of the user periodically.

Source Modification: Attempts at source modification usually begin with locating the source of the noise. Once located, the source should be eliminated, modified, or replaced. A detailed examination of engineering control procedures is beyond the scope of this chapter, but the interested reader is directed to the many detailed presentations of this topic (10-13). Suffice it to point out that the use of engineering control procedures on noisy equipment already in operation may be difficult and, in many cases, ineffective. Engineering noise control measures can be used most effectively at the design stage of potentially noisy equipment. Until recently there has not been a strong demand by many people for quiet equipment, and available technology has not been used to full advantage in product design. By all means, the purchase orders for potentially noisy equipment should have adequate specifications to provide an incentive for the design of quiet products.

Path Modification: If it is not possible to obtain enough reduction of noise level by treatment of the source, the next step is to reduce the exposure level by modification of the sound vibration path. A number of steps can be taken to reduce the production and propagation of noise (10-13). These include the use of:

1) partial and complete barriers placed between the observer and the source to reduce the level of sound propagated,
2) absorption materials placed on room surfaces and inside of enclosures to prevent reflection and build-up of noise levels,

3) damping materials placed on vibrating surfaces to reduce vibration and in turn the level of noise emitted,

4) vibration isolators placed under or around a noise source to prevent vibration from being transmitted to other surfaces, such as floors, walls, or enclosure panels, where additional sound may be generated.

6.3.3 Hearing Assessment

One of the most important phases of the hearing conservation program involves the measurement of hearing levels of persons exposed to noisy environments. A program of periodic audiometric evaluations must be implemented and carried out by a trained technician. Although there are numerous audiometric tests, most hearing conservation programs rely on a pure tone absolute threshold test as their principal index of hearing sensitivity. If the audiogram indicates that losses or changes in hearing have taken place since the base audiogram was taken, then the person should be referred for professional evaluation of the change.

6.4 Noise Exposure Limits and OSHA

The development of effective and practical requirements and procedures for assuring the health and safety of workers who are exposed to high level noise is very complex. In addition to the very complicated technical aspects related to the effects of exposure to high level noise, the procedures for measuring noise dosage, and the procedures for hearing measurement and impairment assessment, there is also the very important factor of the economic impact on industry. The Occupational Safety and Health Administration, OSHA, of the U.S. Department of Labor must face these difficult problems to meet its responsibility in developing and enforcing rules and regulations to limit exposures to potentially harmful noises.

The noise exposure limits set forth by OSHA (14) are designed for both continuous and impulsive noises. The continuous noise limit is set at 90 dB measured with an A-frequency weighting for exposures of eight hours per day, with higher levels being permitted over less time at the rate of 5 dB for halving of exposure time. For examples see Figure 6.1. Exposure to continuous A-weighted noise levels greater than 115 dB are not allowed under any circumstances. The limit to impulsive noise exposures is 140 dB peak sound pressure level.

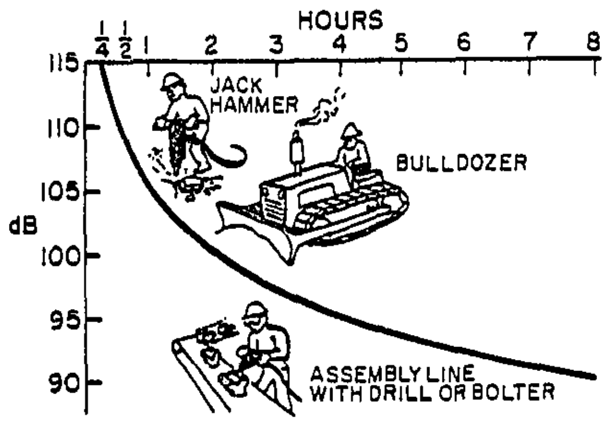


Figure 6.1. OSHA noise exposure limits.

When daily noise exposure is composed of two or more periods of exposure at different continuous, steady-state levels, their combined effect is determined by adding the individual contributions as follows:

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \frac{C_3}{T_3} + --- \frac{C_N}{T_N}$$

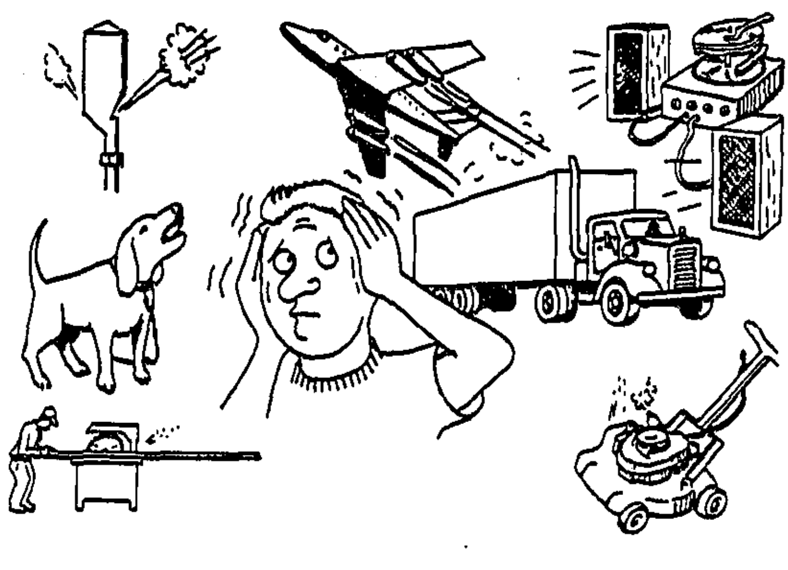
The values C_1 to C_N indicate the time of exposure to specified levels of noise, while the corresponding values of T indicate the total time of exposure permitted at each of these levels. If the sum of the individual contributions $(\frac{C_1}{T_1} + \frac{C_2}{T_2} + ---)$ exceeds 1.0, then the mixed exposures are considered to exceed the overall limit value. For example, if a man should be exposed to an L_A of 90 dB for five hours, 100 dB for one hour, and 75 dB for three hours during an eight hour working day, then the times of exposure are $C_1 = 5$ hr, $C_2 = 1$ hr, $C_3 = 3$ hr; and the corresponding OSHA limits are $T_1 = 8$ hr, $T_2 = 2$ hr, and $T_3 =$ infinity. Therefore, the combined exposure dose for this man would be $5/8 + 1/2 + 3/\infty = 1.125$, which exceeds the specified limit of 1.0.

The impulsive noise exposure limit of 140 dB peak sound pressure level of the 1972 OSHA Rules and Regulations (15) does not specify a limit for the number of impulses that a person can be exposed to in an eight hour working day, but it can be expected that a limit such as 100 impulses for eight hours may be set in a modification of the OSHA noise criteria. Perhaps different peak level limits will be specified for a greater number of impulses, such as 135 dB for 100 to 1000 impulsive sound exposures; and 130 dB for 1000 to 10,000 impulsive sound exposures; and 125 dB for more than 10,000 impulsive sound exposures in eight hours.

The noise exposure limits specified by OSHA are not intended to provide complete protection for all persons. They are set forth as the most restrictive limits that are deemed feasible with due consideration given to other factors, such as economic impact. Therefore, wherever feasible, hearing conservation measures should be initiated at levels considerably below those specified by OSHA. The ideal action point for initiating hearing conservation measures would be an L_A of about 75 dB for continuous steady-state noise exposures of 8 hours. However, the economic impact of limits set at this low sound pressure level may not be feasible in many situations. Many activities away from the work place cause continuous noise exposures greater than 75 dB, so something must be done with the normal life style of this country if exposures are to be changed radically. Certainly, every effort should be made to institute hearing conservation measures for extended exposures above 80 dB.

Lowering noise exposures has very meaningful benefits other than to avoid an OSHA citation. Obviously, the most important benefit is that noise-induced hearing loss may be prevented. In addition, the lower levels will generally afford better working conditions, which should reduce annoyance and improve communication; thus, safety conditions and the general well-being of workers should be improved. Economic advantages of lower noise levels should include increased production and a reduction in compensation claims (in future years) for noise-induced hearing loss. Also, the OSHA limits for noise exposure may be lowered in the future, so it is generally more economical to have noise levels as low as is feasible now rather than attempt control measures twice.

Other widely used noise exposure limits include those developed by the U.S. Air Force (16), the U.S. Army (17), the Mining Enforcement and Safety Administration (MESA) (18), and the Committee on Hearing, Bio-acoustics and Biomechanics (CHABA) of the National Research Council (19).



6.5 Noise Exposure Limits and EPA

The Environmental Protection Agency (EPA) has attempted to identify the environmental noise levels requisite to protect the hearing of the general population. EPA has placed an emphasis on the protection of the hearing of all individuals within an adequate margin of safety as opposed to the compromise position of OSHA. The data base used to derive safe levels recommended by EPA consisted of statistical distributions of hearing levels for populations at various exposure levels. The evidence for noise related permanent threshold shift (PTS) of hearing was derived from the shift in the statistical distribution of hearing levels for a noise exposed population (20). The interested reader is directed to Appendix C of reference 20 for a detailed explanation of how these levels were derived. From these data it was possible to derive the eight hour exposure level which protects virtually all of the population from a PTS greater than 5 dB. This was found to be an L_A of 73 dB.

In order to apply this eight hour figure to the environmental situation, it was necessary to develop several adjustment factors. Adjustments for intermittency, for twenty-four hour exposures, and for yearly exposures were developed. EPA defined intermittent noise as noise which is below 65 dB for about 10% of the time, with peak levels of 5 to 13 dB higher than the background (20). In general, environmental noise should be considered intermittent unless shown otherwise (21). Since intermittent noises are typically less harmful than continuous noises, a correction factor of +5 dB was derived. Thus, eight-hour exposures to intermittent noise should not exceed 78 dB.

The identified L_A of 73 dB is based on eight hour daily exposures. Conversion to a twenty-four hour period requires a reduction of this level by 5 dB. This means that continuous noise of a twenty-four hour duration must be 5 dB less intense than sounds of only eight hours duration.

Correction to yearly dose (365 days) requires that the 73 dB exposure be reduced by 1.6 dB. This is because the original statistical data were based on occupational exposures of only 250 days per year.

Employing the above corrections implies that the average eight-hour continuous daily exposure (based on a yearly average and assuming intermittent noise) should be no greater than $73 + 5 - 1.6 = 76.4$ dB. A similar value for twenty-four hours would be 71.4 dB. EPA suggests that it would be reasonable to round off the 71.4 dB value to 70 dB to account for statistical errors and to insure an adequate margin of safety.

As can be seen, the EPA levels for all types of expsoures are considerably more stringent than those contained in the OSHA limits. The EPA recommendations represent a conservative approach directed to protection of the entire population from hearing loss. The extent to which the attaining of such levels would be technically and economically feasible or compatible with the American lifestyle remains an open question.

REFERENCES

1. Peterson, A.G. and E.E. Gross, Jr., Handbook of Noise Measurement, General Radio, Concorde, Mass., Chap. IV, 1974.

2. Ward, W.D., "Effects of Noise on Hearing Thresholds," in W.D. Ward and J.E. Fricke (Eds.) Noise as a Public Hearing Hazard. American Speech and Hearing Association Reports, Report 4, 40-48, 1969.

3. Ward, W.D., A. Glorig, and D.L. Sklar, "TTS from Octave-Band Noise-Applications to Damage Risk Criteria," J. Accoust-Soc. Am., 31, 522-528, 1959.

4. Glorig, A., Ward, W.D., and Nixon, J., "Damage Risk Criteria on Noise," Arch. Oto-Laryngol., 74, 413-423, 1961.

5. "Public Health and Welfare Criteria for Noise," U.S. Envrionmental Protection Agency, EPA Document Number EPA-550/9-73-002, July 1973.

6. Davis, H., "Guide for the Classification and Evaluation of Hearing Handicap in Relation to the International Audiometric Zero," Trans. Am. Acad. Ophth. and Otol. 69, 740-751, 1965.

7. Niemeyer, W. "Speech Discrimination in Noise-Induced Deafness," Internat. Audiol. 6, 42-47, 1967.

8. Gallo, R. and A. Glorig, "Permanent Threshold Shift Changes Produced by Noise Exposure and Aging," Amer. Ind. Hyg. Assoc. J., 25, 237-245, 1964.

9. Cohen, A., Anticaglia, J., and Jones, H.H. "Sociocusis-Hearing loss from Non-Occupational Noise Exposure," Sound and Vibration, 4, 12-23, 1970.

10. "Industrial Noise Manual" American Industrial Hygiene Association, Southfield, Mich. 1966.

11. Geiger, P.H., Noise Reduction Manual, Engineering Research Institute, University of Michigan, 1953.

12. Hines, W.A., Noise Control in Industry, Business Applications Limited, London, 1966.

13. Harris, C.M., (Ed), Handbook of Noise Control, McGraw-Hill, New York 1957.

14. "Occupational Safety and Health Standards" (Williams-Steiger Occupational Safety and Health Act of 1970), U.S. Department of Labor, Fed. Reg., 36, 10518 (1971).

15. Occupational Safety and Health Standards, Federal Register, 37, No. 202, October 18, 1972.

16. "Hazardous Noise Exposure," Air Force Regulation 160-3, Department of the Air Force, 1956.

17. MIL - STD - 1474 A (MI), Military Standards, Noise Limits for Army Material, Department of Defense, Washington, D.C. 20301.

18. Mandatory Health Standards - Underground Coal Mines, Federal Register, 35, 12739, July 7, 1971.

19. Kryter, K.D., W.D. Ward, J.D. Miller, and D.H.Eldredge, "Hazardous Exposure to Intermittent and Steady State Noise," J. Accoust. Soc. Am., 39, 451-464, 1966.

20. "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," U.S. Environmental Protection Agency, EPA Document Number EPA 550/9-74-004, March 1974.

21. "Community Noise," U.S. Environmental Protection Agency, December, 1971.

Chapter 7

COMMUNITY NOISE SURVEYS: ATTITUDINAL AND PHYSICAL

The complete assessment of a community noise problem usually requires the collection and analysis of attitudinal data. Such data should be collected in conjunction with the actual measurement of noise levels in the environment. The purpose of this chapter is to discuss the major aspects of community noise attitude surveys and to provide a brief introduction to planning physical surveys of community sound levels. Several of the major methodological aspects of survey design will be addressed and recommendations will be made regarding information that should be obtained in a community noise survey.

Traditionally, attitudes have been defined as tendencies to respond either positively or negatively to certain persons or situations. The word noise, by its very definition as unwanted sound, implies a negative attitude with respect to certain sounds. Research to date provides convincing evidence that people's values, beliefs, and attitudes heavily influence their response to noise (1). Some researchers go so far as to say that these variables are at least as important for predicting annoyance from noise as the actual physical properties of the noise itself (2). It is evident, then, that in many cases the impact of noise on a community cannot be adequately assessed by sound pressure level measurements alone. These measurements must be supplemented with attitudinal survey data to include the subjective elements.

7.1 Surveys and Survey Instruments (Interviews and Questionnaires)

The terms survey, interview, and questionnaire are often used interchangeably. However, these terms are not synonymous and should be distinguished from each other. The term survey refers to the general act of acquiring information. It does not refer to an actual method or instrument used for such purpose. Interviews and questionnaires, on the other hand, are two popular ways to collect information; thus, they are two survey instruments. Attitudes then may be surveyed through the use of interviews or questionnaires.

An interview is usually a face-to-face session where the interviewer asks some selected individual (usually called the respondent) a series of questions about the topic of concern. Interviews that involve straightforward questions and answers about topics that are not highly personal or emotional can often be handled on the telephone. Such interviews reduce the time and costs involved in a face-to-face format.

When it is not feasible to use a face-to-face format a written questionnaire is often useful. A questionnaire usually consists of a printed set of questions that is distributed to a respondent. The respondent completes the questions and returns the form, often by mail, to the individual or group doing the survey. Since the respondents read and answer the questions themselves, questionnaires are often referred to as being self-administered.

Part of the confusion in the use of the terms interview and questionnaire is attributable to the fact that many interview situations make use of interview protocols or schedules. These forms resemble questionnaires in that they contain the questions and response formats that will comprise the interview. The interviewer uses this form as an outline from which to administer the interview, and as a form to record the responses. The use of detailed protocols insures that all respondents receive the same questions in the same approximate order.

There are certain advantages in employing interviews rather than questionnaires. In an interview, questions can be explained, unexpected responses can be interpreted, and more in-depth questions can be included. Questionnaires, on the other hand, are usually less expensive, but many people tend not to fill out or return questionnaires.

7.2 Sampling

Interviews and questionnaires are data- or information-collecting strategies. These techniques are usually employed in a situation in which an investigator wishes to be able to make statements about some defined group of people, such as those persons residing within a five mile radius of a large airport. Usually it is not feasible to survey all of the people that comprise the group or population of interest, so a representative sample of these individuals must be selected. A representative sample provides a reasonably accurate representation of the characteristics of the total population. Thus, the findings based on a representative sample of the population are likely to correspond closely to those that would be obtained if the total population were studied. The generalizability of the results of even the best designed interview or questionnaire will be reduced if careful attention is not paid to sample selection.

A basic distinction exists in modern sampling theory between probability and non-probability samples (3). A probability sample, or one of its variants, is necessary in order to insure a representative sample. Non-probability samples should be avoided where possible. For example, it might be convenient to administer a questionnaire to persons attending a citizens' group meeting, but such a non-probability sample group would not be a dependable representative of the total community population.

Three basic types of probability samples are considered below: the simple random sample, the stratified random sample, and the cluster sample.

7.2.1 Simple Random Sample

Each individual in the population has an equal chance of being selected for inclusion in a simple random sample. Take, for example, a hypothetical community which contains 500 households. A simple random sample could be drawn by writing the name of each household on a slip of paper and then placing these 500 slips of paper in a hat. If a sample of 50 names were drawn from the hat at random, a 10% simple random sample of households would have been drawn. By such a procedure, each household has an equal chance of being selected. Obviously, the characteristics of the community are described more completely when a larger sample is selected.

7.2.2 Stratified Random Sample

In a stratified random sample the population is divided into two or more groups or strata. For example, a population might be divided into income level or age level strata. If appropriate measurements were made, a population could be divided into strata according to noise exposure level. After this procedure is accomplished, a simple random sample is taken from each stratum. These sub-samples are then joined to form the total sample.

7.2.3 Cluster Sample

This type of sample is designed for relatively complex situations, and it is characterized by an initial sampling stage in which groupings or clusters of the units to be sampled are selected by means of a simple random or stratified random sampling procedure. If all the individuals in a cluster are not to be included in the sample , then the ultimate selection from within the cluster is also made by a simple or stratified random sampling procedure.

Cluster sampling plans are commonly used in noise surveys. For example, we might find that 30,000 people live within five miles of an airport. Taking a simple random sample of a population this large would be difficult and time consuming. It might be possible to divide this area into 50 neighborhoods of approximately equal size. From these 50 neighborhoods, 12 neighborhoods, or clusters could be selected at random. If noise measurements were available, the 50 neighborhoods might be classified according to noise exposure level--high, moderate, or low. From each of these three strata, four neighborhoods could be selected. In each case, the ultimate samples might consist of 25 residents selected at random from each of the 12 neighborhoods. The total sample would equal 300. For large scale surveys cluster sampling is often more economic and efficient than other sampling procedures.

7.3 Survey Design

In the course of designing a survey, there are several procedural decisions that must be made. First, should the interview be structured or unstructured? Second, should the questions comprising the interview be of the fixed-alternative or open-ended variety? And third, should the interview be direct or indirect?

7.3.1 Structured vs. Unstructured Interview

Structured interviews are organized interviews in which the questions to be asked, their wording, and order of presentation are determined beforehand. In an unstructured interview these matters, within limits, are left to the discretion of the interviewer who works only from a broad agenda.

The principal advantage of the unstructured interview is that it permits the interviewer to pursue any aspect of the subject matter that appears promising. The major disadvantage is that such freedom makes the comparison of responses between different individuals very difficult. Structured items are more appropriate where there is an interest in data quantification. Furthermore, some topics lend themselves better to structured formats than other topics do. Most noise surveys are fairly structured, but often include optional questions or areas of inquiry. Such options are very useful if the interviewer is sophisticated and highly motivated.

7.3.2 Fixed-Alternative vs. Open-Ended Questions

Fixed-alternative items consist of a question followed by a limited set of possible responses to which the respondent is to select the one that is most appropriate. The alternative responses might take the form of a list of activities with which noise in the environment interferes, or the individual might be asked to rate the noisiness of his neighborhood on a seven-point scale, with 1 = very noisy and 7 = very quiet.

Open-ended questions allow the individual total freedom in responding. Responses to open-ended questions are difficult to quantify and analyze, but they often result in providing the researcher with insights or responses that had not previously been anticipated. Generally, it is advisable to include both types of questions because some questions simply cannot be answered by choosing an alternative.

7.3.3 Direct vs. Indirect Interview

Should noise be acknowledged as the topic of concern? The direct interview approach makes no attempt to disguise the purpose of the interview, while the indirect approach attempts to prevent the respondent from knowing that noise is the primary purpose of the interview. The indirect approach makes for a more lengthy or complex protocol, but doing so may result in obtaining a more realistic picture of the noise situation in a particular community. It is possible that the noise problem might appear more serious than it is if the survey deals only with noise. Survey researchers have also argued that, to avoid bias, interviewers should not identify themselves as part of the government structure, but as part of a university or general research organization (4,5). In light of the aforementioned considerations, it might be prudent to begin the interview in an indirect fashion in order to establish how noise ranks as a community issue, and, as the interview proceeds, to focus in a more direct fashion on noise itself.

As is probably obvious from the above discussion, most actual interviews represent compromises on each of the above issues. The actual structure and format of the interview is dependent to a large extent on the nature of the problem area, and on available resources and personnel. Community response to noise is usually studied via a structured interview that includes a fairly high proportion of fixed-alternative questions.

7.4 Model for the Design of Noise Surveys

A widely employed framework for the design of social noise surveys includes the following four factors for consideration (5):

1) perception or awareness of noise
2) activities affected or interrupted by noise
3) annoyance or hostility resulting from interruption by noise
4) complaints resulting from interruption by noise.

The first factor pertains to the large individual differences that exist in terms of perception and awareness of noise. Some people are extremely sensitive to noise, while others are quite insensitive to it. Thus, people who are exposed to the same noise will not all react to it in a similar manner.

The second factor considered in this framework stems from the observation that the adverse effects of noise are closely related to the activities which the noise interrupts. Therefore, in a noise survey, information should be collected concerning the variety of activities intruded upon by noise, and the extent or magnitude of this intrusion.

The third factor involves the extent to which people feel annoyed or irritated by different types of noise. It has been found that certain social, psychological, and situational variables play an important role in mediating the annoyance and hostility responses of the individual (Section 5.1 contains a list of some of these factors).

The fourth factor pertains to complaint activity. A survey of complaint activity should include both the extent to which people desire to complain, and the extent to which they actually do register such complaints. Such information is typically included in noise surveys because there is often administrative interest in predicting complaint activity. Research has shown, however, that complaint rate represents a serious underestimation of annoyance level (6). Complaint activity has been shown to be related to a complex interaction of social and personal characteristics.

Most of the recent community noise surveys have, to some extent, followed this general model. As will be discussed below, each of these factors suggests a general category of questions that should be included in a community noise questionnaire or interview protocol.

7.5 Survey Content

In this subsection, the term interview will be used throughout to denote both "interviews" and "questionnaires." Most large-scale community noise surveys have employed interviews, but the recommendations contained herein apply to both interviews and questionnaires.

The purpose of this section is to outline the major content areas that should be included in a community noise survey. A complete survey should contain items pertaining to the following four content areas: 1) description and assessment of the noise environment, 2) activity disruption and interference from noise, 3) psycho-social situational variables, and 4) personal-demographic background. Each of these areas is discussed in detail.

7.5.1 Description and Assessment of the Noise Environment

Questions contained in this category should be directed at assessing the respondents' perceptions of the noise environment in which they live. This category corresponds to factor 1 in the survey model--perception or awareness of noise.

The first question in this section might be indirect in nature and simply inquire about sources of dissatisfaction in the person's environment. The purpose of this question is to assess how noise compares with other problems in the environment. This permits a valid assessment of the noise problem in that no prompting of the respondent has taken place.

Next, an overall "neighborhood" noise level rating should be obtained. Similar overall ratings might be solicited for noise levels inside the home, and for the city or town in general.

After the overall information has been obtained, the contribution of various noise sources to this level should be assessed. Does the noise come from aircraft, trucks, industry, barking dogs, etc. or some combination of these? Some type of ranking procedure should be used to assess the magnitude of the contribution of each of the sources to the overall level. There are a variety of ways to accomplish this ranking, but the general purpose of such a procedure is to determine the relative contribution of the major noise sources. Information pertaining to the times at which these noises are most obvious should also be obtained, and an overall rating of the severity of "noise problems" is often also included in the section.

Respondents might also be asked if they have ever complained to the authorities about noise, or if they have ever thought of registering a complaint. If they have thought of complaining but did not, it should be determined what prevented them from doing so.

7.5.2 Activity Disruption and Interference from Noise

It has been found that the extent to which noise is annoying depends in part on the extent to which it disrupts ongoing activities. Items in this section of the survey are related to factor 2 in the survey model. Questions should be included that ask the respondent about the types of activities that are disrupted by noise, and the degree of the disruption. A list of such activities might include: TV/radio listening, conversation, telephone use, relaxing outside, relaxing inside, listening to music, sleeping, reading, eating, etc. Some previous noise surveys have taken the number of activities disturbed and calculated a total noise interference score. These scores have been used to represent an indirect measure of annoyance (6). This section should also contain a direct annoyance item. Such an item asks the person to state the overall extent of his annoyance from noise in his living environment. Generally, there is a good correlation between these indirect and direct annoyance measures.

It is often a good idea to include some questions of a more open-ended variety in this section to probe the extent to which the respondent has altered his daily activities to cope with the noise. The individual may not feel that noise interferes with his sleep or TV watching, but almost without awareness of the relationship of the noise to his behavior, may report that he sleeps with the air conditioner on all through the year or that he always keeps the front windows closed. A family may have moved the TV to the back of the house where it is quieter, or perhaps they avoid backyard picnics because of the noise. These are effects of noise that often go unnoticed.

7.5.3 Psycho-social and Situational Variables

Previous survey research has shown that there are a number of intervening personal, social, and situational factors that appear to affect responses to noise (2,5,7-10). For example, reactions to environmental noise have been found to be more adverse if the noise is perceived as being unnecessary, unpredictable or uncontrollable, or if the noise is thought to represent a threat to personal health and safety. Similarly, reactions are more adverse if the respondent feels that the authorities or the propagators of the noise do not care about the problem, or if the respondent is dissatisified with other aspects of the environment. Also, self-ratings of noise sensitivity appear to correlate positively with noise effects. That is, individuals who rate themselves as being sensitive to noise tend to be more adversely affected by it (6).

7.5.4 Personal-demographic Background

Socio-economic background information is typically collected in the course of any type of interview. These data fulfill several functions. They provide information concerning the socio-economic makeup of the sample, and the extent to which the sample is representative of the general population. Also, patterns of response to items in the other parts of the interview may depend on socio-economic variables such as age or income level. Although this information is indispensible for the purposes of the interview, people are often reluctant to answer such questions. A number of survey techniques have been developed which allow solicitation of personal information while respecting the privacy of the respondent. For example, sometimes broad categories of response are used to obtain information on items such as income level. The respondent might be asked to acknowledge only that his income is greater than $10,000 per year but less than $15,000 or greater than $5,000 per year but less than $10,000. This approach avoids asking the individual to reveal an exact dollar figure. Also, sometimes the respondent is asked to write in his own answers instead of presenting them verbally to the interviewer. It must be emphasized that this information should not be omitted from the community noise survey solely on the grounds that it is sometimes difficult to obtain.

Information concerning the age, sex, and national origin of the respondent should be collected. An index of socioeconomic status should be obtained from questions dealing with the respondents educational level, income level, and occupational classification. The interviewee's personal noise exposure history should also be taken. This entails information concerning both the person's previous occupational and non-occupational noise exposures.

Since most interviews are conducted in the home and thus deal primarily with residential exposures, some information concerning the person's residential environment should be gathered. It should be determined whether the property is owned or rented, the type of housing (apartment, single family, - detached, etc.), the length of residence, the desire to relocate, age of building, number of rooms, etc. Factors such as these are often related to annoyance and complaint activity.

7.6 Physical Surveys of Sound Levels

It is useful to accompany attitude surveys with physical surveys of sound levels in areas of interest. In general there is good correlation between A-weighted sound level and the fraction of the population that is greatly annoyed by environmental noise. In view of the limitations of manpower, equipment, and funds, careful planning is required to optimize the utility of physical sound surveys (11).

In planning a sound survey, the first question to be answered is the purpose of the survey, that is, what is the planned use of the data after they have been obtained? If this is the first survey ever made in a region, it can be used both to identify areas in which a sound exposure problem exists, and to provide baseline data that will permit comparisons in the future. If previous surveys have been made, comparison of new and old data permit assessment of the effectiveness of any noise control measures undertaken between surveys. The identification of major noise sources, as in an initial survey, makes it possible to take steps to reduce the noise exposure from such sources. Such steps may require legal action under a noise ordinance. If no such ordinance (or an existing, but ineffective, ordinance) exists, a noise survey can reveal the need for and can arouse community support for the enactment of an effective noise ordinance. Physical surveys also are useful in connection with zoning; for example, a community might forbid residential or other noise-sensitive land uses in areas where the sound level is high, and where adequate reduction of those levels at reasonable cost is impossible. In some cases physical surveys are required to determine whether areas in the community meet the requirements imposed by Federal agencies for funding of highway and housing construction. Although there are reasons for conducting physical sound surveys other than those given above, these are the ones most commonly encountered.

Once the objectives of the physical survey have been chosen, the design of the survey begins. Those areas of the community that need to be surveyed must be selected. Some of these areas can be identified from the results of an attitudinal survey, while others (such as those adjacent to highways and airports) may be chosen because they are major noise sources in nearly every community. Cost considerations probably will limit the number of areas that can be studied. Once these areas have been selected. observation sites within them should be chosen using some kind of random sampling scheme. The type and number of observations, the times of observation, and the instrumentation to be used for observing, all need to be specified. A standard technique for making and recording observations needs to be specified so that the data obtained can readily be analyzed and related to the purpose of the survey.

Specific information on noise descriptors and on instruments for making noise measurements will be found in Chapter 11.

REFERENCES

1. "Effects of Noise on People," U.S. Environmental Protection Agency, December, 1971 (National Technical Institute Document No. 300.7).

2. McKennell, A.C., Noise Complaints and Community Action, In J.D. Chalupnik (Ed.), Transportation Noises: A Symposium on Acceptability Criteria, Seattle: University of Washington Press, 1970.

3. Selltiz, C., Jahoda, M., Deutsch, M. and Cook S.W. Research Methods in Social Relations (revised edition) Holt, Rinehart and Winston, New York, 1959.

4. Bragdon, C.R., Noise Pollution, University of Pennsylvania Press, Philadelphia, PA. 1971.

5. Borsky, P.N., The Use of Social Surveys for Measuring Community Response to Noise Environments, In J.D. Chalupnik (Ed.) Transportation Noises: A Symposium on Acceptability Criteria, University of Washington Press, Seattle, 1970.

6. Tracor, "Community Reaction to Airport Noise, NASA Report CR-1761, 1971.

7. Graeven, D.B., Necessity, Control and Predictability of Noise as Determinants of Noise Annoyance, Journal of Social Psychology, 95, 85-90, 1975.

8. Graeven, D.B., The Effects of Airplane Noise on Health: An Examination of Three Hypotheses, Journal of Health and Social Behavior, 15, 336-343, 1974.

9. Humphrey, C.R., and Krout, J.A., Traffic and the Suburban Highway Neighbor, Traffic Quarterly, 593-613, October, 1975.

10. Wyle Research, "Community Noise Assessment Manual/Attitudinal Survey," Report WR78-17, April 1978.

11. Wyle Research, "Community Noise Monitoring Manual," Report WR77-17, November 1977.

Chapter 8

SOUND PROPAGATION CHARACTERISTICS

Sound propagation over long distances outdoors is affected by several factors that include:

1) Spherical and cylindrical spreading;
2) Absorption from the earth's surface, from objects in the propagation path, or from the atmosphere;
3) Reflections from objects in the propagation path;
4) Transmission loss, or attenuation, from barriers in the propagation path;
5) Weather conditions
    a. humidity gradients
    b. precipitation
    c. temperature gradients
    d. turbulence
    e. wind gradients.

Each of these factors will be reviewed in this chapter.

Sound propagation over short distances is affected by these same factors; however, the effects of the absorption in the air and the effects of weather are generally insignificant because there are only slight changes over the short distances involved. The prediction of sound levels near to the sound source (near field) is difficult, if not impossible, in most cases because of complex interactions between factors that include the sound spectra, the shape and size of the source, the distance from the source, and other factors. The effects of weather may become important for distances greater than about 30 meters (100 feet). Specifics of short distance propagation will not be covered here but details can be found in several references (1-5).

8.1 Spherical and Cylindrical Spreading

The term "long-distance" when applied to sound propagation usually is intended to mean any distance greater than about 10 times the maximum dimension of the sound source. However, in community noise work, long distance generally implies distances greater than a city block.

In most cases sound propagation over long distance also means the sound source is far enough from the points of measurement so that the source can be considered to be a point or "point source". Sound will spread from the point source in a spherical manner and each doubling of distance from the source will reduce the sound level by about 6 dB when the propagation path is considered as homogeneous (see Figure 8.1).

When the distance from the source to the receiver is small, as might be the case when measurements are made adjacent to a high traffic density road where the source consists of many vehicles along the road (the sound

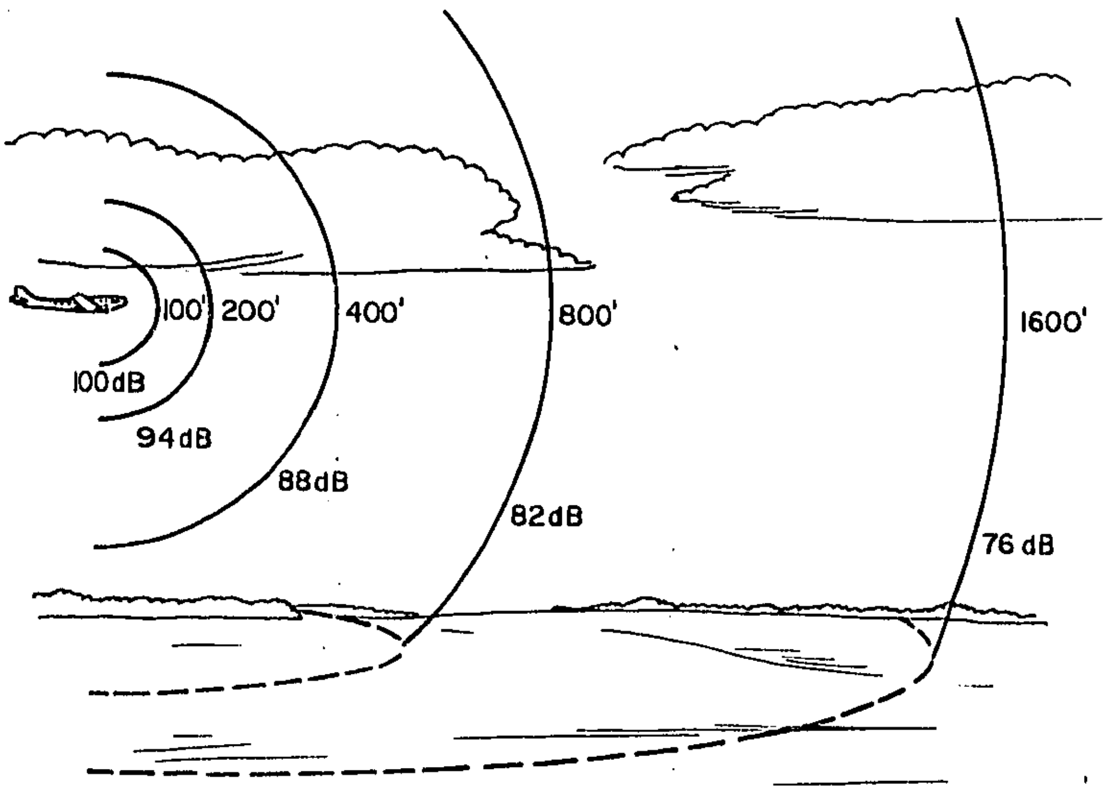


Figure 8.1. Spherical wave spreading

source is more like a line than a point), the sound spreads in a cylindrical manner. Cylindrical sound spreading usually produces a sound level drop-off rate approaching 3 dB with doubling of distance (see Figure 8.2). Obviously, there are situations where the sound level drop-off rate will fall between 3 and 6 dB with doubling of distance, and the drop-off rate may be even lower than 3 dB with doubling of distance in areas where there are large reflecting surfaces.

8.2 Absorption Effects from Earth Surfaces and the Atmosphere

It is difficult to discuss the effects of absorption, reflection, or transmission loss exclusively because of their complex interactions in practical situations. However, an appreciation of each of these factors can be developed from practical examples and from some simple theoretical consideration.

Any material can have an absorption coefficient, α, assigned to denote the fraction of sound energy that is absorbed by the material from an incident sound wave (see Table 8.1). For example, an absorption coefficient of $\alpha = 0.3$ would indicate that 30 percent of the incident energy is absorbed by the material. In terms of decibels (dB) this reduction in energy would be:

$$10 \log \frac{\text{incident minus absorbed energy}}{\text{incident energy}}$$

$$\text{or} \quad 10 \log \frac{1 - 0.3}{1} = -1.6 \text{ dB}$$

Unfortunately, the treatment of absorption is not this simple because the absorption coefficient of each material depends upon the spectrum of the sound and the angle of incidence. Thus, the spectrum of the sound must be determined and high-level frequency bands of interest must be treated separately, or an approximate absorption coefficient must be determined for an overall weighted sound level. In addition, absorption coefficients are normally given for randomly incident sounds and these values may not accurately describe the coefficients at specific angles of incidence.

Absorption materials may be divided into two categories:

1. Poor absorbers and efficient reflectors. Acoustically hard and smooth surfaces of materials such as brick, concrete, stone, wood, plaster, water (mud), etc., generally absorb less than 20 percent of the energy from incident sound waves (see Table 8.1). Thus, this category of materials can be considered to be insignificant absorbers of sound (less than 1 dB reduction).

2. Moderate and frequency selective absorbers. Materials such as thin panels and porous building materials afford a significant amount of absorption of sound as shown in Table 8.1. It should be noted that the absorption coefficients of some of these materials can be changed considerably by treatment of the surfaces with paint or glazing.

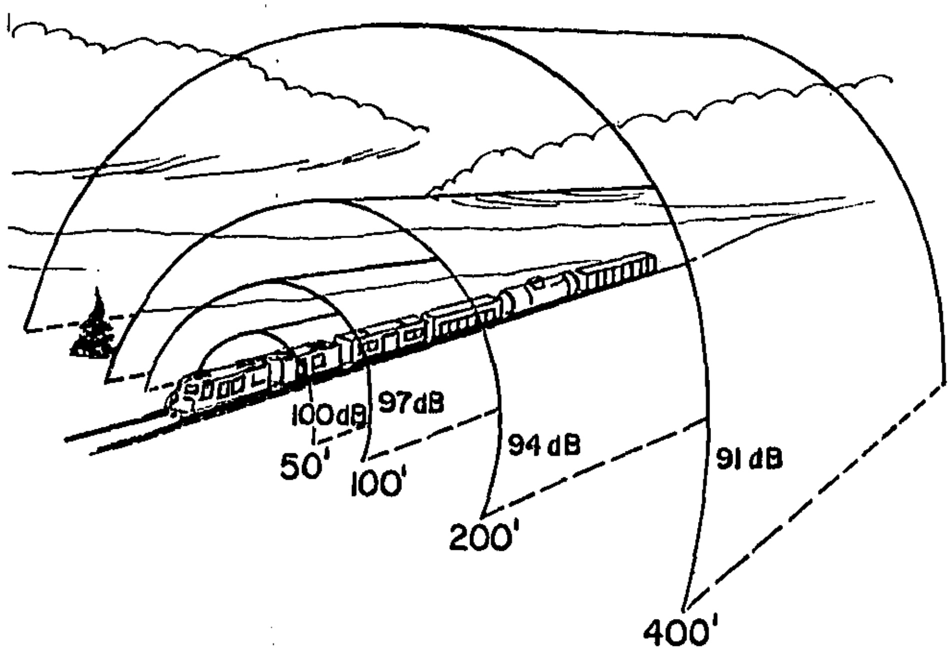


Figure 8.2. Cylindrical wave spreading

Table 8.1

SOUND ABSORPTION COEFFICIENTS OF TYPICAL MATERIALS

The absorption coefficient (α) of a surface that is exposed to a sound field is the ratio of the sound energy absorbed by the surface to the sound energy incident upon the surface. For instance, if 55% of the incident sound energy is absorbed when it strikes the surface of a material, the α of that material would be 0.55. Since the α of a material varies according to many factors, such as frequency of the noise, density, type of mounting, surface conditions, etc., be sure to use the α for the exact conditions to be used and from performance data listings such as shown below. For a more comprehensive list of the absorption coefficients of acoustical materials, refer to the bulletin published yearly by the Acoustical Materials Association, 335 East 45th Street, New York, NY 10017.

Materials	Frequency (Hz)					
	125	250	500	1000	2000	4000
Brick--glazed	.01	.01	.01	.01	.02	.02
--unglazed	.03	.03	.03	.04	.05	.07
--unglazed, painted	.01	.01	.02	.02	.02	.03
Carpet--heavy, on concrete	.02	.06	.14	.37	.60	.65
--on 40 oz. hairfelt or foam rubber (carpet has coarse backing)	.08	.24	.57	.69	.71	.73
--with impermeable latex backing on 40 oz. hairfelt or foam rubber	.08	.27	.39	.34	.48	.63
Concrete block--coarse	.36	.27	.39	.34	.48	.63
--painted	.10	.05	.06	.07	.09	.08
--poured	.01	.01	.02	.02	.02	.03
Fabrics						
Light velour--10 oz. per sq yd hung straight, in contact with wall	.03	.04	.11	.17	.24	.35
Medium velour--14 oz per sq yd draped to half area	.07	.31	.49	.75	.70	.60
Heavy velour--18 oz. per sq yd draped to half area	.14	.35	.55	.72	.70	.65
Floors						
Concrete or terrazzo	.01	.01	.015	.02	.02	.02
Linoleum, asphalt, rubber or cork tile on concrete	.02	.03	.03	.03	.03	.02
Wood	.15	.11	.10	.07	.06	.07
Wood parquet in asphalt on concrete	.04	.04	.07	.06	.07	

Table 8.1 (continued)

Materials	Frequency (Hz) 125	250	500	1000	2000	4000
Glass						
Large panes of heavy plate glass	.18	.06	.04	.03	.02	.02
Ordinary window glass	.35	.25	.18	.12	.07	.04
Glass Fiber--mounted with impervious backing--3 lb/cu ft, 1" thick	.14	.55	.67	.97	.90	.85
--mounted with impervious backing--3 lb/cu ft, 2" thick	.39	.78	.94	.96	.85	.84
--mounted with impervious backing--3 lb/cu ft, 3" thick	.43	.91	.99	.98	.95	.93
Gypsum Board--1/2" nailed to 2 x 4's, 16" o.c.	.29	.10	.05	.04	.07	.09
Marble	.01	.01	.01	.01	.02	.02
Openings						
Stage, depending on furnishings				.25-.75		
Deep balcony, upholstered seats				.50-1.00		
Grills, ventilating				.15-.50		
Grills, ventilating to outside				1.00		
Plaster--gypsum or lime, smooth finish on tile or brick	.013	.015	.02	.03	.04	.05
--gypsum or lime, rough finish on lath	.14	.10	.06	.05	.04	.03
--with smooth finish	.14	.10	.06	.04	.04	.03
Plywood paneling--3/8" thick	.28	.22	.17	.09	.10	.11
Sand						
Dry 4" thick	.15	.35	.40	.50	.55	.80
Dry 12" thick	.20	.30	.40	.50	.60	.75
14 lb water per cu ft, 4" thick	.05	.05	.05	.05	.05	.15
Water	.01	.01	.01	.01	.02	.02

Absorption or attenuation of sound traveling over the earth's surface depends upon the structure and the covering of the ground, and upon the heights of the source and receiver. Attenuation data have been developed only for general cases, usually with the assumption that the sound is traveling parallel to the earth's surface, less than 10 feet above low ground cover (grass or shrubs) and less than 30 feet above high cover (trees). For these conditions the approximate attenuation for grass, shrubs and trees are presented in Figures 8.3 and 8.4 (4). Details on theoretical calculations and actual measurements may be found in references 2, 4 and 6-28. A recent study by Borthwick (29) demonstrates that the attenuation provided by ground cover should not be considered as linear. In other words it should not be described in units of dB/m. Narrow belts of trees have been shown to be far more effective for attenuating sound than wider belts. However, data are usually presented in this manner for convenience because of the complex alternatives. In any case, such attenuation data must be considered as applicable only for that particular situation, and only an approximation for general situations.

Absorption of sound by the atmosphere must be described in terms of the frequency characteristics of the sound, and the parameters of relative humidity and temperature. A-weighted sound pressure levels depend mainly upon the strength of high frequency components; thus, relative humidity is of primary concern, while temperature changes contribute only second-order effects (30). Figure 8.5 shows the distances for 3 dB reductions in A-weighted levels due to atmospheric absorption as a function of relative humidity for sources with the noise spectra shown in Figure 8.6.

8.3 Reflection and Transmission Loss from Barriers

The capability of a material for preventing the passage of sound through it is described by the transmission loss, TL, which is defined by

$$TL = 10 \log \frac{\text{sound energy incident}}{\text{sound energy transmitted.}}$$

Materials having high TL are usually heavy and impervious. In contrast, absorbers are generally lightweight and porous.

Long distance outdoor sound propagation is affected by surface reflection and by reflections from, transmission loss through, and diffraction around, barriers in the sound propagation path. Figure 8.7 shows reflection from, and transmission through, a barrier. As a general rule the losses in propagated sound levels are significant only if either the sound source or the receiver is closer to the barrier than about 10 times the maximum dimension of the barrier. In an area where there are strong reflections (a highly reverberant sound field) sound levels may remain the same or even increase as the distance between the source and receiver is increased.

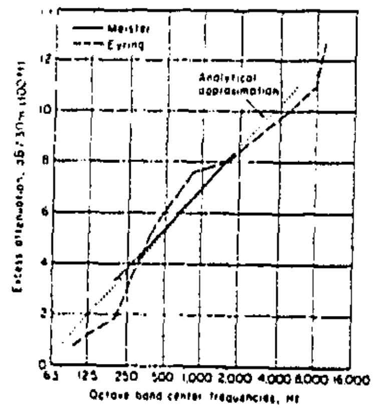


Figure 8.3. Attenuation for sound propagation through continuous shrubbery and over thick grass; Measured data and analytical approximation. The attenuation shown should not be used when the path from source to receiver exceeds about 30 meters (100 feet).

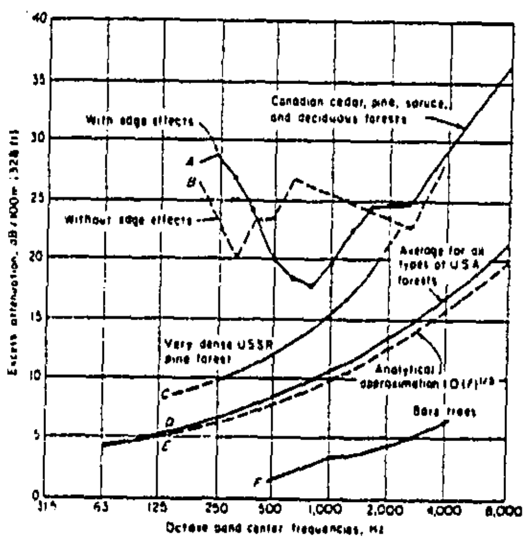


Figure 8.4. Attenuation for sound propagation in continuous tree zones; Measured data and analytical approximation for average U.S.A. forests. The attenuation shown should not be used when the path from source to receiver exceeds about 100 meters (328 feet).

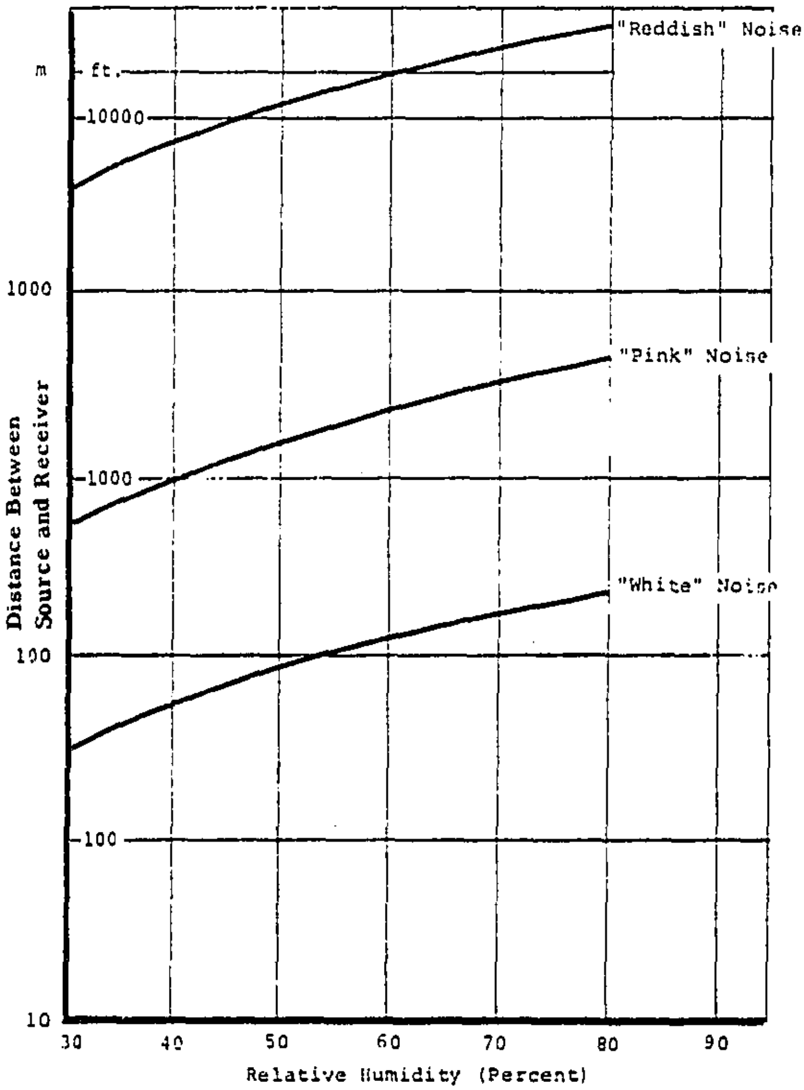


Fig. 8.5. Distance for 3 dB deviation from inverse square law spreading due to atmospheric absorption vs. relative humidity at a temperature of 20C (68F). Parameter: Spectral distribution of intensity. (See Fig. 8.6.)

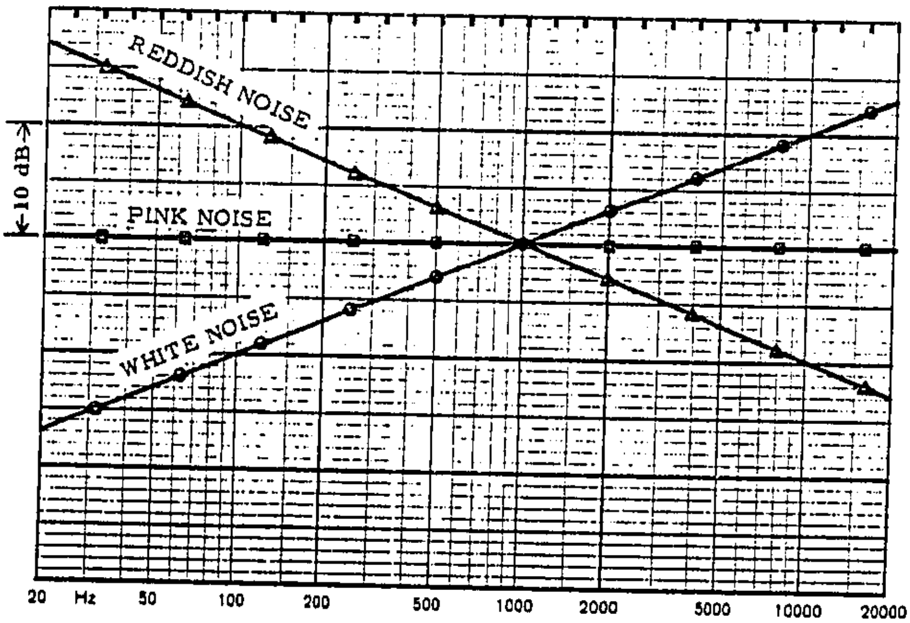
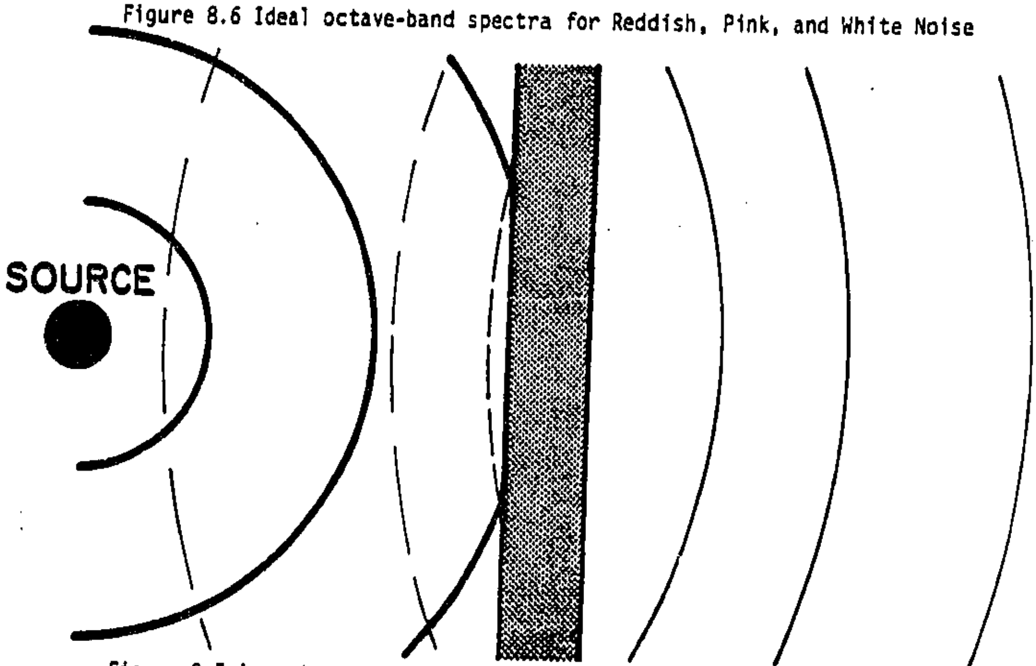


Figure 8.6 Ideal octave-band spectra for Reddish, Pink, and White Noise



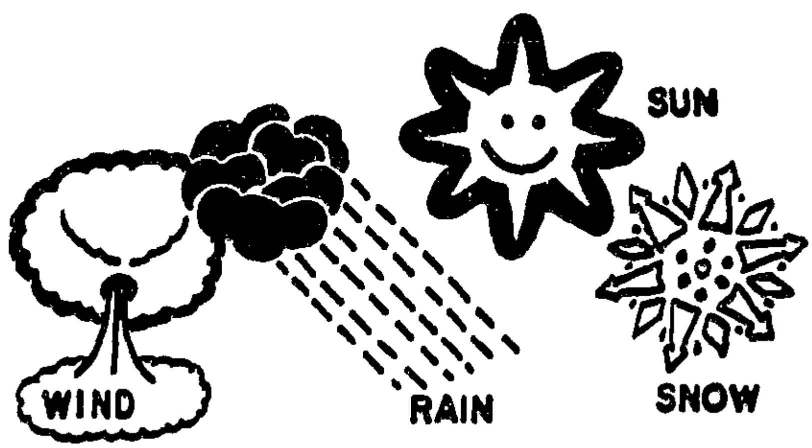
.Figure 8.7 Asound wave striking a barrier

Reflections from the earth's surface may also increase the level of sound propagated but this effect is generally less than 2 dB over flat ground surfaces and it is extremely complex to predict over large distances. Generally, a hard smooth surface such as concrete, asphalt, or packed dirt must cover more than half of the distance between the observer and the sound source for the level to be raised by as much as 2 dB assuming there are no prominent discrete tones in the noise.

The attenuation of sound provided by a barrier depends upon the density and the physical size of the barrier, and upon the spectrum of the sound source. To achieve maximum attenuation the barrier must be airtight so that there will be no sound leaks. The propagation of sound through or around a barrier also depends upon the acoustical environment on both sides of the barrier. As a general rule, the transmission loss provided by an airtight barrier will increase with increasing density of that barrier up to about 4 lb/sq.ft. However, atmospheric scattering imposes a practical limit of about 24 dB on the reduction in A-weighted sound level that can be expected from a barrier. Ground contours and covers can of course change these limits significantly in some cases. For additional information use references 13 and 30-33.

8.4 Effects of Weather Conditions on Noise Propagation

The effects of weather conditions on noise propagation are extremely difficult to predict because of the very large number of different atmospheric conditions that may have an effect on propagation. When noise travels over considerable distances through the atmosphere, the sound pressure level received may fluctuate more than 25 dB at large distances from the source depending upon wind direction, temperature inversions, precipitation, and other variables. Also, the sound pressure level will often fluctuate over short periods of time. Thus, community noise measurements are normally done under calm and stable weather conditions in order to get the most conservative and consistent readings.



Wind and temperature gradients may cause "shadow zones" where the sound is bent upwards, but these effects are very complex and difficult to predict. On a clear sunny day with winds as low as 10 mph, the excess attenuation at a given point upwind may be 20 dB higher than for the same distance downwind.

The presence of fog or precipitation normally reduces the excess attenuation because wind and temperature gradients tend to be small under these conditions. Also, there is some laboratory evidence that fog may provide increased attenuation above that predicted for molecular absorption. (34)

Sound traveling through air loses energy from the effects of heat conduction, viscosity, diffusion, and from molecular absorption. In most cases, molecular absorption causes the major loss of sound energy. In calculations to determine the amount of sound absorption in air, the frequency characteristics of the sound, the air temperature, and the humidity are important factors. For example, for sounds with major frequency components in the center of the audible band, the excess attenuation due to molecular absorption will be about 5 dB for distances of about 2000 feet. At larger distances and higher frequencies the major reduction in sound reaching the receiver is due to wind shear, temperature gradients, and turbulence. Measurements within distances of less than about 33 meters (100 feet) are not often affected by such meteorological conditions.

It is apparent from this section that sound propagation depends on the physical characteristics of the sound source, the characteristics of the medium through which it passes, and the characteristics of objects and surfaces it encounters along the path from source to receiver. Knowledge of these principles can aid in controlling the level of sound exposures.

REFERENCES

1. Morse, P.M. and Bolt, R.H., Sound Waves in Rooms, Rev. Modern Physics, 16, no. 2, 69-150, April, 1944.

2. Delany, M.E. and Bazley, E.N., Acoustic Properties of Fibrous Absorbent Material, Applied Acoustics, 3, 10-5116, 1970.

3. Wesler, J.E., "Manual for Highway Noise Prediction," U.S. Department of Transportation Report No. DOT-TSC-FHWA-72-1, March, 1972.

4. Winer, F.M. and Keast, D.M., Experimental Study of the Propagation of Sound Over the Ground, Journal Acoustical Society of America, 31, pp. 724-733, 1959.

5. Wenzel, A.R., Saturation Effects Associated with Sound Propagation in a Turbulent Medium, Progress in Astronautics and Aeronautics, MIT Press, pp. 67-75, 1976.

6. Embelton, T.F.W., Piercy, J.E. and Olson, N., Outdoor Sound Propagation Over Ground of Finite Impedance, J. Acous. Soc. Am., 59, no. 2, pp. 267-277, Feb., 1976.

7. Pao, S.P. and Evans, L.B., Sound Attenuation Over Simulated Ground Cover, J. Acoust. Soc. Am., 49, no. 4, (Part I), pp. 1069-1075, April, 1971.

8. Delany, M.E., and Bazley, E.N., A Note on the Effect of Ground Absorption in the Measurement of Aircraft Noise, JSV, 16, 315-322, 1971.

9. Piercy, J.E., Embleton, T.F.W., and Olson, N., Impedance of Soft Ground and Its Effect on Practical Measurements, JASA, 54, p. 341(A), 1973.

10. Piercy, J.E., Embelton, T.F.W. and Olson, N., Effect of the Ground on Near-Horizontal Sound Propagation, Society of Automotive Engineers, reprint 740211, 1974 SAE Transactions, Sec. 1, vol. 83, 1974.

11. Piercy, J.E., Donato, R.J. and Embleton, T.F.W., Near-Horizontal Propagation of Sound Over Grassland, JASA, 60, Suppl. 1, 1976, San Diego, CA.

12. Dickinson, P.J. and Doak, P.E., Measurements of the Normal Acoustic Impedance of Ground Surfaces, J. Sound Vib., 13, no. 3, 309-322, 1970.

13. Jonasson, H.G., Sound Reduction by Barriers on the Ground, J. Sound Vib, 22, no. 1, 113-126, May 8, 1972.

14. Lanter, Sean K., A Method for Determining Acoustic Impedance of Ground Surfaces, Master's Thesis, Department of Mechanical and Industrial Engineering, University of Utah, June 1977.

15. Tillotson, J.G., Attenuation of Sound Over Snow-Covered Fields, J. Acoust. Soc. Am., 39, no. 1, 171-173, January 1966.

16. Nyborg, W.L., Rudnick, I., and Schilling, H.K., Experiments on Acoustic Absorption in Sand and Soil, J. Acoust. Soc. Am., 22, no. 4, 422-425, July 1950.

17. Embleton, T.F.W., Thiessen, G.J., and Piercy, J.E., Propagation in an Inversion and Reflections at the Ground, JASA, 59, 278-282, 1976.

18. Scholes, W.E. and Parkin, P.H., The Effect of Small Changes in Source Height on the Propagation of Sound Over Grassland, J. Sound Vib., 6, 424-442, 1967.

19. Oncley, P.B., Low Frequency Ground Attenuation in Outdoor Noise Measurements, J. Acoust. Soc. Am., 31, 724-733, 1959.

20. McDaniel, O.H. and Reethof, G., The Use of Forests for Noise Control, Proceedings of the Third Interagency Symposium on University Research in Transportation Noise, University of Utah, November 12-14, 1975.

21. Leonard, R.E., and Herrington, L.P., "Noise Abatement in a Pine Plantation," USDA Forest Service Research Note NE-140, 1971.

22. Wenzel, A.R., Propagation of Waves Along an Impedance Boundary, J. Acoust. Soc. Am., 55, 956-963, 1974.

23. Embleton, T.F.W. Piercy, J.E., and Olson, N., Outdoor Sound Propagation Over Ground of Finite Impedance, J. Acoust. Soc. Am., 59, 267-277, 1976.

24. Pao, S.P. and Evans, L.B., Sound Attenuation Over Simulated Ground Cover, J. Acoust. Soc. Am., 49, 1069-1075, 1971.

25. Attenborough, K., and Heaps, N., Sound Attenuation Over Ground Cover, The Shock and Vibration Digest 1, 73-83, Oct., 1975.

26. Officer, C.B., Introduction to the Theory of Sound Transmission, McGraw-Hill, 1958.

27. Zwikker, C. and Kosten, C.W., Sound Absorbing Materials, Elsevier, 1949.

28. Reethof, G., Frank, L.D., and McDaniel, O.H., The Contribution of the Forest Floor as a Sound Absorbing Element Within a Forest, In press, to be published as a USDA Forest Service Research Paper.

29. Borthwick, Jesse O., Attenuation of Highway Noise by Narrow Forest Belts, M.S., Thesis, Aug., 1977, The Pennsylvania State University.

30. "A Study of the Magnitude of Transportation Noise Generation and Potential Abatement. Final Report. Vol IV, DOT Report No. OST-ONA-71-1, November, 1970.

31. Donato, R.J., Propagation of a Spherical Wave Near a Plane Boundary with a Complex Impedance, J. Acoust, Soc. Am., 60, no. 1, 34-39, July, 1976.

32. Donato, R.J., Spherical-Wave Reflection from a Boundary of Reactive Impedance Using a Modification of Cagniard's Method, J. Acoust. Soc. Am., 60, no. 5, 999-1002, Nov., 1976.

33. Briquet, M. and Filippi, P., Diffraction of a Spherical Wave by an Absorbing Plane, J. Acoust. Soc. Am., 61, no. 3, 640-646, March, 1977.

34. Paul, D.I., Wave Propagation in Acoustics Using the Saddle Point Method, J. Math. Phys., 38, 1-15, 1959.

Chapter 9

LAND USE PLANNING AND NOISE CONTROL TECHNIQUES

Acceptable noise levels are based for most communities upon the reactions of the residents. The achievement of acceptable noise levels in the community requires that the community include noise as an element in its planning effort. Care should be taken to assess the noise impact of new developments, highways, and airports before they are built. It is much easier to control noise in this manner. There are, however, some techniques that can be used to ameliorate existing noise problems. The present chapter will discuss both the prevention of noise problems through intelligent planning and the reduction of noise through physical control measures.

9.1 Land Use Planning

The demands of expanding urbanization coupled with the diverse interests to be accommodated in the typical community necessitate that communities take positive steps to plan their futures. As part of this effort, consideration should be given to the noise environment of the community. Several extensive discussions of planning and noise control have been published (1-4), and from these reviews four major planning or planning-related techniques applicable to the problem of noise control can be identified. These include: comprehensive planning, zoning, site planning, and building design. It should be pointed out that planning related solutions are future oriented--they seldom provide immediate answers.

9.1.1 Comprehensive Planning

Most communities spend considerable time and money developing a comprehensive plan. This usually takes the form of a public document that contains policy guidelines for the community's future physical development. The typical comprehensive plan contains statements pertaining to the private uses of land, community facilities, and transportation (5). Almost without exception, a major aspect of these plans is land use compatibility. The problem is to provide areas compatible for different land uses such as industry, commerce, recreation, and residential living, and to interconnect these areas with a transportation network (4).

Land use policies should not be set without serious consideration of the noise environment. But only recently have attempts been made to give such consideration. The impetus for this has come from several directions. First, there is an increasing awareness of and concern for environmental quality among the general public. Second, the National Environmental Policy Act (6) passed in 1969 requires the preparation of environmental impact statements for all Federal government related projects affecting the quality of the human environment. And third, various Federal agencies such as the U.S. Department of Housing and Urban Development (HUD) and the Federal Highway Administration have issued noise standards which must be met before funds can be obtained from them* (7,8). In addition, other environmental and health and safety legislation passed in the previous 10 years has had at least an indirect influence on concern with noise pollution. Given these circumstances, planning without respect to noise can prove costly to the community both in terms of time and money.

In the development of the comprehensive plan, primary attention should be given to airports and surface transportation systems as these are the most pervasive noise sources in the typical community. Care should be taken to insure that development in the immediate environs of these sources is either discouraged or closely scrutinized in terms of its compatibility with the existing environment. Compatible uses for lands surrounding airports and other high noise areas might include (3):

1) Land uses involving few people, such as warehouses, sewage treatment plants, reservoirs, etc.
2) Uses which are inherently noisy, such as truck terminals, printing plants, etc.
3) Indoor uses -- where sound insulation would protect those indoors.

Industrial and recreational areas provide other major sources of noise in the community. Very often the development of industrial parks serves to separate industrial areas from residential areas. In the planning of recreation areas care should be taken to separate these facilities from noise sensitive areas such as hospitals and schools. Sometimes the inclusion of recreation areas in large sections of open space allows the noise emanating from such a facility to dissipate before it intrudes into a more sensitive area. For the most part it is desirable to separate certain types of recreation areas from high noise areas as well.

At this time, it is not possible to enumerate a list of do's and don'ts for controlling noise through comprehensive planning. The important point is that each community should consider noise as an element in its planning strategy. In any event, a noise map of the community should be developed. This map should identify areas of high noise as well as noise sensitive areas. Such a map could serve as a guide to future development, and insure that noise impact is a consideration in land use decisions affecting the future of the community.

---

*Although Federally established noise standards are intended to encourage planning for quiet communities, they are no guarantee the intended goals will be realized. Since the standards can be circumvented, the most effective way to insure a quiet community is to enact workable local noise control legislation.

9.1.2 Zoning

Zoning is probably the most popular means of implementing the comprehensive plan. Zoning is a legal technique which classifies an area into districts, and specifies permitted land uses for each district. These ordinances often contain building height, size, and setback limitations as well as open space and population density regulations. Traditionally zoning ordinances have specified the type of land use permitted in an area, but more recently many zoning efforts have become performance based. For example, an area zoned as light industrial might be required to meet a set of performance standards such as maximum allowable noise levels. The ordinances in effect today show wide variation in the noise levels permitted at area boundaries (9, 10). Data from more than 100 cities with established noise ordinances show an average daytime allowable L_A of 57 dB and an average nighttime allowable L_A of 52 dB for residential neighborhoods. In business and commercial districts, the average allowable L_A is 63 dB in the daytime and is 59 dB at night. The average allowable L_A in manufacturing and industrial areas is 68 dB in daytime hours and 64 dB at night. Individual cities in this survey have established higher or lower allowable levels based on consideration of individual city problem areas and realistically achievable noise reduction goals.

The EPA model community noise ordinance (see Appendix A) contains a section on land use provisions. These provisions are designed either to be included as part of the noise ordinance itself, or as amendments to existing land use or zoning laws. Since, in terms of its noise problems, each community is somewhat unique, the drafters of the model ordinance made no attempt to set specific limitations for particular zones or land uses. The determination of performance standard noise levels and hours of curfew are left up to the discretion of the community. However, guidelines concerning safe levels of environmental noise have been compiled by the EPA (11). Table 9.1 contains a brief summary of those noise levels that have been deemed by EPA as being adequate to protect the individual from hearing loss and from disruption of indoor or outdoor activities.

Zoning is not without its problems. One major problem centers on the issue of jurisdiction. For example, regional airports are often located in more than one political unit, and thus adequate zoning requires the enactment of laws from more than one unit. Solution to this type of problem requires some form of cooperative activity among the units involved, or the establishment of a single metropolitan agency empowered to zone the total area. In any case, all zoning and land use plans should require approval by the city officials responsible for control of community noise.

For zoning approaches to noise control to be successful, there must be a serious commitment to noise control in the community. In many communities variances are routinely granted, and this counteracts the best designed zoning attempt.

Table 9.1

SUMMARY OF NOISE LEVELS IDENTIFIED AS REQUISITE TO PROTECT PUBLIC HEALTH AND WELFARE WITH AN ADEQUATE MARGIN OF SAFETY

EFFECT	LEVEL[1]	AREA
Hearing Loss	$L_{eq(24)}$ 70 dB	All areas
Outdoor activity interference and annoyance	L_{dn} 55 dB	Outdoors in residential areas and farms and other outdoor areas where people spend widely varying amounts of time and other places in which quiet is a basis for use.
	$L_{eq(24)}$ 55 dB	Outdoor areas where people spend limited amounts of time, such as school yards, playgrounds, etc.
Indoor activity interference and annoyance	L_{dn} 45 dB	Indoor residential areas
	$L_{eq(24)}$ 45 dB	Other indoor areas with human activities such as schools, etc.

[1]Detailed discussions of the terms L_{dn} and L_{eq} appear in Chapter 11. Briefly, $L_{eq(24)}$ represents the sound energy averaged over a 24-hour period while L_{dn} represents L_{eq} with a 10 dB nighttime weighting.

9.1.3 Site Planning

Good site planning can aid in the attenuation of noise from exterior sources as well as the restriction of noise levels at the surrounding property line boundaries. The achievement of noise reduction through site planning requires a thorough knowledge and understanding of the characteristics of sound propagation (see Chapter 8). In noise-sensitive areas developers should be required to present noise contours for proposed development sites, and these should be reviewed by some appropriate agency or authority to insure that noise levels do not exceed prescribed limits. Building heights, densities, and configurations all influence noise levels. An extreme example of this is the placement of tall skyscrapers close together virtually at the curbs of busy streets. Such an arrangement creates a pattern of reflections and reverberations called a "noise corridor" (4). Consideration should be given to the elevation and topography of the proposed site as they can influence the noise characteristics of the site. For example, the construction of an apartment building on the crest of a hill may subject residents to considerable noise from the traffic arteries below (12). At the same time, the physical characteristics of the land surrounding the site, such as forests, hills, bodies of water, etc. also contribute to the total noise environment and thus should not escape scrutiny.

In large scale developments the buildings comprising the development can be oriented in various ways to form optimum acoustical shielding. The orientation of a U-shaped building so that its open side directly faces the roadway creates a highly reverberant and thus undesirable location. Simply turning the building around and orienting it away from the street reduces this problem, while at the same time providing a protected outdoor courtyard (12). Separation of play fields from classrooms in a school site, or the location of an apartment complex swimming pool away from an apartment courtyard can also contribute to noise level reduction. Noise factors should be a central aspect of a good site plan.

Highways that must go through residential areas should be designed with as few intersections as possible. Sharp grades requiring hard acceleration or deceleration should also be avoided. One way to reduce highway noise is to build a "depressed" highway below the general elevation of the landscape. Changes such as these often accompany development. Such secondary impacts as poorly designed traffic patterns or poorly synchronized traffic lights should be anticipated in any development.

9.1.4 Building Design

It should be pointed out that noise reduction achieved through good building design protects the individual only while he or she is inside the structure. The use of sound absorbing materials on the exteriors of buildings can result in somewhat lower outdoor noise levels. The shape of the building itself can also affect the outside noise level. Interior design considerations such as location and arrangement of sleeping and living quarters in homes or classrooms and cafeterias in schools can contribute to the reduction of interference from noise and provide acoustic privacy. The use of sound absorbing materials and furnishings also aids in interior noise reduction.

At the heart of the building design aspect of noise control is the issue of building codes. There are two general types of building codes -- performance codes and material codes. Performance codes specify a certain performance level in noise reduction for the particular structure, component, or machine in question. Material codes specify in detail the particular material to be used in a particular type of construction. Overall, performance codes are more effective if properly enforced, while material codes take the burden off enforcement requirements. On the other hand, material codes have been accused of discouraging innovation in building materials (2).

Largely as a matter of necessity, many European countries have developed building codes that are more advanced than those in the U.S. However, the pressures of urbanization, population growth, and energy conservation should contribute to the improvement of building codes in the U.S.

9.1.5 Other Planning Related Techniques

In addition to the techniques and actions discussed above, there are other actions that a community can take to control noise. Most of these techniques have been employed in the past to curb airport noise.

The community can pass restrictions that, although not eliminating a source, will reduce its disruption of human activity. Communities can ban aircraft landings at certain times of the day or night. Within safety limits, airports can alter runway usage to reduce noise. Steps can be taken to closely monitor noise levels under flight paths and thus insure the enforcement of FAA promulgated flight procedures. Truck noise can be reduced through the establishment of truck routes or through the banning of truck traffic in selected areas at certain times of the day or night.

The use of financial incentives also may be an effective means of controlling noise. Landing fees at airports can be manipulated to encourage landings at certain times and to discourage landings at other times. Preferential tax treatment can be used to discourage development in high noise areas, or to encourage the use of sound proofing. A limitation in extension of utilities such as electricity, gas, etc. might also be used to discourage development in certain areas.

Communities can defend themselves from a noise source by the direct purchase of land surrounding the source. This action provides a noise "buffer zone" that discourages both development near the source and the further encroachment by the source into the community. Direct payments of money to compensate those whose property use is interfered with by noise (aviation easements) is another possible action. Obviously, this approach does nothing to improve environmental quality.

Community noise ordinances often help in noise reduction. Most ordinances have traditionally fallen under the category of nuisance-type laws, which prohibit noises that are deemed "excessive and unnecessary". Nuisance ordinances are by definition subjective, and have in practice proved difficult to enforce. Recent attempts have been made to define unlawful noise in measureable terms (dB), and to use technical measurements in enforcement. These laws typically provide disturbance provisions as well as performance standards for motor vehicles and other sources of community noise (see Appendix A). Some examples of noise ordinances incorporating land use planning are included in references 13 and 14. Reference 14 gives simple procedures for developing a land use plan for noise control.

9.1.6 Summary

The purpose of this section has been to discuss some of the planning and planning-related techniques for noise control. The major point of this section is that active consideration to noise should be given in the planning efforts of every community. The approach to noise control taken by a particular community depends on the nature of the noise sources and their impact, and on the environmental and economic circumstances of the community. It is the responsibility of each particular community to select those tools and actions that are most appropriate for its particular noise problems.

9.2 Physical Noise Control Procedures

The goal of any noise control procedure is to reduce the sound reaching the observer's ears. Obviously reducing the sound produced by the source will accomplish this purpose and should be the ultimate goal of any noise control program. However, since reduction of noise at the source is usually limited, or beyond the control of the local community, it may be necessary to use noise control procedures around the source or the observer, or along the sound propagation path.

9.2.1 Fundamentals of Noise Control

An explanation of basic techniques of noise control will help to understand how noise can be reduced in a community. Figure 9.1 shows a machine which produces noise over a wide range of frequencies. A sound level meter represents the receiver of the sound. The sound level reading will, of course, depend on the distance separating the sound source and the receiver, and the location of reflecting surfaces. If there are no nearby reflecting surfaces, simply increasing the distance between the noise source and the receiver can be a very effective method of reducing the received noise. About six dB for each doubling of distance is the maximum reduction possible but if there are reflecting surfaces nearby the reduction may be much less than expected or non-existent.

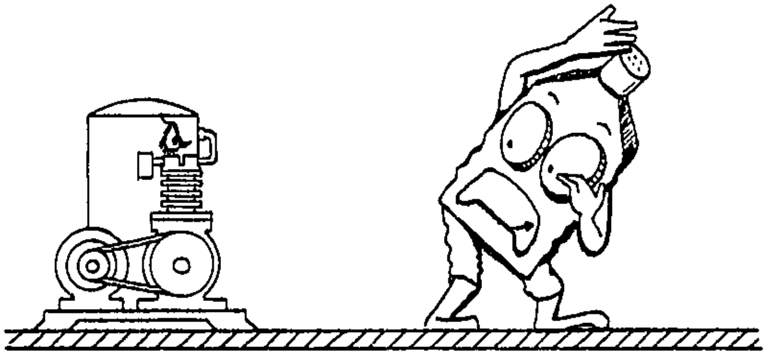


Figure 9.1. A machine producing a high level of noise over a wide range of frequencies.

A single-wall barrier placed in the path between the noise source and the receiver as shown in Figure 9.2 may reduce the sound level at the receiver. The effectiveness of a single-wall barrier is proportional to the mass of the barrier, its physical dimensions relative to the size of the source of noise, the distance of the source and receiver from the barrier, and the distribution of sound energy with frequency. High frequencies will generally be reduced more than low frequencies. Absorbing material on the sides of the barrier will help reduce build-up of high frequency standing waves if reverberant energy is present.

Often, noisy machines are placed behind a heavy wall to block the sound from an office or otherwise occupied space. When the wall is not completed to the floor above, some sound will leak over the top of the wall into the occupied space (see Figure 9.3). While a dropped acoustical ceiling will improve the physical appearance and will reduce sound build-up in the occupied space, the acoustical ceiling has very little effect on the sound passing over the top of the barrier into the space above the acoustical ceiling.

Completely enclosing the noise source with rigid, massive walls as in Figure 9.4 can result in a significant reduction in the observed sound level. The noise reduction will be proportional to the mass and stiffness of the enclosure walls but this reduction may be less than expected due to flanking paths that may cause sound to be re-radiated from solid-borne vibration and from airborne sound leaking through openings such as doors, windows, ventilation ducts, electrical outlets, etc.

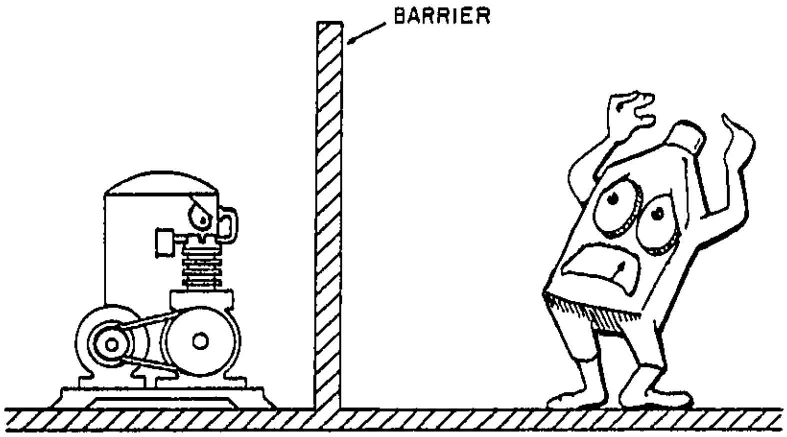


Figure 9.2. A single-wall barrier, placed in the sound path, produces a measurable drop in high-frequency noise levels received, particularly when the source and receiver are close to the barrier.

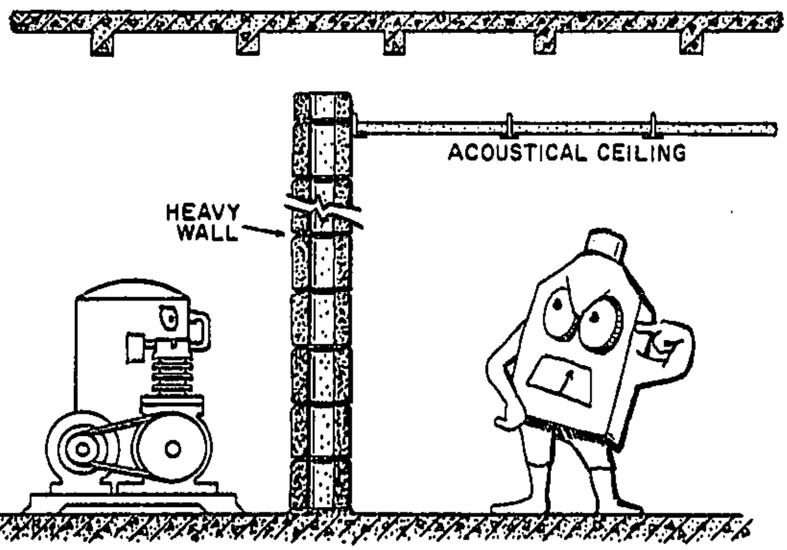


Figure 9.3. An acoustical ceiling is often effective for reducing sound build-up within a room, but provides little reduction (transmission loss) of sounds coming over the top of a wall.

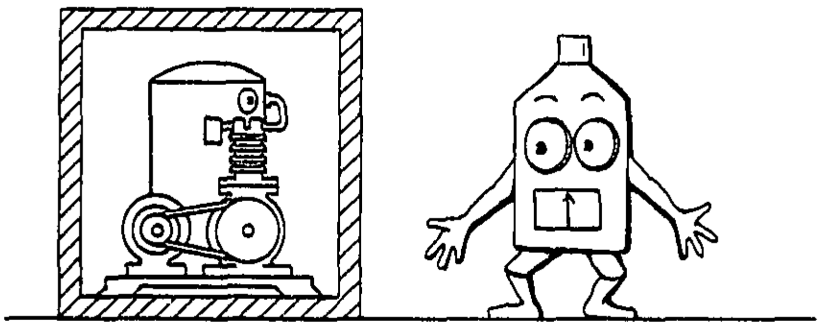


Figure 9.4. A complete rigid-walled enclosure results in a measurable reduction in the noise level.

Ratings of the sound attenuation provided by barriers are based on the assumption that all of the sound energy incident upon one face of the barrier is radiated from the opposite face. Any opening in the barrier including cracks caused by shrinkage of the material may seriously degrade the performance of the barrier. For example, a crack only 0.01 inch wide and 12 ft long in a wall 8 ft x 12 ft can reduce the attenuation from 40 dB to 37 dB or from 50 dB to 40 dB. A good rule of thumb is that if air can get through the barrier, sound will also get through.

Significant levels of mechanical vibrations from a noise source such as in Figure 9.4 may be transmitted directly to the walls of the enclosure or to other surfaces outside the enclosure when the device is mounted rigidly to one of the inside surfaces. Proper vibration isolators placed under the mounting points of the noise source as shown in Figure 9.5 will reduce the coupled vibration and can significantly reduce the level of radiated sound outside the enclosure.

Although the rigid walls of the enclosure in Figure 9.5 may be effectively blocking the sound from passing through, they are also effective in reflecting the sound back inside the enclosure and can result in a build-up of sound within the enclosure. This build-up of sound can be reduced, especially at high frequencies, by lining the inside of the enclosure with sound absorbing material as indicated in Figure 9.6.

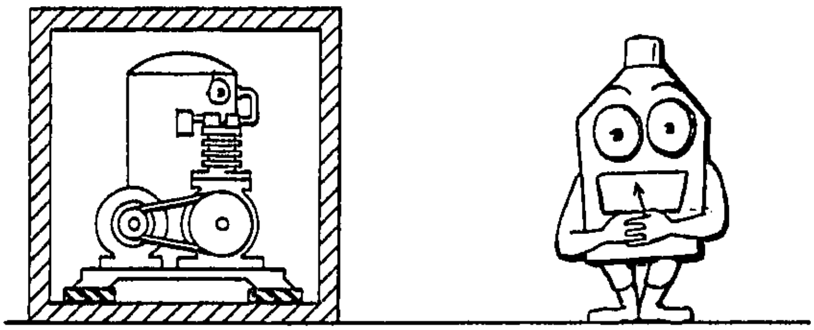


Figure 9.5. Vibration isolators under the machine inside the enclosure help to reduce structure-borne sound.

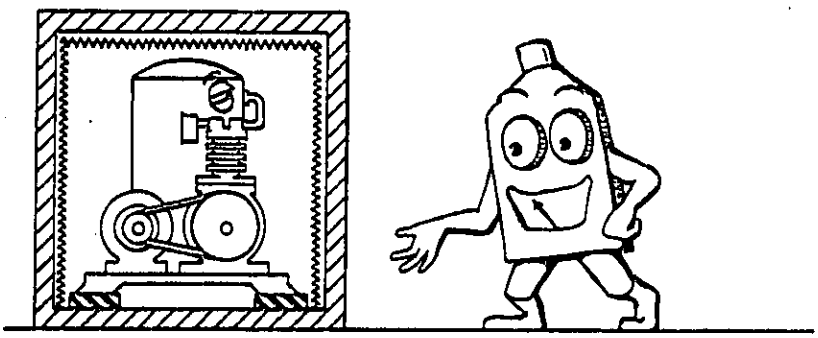


Figure 9.6. Sound absorbing material on the inside walls reduces the build-up of sound levels within the enclosure, thereby reducing the noise levels received.

Mechanical vibrations of the source can cause sound to be radiated by structural members or components of the device or by other structures rigidly attached. When the frequency of the driving force equals the natural frequency of the member being vibrated, very large surface displacements can result. This condition is called resonance. Certain structural members will continue to radiate sound at this resonant frequency after being excited by only a simple mechanical impulse that may be generated in the operation of the device. This resonant vibration and the resulting radiation of sound can be limited very effectively by applying damping material to the resonant part. Common damping materials are felt, sheet lead and certain elastomer sheets (15).

The effectiveness of the individual noise control principles described above will depend greatly on the spectrum of the noise, the mechanism by which the noise is generated, and environmental conditions. The order in which the noise control principles are applied can make any one procedure appear to be more or less effective than others. Examples of the use of multiple noise control procedures may be found in window-mounted air conditioners, automobile engine compartments, and some quieted lawn mowers or power boat engines. When the sound reduction afforded by a package such as shown in Figure 9.6. is still insufficient, additional quieting can be accomplished by mounting the package on vibration isolators inside a second sound-treated enclosure as indicated in Figure 9.7. Although this treatment may be bulky and expensive the sound reduction afforded may offset the disadvantages. As with any of the sound control procedures described, extreme care must be taken to avoid rigid connections such as electrical conduit or ventilation ducts that could allow sound or vibration to be passed through the enclosure.

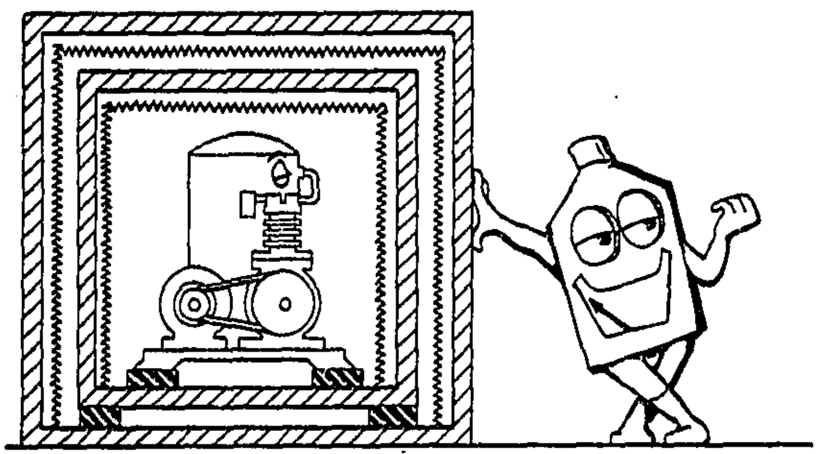


Figure 9.7. Additional noise reduction for extremely noisy sources can be accomplished by using a double-walled sound-treated enclosure.

The procedures just described represent basic noise control principles. The following sections describe some practical applications of these procedures.

9.2.2 Complete Enclosures

In certain situations either the sound source or the receiver can be completely enclosed by the barrier. In homes and offices noisy machines can be installed in a separate room that will contain the noise. In homes, the heating plant and laundry equipment are often installed in a separate room that can be closed off from the living spaces. Noisy machines in work places can often be completely enclosed to reduce emitted noise levels. When an enclosure is used to reduce the sound radiated by a machine, it is often necessary to mount the machine on vibration isolators before installing the enclosure. For larger, more complex noise sources, the machine operator can be enclosed in a sound isolating room where the machine's controls can be located. For example, the operator of a tractor, crane, or even a room full of machines may be completely enclosed by the body of the cab or operations room. The amount of sound reaching the operator's ears is then dependent on the ability of the cab or operations room to shut out noise. Complete enclosures of practical designs generally can provide a noise reduction in excess of 10 dB in the low frequencies and in excess of 30 dB in the high frequencies. Caution must be taken to ensure that there are no unnecessary openings in any barrier or enclosure. A table of sound transmission loss of general building materials and structures is included for general reference in the appendix to this chapter.

9.2.3 Partial Enclosures

In dealing with noise problems which are frequently encountered in communities, it may not be possible to employ complete enclosures; however, partial enclosures can be effectively employed in many situations. One of the most common uses of partial barriers is to reduce the noise radiated from busy highways. These partial barriers can be either natural structures, such as earth berms or ridges due to natural land contours, or man-made structures in the form of walls erected between the highway and the sensitive areas. The design principles are the same for either type of barrier and will be summarized below.

The geometry of a simple barrier is shown in Figure 9.8. Traffic noise is transmitted directly to observers who may be along the line-of-sight with the source of sound. Normally, sound traveling along this path will be attenuated only by spherical propagation, i.e., 6 dB per doubling of distance. Sound diffracted into the shadow zone will be subjected to additional attenuation due to the bending of sound around the edge of the barrier. The amount of attenuation is proportional to the amount of bending. Although a certain amount of sound may be transmitted directly through the barriers, the contribution of the transmitted sound to the total sound level in the shadow zone is usually negligible for most practical barrier designs. Of course, an observer on the side of the roadway opposite from the barrier will receive not only the direct sound propagated in that direction, but will also receive sound reflected from the barrier. This reflected sound must be taken into account when considering the impact of the barrier on the surrounding community. The length of the barrier along the roadway must also be considered when estimating the sound attenuation as illustrated in Figure 9.9. Sound from the roadway can also reach the observer (receiver) by a direct path past the end of the barrier.

The noise reduction achieved through various configurations of specific barriers or enclosure materials may vary significantly. Generally, a well designed single-wall barrier with no openings between the source and the person exposed might result in a 2 to 5 dB reduction in the low frequencies and a 10 to 15 dB reduction in the high frequencies. If the noise source and the observer are close to the barrier, higher reduction values are possible. The effects of two- or three-sided barriers are difficult to predict on a general basis because the overall reduction depends on other factors such as the location of reflecting surfaces and the frequency characteristics of the source.

Complete information on the design of barriers for reducing highway noise in residential areas may be found in references 16 through 20. Anecdotal accounts of community experiences with barriers and their reaction to them can be found in reference 19. Table 9.2 is a practical guide to the amount of attenuation that can be attained by the use of single-wall barriers. This table indicates the difficulty of achieving various amounts of transmission loss by the use of sound barriers.

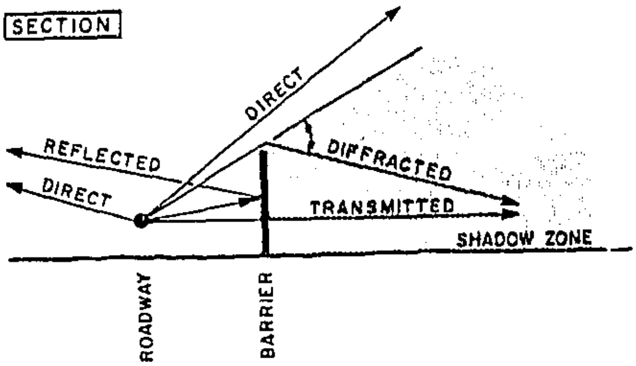


FIGURE 9.8. NOISE PATHS FROM ROADWAY TO RECEIVER

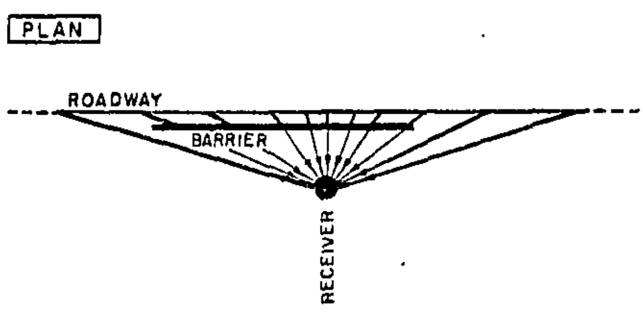


FIGURE 9.9. SHORT-CIRCUIT OF BARRIER AROUND ENDS

Table 9.2

BARRIER ATTENUATION OF TYPICAL HIGHWAY NOISE

A-weighted Transmission Loss*	Attainability
5 dB	Simple
10 dB	Attainable
15 dB	Difficult
20 dB	Attainable only by careful design
25 dB	Maximum attainable under ideal conditions

*Note: A barrier modifies the sound spectrum in that it attenuates high frequencies more than low frequencies. For this reason, the difference between sound levels measured at the receiver before and after installation of the barrier will depend on the sound level meter weighting used. That is, the attenuation measured with A-weighting may be different from attenuation measured with C- or Flat-weighting. In most cases the A-weighting network will be used for noise measurements, but octave- or third octave-band levels may be required to provide additional information on the attenuation characteristics of barriers.

9.2.4 Landscaping

Careful planning of land contours and suitable planting of trees and shrubs along the edge of highways can also be used as barriers for sound reduction. "Natural" barriers of this type are generally more pleasing to the eye and consequently are more readily accepted by residents in the area; however, the amount of sound reduction that can be attained with these barriers is limited.

A dense planting of trees that have abundant foliage used with dense underbrush or ground cover should afford about 5 dB reduction in noise level. Additional plantings may provide an additional 5 dB reduction in noise but this is the maximum that can be expected from this type of acoustic barrier. The attenuation of this "natural" barrier is usually much less when the vegetation is first planted and increases to this maximum limit as the foliage develops over a period of years. Additional information on the effectiveness and design of "natural" forest-type sound barriers may be found in Chapter 8 references(20,21,28, and 29).

REFERENCES

1. Bragdon, C.R., Urban Planning and Noise Control, Sound and Vibration, 26-32, May, 1973.

2. Bugliarello, G., Alexandre, A., Barnes, J., and Wakstein, L., The Impact of Noise Pollution, Pergamon Press, New York, 1976.

3. "Promoting Environmental Quality Through Urban Planning and Control," U.S. Environmental Protection Agency, Environmental Studies Division, 1973.

4. White, F.A., Our Acoustic Environment, John Wiley & Sons, New York, 1975.

5. Goodman, W.I., and Freund, E.C., Principles and Practices of Urban Planning, International City Managers Association, Washington, D.C., 1968.

6. National Environmental Policy Act of 1969, Public Law 91-190, 91st Congress, January 1, 1970.

7. "Noise Abatement and Control: Departmental Policy Implementation Responsibilities and Standards", Department of Housing and Urban Development, Circular 1390.2, August 4, 1971 (amended September 1, 1971).

8. "Interim Noise Standards and Procedures for Implementing Section 109 (i) Title 23, U.S.C.", U.S. Department of Transportation, Federal Highway Administration, Policy and Procedure Memorandum PPM90-2, April 26, 1972.

9. Bragdon, C.R., Municipal Noise Ordinances, Sound and Vibration, 22-27, December, 1976.

10. "Model Community Noise Control Ordinance", U.S. Environmental Protection Agency, September, 1975. EPA Document Number EPA-550/9-76-003.

11. "Information on Levels of Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety", U.S. Environmental Protection Agency, March, 1974, EPA Document Number 550/9-74-004.

12. Berendt, R.D., Corliss, E.L.R., and Ojalvo, M.S., "Quieting: A Practical Guide to Noise Control", National Bureau of Standards, Report No. NBS HB-119, July, 1976. Library of Congress 76-5500.

13. "The Incorporation of Noise as an Element to be Considered in Land Use Planning", Draft document prepared by area-wide Environmental Noise Program, Metropolitan Washington Council of Governments, June, 1978.

14. "Land Use Techniques for Noise Control: A Handbook for County and City Officials". Draft document prepared by National Association of Counties Research, Inc., 1735 New York Avenue, N.W., Washington, D.C. 20006, September 8, 1978.

15. <u>Industrial Noise Manual</u>, American Industrial Hygiene Association, 66 S. Miller Rd., Akron, Ohio 44313, 1975.

16. "Fundamentals and Abatement of Highway Traffic Noise, Vol. 1, U.S. Dept. of Transportation, Federal Highway Administration, National Highway Institute, June, 1973.

17. "Fundamentals and Abatement of Highway Traffic Noise, Vol. 2, Noise Barrier Design and Example Abatement Measures", U.S. Dept. of Transportation, Federal Highway Administration, National Highway Institute, April, 1974.

18. "Fundamentals and Abatement of Highway Traffic Noise, Vol. 3, Noise Prediction Charts and Sample Problem", U.S. Department of Transportation, Federal Highway Administration, National Highway Institute, February, 1974.

19. Snow, C.H., "Highway Noise Barrier Selection, Design and Construction Experiences -- A State of the Art Report -1975", U.S. Department of Transportation, Federal Highway Administration Implementation Package 76-8.

Appendix 9-I

SOUND TRANSMISSION LOSS DATA

Table 9.3

Sound transmission loss (in dB) of general building materials and structures (15)

The sound attenuation provided by a barrier to airborne diffuse sound energy may be described in terms of its sound transmission loss (TL). TL is defined (in dB) as ten times the logarithm to the base 10 of the ratio of the acoustic energy transmitted through a barrier to the acoustic energy incident upon its opposite side. It is a physical property of the barrier material and not of the construction techniques used.

Material or Structure	Frequency (Hz)								
	125	175	250	350	500	700	1000	2000	4000
Doors									
Flush--hollow core; well-sealed at door casing and threshold	14	21	27	24	25	25	26	29	31
Solid oak--with cracks as ordinarily hung; 1.75" thick	12		15		20		22	16	
Steel clad door--well-sealed at door casing and threshold	42	47	51	48	48	45	46	48	45
Glass									
0.125" thick; 1.5 lb/sq ft	27	29	30	31	33	34	34	34	42
0.25" thick; 3 lb/sq ft	27	29	31	32	33	34	34	34	42
0.5" thick; 6 lb/sq ft	17	20	22	23	24	27	29	34	24
1" thick; 12 lb/sq ft	27	31	32	33	35	36	32	37	44

(Continued)

Material or Structure	125	175	250	350	500	700	1000	2000	4000
	Frequency (Hz)								
Walls--Homogeneous									
Steel sheet--fluted; 18 gauge stiffened at edges by 2 x 4 wood strips; joints sealed; 4.4 lb/sq ft	30	20	20	21	22	17	30	29	31
Sheet steel--3/8" thick; 15 lb/sq ft	26	31	39	36	42	41	47	41	51
--1/2" thick; 20 lb/sq ft	28	33		38		43		48	53
Sheet aluminum--16 gauge; 0.051" thick; 0.734 lb/sq ft	5	8		13		18		23	28
--10 gauge; 0.102" thick; 1.47 lb/sq ft	8	14		19		24		29	34
Plywood--1/4" thick; 0.73 lb/sq ft		20		19		24		27	22
--1/2" thick; 1.5 lb/sq ft	8	14		19		24		29	34
--3/4" thick; 2.25 lb/sq ft	12	17		22		27		32	37
Walls--Nonhomogeneous									
Gypsum wallboard--two 1/2" sheets cemented together; joints wood battened; 1" thick; 4.5 lb/sq ft	24	25	29	32	31	33	32	30	34
1/4" plywood glued to both sides of 1 x 3 studs; 16 in. o.c.; 3" thick; 2.5 lb/sq ft	16	16	18	20	26	27	28	37	33

(Continued)

Material or Structure	Frequency (Hz) 125	175	250	350	500	700	1000	2000	4000
Same as above, but 1/2" gypsum wallboard nailed to each face; 4" thick; 6/6 lb/sq ft	26	34	33	40	39	44	46	50	50
Soft-type fiberboard (3/4") on both sides of 2 x 4 wood studs, 16" o.c.; fiberboard joints at studs; 5" thick; 4.3 lb/sq ft	21	18	21	27	31	32	38	49	53
1/2" gypsum wallboard on both sides of 2 x 4 wood studs, 16" o.c.; 4.5" thick; 5.9 lb/sq ft	20	22	27	35	37	39	43	48	43
Two 3/8" gypsum wallboard sheets glued together and applied to each side of 2 x 4 wood studs; 16" o.c.; 5" thick; 8.2 lb/sq ft	27	24	31	35	40	42	46	53	48
Masonry									
Reinforced concrete; 4" thick; 53 lb/sq ft	37	33	36	44	45	50	52	60	67
Brick--common; 12" thick; 121 lb/sq ft	45	49	44	52	53	54	59	60	61
3-3/4 x 4-7/8 x 8 glass brick; 3.75" thick	30	36	35	39	40	45	49	49	43

(Continued)

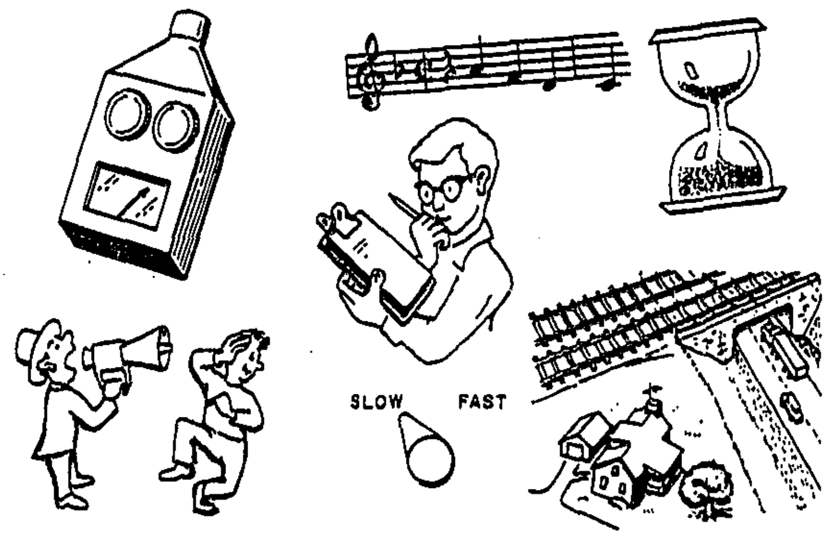
	Material or Structure	125	175	250	350	500	700	1000	2000	4000
		Frequency (Hz)								
Concrete Block										
Cinder Aggregate	-4" hollow, one coat cement base paint	37	40	43	45	46	49	54	56	55
Cinder Aggregate	-6" hollow, no surface treatment	28	34	36	41	45	48	51	52	47
Cinder Aggregate	-8" hollow, no surface treatment	18	24	28	34	37	39	40	42	40
Cinder Aggregate	-8" hollow, one coat cement base paint	30	36	40	44	46	48	51	50	41
Dense Aggregate	-8" hollow, no surface treatment	40	47	53	54	54	56	58	58	50

Chapter 10

BASIC INFORMATION FOR NOISE MEASUREMENT -- SOURCE CHARACTERISTICS

Most outdoor sound sources may be placed under two broad classifications: 1) stationary sources and 2) transportation sources. A stationary source is broadly defined as any source or combination of sources that lies within legally defined boundaries, property lines, or zoning lines as established by recorded deeds or other legal documents. This includes, but is not limited to, all machinery, vehicles, or other devices, whether fixed or in motion, that are associated with the normal operation of commercial, industrial, or residential land use. These sources remain within the recognized boundaries, property lines, or zoning lines. Some examples of stationary sources are fans, blowers, compressors, refrigeration units, cooling towers, power stations, bus and rail depots, cranes, derricks, and trucks while being operated within the boundaries. A transportation source is somewhat more obvious in that it can be considered as any source that normally moves outside or across the aforementioned boundaries.

Both stationary sources and transportation sources can be defined and differentiated in terms of the following characteristics:



1) level
2) frequency distribution
3) temporal distribution
4) directional distribution
5) operating conditions of the source
6) description of measurement site and the location of measurement point with respect to the source.

All of these parameters must be considered carefully to provide an accurate description of the sound. Such descriptions may be needed for legal as well as technical purposes.

10.1 Sound Level

The level or magnitude of a sound can be described in a number of ways. It may be reported in terms of an overall sound pressure level with various frequency weightings, in octave, one-third octave, or narrower frequency bands, or it may be reported in equivalent energy or statistical sound pressure levels. Most sound level measuring instruments, such as the sound level meter (discussed in Chapter 11), are calibrated to provide a reading in decibels (dB). The term "level" generally refers to a level (L_p) above a given pressure reference of 20 micropascals (μPa). Mathematically, L_p is written:

$$L_p = 20 \log \frac{p}{p_0} \text{ dB}$$

where p is the sound pressure measured and p_0 is the reference pressure. Chapter 1 should be consulted for additional details on sound levels.

10.2 Frequency Distribution

There are two basic ways to describe the frequency distribution or spectrum of a sound. The first and most widely used procedure provides a single overall sound pressure level measurement that includes a specified overall frequency weighting. The specified frequency weighting emphasizes some frequencies more than others in much the same manner as the human ear (1). The second way to describe frequency distribution is to measure the sound pressure level in each of several contiguous frequency bands (2). Obviously, the band measurement procedure provides much more detailed information that may be useful, or necessary, in cases: 1) where the contribution of a specified source must be determined when several other sources are also contributing to the sound, 2) when the efficacy of noise control actions must be appraised, or 3) when a high percentage of the sound lies within narrow frequency bands requiring an adjustment of the effective sound level. However, this procedure is considerably more complex and time-consuming than the single overall measurement, and the additional complexity is not necessary in a very large majority of cases. Therefore, this text will concentrate on the single overall sound pressure level measurement procedures.

Several different overall frequency weightings have been established for various purposes (1) but the A-weighting is by far the most widely accepted for evaluation of subjective and physiological effects of sound. The A-weighting is specified for use in the rules and regulations published by several Federal agencies including the Environmental Protection Agency (EPA), the Department of Labor (DOL), the Department of Transportation (DOT), the National Institute of Occupational Safety and Health (NIOSH), and the Department of Housing and Urban Development (HUD). The A-weighting is used for steady and intermittent sound evaluations but not for short impulsive sounds. It is also used as the basic frequency weighting for time averaging (L_{eq}) or statistical (L_x) measurements, which will be discussed in Chapter 11.

An advantage of a single overall frequency-weighted sound measurement procedure is particularly obvious when rapidly varying sound levels are to be measured. A single measure of a varying sound can be recorded in a relatively simple manner, but very complex and expensive equipment must be used to obtain instantaneous sound levels in several contiguous frequency bands.

Sounds that have a high concentration of energy in narrow frequency bands (pitched or tone-like sounds) are usually regarded as more annoying than wide-band sounds of the same level. Unfortunately, the single, overall, frequency-weighted sound measurements do not reflect the additional annoyance of these pitched sounds. Therefore, if the objective of the measurements is to assess annoyance it may be necessary to add about 5 dB to the measured values if a pitched sound is evident (3).

10.3 Temporal Distribution

The time or temporal variation in exposure to noise is of major significance in predicting both physiological and psychological reactions of humans to these exposures. Measurement methodologies use three broad categories of noise temporal patterns:

1) steady-state
2) time-varying/fluctuating
3) impulsive.

Both the steady-state and the fluctuating categories can be divided into continuous or intermittent patterns. That is, there can be continuous or intermittent steady-state noises as well as continuous or intermittent fluctuating noises.

Steady-State Noise: The American National Standards Institute, ANSI, defines a steady-state noise as "a noise whose sound pressure level remains essentially constant (that is, the fluctuations are negligibly small) during the period of observation." For the purposes of community noise measurements it is convenient to use a maximum fluctuation limit of plus or minus 3 dB to define steady-state noise. Hence, a steady-state noise may be considered to be:

> a noise whose A-weighted sound pressure level does not fluctuate by more than plus or minus 3 dB about a mean, or a total fluctuation or no more than 6 dB, when measured with the fast response of a sound level meter.

(A few sound sources produce an essentially unvarying sound level. When this is the case, the level can quickly be determined by a short measurement using either the slow or fast response of a sound level meter. Examples of such sounds are transformer hum and the sound of a fan.)

Steady-State Continuous: A steady-state continuous noise has a level that remains within 3 dB of its mean, or has total fluctuations of no more than 6 dB, throughout the observation period. Generally, any device or facility that operates over periods of several hours and radiates steady-state noise is considered as a steady-state continuous noise source. Figure 10.1 shows one example of a steady-state continuous noise. Other examples are the sounds of rush hour traffic and of cooling towers. The fast response of the sound level meter should be used for such sounds.

Steady-State Intermittent: A steady-state intermittent noise meets the conditions for steady-state sounds described earlier, but operates in an intermittent, or on/off manner. The ANSI definition of intermittent noise is "a noise whose sound pressure level equals the ambient level two or more times during the period of observation". The period of time during which the level of sound remains at an essentially constant value different from that of the ambient is about one second or more (4). Figure 10.2 shows an example of steady-state intermittent noise. Other examples are the sounds of cycling air compressors and of cycling air conditioners. The fast response of the sound level meter should be used.

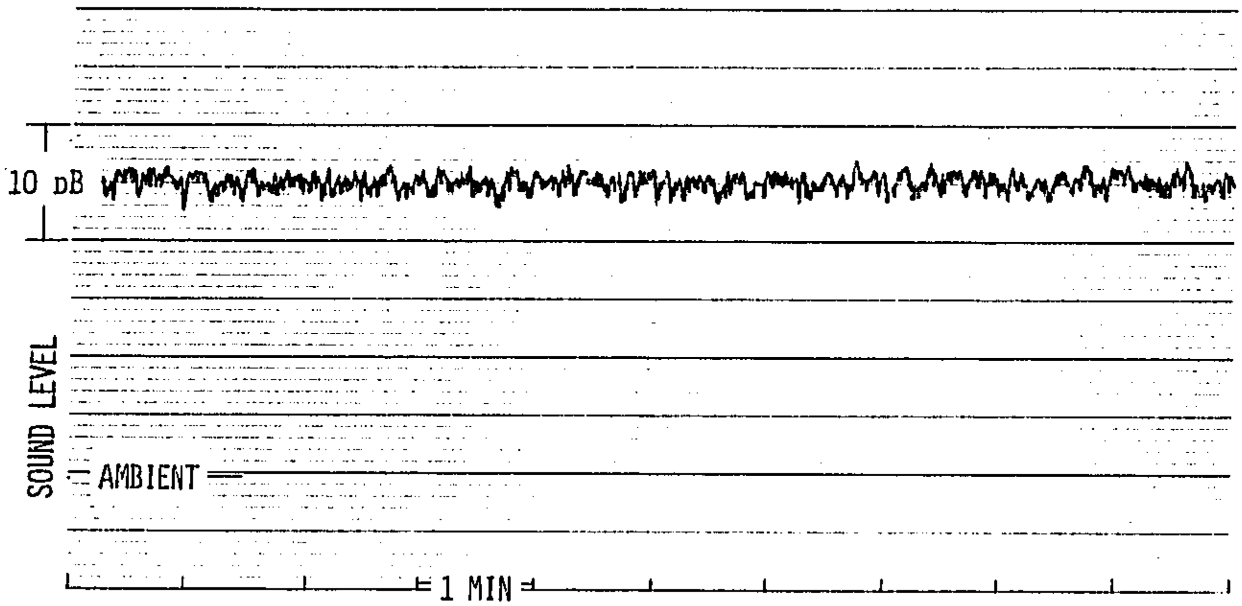
Fluctuating Noise: The ANSI definition of a fluctuating noise is "a noise whose sound pressure level varies significantly, but does not equal the ambient level more than once during the period of observation." A compatible definition with the specific numbers required for practical application might be:

> a noise whose A-weighted sound pressure level, when measured with the fast response on a sound level meter, fluctuates more than 6 dB but does not equal the ambient level more than once during the period of observation.

Fluctuating Continuous: As with the "steady-state continuous" definition, a fluctuating noise exists over a long period of time and does not drop to the ambient level more than once during the period of observation. Figure 10.3 illustrates such a sound. Other examples are highway traffic noise, construction noise, and industrial noise. Use the fast response on the sound level meter.

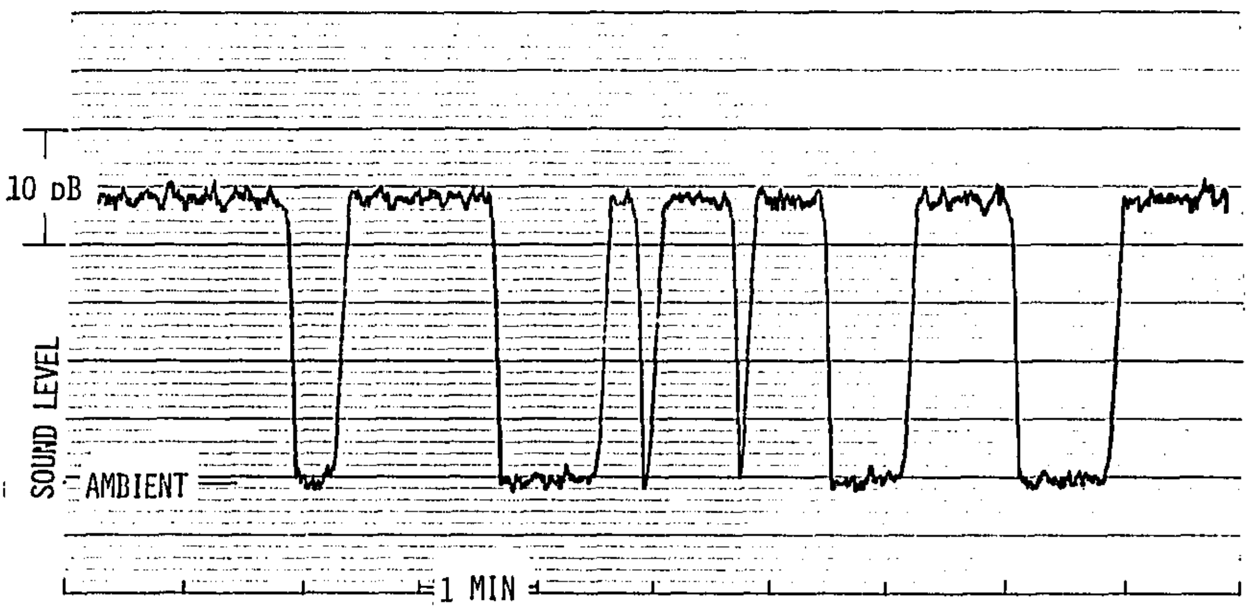
Fluctuating Intermittent: Obviously, a fluctuating intermittent noise does not meet the criterion of continuous sound. A noise level that drops to the ambient noise level more than once during the period of observation and has fluctuations in excess of 6 dB can be considered as fluctuating intermittent noise. Again, knowledge of the source operating conditions and of the ambient noise characteristics will determine the necessary period of observation. Figure 10.4 shows an example of a fluctuating intermittent sound. Other examples are the sound produced by a passing aircraft and that of sporadic late night trains. The fast response of the sound level meter should be used.

Impulsive Sounds: Generally, an impulsive sound occurs over such a short time period that ordinary sound level meters cannot respond fast enough to provide an accurate measurement of level. A special peak-reading sound level meter or an oscilloscope must be used to measure impulsive sounds. An exception to this generalization is a series of ten or more impulses occurring within one second. Then any ordinary sound level meter



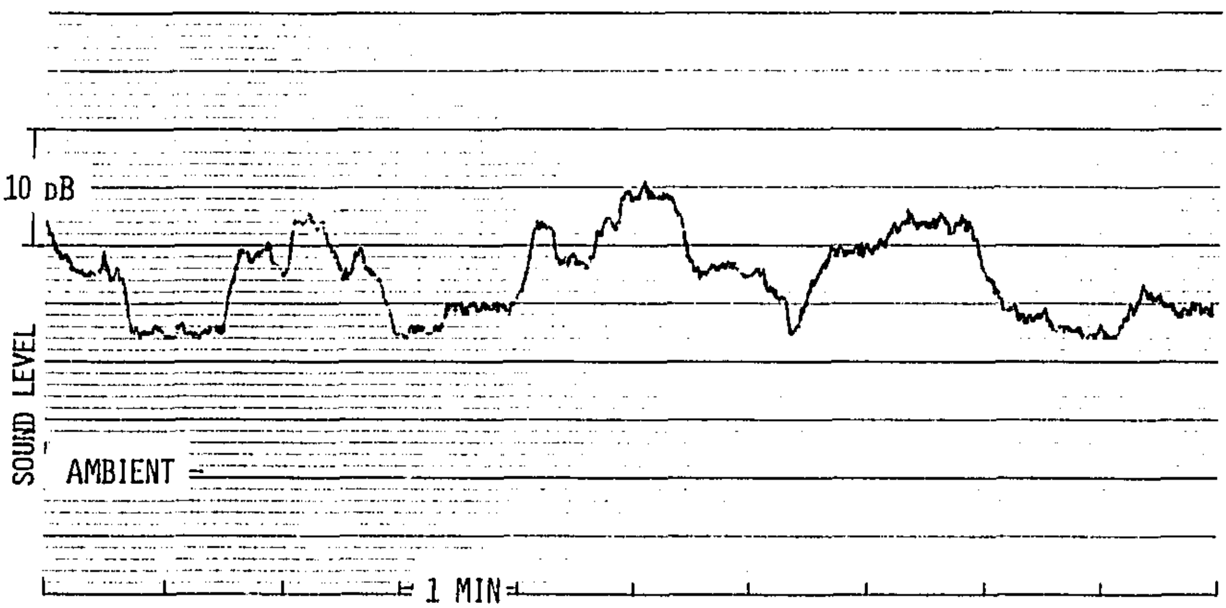
STEADY STATE CONTINUOUS SOUND

FIGURE 10.1



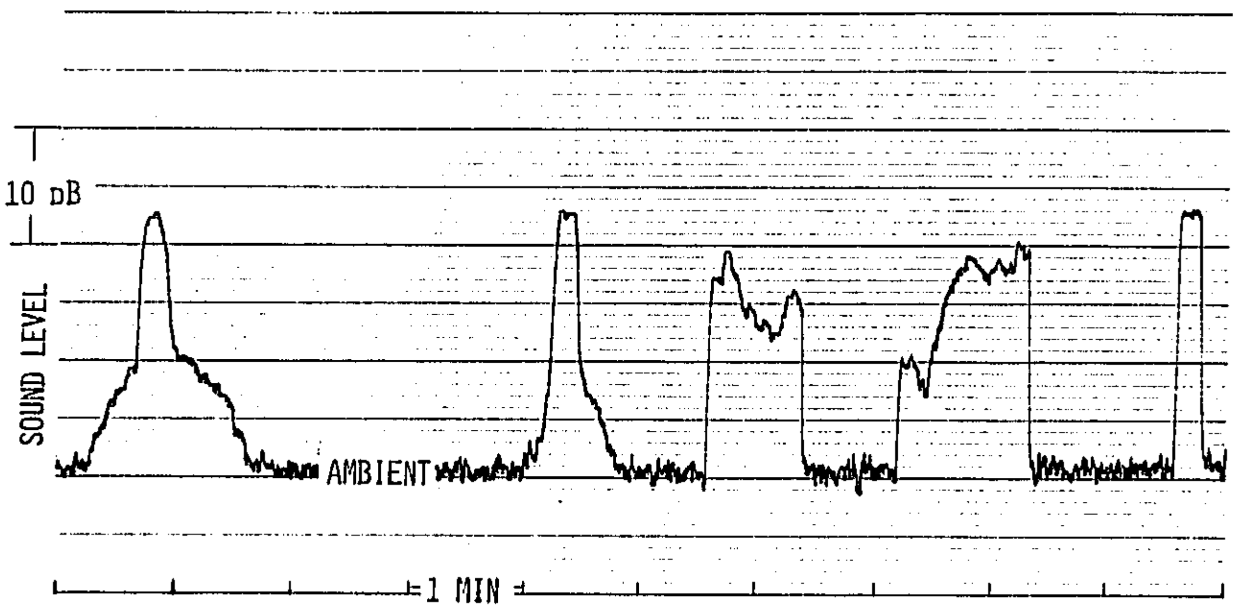
STEADY STATE INTERMITTENT SOUND

FIGURE 10.2



FLUCTUATING CONTINUOUS SOUND

FIGURE 10.3



FLUCTUATING INTERMITTENT SOUND

FIGURE 10.4

can be used to provide a reasonably accurate assessment of level. Figure 10.5 shows an example of impulsive sound. Other examples are the sounds of hammering, barking dogs, and gunshots. Impulsive sounds should be measured with either an oscilloscope, a high speed level recorder, or a peak reading sound level meter.

There are several factors that are used to describe an impulsive sound. These factors include: 1) the time necessary to reach a peak sound pressure level (rise time); 2) the peak sound pressure level (not A-weighted); 3) the time elapsed, after the peak pressure has been reached, for the pressure level to fall a specified number of decibels; and 4) the amount of reflected sound energy that is received.[1] Criteria for impulsive sounds are less well defined than for more steady sounds.

10.4 Directional Distribution

The directional characteristics of a sound source must be considered in order to use the sound measurement equipment properly. For example, some microphones must be pointed toward the sound source and other microphones must be directed so that the sound grazes the diaphragm in order for them to perform as calibrated. Instructions for microphone orientation provided by the manufacturer must be followed.

Directional characteristics of sound may also be used to pinpoint major contributors to sounds that have many different sources. A directional microphone, one with a narrow beam of sensitivity, is often useful in pinpointing major sources for noise control work.

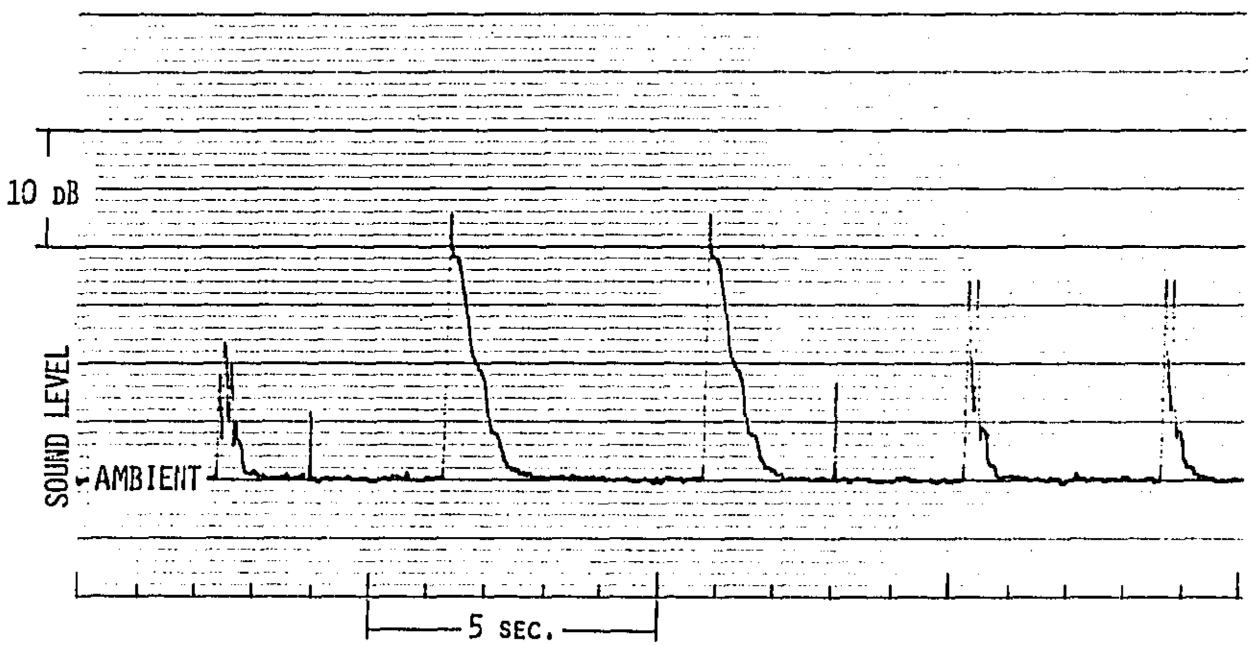
A complete and accurate description of the sound sources and measurement locations is particularly important when measurements are to be repeated and compared at some future time. For example, before-and-after measurements may be required to determine the effectiveness of noise control procedures. Also, sound levels produced at a particular location at different hours of the day or night must be compared. In any of these situations it is very important to precisely and completely describe the characteristics of the source.

Some of the common descriptive factors for sound sources are:

1) physical description and purpose
2) power rating
3) speed of operation
4) temporal pattern of operation
5) spectrum shape
6) tonal content
7) impulsive content
8) noise control measures (barriers, enclosures, silencers, etc.)
9) characteristics of other sources that may contribute to the overall level.

---

[1]A distinction must be made between maximum and peak values. Maximum is read with the ordinary sound level meter, usually set on fast, and is the maximum for the event or time period concerned. Peak is the maximum instantaneous sound pressure and cannot be read on the ordinary averaging SLM. Special laboratory grade SLM's may be required.



IMPULSIVE SOUND

FIGURE 10.5

10.5 Source Operating Conditions

The physical and meteorological conditions under which the sound source is operating at the time of measurement must be specified. This is especially necessary if the data are to be used in litigation. Adjustments for various weather conditions are difficult, if not impossible, so repeated measurements may be required at times when weather conditions are suitable (see Chapter 8).

10.6 Description of the Measurement Site

A complete description of the measurement site must be provided along with a description of the source or sources in order to make sound measurements meaningful. Various building surfaces, walls, trees, large signs and other surfaces may either reduce, or increase, the amount of sound at given locations by blocking or reflecting sound coming from the source or sources. Therefore, it is important to describe the exact positions of the sound sources and any potential sound barriers or reflectors with respect to measurement locations.

Generally, it is not necessary to make adjustments for sound barriers or reflectors if measurements are to be repeated in precisely the same location, that is, when the measurements are being conducted for the purpose of comparing the levels and not for obtaining absolute levels at that location. If the measurement data are to be used for purposes where absolute levels with the highest possible accuracy are required (i.e., for ordinance enforcement) then it may be necessary to use adjustment factors when measurements must be made close to walls or in other locations where the sound levels may be altered significantly by environmental factors (see Chapter 8).

REFERENCES

1. American National Standard Specification for Sound Level Meters, S1.4 - 1971, American National Standards Institute, Inc., 1430 Broadway, New York, New York 10018.

2. American National Standard Specification for Octave, Half-Octave, and Third-Octave Filter Sets, S1.11 - 1971, American National Standards Institute, Inc., 1430 Broadway, New York, New York 10018.

3. Kryter, K.D. and Pearson, K.S. "Some Effects of Spectral Content and Duration on Perceived Noise Level," J. Acous. Soc. Am., 35, 866 (1963).

4. American National Standard Methods for the Measurement of Sound Pressure Levels, S1.13 - 1971, American National Standards Institute, Inc., 1430 Broadway, New York, New York 10018.

Chapter 11

INSTRUMENTATION AND DATA ANALYSIS

Definitive community noise ordinances are written in terms of the maximum sound levels permitted. Various measurement descriptors have been developed to express these limits, but in almost all cases an A-weighted frequency response is used. If an ordinance specifies a maximum sound pressure level limit, measurements can be made directly with a sound level meter (SLM). If the ordinance specifies an average reading, this too can be obtained easily from SLM readings _if_ the noise levels are constant over reasonably long periods of time. An average kind of measurement is extremely difficult to obtain, however, if the noise levels vary unpredictably with time.

Statistical or averaging equivalent assessments are often required if complex noises must be measured. Two such descriptors are the A-weighted energy equivalent sound level, L_{eq}, and the 24-hour day/night energy equivalent level, L_{dn}. A single event level, SEL is being accepted more widely for measuring the total amount of sound from a source of finite duration, such as a single pass of a vehicle or aircraft. The international symbol for the SEL is L_{AX}.[1]

Whatever the descriptor of the allowable noise level, a specified type of instrumentation is required to measure the sound levels, and a specified procedure must be followed to produce the descriptor. In this chapter, the instrumentation and basic noise measurement techniques will be discussed as well as the procedural steps required to obtain specific descriptors.

11.1 Sound Level Meters

The sound level meter (SLM) (see Figure 11.1) is the basic instrument for measuring the overall sound pressure level of continuous or moderately fluctuating kinds of sounds. A sound level meter consists of a microphone, calibrated amplifier-attenuator circuits, frequency weighting networks, and an indicating meter. The microphone transforms the acoustic signal received at its diaphragm to an equivalent electrical signal with the same frequency and amplitude characteristics. The weighting networks modify the frequency spectrum of the electrical signal with selective characteristics patterned after those of the human ear. This frequency weighting therefore provides the means whereby the measured level of the sound may be correlated to the perceived level. The carefully calibrated amplifier-attenuator circuits provide a regulated level of signal to the indicating meter where the sound level is displayed in decibels.

The operational characteristics of a sound level meter are specified by both national and international standards. The American National Standards Institute, ANSI S1.4-1971 "Specifications for Sound Level Meters" (2) provide the maximum allowable tolerances used for most applications

---

[1]Many measures applicable for rating community noises are included in the Handbook for Regional Noise Programs (1).

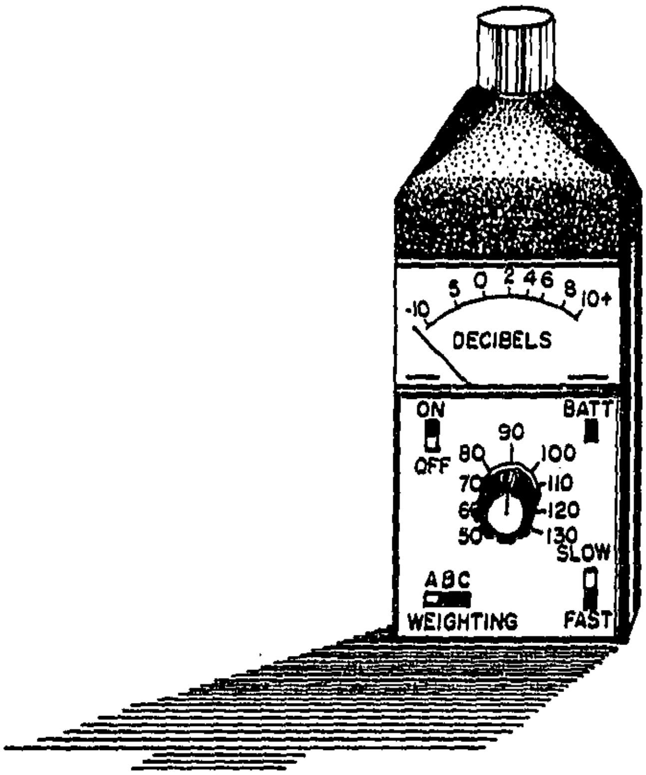


Figure 11.1 Basic Sound Level Meter.

in the USA, and for the two types of sound level meters (Precision Type 1, and General Purpose Type 2) recommended for community noise measurements.

There are several new special-purpose sound level meters designed for direct reading in energy equivalent levels, L_{eq}, that provide averaging times ranging from 1/8 second to 24 hours. Some have a standby or pause control to stop integration for a given time period.

11.1.1 Weighting Networks

Sound level meter frequency weighting networks were originally intended to provide reasonable correlations between meter readings and loudness. They are also used to determine roughly how sound energy is distributed with frequency. In community noise measurements the most often used A-weighting gives good correlation with human response. Differences between the A-weighted and C-weighted (or flat-weighted) levels afford a good approximation of the ratio of high-to-low frequency distribution of the sound.

The ideal A-, B-, and C- frequency weightings, relative to a flat or overall frequency response, as specified by ANSI S1.4-1971 are shown in Figure 11.2. Tolerances may be found in the Specifications. The D-weighting network, which emphasizes frequencies between 1000 and 10,000 Hz, is included in certain foreign sound level meters and is used primarily for noise measurements around airports.

11.1.2 Meter Indication and Response

The indicating meter or readout of the SLM must have a scale covering a range of at least 15 dB. The accuracy of the scale gradations must be at least ± 0.2 dB except in the lower part of the scale that is overlapped by a change in attenuator setting where the accuracy requirement is ± 0.5 dB. The response time of the indicator (generally measured as the response time of the complete SLM) must be in accordance with the "Fast" or "Slow" dynamic characteristics specified. The Fast response specifications require the meter to be within 0 to 4 dB less than the correct reading for a Type 2 instrument and 0 to 2 dB less than the correct reading for a Type 1 instrument for a 1000 Hz signal with a duration of 200 milliseconds. The Slow response specifications require the meter to be within 2 to 6 dB less than the correct reading for a Type 2 instrument and 3 to 5 dB less than the correct reading for a Type 1 instrument for a 1000 Hz signal with a duration of 500 milliseconds.

If sound level fluctuations are rapid but of a duration of 500 milliseconds or longer, the SLM may be used with reliable accuracy. With the exception of impulsive sounds, most community noises may be measured with the fast or slow meter characteristics. Fast meter characteristics should be used wherever possible for the greatest accuracy; however, when the sound levels are fluctuating rapidly, it may be necessary to use the slow meter characteristics to get reproducible readings. The slow response averages the sound input so that there are smaller ranges of level change and the rates of change are reduced so that the meter can be read more accurately. The slow response is particularly useful when widely fluctuating sound levels are to be compared from one time to another (i.e., before and after noise control measures). If the sound level is fluctuating 6 dB or less a subjective judgment of central tendency is usually acceptable. If the sound level is fluctuating more than 6 dB, manual or automatic sampling of sound levels may be required. Manual sampling requires less equipment, but it requires the presence of a data taker. The more expensive automatic field-type sampler will usually operate by itself once it is calibrated and set up in a selected location. Manual sampling procedures are described in Section 11.3.

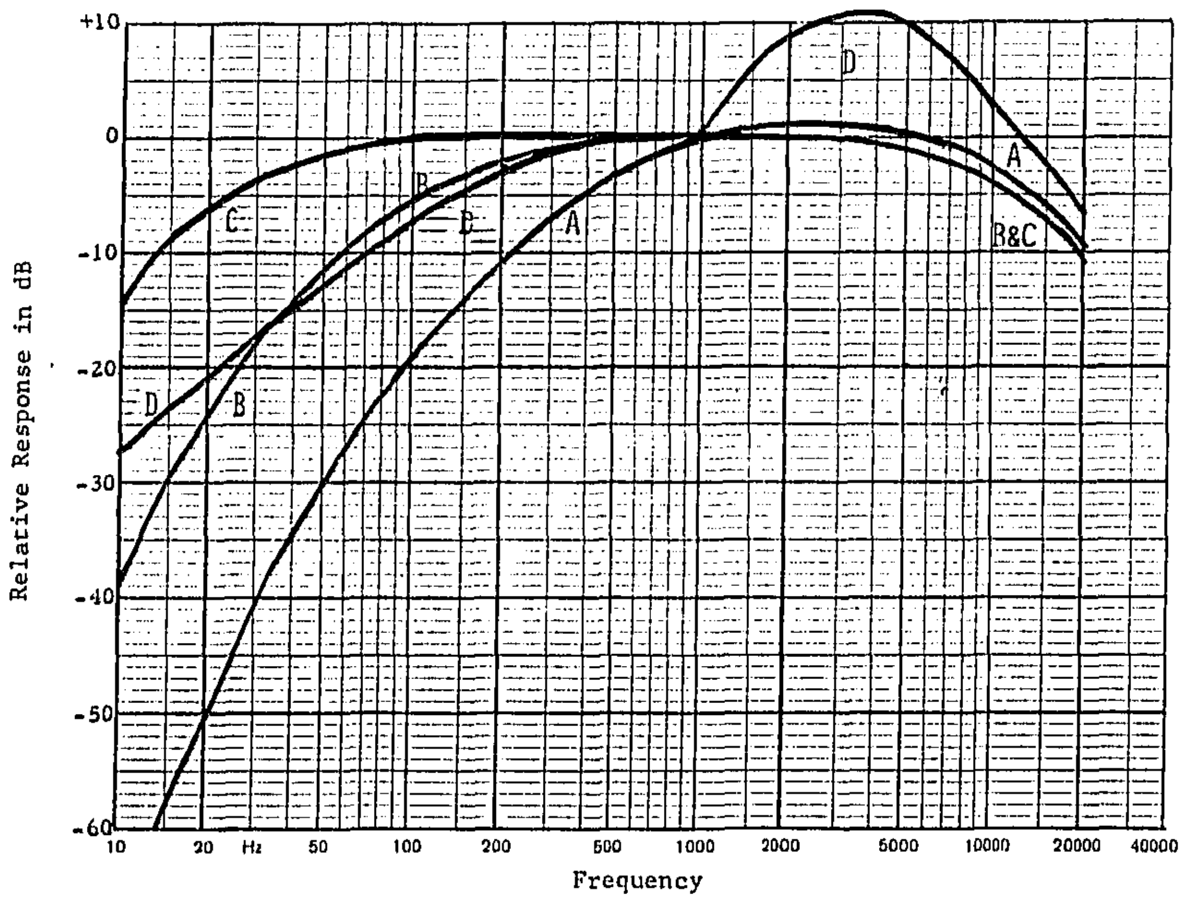


Figure 11.2 Relative response for A, B, C, and D weighting.

When impulsive sounds such as those from gun shots, pile drivers, drop forges, or jack hammers, are encountered, an oscilloscope or an impulsive-type SLM must be used (3,4,5). Impulsive sounds are considered to be those whose sound pressure levels rise above the ambient by 10 dB or more in a time less than 0.2 second. The measuring instrument must be capable of reading the peak sound pressure level (unweighted). If an impulsive-type SLM is used, it should include a peak detector and holding circuitry so that the peak level is held long enough to be read or until manually reset. Peak sound pressure levels should be recorded for at least 10 impulses in close succession so that a numerical average level can be determined. Generally, the average, the highest, and the range of impulsive levels should be recorded. Extreme care must be taken to follow the instrument manufacturer's instructions so that accurate impulse sound level data can be obtained.

11.1.3 Microphones

Each type of microphone has advantages and disadvantages that depend upon the specific measurement requirements. Calibration and frequency-response curves, and stability characteristics with respect to temperature, humidity, vibration, and electromagnetic fields are generally available from the instrument manufacturer. Performance limitations for the microphone system may be found for Types 1 and 2 sound level meters in ANSI S1.4-1971.

Orientation: Some microphones are calibrated to perform correctly when sound approaches perpendicular to the diaphragm (0°), while others are calibrated for grazing incidence (90°), or for random incidence. Figure 11.3 shows the microphone response for these different angles of incidence. Any microphone must be oriented as specified in the manufacturer's instructions; otherwise errors will result that will be particularly prominent at high frequencies. The most frequently specified orientation is illustrated in Figure 11.4. The preferred height of the microphone above the ground or supporting surface is 1.2 meters (4 feet), although any height between 0.6 and 1.8 meters (2 and 6 feet) is acceptable for specific measurement conditions. A record of microphone position should be carefully documented, preferably on a plan view of the measurement site so that measurements can be repeated at a later date if necessary (see Figure 12.1)[2].

The choice of a microphone may depend upon several factors, including the location of the sound source. If the sound is coming from a particular fixed direction, a microphone calibrated at perpendicular incidence (free field type) may be selected because it will discriminate against potential masking noises coming from other directions and generally it will have very good high frequency response characteristics. If, on the other hand, the source is in motion, such as in the case of a vehicle traveling on a road, a microphone calibrated for grazing incidence (pressure-type) may be preferred because it can be mounted in a fixed position pointing upward

---

[2]Additional calibration data should be recorded when using the SLM in a noise survey. Figure 12.1, the Community Noise Survey Data Sheet, provides a simple form for such record keeping. The appropriate procedure for completing this data sheet is described in Chapter 12.

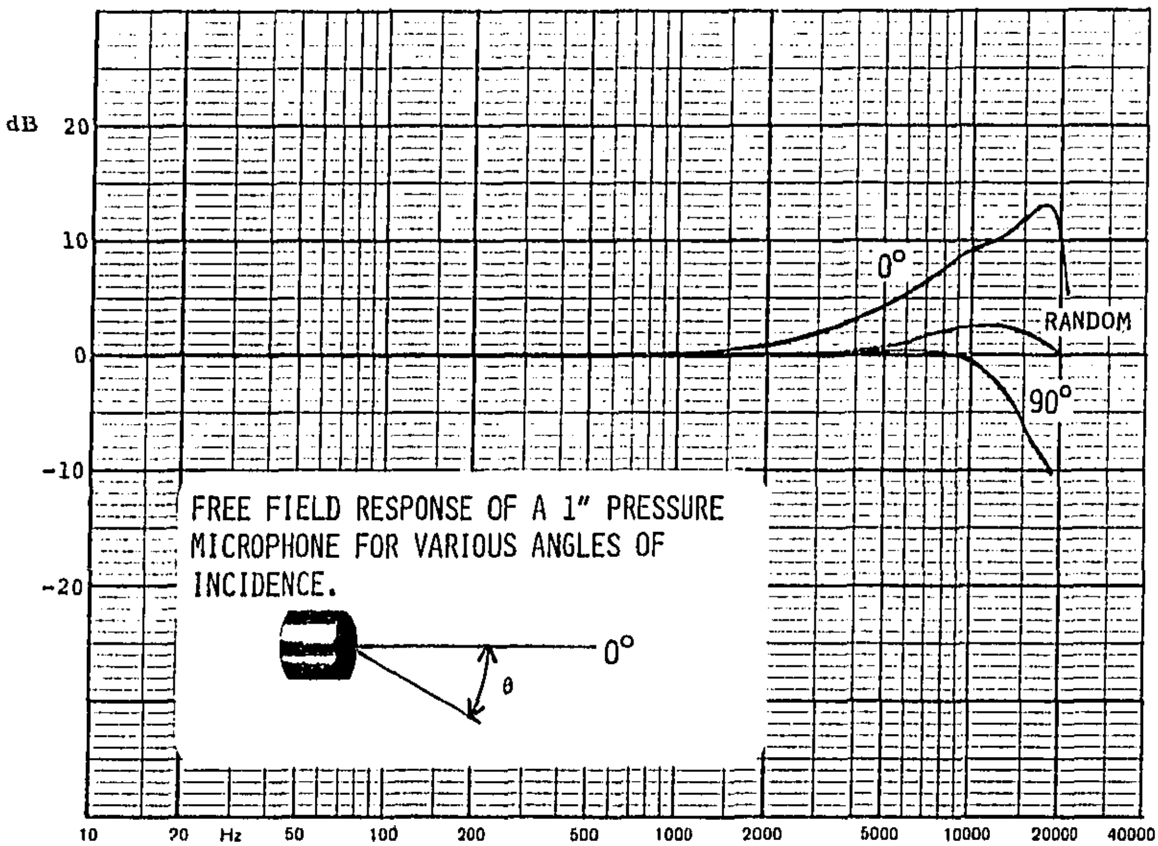

dB
20
10
0
-10
-20
0°
RANDOM
90°
FREE FIELD RESPONSE OF A 1" PRESSURE MICROPHONE FOR VARIOUS ANGLES OF INCIDENCE.
0°
θ
10
20
Hz
50
100
200
500
1000
2000
5000
10000
20000
40000

Figure 11.3

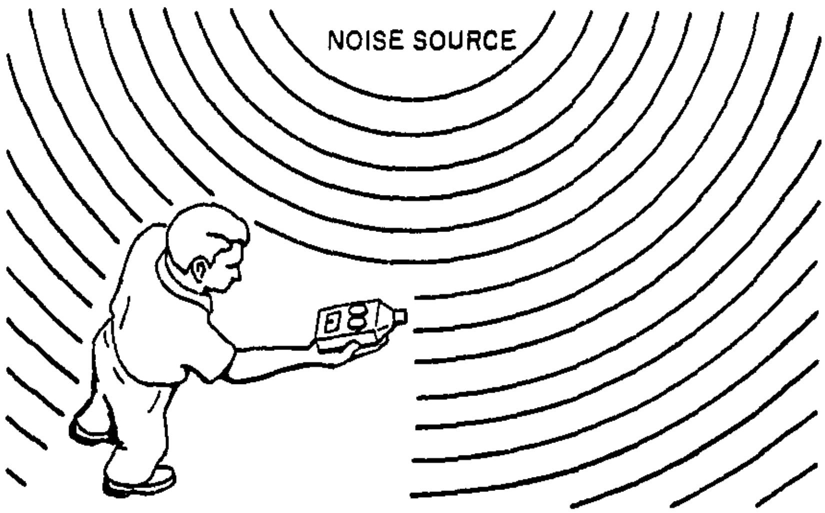


Figure 11.4 The sound level meter should be oriented with respect to the source of sound as recommended in the SLM instruction manual for the microphone being used. Most microphones should be pointed at a right angle to the sound path as shown here.

and receive the sound at grazing incidence as the vehicle moves. The microphone calibrated for random incidence is generally a good choice for measurements in a diffuse sound field where the sound is coming from all directions. These microphones may be used interchangeably in most situations, but the manufacturer's instructions must be followed on orientation in each situation or errors will result.

Temperature and Humidity: Most modern microphones are not permanently damaged by normal ranges of temperature and humidity. However, temporary erroneous readings may result from condensation if the microphones are moved from very cold to very warm areas. To avoid errors from condensation, the instruments should be turned on and allowed to sit in the measurement area for at least five minutes prior to making measurements. Temperature and humidity correction curves are generally supplied with the microphone and should be consulted.

Microphone Cables: In most community noise assessment situations, sound level measurements should be made with the microphone mounted on the sound level meter. However, there are special situations where an operator's body, or even the instrument case, should be removed from the measurement area to obtain accurate data. In most cases where cables are required the sound has a high proportion of its energy concentrated in high frequencies (above 1000 Hz). The higher the frequencies of major sound components the more likely it is that there will be errors introduced as the result of reflection from the operator's body or from the instrument case.

When extension cables are required for microphones, care must be taken to make the necessary corrections to the sound level reading according to the instrument manufacturer's instructions. Some microphones require special electronic circuitry when used with cables and others do not. The amount of correction for given lengths of cable also varies from one instrument system to another. Therefore, the manufacturer's instructions should be followed precisely. Finally, the microphone must always be calibrated while it is mounted on the cable before and after it is used.

Windscreen: Rapid air movement over a microphone causes turbulence that in turn generates extraneous noise. This noise can effectively mask the sound being measured and cause erroneous high level readings. The use of earphones connected to the SLM output jack (consult manufacturer's recommendations) often will enable the operator to detect wind-generated noise; however, low level masking may occur that will be inaudible. Therefore, it is good practice to use microphone windscreens in any case when wind or wind gusts are suspected during the course of measurements.

Generally, windscreens are either spherical or cylindrical shaped open-celled polyurethane, or silk-covered grids. The windscreens are attached directly over the microphone so that the effects of wind are reduced. However, there are limits to their effectiveness. Three rules-of-thumb are:

1) measurements should never be made, even with windscreens, in winds having velocities greater than 20 km/hr (12 mph);
2) measurements should not be made if wind noise is audible through a monitoring headset connected to an SLM when using the A-weighting and the lowest attenuator setting (setting for measuring the lowest sound level to be measured);
3) measurements may be made utilizing a windscreen and an octave, or narrower, band analyzer as long as it can be determined that the wind noise remains at least 10 decibels below the sound being measured in any of the frequency bands.

In all cases, the windscreen should be one provided by the SLM manufacturer for that instrument. Corrections should be available for these windscreens. If such a windscreen is not available, if no corrections are available for a windscreen, or if a windscreen is old or soiled, tests should be made by presenting reproducible sounds to the microphone with and without the windscreen in place. The test sounds used should contain low, medium, and high frequency components (i.e., 500, 1000, 2000, 4000, and 8000 Hz). In particular, the windscreen should be tested with similar frequency components to those expected from the sounds to be measured. Corrections should be developed and used for differences up to 2 dB. If the windscreen causes changes greater than 2 dB, the windscreen should be discarded.

11.1.4 Calibration

There are two kinds of instrument calibration procedures that must be used to insure that accurate measurements are obtained. A laboratory calibration should be performed at regular intervals not wider spaced than one year. These calibrations should be done by the instrument manufacturer or qualified personnel at acoustical laboratories. Equally important field calibrations should be made before and after each use of the measurement equipment. Field calibrations are conducted with acoustic calibrators provided by the instrument manufacturers.

Generally, the field calibrators are compact, battery operated devices that provide a means for conducting an overall system calibration check. Some calibrators generate a single frequency and others provide several different test signals, all at specified sound pressure levels. Field calibrators are designed to be used on specific microphones and they should be used only on these microphones. Otherwise, errors may result or microphones may be permanently damaged.

In use, the sound level generated by the calibrator should correspond to the SLM reading. If it does not, the instrument instruction book must be consulted to determine how adjustments are to be made. All calibrations should be made using the Flat- or C-weighting settings on the SLM unless otherwise specified by the manufacturer. As a secondary check on the performance of the A-weighting, the difference in levels between SLM reading and the calibrator level may be compared with the specified A-weighted relative response at each test frequency (see Figure 11.2).

Caution should be exercised when using calibrators at atmospheric pressures different from that at sea level. Normally, correction data are supplied by the instrument manufacturers.

11.2 Field Measurements

Systematic procedures must be followed to prepare for sound pressure level measurements. These steps may be conveniently divided between those taken before leaving for the measurement site and those taken after reaching the site.

A. Before leaving for the measurement site:

1. Determine the purpose of the measurements and obtain a complete description of the measurement sites and noise sources.
2. Assemble the necessary equipment and supplies:
   - a) SLM
   - b) calibrator
   - c) windscreen
   - d) tripod
   - e) cables
   - f) batteries
   - g) data forms

h) pens and pencils
i) auxiliary apparatus (e.g., anemometer, measuring tape, compass, thermometer, timer, analysis equipment, etc.)

3. Check batteries and replace if necessary
4. Calibrate all equipment.

B. At each measurement site:

1. Record wind speed and temperature. Do not attempt measurements:

   a) if wind speed is greater than 20 km/hr (12 mph)
   b) if temperature is outside range recommended by the SLM manufacturer
   c) during periods of precipitation.

2. Select the measurement positions.

   a) make a sketch of the site and describe the location of the SLM positions accurately.
   b) determine distances to sources and describe ground conditions and possible barriers or reflectors on or near the path from the measurement point to each source.
   c) mount the SLM or microphone on a tripod if measurements cover an extended period of time.

3. Check batteries and replace if necessary
4. Check calibration of equipment and adjust if necessary. Make a note of all calibrations and adjustments in ink on the data form.
5. Select the frequency weighting network and adjust the SLM attenuator (level adjustment) until the meter reads on-scale (preferably to the right side of the meter where dB indications are widely spaced).
6. Follow the SLM manufacturer's directions in operating the instrument and in positioning the microphone. Use a clean recommended windscreen for all outdoor measurements.
7. Record all measurement data and source descriptions in ink.
8. Check calibration of SLM when measurements have been completed at each site.

11.3 Manual Sampling Procedures

11.3.1 Determination of Statistical Distribution of Noise Levels (L_N)

A statistical distribution of noise levels uses sound pressure level measurements taken at predetermined time intervals over some specified observation period. From these data the percentage of time that any specified sound level is exceeded can be determined. Alternately, the sound level that is exceeded a specified percentage of the observation time such as L_{10}, L_{50}, and L_{90}, which are the percentile levels exceeded 10, 50, and 90 percent of the observation time, can be determined. The most common percentile level used to describe community sounds is the L_{10}. The L_{50} is generally taken as the mean level while L_{90} is taken as the ambient (background) level.

The length of the observation period must be adequate to describe the variation in sound level. A rule-of-thumb for determining the required period of observation is that the time period should be long enough to accumulate at least a number of samples equal to 10 times the total sound level fluctuation. For example, if the sound levels fluctuate over a range of 14 dB (± 7 dB), the total number of samples should be in excess of 140. The total time in which the samples are taken depends upon the interval between samples and the sample time. From previous studies (6,7,8) it has been determined that a sampling rate of once every ten seconds yields a 95 percent confidence limit.[3] In other words, the L_{10} value will be within ± 3 dB of the correct value for this sampling rate. For the example given above, the total observation time necessary to take 140 samples will be about 23 minutes.

Equipment: The basic equipment required for manual sampling is a sound level meter, a timing device, and a data sheet (see Figure 11.5). The timing device may be a watch with a second hand, or an automatic timer with an audible or visual indicator that can be set to various time intervals.

A small tape recorder also may be desirable to use to describe source and measurement conditions (not for recording the sound being measured). Care should be taken to prevent verbal communications between the operator and the recorder from being picked up by the SLM microphone during measurements.

Procedure: The procedure for determining the statistical distribution and the corresponding L_{10} and L_{90} value is as follows:

1) Check the battery of the SLM and other battery operated equipment
2) Check the calibration of the SLM according to the instrument manufacturer's instructions (also see Section 11.1.4)
3) Consult the SLM manufacturer's instructions and Section 11.1.3 to determine proper operating procedures.
4) Locate the SLM microphone at the point of interest
5) Set the SLM weighting switch to the "A" position and the meter response switch to the "Fast" position.
6) Turn the SLM ON and observe the range of the meter fluctuations. Multiply this range by 10 to compute the total number of samples required. (If this range increases during the course of taking data, the number of samples required will also increase; however, the number of samples required is not changed if the fluctuation range decreases.)

---

[3] The mathematically correct procedure for determining the error associated with a sampling method is to have the sample spaced randomly in time. However, this is inconvenient for field measurements. An equally correct error analysis can be performed if the samples are regularly spaced, but the signal varies randomly in time. This is the approach taken here.

MANUAL SAMPLING DATA

DAY OF WEEK *Wednesday* MONTH *Nov.* DAY *30* YEAR *1977*

LOCATION *721 Greenstreet, Pleasantville*

Residential

SOUND LEVEL METER TYPE *G.R. 1565B* SERIAL *08186*

STARTING TIME *2:00* AM PM ✓

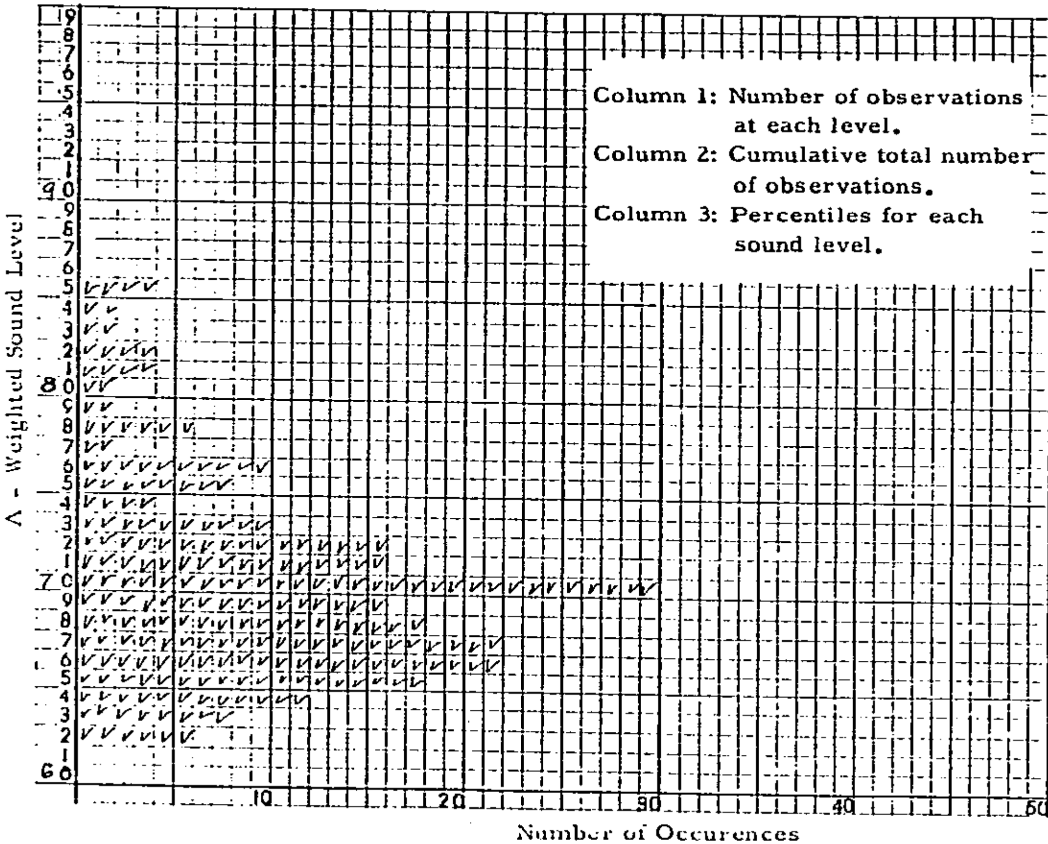
SAMPLING INTERVAL *10 Seconds*

TOTAL OBSERVATION TIME *40 minutes*

PRIMARY NOISE SOURCE *Air Compressor*

SECONDARY NOISE SOURCE *Traffic on Street*

COMMENTS



Column 1: Number of observations at each level.
Column 2: Cumulative total number of observations.
Column 3: Percentiles for each sound level.

Level	1	2	3
85	4	4	2
84	2	6	2
83	2	8	3
82	4	12	5
81	4	16	7
80	2	18	7
79	2	20	8
78	6	26	11
77	2	28	12
76	10	38	16
75	8	46	19
74	4	50	21
73	10	60	25
72	16	76	31
71	16	92	38
70	30	122	50
69	16	138	57
68	18	156	64
67	22	178	74
66	20	198	82
65	18	216	89
64	12	228	94
63	8	236	98
62	6	242	100

Figure 11.5 Completed Manual Sampling Data Sheet

7) Every 10 seconds read the instantaneous A-weighted sound level and record this level as an occurrence by making a check in the appropriate row of the data sheet (see Figure 11.5). Work from left to right within each row as sample levels re-occur.
8) After the appropriate number of samples has been taken, add the number of check marks in each row and record this number in column one of the data sheet (see Figure 11.5).
9) Add the row totals in column one beginning with the highest sound pressure level total (top figures) and record these numbers in column two (i.e., from the top of column 2, 4=4, 4+2=6, 4+2+2=8, etc.)
10) Divide each number in column two by the total number of occurrences (bottom number in column 2) and multiply by 100 (i.e., (4÷242)x100, (6÷242)x100, etc.). Enter these numbers in column three.

The numbers in column 3 are percentiles for each sound level that correspond with the percentage of time that the sound level was exceeded. In the work sheet example, 80 dB was exceeded 7 percent of the time and 78.5 dB was exceeded 10 percent of the time (i.e., L_{10}=78.5 dB, L_{50}=70.0 dB, L_{90}=64.8 dB. These percentile determinations are accurate within ±3 dB.

11.3.2 Determination of the Energy Equivalent Continuous Level (L_{eq})

An energy equivalent continuous level, L_{eq}, is another effective means for describing sounds with fluctuating levels. The Environmental Protection Agency considers this A-weighted energy equivalent sound level, L_{eq}, and the 24-hour day/night energy equivalent level, L_{dn}, to be the best measures of environmental noise as it relates to public health and welfare (9). The L_{eq} descriptor accounts for both duration and level of all sounds during the measurement period. Because L_{eq} is related to energy, it provides weighting toward the occasional high-level events such as the passing by of trucks, motorcycles, and aircraft. The L_{eq} also affords a reasonably good measure of intrusiveness. The advantage of using L_{eq} may be summarized as follows:

1) It is responsive to the effects of high amplitude events that can contribute significantly to the intrusiveness and unacceptability of noise;
2) Because it is energy-based, the effects of adding or subtracting sources can be handled relatively easily and directly;
3) Because of (2), predictions required by environmental impact statements can be made with much greater certainty than with maximum or statistical level descriptors which cannot be combined with certainty by any simple means to yield predicted values.

The following simple example of an L_{eq} calculation is helpful in understanding the L_{eq} descriptor. Assume that the A-weighted sound pressure levels measured over three equal time periods are 20, 40, and 60 dB respectively. The average intensity (energy per unit time per unit area) at the location where the sound pressure levels L_A were measured is calculated by:

$$L_A = 20 \text{ dB} = 20 \log_{10} \frac{p}{p_{ref}}$$

and $\frac{p}{p_{ref}} = 10$

where p is the sound pressure at that location and p_{ref} is 20 μPa (0.00002 N/m^2).

In the same manner $\frac{p}{p_{ref}}$ = 100 and 1000 for 40 and 60 dB respectively.

Then, for L_A = 20 dB:

$$p_1 = 10 \times .00002 = .0002 \text{ N/m}^2$$

and $I_1 = p_1^2/\rho c = .00000004/\rho c$ watts/m^2

where I_1 is the sound intensity for sound pressure p_1, and ρc is a constant (called the impedance) characteristic of air.

For L_A = 40 dB: $p_2 = 100 \times .00002 = .002$ N/m^2

and $I_2 = p_2^2/\rho c = .000004/\rho c$ watts/m^2

For L_p = 60 dB: $p_3 = 1000 \times .00002 = .02$ N/m^2

and $I_3 = p_3^2/\rho c = .0004/\rho c$ watts/m^2

Now the average intensity is

$$I_{avg} = \frac{I_1+I_2+I_3}{3} = \frac{.0004 + .000004 + .00000004}{3\rho c}$$

$$= \frac{.00040404}{3\rho c} = .000135/\rho c \text{ watts/m}^2,$$

and the sound pressure equivalent for this average intensity is:

$$p = \sqrt{I_{avg}\ \rho c} = \sqrt{(.000135/\rho c) \times \rho c} = .0116 \text{ N/m}^2$$

Then $\frac{p}{p_{ref}} = \frac{.0116}{.00002} = 580$

and L_{eq} = 20 log 580 = 55 dB.

The SLM may be used to approximate L_{eq} by using fast response measurements made periodically. If sample levels are denoted by L_i and the total number of samples by N, then

$$L_{eq} = 10 \log [(\Sigma 10^{L_i/10})/N].$$

Another convenient method of calculating L_{eq} from L_{50} and L_{10} values may be used for sounds having a Gaussian distribution (10). The formula is as follows:

$$L_{eq} = L_{50} + 0.07(L_{10}-L_{50})^2.$$

For example, if L_{50} = 70.0 dB and L_{10} = 78.5 dB, as in the example shown in 11.3, then

$$L_{eq} = 70 + 0.07\ (78.5-70)^2 = 75.1 \text{ dB}.$$

Obviously, measurements of L_{eq} must have the same general guidelines for the length of measurement times as those described above for L_{10} and L_{50}. Shortcuts can be taken if the source operates with highly repeatable periodic cycles, as with trash compactors or domestic air conditioners. Also, short term measurements may be justified in situations where it is only necessary to determine that a prescribed L_{eq} level has been exceeded. Table 11.1 shows the equivalent L_{eq} for time durations of one hour or less. If the levels in the table persist longer than the measurement times shown, then the one-hour L_{eq} value heading the columns will be exceeded, even if the source is quiet for the remainder of the hour.

The most straightforward method for determining L_{eq} is, of course, to measure it directly. Unfortunately, instruments for this purpose are expensive and they are not widely used at this time.

11.3.3 Determining Day-Night Level (L_{dn})

The L_{dn} descriptor is similar to the energy-based L_{eq} except that it provides greater weight to nighttime noises. Normally it is equivalent to the 24-hour L_{eq} level with a 10 dB nighttime penalty added to the noise levels between 10 p.m. and 7 a.m. Thus, this measure takes into consideration the greater intrusiveness of nighttime noises.

L_{dn} can be calculated using measurements of L_d (the L_{eq} level for the hours from 7 a.m. to 10 p.m.) and L_n (the L_{eq} level for the hours from 10 p.m. to 7 a.m.). The relationship among L_d, L_n, and L_{dn} can be determined conveniently from the graph in Figure 11.6. For example if L_d = 65 dB and L_n = 57 dB then L_n-L_d = -8 dB. This L_n-L_d value corresponds to an L_{dn}-L_d = 1 dB, so L_{dn} = 65 + 1 = 66 dB.

Table 11.1

Short Time Determination of L_{eq}

If levels shown persist for longer than the time shown, the one-hour L_{eq} will be exceeded, even if the source was quiet for remainder of the hour.

Measurement (minutes)	Equivalent L_{eq} Values						
60	45 dB	50 dB	55 dB	60 dB	65 dB	70 dB	75 dB
30	48	53	58	63	68	73	78
15	51	56	61	66	71	76	81
8	54	59	64	69	74	79	84
4	57	62	67	72	77	82	87
2	60	65	70	75	80	85	90
1	63	68	73	78	83	88	93
0.5	66	71	76	81	86	91	96
0.25	69	74	79	84	89	94	99

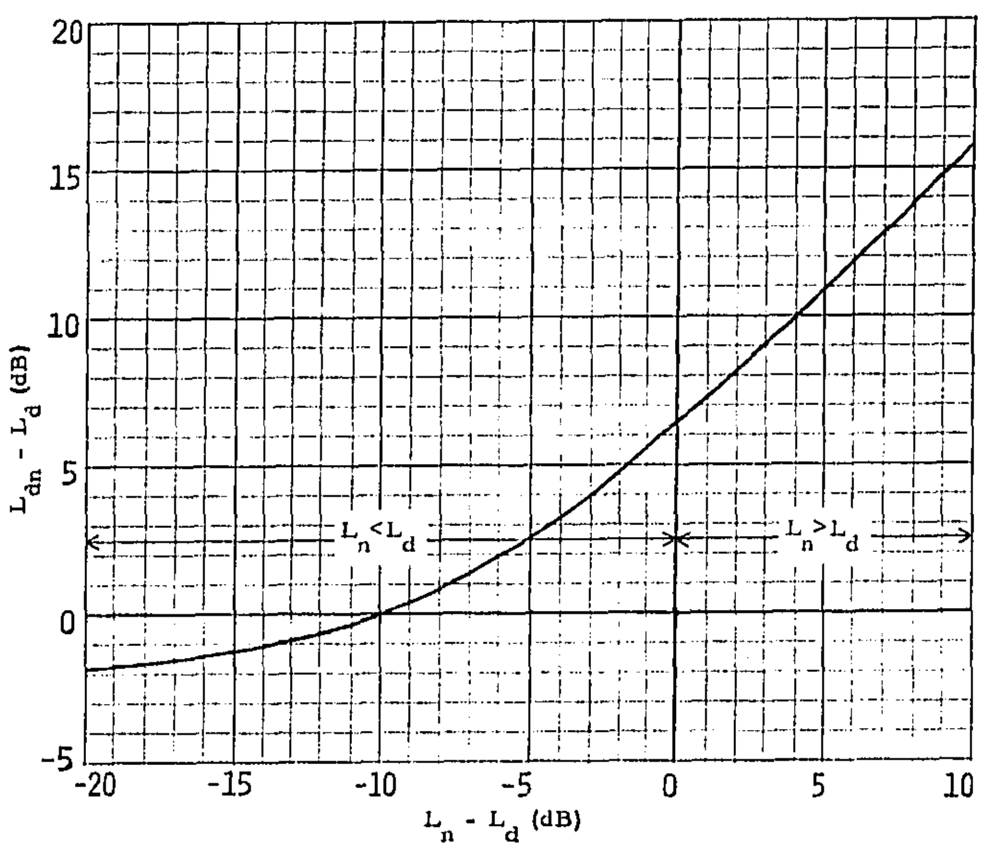


Fig. 11.6 Graph for determining L_{dn}

11.4 Analyzers

Adequate assessment of community noise is provided in most cases by sound level meters. However, in a few cases where most of the sound energy is concentrated in narrow frequency bands, additional information may be required. Additional information is particularly useful when:

1) it is necessary to determine which one of several contributing sources is the principal contributor;

2) noise control measures are to be selected or evaluated.

Basically, a sound analyzer is an electronic filter that selectively passes on those signals having frequency components for which it is tuned. Thus, an analyzer makes it possible to read the sound pressure levels contributed by those frequencies selected by the analyzer.

Two basic analyzers of primary concern for community noise measurements are the octave- and the 1/3-octave-band analyzers. These analyzers may be an integral part of a sound level meter system or they may be separate units that must be attached to separate readout devices. In any case, instructions from the manufacturer must be followed carefully.

11.4.1 Octave-Band Analyzers

Octaves are the most common bandwidths found in sound analyzers. Octave bandwidths are the widest bands used; they provide an adequate analysis with a minimum number of measurements.

An octave band is defined as any bandwidth having an upper band-edge frequency, f_2, equal to twice the lower band-edge frequency, f_1. In other words, $f_2=2f_1$. The center frequency, f_c, (geometric mean) of an octave band is equal to the square root of the product of the upper and lower band-edge frequencies ($f_c=\sqrt{f_1 f_2}$). ANSI preferred center frequencies (31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000, 16,000 Hz) are used to specify the various octave bands. (11) For example, 100 Hz is the center frequency of the octave band with band-edge frequencies $f_1=71$ and $f_2=142$ Hz. Also, 1000 Hz is the center frequency for the band-edge frequencies $f_1=707$ and $f_2=1414$ Hz, and 10,000 Hz is the center frequency for the band-edge frequencies $f_1=7070$ and $f_2=14{,}140$ Hz. Figure 11.7 provides an example of a Noise Survey Data Sheet designed for recording octave band data.

Tolerances for octave analyzers are specified by ANSI S1.11-1966. (12) Either Class I or Class II instruments described in this Standard are acceptable for community sound measurements.

11.4.2 One-Third Octave-Band Analyzers

When more precise information on the sound pressure spectral distribution is required than can be extracted with octave-band analyzers, the next step is one-third octave-band analyzers. The upper band-edge frequency of a

NOISE SURVEY DATA

DATE *30 November 1977*

LOCATION →	*Air Compressor Measured at position #1 shown on Noise Level Data Sheet for 721 Green Street*						Sound Measuring Equipment: Type *SLM* Model # *1933* Serial # *17432* Type ____ Model # ____ Serial # ____
OCTAVE BAND (Center Freq.)	DECIBELS	DECIBELS	DECIBELS	DECIBELS	DECIBELS	DECIBELS	OCTAVE BAND (Center Freq.)
Overall-Linear	86						Overall-Linear
A-Frequency Weighting	83						A-Frequency Weighting
31 Hz	70						31 Hz
62 Hz	74						62 Hz
125 Hz	74						125 Hz
250 Hz	78						250 Hz
500 Hz	80						500 Hz
1000 Hz	76						1000 Hz
2000 Hz	76						2000 Hz
4000 Hz	72						4000 Hz
8000 Hz	71						8000 Hz
Indicate Fast or (Slow) Response	Time: *10:30 AM*	Time: ____	Time: ____	Time: ____	Time: ____	Time: ____	FIELD CALIBRATION Cal. Type *1562A* Time *10:25 AM*
Taken By: *[signature]*	Remarks: *Compressor operating with pneumatic pavement breaker*	Remarks:	Remarks:	Remarks:	Remarks:	Remarks:	Hz. dB: 125. *114.0*; 250. *114.0*; 500. *114.0*; 1000. *114.0*; 2000. *114.2*

Figure 11.7. Noise Survey Data Sheet

one-third octave-bandwidth is determined by multiplying the lower band-edge frequency by $\sqrt[3]{2}$. The lower band-edge is 0.891 times the center frequency which is selected from the preferred frequencies as with octave bands' center frequencies. (11) Performance standards for one-third octave-band analyzers are also given by ANSI S1.11-1966.

11.4.3 Statistical Analyzers

Sounds with fluctuating levels are extremely difficult to measure and to describe in a meaningful way. One effective way to perform this difficult task is to use statistical analysis techniques as discussed earlier in this chapter. Statistical analyzers make this task easier by performing many of the operations automatically.

Basically, statistical analyzers are instruments that measure sound pressure levels at fixed intervals of time and store this information. In most instruments various levels are stored as events each time they occur. Generally, the event registers are calibrated in one, two, or five decibel increments over a range of 50 to 100 decibels. The sampling rate, or the interval between event measurements is generally selectable from 0.1 to 10 samples per second for any preselected observation period up to 24 hours. At the end of the observation period the registers may read out in terms of total number of occurrences in each level register or in terms of the decibel level exceeded for a given percentage of the observation time.

The accuracy of the statistical data obtained from such an analysis depends upon the sampling rate and the spread in level (decibels) between registers. The higher the sampling rate and the smaller the spread between registers, the greater the accuracy.

Statistical distribution analyzers are expensive and they may not always be available. When they are not available, these data may be obtained with the manual procedures using sound level meters as described in Section 11.3.

11.5 Tape Recorders

For special cases, it may be convenient to record a sound so that an analysis may be made at a later date. A tape recording is particularly helpful when a series of analyses are required or when the sound source is on for only a short period of time. Extreme care must be taken, however, in the use of tape recorders. Tape recorders are difficult to calibrate and to use, so this work should be left to highly qualified professionals whenever possible.

Obviously, when a tape recorder is used, the manufacturer's instructions must be followed closely. Also, the specifications of the tape recorder should be studied closely to determine if it will provide the required frequency range and overall accuracy. It is strongly recommended that "instrumentation-type" recorders be used (rather than the less expensive "audio-type") because of their tight tolerances, their long-term stability, and the convenience of calibration and use. A discussion of tape recording is provided in the Society of Automotive Engineers recommended practice SAE J184 (13).

REFERENCES

1. "Handbook for Regional Noise Program," Office of Noise Abatement and Control, Washington, D.C. 20460, April, 1974, EPA Document Number 550/9-74-006.

2. American National Standards Institute Specification for Sound Level Meters, ANSI S1.4-1971.

3. Peterson, A.P.G. and Gross, E.E., Jr., Handbook of Noise Measurement General Radio Co., Concord, Mass., Seventh Edition, Form No.5301-8111-K, 1972.

4. Broch, J.T., Acoustic Noise Measurements, Bruel & Kjaer, 1975.

5. Sataloff, J. and Michael, P.L., Hearing Conservation, Charles C. Thomas, publisher, 1973.

6. Safeer, H.B., Wesler, J.E., and Ricley, E.J., Errors Due to Sampling in Community Noise Level Distribution," J. Sound Vib, 24, (3), 365-376, 1972.

7. Yerges, J.F. and Bollinger, J., Manual Traffic Noise Sampling -- Can it be Done Accurately? Sound and Vibration, 23-30, December, 1973.

8. "Fundamentals and Abatement of Highway Traffic Noise," Report prepared by Bolt, Beranek and Newman, Inc. for U.S. Dept. of Transportation, Federal Highway Administration, under contract No. DOT-FH-11-7976, June, 1973. Available from National Technical Information Service, Springfield, VA 22151 (PB-222 703).

9. "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," U.S. Environmental Protection Agency. 550/9-74-004, March 1974.

10. Unpublished work, Michael, P.L., Oslac, M., Kerlin, R., Prout, J., "Development of Measurement Methodologies for Stationary Sources," Contract No. 68-01-3304, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460.

11. American National Standards Institute Preferred Frequencies and Band Numbers for Acoustical Measurements, ANSI S1.6-1967.

12. American National Standards Institute Specifications for Octave, Half-Octave, and Third-Octave Filter Sets, ANSI S1.11-1966.

13. "Qualifying a Sound Data Acquisition System," Society of Automotive Engineers, Recommended Practice J184, July, 1972.

Chapter 12

SOUND MEASUREMENT LABORATORY AND FIELD EXERCISE

The hands-on sound measurement laboratory and field exercise consists of four parts. Initially, there will be a one-hour review of sound measurement instruments and procedures. This review will be followed by a three-hour laboratory exercise that covers the function and use of sound level meters and analyzers. Recorded sounds will be available for these exercises. Another three-hour period will then be spent at pre-selected locations in the community taking noise measurement data if the weather permits. Laboratory exercises will continue if it is impractical to go out into the community. After these field measurement exercises have been completed, a summary discussion period will be held.

The review of sound measurement will cover the materials presented in Chapter 11. The hands-on instruction will cover familiarization with operational characteristics, calibration and maintenance of sound level meters, and the effective use of analyzers and tape recorders.

Instructions are given in Appendix I to this chapter for course directors on how to present sounds to be measured in the laboratory.

12.1 Sound Level Meter

The following are examples of instructions to be given to the students.

12.1.1 Instruction Manual

Use the instruction manual for the sound level meter to determine:

1) overall accuracy -- ANSI Type 1 or 2
2) range of sound levels and frequencies that can be measured
3) recommended battery type and how to check and to change batteries
4) recommended microphone orientation with respect to the direction of arrival of the sound
5) recommended procedure for connecting external equipment such as tape recorders, analyzers, or headphones.

12.1.2 Operating Controls

Handle the sound level meter[1] to become familiar with the following controls and functions (certain specialized SLMs may not have all these functions):

1) ON-OFF switch
2) battery check switch
3) battery compartment -- Are the batteries properly installed?

[1]One sound level meter should be provided for each pair of students.

4) sound level range switch -- Are the ranges indicated on the knob or are they shown on the meter face? Understand how to read the meter after the range has been selected.
5) weighting switch -- Does the SLM have A, B, and C weightings? (Certain special meters have A-weighting only or may include D-weighting.)
6) fast-slow meter response switch
7) calibration adjustment screw.

In addition to these basic functions, some sound level meters may also include:

8) L_{eq} selector switch with pause control
9) digital display selector switch
10) maximum hold control
11) peak/rms selector switch
12) meter reset control (for functions 9-10)
13) external filter switch and connecting jacks
14) earphone jack
15) DC and/or AC output jacks
16) meter light switch.

12.1.3 Preparation for Sound Measurements

A sound level meter should be calibrated before leaving home base and again at each new measurement site by using a field calibrator. A field calibrator is a small, hand-held device that can be placed over the SLM microphone to introduce a steady sound of known level to the instrument. The sound level meter can then be adjusted to indicate the level of the sound from the calibrator.

Always use a field calibrator that is specified by the SLM manufacturer. Field calibrations should be made and recorded prior to and after each day's use of an SLM.

To calibrate and prepare a sound level meter for use in the field, follow these steps:

1) Turn the sound level meter ON and check the battery. If the battery check is OK, set the sound lever meter controls to:
   a) C or Flat frequency weighting
   b) Fast meter response
   c) dB range to read the sound pressure level to be produced by the calibrator. (For instance, if the calibrator produces 114 dB, set the range switch so that the meter can read 110 to 120 dB. On most basic meters, this is called the "110 dB range".)

2) Turn the calibrator ON and check its battery as described in the instruction manual for the calibrator. If the battery check is good, slowly fit the calibrator over the microphone on the sound level meter[2]. Be sure the calibrator is firmly seated on the microphone. (Some calibrators seal around the microphone with a rubber "O" ring and require extra effort to slide the microphone past this "O" ring to seat firmly in the microphone cavity.)

If the battery check indicates weak batteries in either the SLM or the calibrator, install fresh batteries. Use only batteries recommended by the equipment manufacturer. Many sound level meters use more than one battery. Replace all batteries even if only one appears to be bad. If correct operation is not restored, check battery connectors to be sure they are making firm, positive contact. Failure to achieve a correct battery indication after these steps means an internal defect which sould be referred to the instrument manufacturer or a competent repair facility.

3) ADJUST the sound level meter calibration adjustment screw so that the meter reads the correct level.

Turn the calibrator OFF and gently remove it from the sound level meter. The sound level meter is now field calibrated and ready for use.

4) MEASURE sound levels.

After a series of measurements, the calibration should be checked before leaving the measurement site. The sound level meter should read the level specified for the calibrator within the specified accuracy, typically 0.5 dB.

Record the reading of the calibrator level before re-adjusting the calibration screw and record the time of calibration.

12.1.4 Maintenance and Trouble-Shooting

1) Damage due to accidents -- If either the SLM or its calibrator is dropped or impacted in any way its accuracy is suspect and checks should be made against other instruments known to be operating properly. A low or high calibration reading that cannot be corrected by the SLM adjustment screw may mean a damaged microphone or defective SLM or calibrator. In any case, the SLM, microphone and calibrator should be cross-checked with other instruments known to be operating properly or referred to the manufacturer or a competent facility for repair. Field calibrators are intended primarily for short-term checks and most are quite stable and accurate for this purpose.

---

[2]Some calibrators provide more than one calibration tone or signal. These alternate frequencies provide a means for checking the instrument performance more thoroughly and they can be used to check the response of the A-weighted network by comparing the A-weighted reading with the response curves published in the instruction manual (see also Figure 11.2).

However, the calibrator can become defective so this possibility should be kept in mind. If adjustments are found to be necessary to make an SLM reading correspond to that of the calibrator, it is highly probable that the calibrator is correct. However, if the adjustment is significant (greater than 1.0 dB), a note should be made of this adjustment and at some convenient time in the future the calibrator should be checked. The calibrator can be checked by comparing its output with that of another calibrator on an SLM, or it can be sent to the manufacturer or a competent laboratory for evaluation. In any case, the calibrator accuracy should be checked at least once each year.

2) Fast-slow responses -- The dynamic characteristics of the indicating meter can be checked by talking into the microphone with the dB range set to 70 dB and the meter response set to FAST. The needle should jump and fall back with each word in a sentence. With the meter response set to SLOW, the needle should not drop noticeably between words but should follow the inflection of a spoken sentence. Although this test does not give a quantitative check of the FAST-SLOW time constants, it will indicate whether the switch is making contact and is, indeed, changing the meter response.

3) Self-noise -- Listen to the SLM output through earphones recommended by the SLM manufacturer. Crackling or hissing sounds different from those received by the microphone indicate improper functioning of the SLM. Do not attempt to continue to use the SLM until the difficulty has been cleared up.

12.2 Analyzers

The basic steps to be taken for an octave-band or one-third octave-band analysis are as follows:

1) Obtain a sound level measurement with the weighting control set at "Linear" or "Flat" response. Record this reading on the survey data sheet.

2) Switch to A-weighting and record this reading also.

3) Next, switch in the analyzer and record the level read in each of the frequency bands selected. Be particularly careful to follow the instrument manufacturer's instructions to avoid errors that may result from overloading in some instruments. A suggested data form for recording octave-band data is discussed in Chapter 11. A blank data sheet for octave-band measurement is included in Appendix II to this chapter. Note: On certain instruments, the A-weighting network must be switched out separately when using the analyzer. When making an analysis, the signal fed to the analyzer should not be modified by any weighting network. That is, the "Linear" weighting should be used. If "Linear" is not available, "C" weighting can be used but should be noted on the data sheet. On most instruments this is done automatically when the instrument is switched to the analyzer bands if the procedure outlined in the instruction manual is closely followed.

12.3 Sound Measurement

Hands-on exercises in sound measurement will be made in the laboratory using the taped sounds described in Appendix I to this chapter. Field exercises will be based on the community noise sources that are available. Suggested forms for noise level surveys are shown in Figure 12.1 Blank copies of these forms, the Noise Level Data Sheets, are provided in Appendix II to this chapter. Copies of these blank forms (or the forms, if different, that will be used) will be supplied to each participant. During this laboratory period the use of the forms will be explained in preparation for the field exercise.

12.4 Community Sound Measurement

The outdoor sound measurements will be made at pre-selected locations within the local community when weather permits. Measurements will not be made outdoors when it is raining nor when wind exceeds 12 mph. Trips will be planned to measurement sites such as construction sites, hospital zones, playground areas or congested downtown areas. Measurements will be made according to procedures described in the local noise ordinance whenever possible. At least one statistical time sampling should be made using the procedures and data form suggested in Chapter 11 (see Appendix II to this chapter for blank data sheet).

12.5 Question and Answer Session

A question and answer session will be held at the end of the day to cover all of the measurement exercises.

NOISE LEVEL DATA

Day of week Wed Month Nov Day 30 Year 1977

Location 721 Green Street

Pleasantville Residential

Measurements made by J. Prout

Weather:

Temperature 45 °F Cold ____ Cool ____ Moderate ____ Hot ____

Humidity ____ % Dry ____ Humid ✓ Rain* ____ Snow* ____

Wind ____ mph. Calm ____ Breezy ✓ Gusty ____ Strong* ____

Sound sources in area Air Compressor at construction site adjacent. Light traffic on street.

Sound level meter	Type GR 1565-B	Serial No. 08186
Calibrator	Type GR 1562-A	Serial No. 5977

Battery check Time:	0800 hrs	1300 hrs	1630 hrs	____ hrs
Sound level meter	ok	Bad-replaced ok	ok	
Calibrator	ok	ok	ok	

Calibration of Sound level meter

1000Hz	114.0 dB	114.0** dB	114.0 dB	____ dB

Notes: ** Calibration made after battery replacement. Sound level measurements between 0800 and 1300 are in question and should be repeated.

* Measurements not recommended in unusual weather conditions.

Figure 12.1 Noise Level Data Sheets

NOISE LEVEL DATA

Sketch of area.

Day of week Wednesday Month Nov Day 30 Year 1977

Location 721 Green street

Pleasantville Residential

Show buildings, trees, bushes, parked vehicles, distances to sound sources. Mark location of microphone with ⊗. Show microphone height.

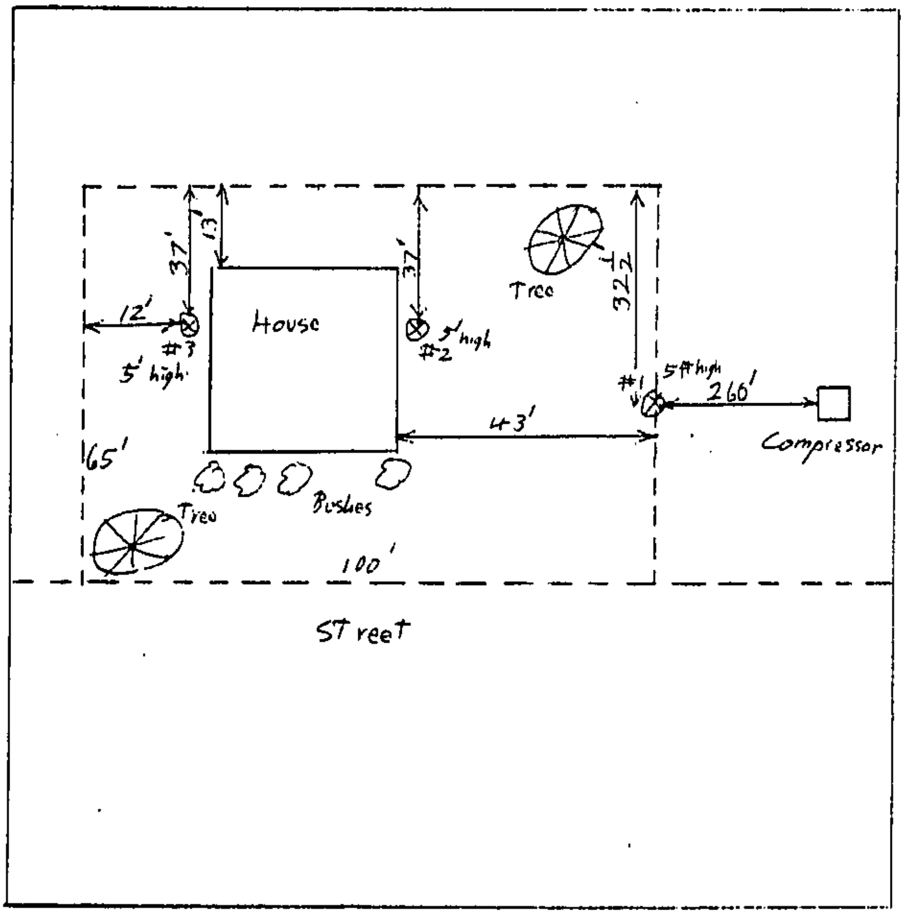


Figure 12.1. (continued)

NOISE LEVEL DATA

Sound pressure level measurements

Day of week *Wed.* Month *Nov* Day *30* Year *1977*

Location *721 Greenstreet, PleasanT ville*

Time	Measurement Site	Sound Level dB	Weighting	Meter Response	Source
0810	1	86	A	Slow	Compresser ON
0820	2	83	A	Slow	Compresser ON
0830	2	55	A	Slow	Compressor OFF
0845	3	71	A	Slow	Compressor ON

Figure 12.1. (continued)

Appendix 12-I

INSTRUCTIONS TO COURSE DIRECTOR

Appendix 12-I

INSTRUCTIONS TO COURSE DIRECTOR

Sound Measurement Laboratory

Taped sound sources used in laboratory exercises are extremely valuable because sounds can be repeated as necessary and background noises (and visual distractions) can be avoided during instruction periods. These sessions are also valuable because they can be carried out in any kind of weather.

Sound Measurement Training Tape

A collection of special sounds will be supplied on a monaural cassette tape recording for realistic laboratory exercises. The following equipment is recommended for reproducing these sounds:

1) Monaural cassette player
2) Amplifier-speaker system with minimum of 10 watts audio power delivered to the speaker
3) Necessary connecting cables.

Do not attempt to use the loudspeaker built into the cassette player. Although reproduction of the original sound level is not necessary, the audio power available in portable, battery operated cassette players is inadequate to reproduce these sounds for laboratory instruction.

A description of the taped materials is listed in Table 12.1 The musical selection at the beginning of side 1 is provided so that a satisfactory sound level can be set. The following procedure is suggested:

1.) Adjust the system volume controls to produce an average music level somewhere between 80 and 85 dB measured with C-weighting at 3 to 4.5 meters (10 to 15 feet) from the loudspeaker. This should be achieved without noticeable distortion of the music. The controls should remain at this setting for the remainder of the recorded material.

2) In the event that your amplifier-speaker system will not operate at this level without objectionable distortion, reduce the level until a satisfactory, clear sound is achieved.

These demonstration tape selections are intended to illustrate the nature of some sounds that may be encountered in a community. The selections are arranged approximately in order of increasing difficulty of measurement.

Table 12.1

NOISE TRAINING TAPE

Two sides of one C-30 cassette

Side	Selection	Subject	Time
1	1	Music to check system	2:22
	Blank		:10
	2	Selected noise spectrum	8:00
	Blank		:10
	3	Selected spectrum with 250 Hz pure tone	4:00
2	1	Traffic sound at busy intersection	4:00
	Blank		:05
	2	Garbage truck two dumps	5:15
	Blank		:05
	3	Lawn mower	1:30
	Blank		:05
	4	Children at Play	3:30

Notes:

The selected spectrum is filtered from Pink Noise with Lo pass filter set at 500 Hz and Hi pass filter set at 2500 Hz.

Garbage truck sequence:

Dump first container
Back up
Compact
Dump second container
Flip lid closed on container
Back up
Leave

Lawn mower approaches edge of lot next door. (Recorded from bedroom window.)

Children are playing approximately 100 feet from microphone.

Use of Recorded Materials

After the system volume controls have been adjusted by using the musical selection, a selected noise is provided that can be repeated as often as necessary for initial familiarization with the operation of sound measuring instruments. This sound spectrum has been chosen because it is easier to measure and because it affords reasonable voice communication during measurement exercises. This spectrum is a "pink" noise[3] that is modified by reducing the sound level in the speech frequencies between 500 and 2500 Hz. This recording is particularly useful to demonstrate the differences in A-weighted and C-weighted sound levels.

The variation in sound level readings at different locations within the classroom will illustrate the way sound propagates through the room. (The propagation loss should be observed to be something less than 6 dB per doubling of distance from the loudspeaker because of reflections from the walls of the room.)

The last four minutes of side 1 of the tape contains the same sound spectrum (level and frequency distribution) but with an added 250 Hz pure tone (single frequency). Note that the sound level reading increases due to the added energy of the pure tone. The level may also vary due to standing waves set up in the room by reflections from the walls and other surfaces. The variations in level due to standing waves may be observed on the SLM when it is moved short distances within the room. This kind of sound is often produced by a rotating machine or a resonant device such as an ultrasonic cleaner.

Sound level meters and sound analyzers can be used to measure the material on the demonstration tape. The notch in the first sound spectrum presented after the musical selection on side 1 of the tape will produce a difference between A- and C-weighted sound level meter readings but the shape of the notch cannot be deduced. More information regarding the shape of the notch will be provided by the octave bands centered at 250, 500, 1000, or 2000 Hz. However, it will be obvious that the one-third octave analysis will provide much more complete information on the notch shape using the one-third octave bands between 315 and 3150 Hz.

Side 2 of the demonstration tape contains some frequently encountered community sounds. The first is the sound of vehicles at a major signal-controlled intersection during the early morning rush period. The second selection is the sound of a garbage truck dumping two containers. The third selection is the sound of a lawn mower as the mower approaches the observer. The final selection is the sound of children at play in a school yard.

The selections on side 2 demonstrate the problems of measurement of time-varying sounds. The effects of FAST and SLOW meter responses and the difference between A- and C-weightings should be especially noted. It is instructive to note the levels of these sounds above the ambient and, in the case of the garbage truck, to note the very high peak levels that occur

[3]Pink noise is a common term used to describe a sound having equal energy in each octave band (Figure 8.6 shows pink noise).

with the slamming of the container lids. The demonstration tape can be rewound and the sounds repeated as necessary during the training periods. Time will be allowed during this training period to answer questions regarding the operation of the sound level meter and to discuss problems of measuring real, fluctuating sounds in compliance with the local noise ordinances.

Appendix 12-II

NOISE SURVEY DATA SHEETS

NOISE LEVEL DATA

Day of week________ Month_____ Day_______ Year_____

Location____

____

Measurements made by____

Weather:

Temperature___ °F Cold______ Cool______ Moderate______ Hot____

Humidity______ % Dry_______ Humid____ Rain*_____ Snow*______

Wind_________ mph. Calm_____ Breezy____ Gusty____ Strong*_____

Sound sources in area____

____

____

Sound level meter Type_______________ Serial No.___________

Calibrator Type_______________ Serial No.___________

Battery check Time: _____hrs _____hrs _____hrs _____hrs

Sound level meter_____ _____ _____ _____

Calibrator _____ _____ _____ _____

Calibration of Sound level meter

1000Hz _____dB _____dB _____dB _____dB

Notes:____

____

____

____

____

* Measurements not recommended in unusual weather conditions.

NOISE LEVEL DATA

Sketch of area.

Day of week__________________ Month_____ Day_______ Year_______

Location____

____

Show buildings, trees, bushes, parked vehicles, distances to sound sources. Mark location of microphone with ⊗. Show microphone height.

NOISE LEVEL DATA

Sound pressure level measurements

Day of week________ Month_____ Day_______ Year_______

Location____

Time	Measurement Site	Sound Level dB	Weighting	Meter Response	Source

NOISE SURVEY DATA

DATE ____________

LOCATION →							Sound Measuring Equipment: Type ______ Model # ______ Serial # ______ Type ______ Model # ______ Serial # ______
OCTAVE BAND (Center Freq.)	DECIBELS	DECIBELS	DECIBELS	DECIBELS	DECIBELS	DECIBELS	OCTAVE BAND (Center Freq.)
Overall-Linear							Overall-Linear
A-Frequency Weighting							A-Frequency Weighting
31 Hz							31 Hz
62 Hz							62 Hz
125 Hz							125 Hz
250 Hz							250 Hz
500 Hz							500 Hz
1000 Hz							1000 Hz
2000 Hz							2000 Hz
4000 Hz							4000 Hz
8000 Hz							8000 Hz
dicate ast or Slow esponse ken By: ______	Time: ______ Remarks:	Time: ______ Remarks:	Time: ______ Remarks:	Time: ______ Remarks:	Time: ______ Remarks:	Time: ______ Remarks:	FIELD CALIBRATION Cal. Type ______ Time ______ Hz. dB 125. . ______ 250. . ______ 500. . ______ 1000. . ______ 2000. . ______

MANUAL SAMPLING DATA

DAY OF WEEK__________ MONTH__________ DAY_____ YEAR_____

LOCATION____

____

SOUND LEVEL METER TYPE________ SERIAL ______

STARTING TIME______AM____PM____

SAMPLING INTERVAL________

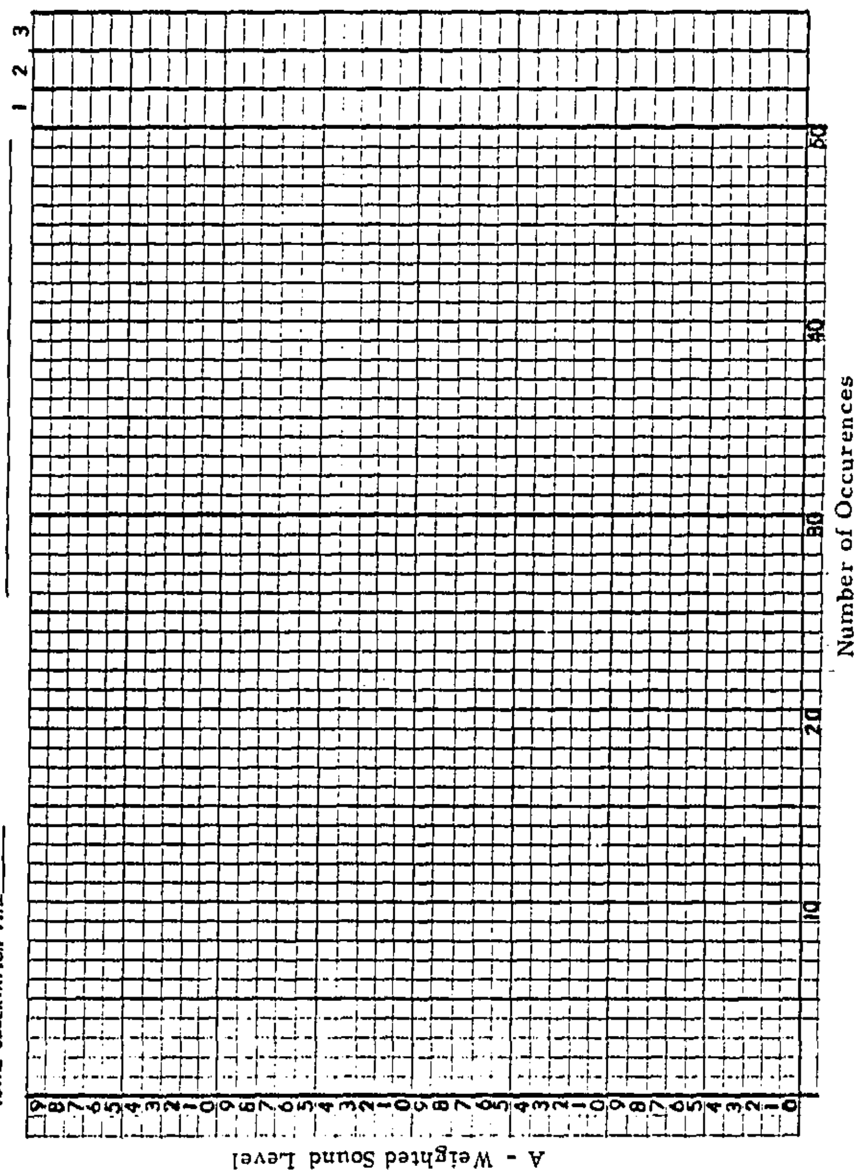
TOTAL OBSERVATION TIME________

PRIMARY NOISE SOURCE________

SECONDARY NOISE SOURCE________

COMMENTS________

____



Appendix A

NOISE ABATEMENT TOOLS: LEGISLATION, PUBLICATIONS AND OTHER RESOURCES

In the language of community noise programs, the term "tool" is broadly defined to include anything that may be used by a community as a resource in the process of noise abatement. The many tools available to communities include such varied things as texts, reports, documents, legislation, services, equipment, and organizations. Because individual programs will vary substantially, it is not possible to list all the tools that may prove beneficial to every program. However, there are a number of basic tools of fundamental importance to the development and maintenance of effective community noise programs that will be discussed in this appendix. It should be recognized that new tools are continually being developed. Noise control personnel should consider incorporating these new tools into their program as they become available.

A.1 Federal Legislation and Documents

A.1.1 Noise Control Act of 1972 (1)

The Noise Control Act of 1972 (U.S. Public Law 92-574) provides a basis for the scope and direction of noise abatement activities throughout the country at every level of public and private involvement. It sets as its goal the promotion of an environment for all Americans free from noise that jeopardizes their health and welfare. The Act mandates the U.S. Environmental Protection Agency (EPA) to undertake major coordinating actions for a comprehensive national noise abatement program. An outline of some major provisions of the Act follows.

Section 4 of the Act requires: 1) each Federal agency to comply with Federal, state, interstate, and local noise control requirements, and 2) EPA to coordinate all Federal noise research and control programs.

Section 5 requires EPA to publish the criteria (Sec. A.1.3) and levels (Sec. A.1.4) documents. It also requires EPA to identify products which are major sources of noise. Section 6 authorizes EPA to promulgate standards for any products identified as major noise sources, or for products for which standards are considered both feasible and necessary. Section 6 prohibits any state or political subdivision of a state to adopt or enforce noise emission standards that are not identical to those published by EPA. However, states and political subdivisions have the right to establish and enforce controls on environmental noise through the licensing, regulation, or restrictions on the use, operation, or movement of any product or combination of products.

Section 7 of the Act covers aircraft noise standards in a special way. It directs EPA to study the adequacy of aircraft noise controls and standards, and report its findings to Congress. The latter part of this Section is an amendment to the Federal Aviation Act of 1958 giving aviation noise regulatory authority to the Federal Aviation Administration (FAA), with EPA playing a significant role in the process by submitting proposed rules to FAA.

Section 8 gives EPA authority to designate products that either may emit adverse kinds of noise or are sold on the basis of reducing noise. These products must be appropriately labeled to provide notice to the prospective user concerning the level of noise emitted or the effectiveness of the product in reducing noise. States or political subdivisions are not prevented from similar product labeling regulations so long as they do not conflict with EPA regulations.

In Sections 9 through 13 of the Act, further authority is assigned to agencies, and provisions are made as follows. The Secretary of the Treasury issues regulations for new products to be imported into the country (section 9). Prohibited acts with regard to the new products and labeling requirements of Sections 6 and 8 are specified in Section 10, while Section 11 provides for enforcement and for penalties for such prohibited acts. Section 12 makes provision for citizen suits to prevent and/or correct violations of noise control requirements, standards, rules, or regulations contained in or issued under provisions of the Act. EPA is given authority in Section 13 to require records, reports, and information from manufacturers for those products to which emission or labeling regulations apply.

Section 14 provides EPA with certain authority to: (a) conduct and finance research, (b) advise on training of noise control personnel and on selection and operation of noise abatement equipment as part of technical assistance to state and local governments, (c) develop improved methods of measuring and monitoring noise (in cooperation with the National Bureau of Standards), (d) prepare model state or local legislation for noise control, and (e) disseminate information to the public.

Section 15 of the Act provides for development of procedures to certify products as "low-noise emission" products if they emit noise in amounts significantly below the levels specified in noise emission standards. As such, these products would be subject to special rules and cost allowances for their procurement by the Federal government. In Section 16, procedures are spelled out for judicial review of the actions taken by EPA under certain Sections of the Act (promulgating standards, regulations, and labeling requirements).

In Sections 17 and 18, provisions for regulation of railroad and motor carrier noise emission standards are given. These regulations require EPA to promulgate noise emission standards and for the Department of Transportation (DOT) to issue compliance (enforcement) regulations. Both Sections provide that states and political subdivisions 1) may neither adopt nor enforce any noise emission standards that are not identical with those promulgated by EPA under these sections, and 2) have the right to establish and enforce standards or controls on levels of environmental noise, and/or otherwise control, license, regulate, or restrict the use, operation, or movement of any related product if EPA and DOT concur that such programs are necessitated by special local conditions and are not in conflict with Federal regulations. (This is an example of how the Noise Control Act contains provisions which recognize the rights of state and local governments to regulate and control noise, and which spell out the basis for coordination between governmental programs at different levels.)

A.1.2 Report to the President and Congress on Noise (2)

Prepared by the EPA in compliance with the Clean Air Act of 1970, this report chronicles the earlier noise control efforts by EPA. The report, submitted in 1972, was prepared from 1) a number of technological information documents prepared by EPA and outside contractors and 2) testimony obtained at eight public hearings held throughout the country. The Noise Control Act of 1972 (sec. A.1.1) was originally introduced as a proposed bill in this report.

The report contains 383 pages of textual materials in six chapters on the following topics:

1) Effects of Noise on Living Things and Property
2) Sources of Noise and Their Current Environmental Impact
3) Control Technology and Estimates for the Future
4) Laws and Regulatory Schemes for Noise Abatement
5) Government, Industry, Professional and Voluntary Association Programs
6) An Assessment of Noise Concern in Other Nations.

As a resource document, this report provides a valuable consensus of opinion regarding the effects of noise on public health and welfare circa the early 1970s. It was also intended to aid state and local governments and the general public in making decisions regarding the environmental noise pollution problem.

A.1.3 Public Health and Welfare Criteria for Noise (3)

This document was developed and published by the EPA in accordance with a requirement set forth in the Noise Control Act of 1972. The purpose of this document was to "reflect the scientific knowledge most useful in indicating the kind and extent of all identifiable effects of noise on the public health and welfare which may be expected from differing quantities and qualities of noise." The information presented, unlike standards and regulations, does not take into account either feasibility or cost of the control measures. Rather, the document was written to provide a basis for the establishment of environmental noise level goals (see Section A.1.4).

The document contains twelve sections on the topics:

1) Noise and Noise Exposures in Relation to Public Health and Welfare
2) Rating Schemes for Environmental Community Noise
3) Annoyance and Community Response
4) Normal Auditory Function
5) Noise-Induced Hearing Loss--Temporary and Permanent
6) Masking and Speech Interference
7) Additional Physiological and Psychological Criteria
8) Effects of Noise on Performance
9) Interactions of Noise and Other Conditions or Influences
10) Effects of Infrasound and Ultrasound
11) Effects of Noise on Wildlife and Other Animals
12) Effects of Noise on Structures.

This document, which is frequently referred to as the "criteria document", was published in July 1973. In its preparation, EPA sought to include the views and opinions of many of the leading experts on the effects of noise. Towards that end, EPA sponsored an International Conference on Public Health Aspects of Noise in Dubrovnik, Yugoslavia in May 1973.[1]

A.1.4 Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety (4)

Like the preceding "criteria document", this "levels document" was also prepared by EPA in compliance with the Noise Control Act of 1972. This Act required the publication of information on which to base goals for environmental noise control programs. As in the preceding document, neither cost nor feasibility were considered in determining these levels and therefore the EPA has not adopted them in its regulations and standards. However, this document does present reasoned judgments based on the best scientific work available. The levels presented in this document are based on statistical determinations and incorporate a safety margin. These statistical generalizations should not be applied to a particular individual, and states and localities should approach this information according to their individual needs and situations (see Section A.2.1, for instance).

Following an introductory section, the report addresses the details of characterizing and measuring human exposure to environmental noise in Section II of the document. Section III summarizes cause and effect relationships and presents them as the basis and justification for the environmental noise levels that are identified in Section IV. These

---

[1]Proceedings of the International Congress on Noise as a Public Health Problem, Dubrovnik, Yogoslavia, May 13-18, 1973 are available as NTIS Document No. PB-241 060/AS from the office of NTIS, 425 13th Street, N.W., Room 620, Washington, D.C. 20004 (Phone 202/296-4348).

levels for various indoor and outdoor areas in the public and private domain are presented in terms of L_{eq} and L_{dn}[2]. Sections V and VI present a list of references and are followed by several appendices containing related material and information.

A.1.5 EPA Noise Control Program Progress to Date (5)

This 37-page booklet describes the progress made by EPA to date (March 1977) in accomplishing the mandated requirements of the Noise Control Act of 1972. This report also includes EPA's plans for future actions. The information is presented in a format that relates the material to the appropriate sections of the Noise Control Act. Listings of all available EPA noise-related publications, and the names and addresses of the EPA Regional Office Noise Representatives, are also included. This booklet is concise and informative. In particular, it should prove useful to those persons interested in a coordinated national program for a quieter America (see strategy document below).

A.1.6 Toward a National Strategy for Noise Control (6)

This document has been developed by EPA for its use in the completion of a comprehensive noise strategy. The Agency sought public comment in its preparation and intends to continue to seek public participation and involvement as the strategy is shaped. The purpose of the document is to present a report of the continuing dialogue on 1) the overall goals of the noise program and 2) the roles of government, industry, and consumers in noise control, along with the selection of specific abatement and enforcement activities for EPA. On the basis of the directives of the Noise Control Act of 1972, having completed its first priority tasks, the Agency intends to broaden its approach to national noise control. It has designed a program intended to maximize the effectiveness of its authority, as well as to encourage other parties to use their authority effectively.

The document contains 53 pages of text in six sections of the following topics:

1) Introduction -- Background and purpose
2) Nature and Scope of the Noise Problem -- Effects and pervasiveness of noise
3) Tools Available for the Control of Noise -- Regulatory measures
4) Goals for the National Effort -- General and specific
5) Relative Emphasis Among Alternative Approaches -- Interrelationship of program components; National source regulations and state and local programs; Labeling

[2] See Glossary for definitions of these terms.

6) National Programs -- Recommended programs; Role of research and development; Cost and economic impact data; Source regulations; State and local programs; Labeling; Awareness and public information; Aircraft/airport noise; Enforcement; Other Federal programs.

This strategy recognizes the essentiality of non-Agency endeavors including state and local programs. As a result, EPA will be expanding its assistance to state and local agencies. This strategy document is of particular interest to a large audience of officials and individuals interested in noise abatement.

A.2 Resources for State and Local Noise Control Legislation

A.2.1 Model Community Noise Control Ordinance (7)

This report contains a model ordinance for use by cities and counties in the development of noise control ordinances tailored to meet local conditions and goals. It is a comprehensive, performance-standard noise ordinance intended to overcome enforcement problems associated with the nuisance law approach to noise control. This report contains sections on the control of noise from both stationary and mobile sources and includes land use planning provisions. A preamble gives important explanatory information for certain ordinance sections. This model ordinance was prepared by the National Institute of Municipal Law Officers in conjunction with the EPA. The model ordinance does not contain recommended values for sound levels in the performance standards because there were not any single numbers that could be chosen as appropriate for all communities. Rather, localities are referred to the EPA "levels document" (see Section A.1.4) for a specification of national maximum noise exposure guidelines.

A.2.2 Guidelines for Developing a Training Program in Noise Survey Techniques (8)

This report contains guidelines for the content, format, organization, and administration of a training program for noise survey technicians. It is intended to provide assistance to state and local governments in setting up a program to train technicians to assist in the enforcement of noise ordinances and investigation of noise complaints. The program is directed toward trainees with a minimum of a high school education and no previous experience in acoustics. The report outlines and explains material to be covered in a 4-1/2 day training program.

A.2.3 Chicago Urban Noise Study (9)

The city of Chicago has a noise ordinance that is one of the most comprehensive and effectively enforced in the country. The basis for this exemplary program is found in the document "Chicago Urban Noise Study" which was submitted by Bolt Beranek and Newman, Inc. in November 1970 under contract to The City of Chicago. The document is actually a compilation of three separate reports on four phases of the study. These are:

- Phase I. Noise in the Urban Environment
- Phase II. Noise Control by Law
- Phase III. Noise Control Technology and Federal Aid for Noise Abatement
- Phase IV. Noise Control Program Recommendation

The first report on Phase I draws from a review of the then current literature to present material on needs for noise abatement and measurement of urban noise. It describes the noise environment, discusses the urban vibration environment, and provides a summary of existing noise and vibration ordinances. In the second report, on Phase II, a new noise control ordinance is proposed along with relevant background and supplementary material. The third and final report contained in the study document presents results of the Phase III study on available noise control technology and Federal assistance. In addition, a concise report under Phase IV requirements is presented that gives seven recommendations to improve Chicago's urban noise environment. This document is a valuable reference that presents a comprehensive treatment of the urban noise problem.

A.2.4 State and Municipal Noise Control Activities 1973-1974 (10)

This report presents an assessment of 1973-1974 state and municipal environment noise control efforts based on an EPA survey of 1) states, and 2) municipalities with populations greater than 75,000. This assessment is designed to provide an overall perspective of the composition and scope of noise control efforts. Areas covered are: organization and orientation of noise control efforts, enforcement, budgetary data, personnel, equipment, program problems, and application of technical assistance.

The survey results have been used by EPA/ONAC as a guide in the present technical assistance program. This document was prepared primarily as a planning and reference guide for public administrators and other officials engaged in the development and implementation of environmental noise control programs. (Note: EPA has a continuing need for information on state and local programs in order to develop an integrated, nationwide noise control program that is to involve a coordinated approach by the varying levels of government. Subsequent surveys are planned that will include a larger number of communities.)

A.2.5 Noise Source Regulation in State and Local Noise Ordinances (11)

This document in its most recent version (February 1975) updates the previous report by EPA on March 1, 1973. It has been prepared as a planning and reference guide for public administrators of environmental noise control programs. It presents a summary of noise source regulations encompassed in current state laws and local ordinances. Data have been extracted from only those laws and ordinances stipulating specific decibel levels. For the states, the laws summarized are grouped under the headings: motor vehicles, recreational vehicles, land use, and general. For localities, the headings are: motor vehicles, recreational vehicles, intrusive noise sources, stationary noise sources, construction noise, and miscellaneous noise regulations. Because of the many variations among local jurisdictional regulations, no attempt is made to list the specific level requirements for recreational vehicles, construction equipment, or land use.

A.2.6 Land Use Techniques for Noise Control: A Handbook for County and City Officials (12)

This document, designed for use by public officials with varying responsibilities for noise control, was published in draft form September 8, 1978 by the National Association of Counties Research, Inc. Part I outlines the steps required in comprehensive land use planning for noise control. Part II presents several implementation techniques, some of which are comprehensive land use regulations, the others being physical techniques. Part III treats several specific community noise problems, and tells which of the techniques of Part II are likely to be useful in solving each of these problems. Part IV deals with the administration of the noise control aspect of land use planning programs. Two appendices present useful material on noise measurement and community noise standards.

A.2.7 Community Noise Ordinance Workbook (13)

Persons who are interested in controlling community noise by the establishment of an appropriate ordinance will find this document, published in draft form August 8, 1975 by Region VIII of EPA very useful. The essential material appears in Chapters 2 and 7. Chapter 2, based on the study of a large number of actual cases, describes in detail a set of steps to follow in the orderly development of an effective community noise ordinance. Chapter 7 contains an extensive list of noise ordinance provisions, together with discussions of the reasons for the provisions and the specific language chosen.

A.3 Resources for Community Planning

A.3.1 Handbook for Regional Noise Programs (14)

This handbook is intended as a working reference manual for EPA regional program managers and staff personnel. Published in April 1974, it provides a (then current) overview of the noise problem and EPA's regional noise program. It was designed to be useful to both non-technically oriented and technically oriented personnel. This handbook provides much valuable and important information through its straightforward format. It contains eleven sections, including noise effects, criteria for rating sounds, sources, measuring noise, and noise reduction. Bibliographic references are provided throughout. The appendices include a glossary of terms, a list of EPA noise documents, and a compilation of ordinances.

A.3.2 FAA Advisory Circular No. 150-5050-4 -- Citizen Participation in Airport Planning (15)

This advisory circular is one of several that contain aviation noise abatement information. These circulars have been prepared by the Federal Aviation Administration (FAA) to present information on Administration policy. Circular No. 150-5050-4 provides guidance for citizen involvement in airport planning. It demonstrates the need for early citizen participation in airport planning and discusses methods by which this participation may be achieved. Of particular note is the discussion of the off-airport land use plan, an element of an airport master plan designed to achieve compatible land uses within areas affected by aircraft noise. The affected citizen, professional planner, and elected official are intended to be involved in the planning and decision-making processes for the long-range development of an airport and its neighbors in the surrounding environment.

A.3.3 DOT Policy and Procedure Memorandum No. 90-2, Noise Standards and Procedures (16)

The purpose of this memorandum is 1) to provide standards and procedures for use by state highway agencies and the Federal Highway Administration (FHWA) in the planning and design of highways approved pursuant to Title 23, United States Code, and 2) to assure that measures are taken in the overall public interest to achieve highway noise levels that are compatible with different land uses. Due consideration is also given to other social, economic and environmental effects. Design noise levels are specified in dB(A) with regard to land uses or activities at the location of a proposed highway section. All projects to which noise standards apply must include noise abatement measures to obtain the design noise levels in order to be eligible for Federal aid participation. Noise abatement measures may include acquisition of property rights for providing buffer zones, the installation of noise barriers, or, in some specific cases, provision to "sound-proof" existing structures. More recent highway noise standards and procedures are discussed in the following FHWA manual.

A.3.4 Federal Aid Highway Program Manual of Federal Highway Administration, Volume 7, Chapter 7, Section 3 -- "Procedures for Abatement of Highway Traffic Noise and Construction Noise" (17)

This directive, effective May 14, 1976, promotes 1) policy and procedures for noise studies and noise abatement measures, 2) design noise levels, and 3) requirements for coordination with local officials for use in the planning and design of highways approved pursuant to Title 23, United States Code. The requirements of this directive were not retroactive and did not supersede prior approval actions such as those in conformance with PPM 90-2 (see Section A.3.3).

A.3.5 Department of Housing and Urban Development Circular 1390.2, Noise Abatement and Control (18)

This circular presents HUD Departmental policy. This policy 1) calls attention to the adverse effects of noise exposure, 2) encourages the control of noise at its source, 3) encourages land utilization that will separate uncontrollable noise sources from residential and other noise-sensitive areas, and 4) prohibits HUD support to new construction on sites having unacceptable noise exposures. The circular presents further explicit information on Departmental policy, namely, implementation responsibilities, and interim external and interior noise exposure standards for residential construction.

A.4 Resources for Aircraft/Airport and Surface Transportation Noise Control, Abatement and Enforcement

A.4.1 Report to Congress on Aircraft/Airport Noise (19)

This report was mandated under requirements of the Noise Control Act of 1972 and was completed by EPA on July 27, 1973. The report presents findings and recommendations in four major areas:

1) Adequacy of FAA flight and operational noise controls
2) Adequacy of noise emission standards on new and existing aircraft, together with recommendations on the retrofitting and phaseout of existing aircraft
3) Implications of identifying and achieving levels of cumulative noise exposure around airports
4) Additional measures available to airport operators and local governments to control aircraft noise.

This report established the need for the submission of regulatory proposals by EPA to the FAA. Activity in this regard has been undertaken and a brief summary of the results appears in EPA's Noise Control Program Progress booklet (pages 13 and 14) (5).

A.4.2 Transportation Noise and Its Control (20)

This 27-page booklet was issued by the Department of Transportation in June 1972. It is meant to serve as a primer on the problem of transportation noise. Concise and well-illustrated, this booklet presents information on transportation noise -- what it is, how it differs depending on sources and distance, and what can be done to curtail or contain it. Included in the material covered are subsonic and supersonic aircraft, highway noise, rapid transit noise, and appendices on measurement of noise, propagation of sound, and residential noise level guidelines. (These latter guidelines are the ones presented in HUD circular 1390.2, see section A.3.5.)

A.4.3 Department of Transportation, Bureau of Motor Carrier Safety Regulations for Enforcement of Motor Carrier Noise Emission Standards (21)

These compliance regulations prescribe procedures for enforcement of the EPA in-use noise emission standards applicable to vehicles having a Gross Vehicle Weight Rating of over 4,536 kg (10,000 lb) that are engaged in interstate commerce. Effective on October 15, 1975, these regulations are enforceable by any special agent of the FHWA or, under provisions of the Noise Control Act of 1972, by states and localities that have adopted identical standards.

A.4.4 Department of Transportation, Federal Railroad Administration Railroad Noise Emission Compliance Regulations (22)

These compliance regulations prescribe procedures for enforcement of the EPA in-use noise emission standards applicable to trains operated by interstate rail carriers. The regulations are enforceable by Federal Railroad Administration inspectors or by qualified persons designated by any state or local jurisdiction that desires to undertake enforcement and notifies the Administration.

A.5 Resources for Industrial/Occupational Noise Reduction

A.5.1 Criteria for a Recommended Standard . . . Occupational Exposure to Noise (23)

The Occupational Safety and Health Act of 1970 emphasized the need for standards to protect the health of workers exposed to an ever-increasing number of potential hazards at their workplace, including that of exposure to loud noise. The National Institute for Occupational Safety and Health (NIOSH) of the U.S. Department of Health, Education, and Welfare, Public Health Service, has projected a formal system of research in order to provide relevant data from which valid criteria and effective standards can be deduced. This NIOSH report, issued in 1972, is a criteria document which presents recommendations for an occupational exposure standard for noise. In addition, the report presents background information, a discussion of acoustical terms and methods, a review of the effects of noise on man, procedures for reducing noise exposure, information on the development of the recommended standard, and a listing of 139 references.

A.5.2 NIOSH Industrial Noise Control Manual (24)

This manual, published in 1975, contains fundamental information to aid the user in understanding, measuring, and controlling industrial noise. It was written for persons having little or no experience in solving noise control problems. There are seven chapters in the manual covering the following subjects:

1) Fundamental principles of sound
2) Noise measurement
3) Noise control techniques
4) Noise control materials
5) Case histories of successful application of noise control methods in actual industrial situations
6) How to choose a qualified consultant
7) References to additional pertinent literature.

The manual is designed to be used as a guide to help the reader develop solutions to his/her particular noise problems using proven methods.

A.5.3 NIOSH Compendium of Materials for Noise Control (25)

This compendium of available, noise reduction materials was developed for use by plant engineers, industrial hygienists, acoustical consultants, and others engaged in noise control. Published in June 1975, it can be used to determine the availability of noise control materials, the characteristics and specifications of the materials, and their supply sources. Also included are data on both sound absorption and transmission loss of materials and a general and technical description of the uses and limitations of the materials listed.

A.5.4 Guidelines on Noise (26)

This medical research report was published by the American Petroleum Institute in 1973. Developed to serve as a noise control manual, it contains four sections that deal respectively with criteria regarding the effects of noise on hearing, speech communication, and community response; procedures for the measurement and evaluation of noise; procedures for the reduction and control of noise; and current data related to noise analysis and control. Together, these sections are intended to deal effectively with all but the most specialized aspects of noise control.

A.5.5 AIHA Industrial Noise Manual (27)

The third edition of the American Industrial Hygiene Association (AIHA) manual appeared in 1975. One of its purposes is to provide effective solutions to problems of noise control. In addition, it is intended to serve as a resource tool for those responsible for establishing a complete hearing conservation program designed to prevent occupational hearing loss in an industrial population. In logical order, this manual presents the physics of sound, discusses noise measuring instruments and noise analysis, surveys medical evaluation methods, examines the means of noise control (both personal hearing protection and control of noise at the source), and, finally, treats the legal aspects and liabilities in detail.

A.6 Miscellaneous Handbooks, Periodicals, and References

A.6.1 Quieting: A Practical Guide to Noise Control (28)

This National Bureau of Standards (NBS) Handbook was issued in July 1976. It offers practical solutions for ordinary noise problems. The discussion describes the ways in which sounds are generated, travel to the listener, and affect his hearing and well-being. Recommendations are given for controlling noise at the source and along its path of travel, and for protecting the listener. The guide instructs the reader to heed "Warning Signs" to determine if he/she is being subjected to prolonged noise exposure in the environment that may be hazardous to his hearing. Remedies are presented for noise problems encountered in the home, at work or school, while traveling and in community development. These remedies include noise prevention techniques and the selection of quiet alternatives to existing noise sources. General principles for selecting quiet appliances are also presented. Ways of searching for the sources of noise and for determining the paths over which it travels are described. A detailed index is given for individual noise sources describing specific solutions to the problems they present. General ways of looking for quiet homes and travel accommodations are described. In the final chapter, suggestions are given for enlisting community help when large external noise sources, such as those arising from public utilities and public transportation, must be quieted.

A.6.2 Commercial Handbooks

There are many companies engaged in commercial activities related to noise control. These firms publish a wealth of material on topics dealing with noise abatement. In particular, there are two handbooks that may be especially helpful. These are Application of B&K Equipment to Acoustic Noise Measurement, 203 pages (29) and Handbook of Noise Measurement, 322 pages (30). Both of these noise measurement handbooks present a comprehensive treatment of the topic and present the fundamentals of noise measurement and analysis.

A.6.3 Periodicals

There are many journals, newsletters and other periodicals that contain material related to noise abatement and control. Among those that are devoted principally to this area are:

1) Noise Control Report (31) - a bi-weekly business newsletter published in Washington, D.C. and available through subscription,

2) Noise Regulation Reporter (32) - a private subscription information service that includes a reference file and a bi-weekly publication report,

3) Noise/News (33) - a bi-monthly newsletter published by the Institute of Noise Control Engineering and dedicated to the publication of new items related to the scientific and engineering aspects of noise, its control, and its effects on people,

4) Sound and Vibration (34) - a monthly trade magazine sent at no cost to persons concerned with noise and vibration control,

5) Noise Control Engineering (35) - a professional journal published bi-monthly by the Institute of Noise Control Engineering in cooperation with the Acoustical Society of America.

A.7 Standards Documents

The object of standardization is to develop and publish a set of rules that facilitate the exchange of goods and/or services and develop mutual cooperation in the spheres of intellectual, scientific, technological, and economic activity. Standards in acoustics and mechanical shock and vibration can be purchased from the American National Standards Institute (ANSI), 1430 Broadway, New York, NY 10018. ANSI standards may also be purchased from the Acoustical Society of America (ASA) along with other ASA standards and an Index to Noise Standards -- ASA STDS. Index 1-1976 (national and international) (36). The source of standards varies among: 1) international organizations such as the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), 2) national organizations such as ANSI, ASA, and the American Society for Testing and Materials (ASTM), 3) professional societies such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the Society of Automotive Engineers (SAE), and 4) industry groups such as the Air Moving and Conditioning Association (AMCA) and the National Electrical Manufacturers Association (NEMA). One representative listing of standards and their sources may be found in appendices material in the Handbook of Noise Measurement (30).

A.8 Environmental Protection Agency Services

The U.S. Environmental Protection Agency has a leadership role in the task of environmental noise abatement. Their past activities, reported in the Agency's "Progress to Date" booklet published in March 1977 (5), and their planned future efforts present a vast array of noise abatement tools that may be used in state and local programs. In the national strategy for noise control document (6), the basis and outline for a cooperative and concerted effort by all segments of the public and private sectors of the nation are presented. In recognition of their roles, the technical assistance and public information services of EPA will receive increasing attention and assume greater importance in the Agency's ongoing program. Two components of this program that may be singled out for their potential usefulness as tools for state and local programs are listed in this final section.

A.8.1 EPA Regional Offices

Assistance to state and local agencies is one of the major roles provided by the ten EPA Regional Offices. These offices are assigned responsibility for geographical areas throughout the country. Each office has an individual designated as a noise representative. Efforts are concentrated on encouraging the development of state and local noise control programs to implement noise control benefits and to complement EPA regulatory efforts. EPA-sponsored noise workshops are administered by regional noise program personnel to train state and local officials in all aspects of environmental noise. Through the Regional Offices, sound level meters and other types of equipment are available for loan to states and localities as well as advice on types and uses of equipment. Newer programs of EPA such as the Quiet Communities and ECHO programs are designed to establish a more intensive and close working relationship between the Regional Offices and these communities.

A.8.2 Noise Enforcement Division

This division was established in 1976 under the EPA Office of Enforcement. This new Division's responsibilities include development and implementation of enforcement regulations applicable to new products for which standards or labeling requirements are prescribed under the Noise Control Act. In addition, the Division is to assist EPA regions, states and localities in enforcing Federal noise control standards and regulations, and in designing and enforcing supplementary state and local controls. Under this Division a Noise Enforcement Facility, located in Sandusky, Ohio, has been set up. In addition to laboratories, this facility has mobile units that may be used to train EPA regional, state and local personnel in noise enforcement.

REFERENCES

Many of the following documents can be purchased through the U.S. Government Printing Office (GPO), Washington, D.C., 20402, Phone: 202/783-3238 or the National Technical Information Service (NTIS), U.S. Department of Commerce, 425 13th St., N.W., Room 620, Washington, D.C. 20004, Phone: 202/296-4348. A GPO or NTIS document number will be included with the reference in such cases.

1. Noise Control Act of 1972, Public Law 92-574, 92nd Congress, H.R. 11021, October 27,1972, 86 Stat. 1234.

2. "Report to the President and Congress on Noise," U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460, EPA Document No. NRC 500.1, December 31, 1971. (GPO Stock No. 5500-0040) (NTIS No. PB-206-716).

3. "Public Health and Welfare Criteria for Noise," U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460, EPA Document No. 550/9-73-002, July 27, 1973. (GPO Stock No. 5500-00103) (NTIS No. PB-241 000/AS).

4. "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With An Adequate Margin of Safety," U.S. Envrionmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460, EPA Document No. 550/9-74-004, March 1974. (NTIS No. PB-239 429/AS).

5. "EPA Noise Control Program Progress to Date," U.S. Environmental Protection Agency, Office of Noise Abatement and Control (AW471), Washington, D.C. 20460, March 1977.

6. "Toward a National Strategy for Noise Control," U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460, April 1977.

7. "Model Community Noise Control Ordinance," U.S. Environmental Protection Agency, Public Information Center (PM215), Washington, D.C. 20460, EPA Document No. 550/9-76-003, September 1975.

8. "Guidelines for Developing a Training Program in Noise Survey Techniques," U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460, EPA Document No. 550/9-75-021, July 1975. (NTIS No. AD-A01 667).

9. "Chicago Urban Noise Study," BBN Report Nos. 1411, 1412, and 1413, prepared by Bolt Beranek and Newman Inc., 1970 Ogden Avenue, Downers Grove, IL 60515 for The City of Chicago, Department of Environmental Control, 320 North Clark Street, Chicago, IL 60610, November 1970.

10. "State and Municipal Noise Control Activities 1973-1974," U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460, EPA Document No. 550/9-76-006, January 1976 (NTIS No. PB-251 999).

11. "Noise Source Regulation in State and Local Noise Ordinances," U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460, EPA Document No 550/9-75-020, February 1975 (NTIS No. PB-245 158/AS).

12. "Land Use Techniques for Noise Control: A Handbook for County and City Officials," National Association of Counties Research, Inc., 1735 New York Avenue, N.W., Washington, D.C. 20006, September 8, 1978.

13. Chanaud, R.C. and Simmons, R.A., "Community Noise Ordinance Workbook," Air and Hazardous Materials Division, Region VIII, U.S. Environmental Protection Agency, 1860 Lincoln Street, Denver, Colorado 80203, August 8, 1975.

14. "Handbook for Regional Noise Programs," U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460, EPA Document No. 550/9-74-006, April 1974.

15. "Federal Aviation Administration Advisory Circular No. 150-5050-4 Citizen Participation in Airport Planning," September 26, 1975.

16. "Federal Highway Administration Noise Standards and Procedures," Policy and Procedure Memorandum 90-2, February 8, 1973.

17. "Procedures for Abatement of Highway Traffic Noise and Construction Noise," effective May 14, 1976, Federal Aid Highway Program Manual of Federal Highway Administration, Volume 7, Chapter 7, Section 3.

18. "Noise Abatement and Control: Departmental Policy, Implementation Responsibilities and Standards," August 4, 1971, Department of Housing and Urban Development, Circular 1390.2 .

19. "Report on Aircraft-Airport Noise," U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460 EPA Document No. Senate 93-8, August 1973 (GPO Stock No. 5270-01936).

20. "Transportation Noise and Its Control," U.S. Department of Transportation, Washington, D.C. 20590, DOT P5630.1, June 1972. (GPO Stock No. 5000-0057).

21. "Bureau of Motor Carrier Safety Regulations for Enforcement of Motor Carrier Noise Emission Standards," Title 19, Code of Federal Regulations, Chapter II, Part 325.

22. "Federal Railroad Administration Railroad Noise Emission Compliance Regulations," Title 49, Code of Federal Regulations, Chapter II, Part 210 (Federal Register 42, 42343, August 23, 1977).

23. "Criteria for a Recommended Standard. . . Occupational Exposure to Noise," U.S. Department of Health, Education, and Welfare, National Institute for Occupational Safety and Health, Cincinnati, OH 45202, HSM 73-11001, 1972 (For sale by GPO).

24. "Industrial Noise Control Manual," U.S. Department of Health, Education and Welfare, National Institute for Occupational Safety and Health, Cincinnati, OH 45202, HEW Publication No. (NIOSH) 75-183, June 1975 (For sale by GPO).

25. "Compendium of Materials for Noise Control," U.S. Department of Health, Education, and Welfare, National Institute for Occupational Safety and Health, Cincinnati, OH 45202, HEW Publication No. (NIOSH) 75-165, June 1975 (GPO Stock No. 1733-00073.

26. "Guidelines on Noise," American Petroleum Institute, Committee on Medicine and Environmental Health, 1801 K Street, N.W., Washington, D.C. 20006, Medical Research Report EA 7301, 1973.

27. Industrial Noise Manual, 3rd edition, American Industrial Hygiene Association, 66 S. Miller Road, Akron, Ohio 44313, 1975.

28. Berendt, R.D., Corliss, E.L.R. and Ojalvo, M.S., "Quieting: A Practical Guide to Noise Control," National Bureau of Standards, Washington, D.C. 20234, NBS Handbook 119, July 1976. (GPO Stock No. 003-003-01646-2).

29. Broch, J.T., "Application of B&K Equipment to Acoustic Noise Measurements," 2nd edition, Bruel & Kjaer Instruments, Inc., 5111 West 164th Street, Cleveland, Ohio 44142, January 1971.

30. Peterson, A.P.G. and Gross, E.E. Jr., "Handbook of Noise Measurement," 7th edition, Gen Rad, Concord, MA, Form No. 5301-8111-L, 1974.

31. "Noise Control Report," bi-weekly business newsletter published from the Nation's Capitol. Editor and publsiher, Leonard A. Eiserer, Business Publishers, Inc., P.O. Box 1067, Blair Station, Silver Springs, MD.

32. "Noise Regulation Reporter," private circulation publication, The Bureau of National Affairs, Inc., 1231 25th Street, N.W., Washington, D.C. 20037.

33. "Noise/News," bi-monthly newsletter of the Institute of Noise Control Engineering, published by Noise Control Foundation, P.O. Box 3469, Arlington Branch, Poughkeepsie, NY 12603.

34. "Sound and Vibration," monthly magazine published by Sound and Vibration, 27101 E. Oviatt Road, Bay Village, OH 44140.

35. "Noise Control Engineering," bi-monthly journal of the Institute of Noise Control Engineering, subscription information: Noise Control Engineering, 9 Saddle Road, Cedar Knolls, NJ 07927.

36. Index to Noise Standards - ASA STDS. Index 1-1976 (national and international), available from Standards Secretariat, Acoustical Society of America, 335 E. 45th Street, New York, NY 10017.

Appendix B

A DISCUSSION OF STRUCTURE-BORNE VIBRATION

In the specific prohibited acts section of the document "Model Community Noise Control Ordinance" (1), there is a change that proposes prohibiting the creation of vibration which is above the perception threshold of an individual. This vibrational motion would be one that is ground - or structure-borne from the location of some source to another site (adjacent property). This provision, as well as each of the other ones in the "Model Ordinance", is proposed to be appropriate only when it is suited to local needs and conditions.

Structure-borne vibration may have physiological and psychological effects on the individuals who are exposed to it. These effects depend on many complicated and interrelated factors, such as the magnitude and frequency of the vibration; its location, area, and direction of application; and individual variations in susceptibility. An individual's susceptibility to vibrational effects is determined in part by his or her physical state, age, muscle tone, size and weight, etc. Further, the effects of vibration may be heightened or diminished by the physical or mental state of exposed individuals, their activity, or the presence of additional environmental stressors such as concurrent exposure to noise or heat. The vibration frequency, which may range from 0.1 to over 1,000,000 Hz, largely determines the kinds of effects experienced (2,3). Adverse effects may range from motion sickness (kinetosis), which occurs primarily from exposure to very low vibration between 0.1 and 1.0 Hz, to local tissue heating and possible cell damage which can result from exposure to vibration with frequencies in the ultrasonic range above 20,000 Hz.

For purposes of this discussion, only structure-borne vibration that commonly has levels above the perception threshold for humans is being considered. Thus, consideration of those vibrations with frequencies above 1000 Hz will be eliminated because: 1) humans are relatively insensitive to these high frequencies, and 2) high frequency vibrations are attenuated very rapidly as they propagate away from the source. An International Standard, ISO 2631, "Guide for the Evaluation of Human Exposure to Whole-Body Vibration," sets forth many of the particulars that define and specify the scope of interest for documenting and describing a vibration environment (4). According to the vibration perception threshold criteria, outlined in this discussion, the descriptive parameters of vibration exposure are specified in terms of vibration frequency, acceleration magnitude, and the way that the human body is vibrated.

B.1 Characterization of Vibration

Temporal Character: Vibration perception criteria normally specify vibration levels that correspond to threshold levels of average or normal individuals in good health. These vibration levels may be either periodic or random in time with a distributed frequency spectrum. Vibration perception criteria do not usually specify durations of exposure to vibration that might lead to various biological and/or performance effects over different times of total exposure.

Spatial Character: Vibration is a vector quantity that may be either angular or rectilinear. Rectilinear vibration specified in any one of the three orthogonal axes with respect to the human body will be used for the purposes of this discussion.

Magnitude: The quantity used to measure the "amount" or magnitude of vibration may refer to the displacement, velocity, acceleration, or jerk of the vibration. The quantity used throughout this discussion refers to the acceleration magnitude of the vibration expressed as a root-mean square value in nondimensional units of g's where 1 g = 980.665 cm/sec^2 is the value of the standard acceleration due to gravity at the earth's surface. (Acceleration magnitude is also commonly found expressed in units of meters per second squared, m/s^2; as a level in dB referenced to some standard value; as peak values, etc.)

Spectral Character: Vibration may occur with many different frequency compositions. Discrete-frequency vibration may consist of a single frequency component or multiple components; distributed-frequency vibration may be composed of a single narrow band of frequencies or a combination of more than one such narrow band of frequencies into a broad-band distributed vibration.

Transmission: The transmission of vibrational energy from a source through the ground and/or structural connections to a reception location may involve many changes in the characteristics of the vibration along the transmission path. Various properties of the transmission medium (or media) and reception structures can be expected to change the magnitude, direction, and frequency spectrum of vibration along its path of propagation. Of particular note will be relatively large-magnitude vibrations that may be induced at particular frequencies that correspond to resonant frequencies of receiving structures. Consequently, the description or measurement of vibration must include a detailed description of the locations selected for measurements.

B.2 Vibration Perception

Both physical and subjective methods of vibration measurement are acceptable; however, the physical measurement is the preferred method. Subjective awareness of vibration will depend upon: 1) the frequency and the magnitude of the stimulus, 2) the individual's response characteristics, and 3) the environmental conditions. Vibration perception threshold may be defined as the minimum vibrational acceleration that is necessary to cause a normal person to have a touch (in contact) or visual sensation of vibration. In some cases an individual may be unaware of levels of vibration higher than those of his threshold of perception because of distracting conditions. However, once attention is directed to the vibration, awareness may be anticipated.

At frequencies below 1 Hz vibration is sensed primarily by means of the vestibular organs along with somatic receptors in the areas of application of the vibration to the body. Above 1 Hz where body resonances and phase shifts in the transmission of vibration occur, the vestibular sensation is augmented by the stimulation of mechano-receptors throughout the body, including those in the muscles, tendons and joints as well as in the skin and in the viscera, and by visual cues. The sensations produced by whole-body vibration at frequencies less than 50 Hz vary with frequency and are related to body resonance. Beginning at about 15 Hz, the skin may be considered the chief sensing mechanism for vibration detection. The threshold of cutaneous perception, tested at a fingertip, is lowest in the region of 200-300 Hz; the sensitivity depends on the area, site and pressure of application and is related to muscle tone.

Threshold criteria for rectilinear vibration perception exist in the literature. One set (5) is based on a simple average of results of laboratory experiments involving human perception of single frequency whole-body vibration in standing, sitting, and lying positions. These data, which cover the frequency range of vibration from 1 to 50 Hz, are used in this discussion as the whole-body threshold perception level for any body orientation (standing, sitting, etc.). Consequently, it may be necessary to measure vibration in several directions and to determine the vector sum of all components before comparing the exposure level with the perception criterion.

In the frequency range from 50 to 1000 Hz, vibration perception criteria are usually expressed in terms of fingertip sensation levels (6). Vibrations with frequencies higher than 1000 Hz are rarely a problem because these vibrations are rapidly attenuated with distance from the source, and because the human perception sensitivity falls off rapidly with increasing vibration frequency. The widely accepted vibration perception criteria for the frequency range from 1 to 1000 Hz are presented in Figure B-1.

B.3 Measurement Methodology

Physical measurements or subjective detection of vibration perception threshold levels are required for the purposes of enforcement of ordinance criteria on exposure to vibration.

Subjective Detection of Vibration: Subjective awareness of vibration should be easily determined when levels of vibration are significantly above perception threshold. When any vibration perceived at all is prohibited, most individuals (including those responsible for enforcement of vibration controls) would be able to confirm the existence of prohibitive levels.

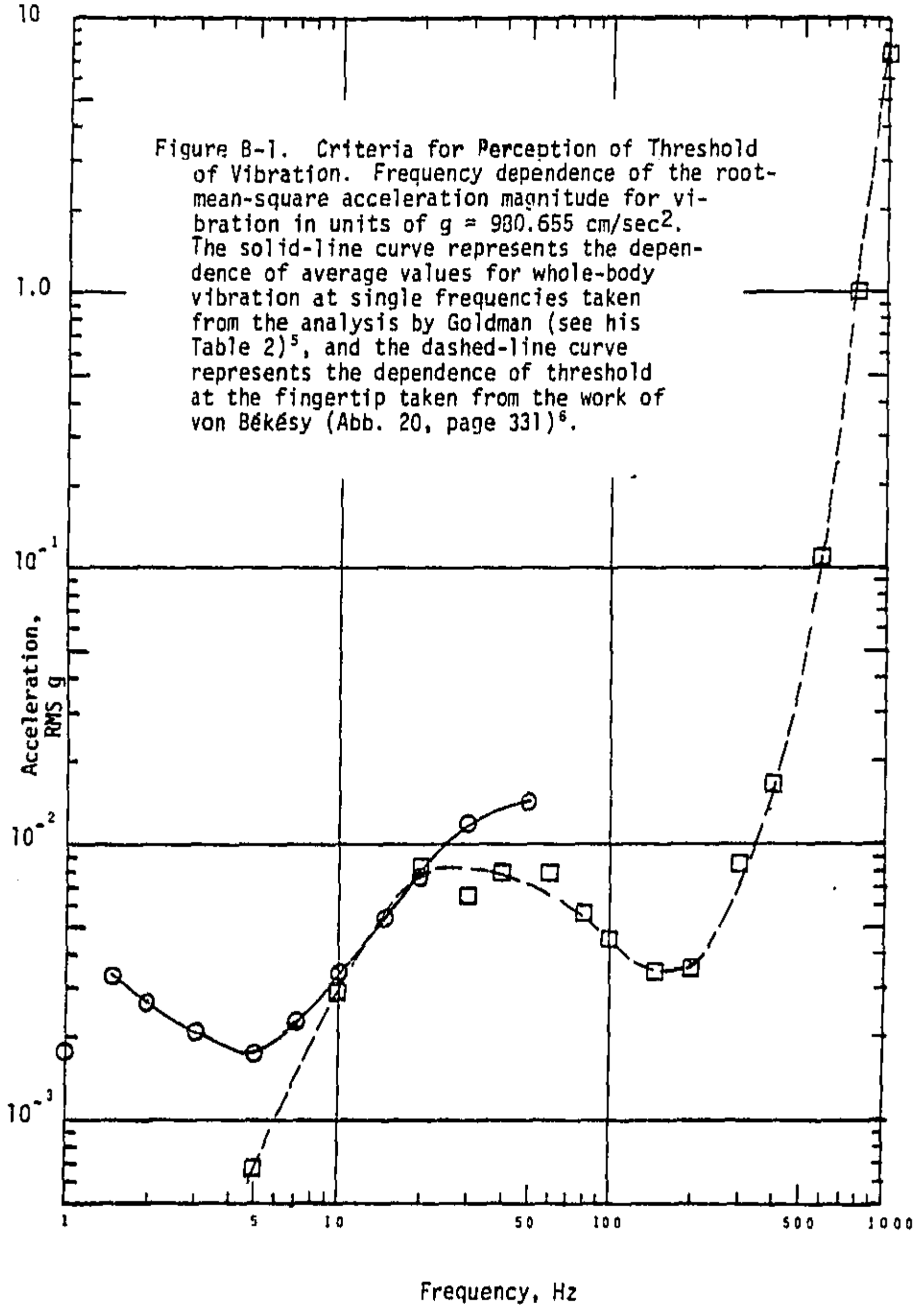


Figure B-1. Criteria for Perception of Threshold of Vibration. Frequency dependence of the root-mean-square acceleration magnitude for vibration in units of g = 980.655 cm/sec^2. The solid-line curve represents the dependence of average values for whole-body vibration at single frequencies taken from the analysis by Goldman (see his Table 2)[5], and the dashed-line curve represents the dependence of threshold at the fingertip taken from the work of von Békésy (Abb. 20, page 331)[6].

When vibration is at a level above and yet close to that for perception threshold, it may require more attention to confirm its presence. The enforcement specialist may be required to assume a particular orientation or location of the body so as to become aware of the vibration. Because the presence of additional persons may reduce the vibration magnitude, care should be taken to duplicate conditions described by those persons initiating a complaint. Depending on the particular circumstances, vibration may be detected through various means such as whole-body vibration input to the supporting surfaces of the body (standing, seated, or lying down), cutaneous perception (as with the hands on a table, shelf, etc.) or visual observation of vibrating objects.

It should be a matter of practical consideration that only normal activities be included among those circumstances of vibration exposure being evaluated for the presence of vibration levels above perception threshold. Thus, for example, vibration of a floor joist that is detectable only through a sense of direct touch with the fingertips would not constitute a condition producing "normal" awareness of the vibration. However, if this same vibration is transmitted from joist to floor surface and then detectably to a person supported by the floor, the vibration may be classified as prohibited, if the criterion is any normally perceived level.

<u>Measurement of Vibration</u>: The root-mean-square (rms) acceleration levels measured in one-third-octave bandwiths with center frequencies beginning at 1 Hz and ending at 800 Hz, which includes the frequency range from 0.9 Hz to 900 Hz are normally used for the physical measurements of vibration. The requisite system of equipment for measuring vibration generally consists of the following parts: a vibration pick-up (transducer), a suitable amplifying and signal conditioning device, and an indicator of output level. More specifically, this system consists of an accelerometer, an amplifier, and an rms-rectifying indicator with provision for inserting a one-third-octave-band analyzer. The system should have sensitivity to accelerations as low as 0.001 g at frequencies between 1 and 10 Hz and as large as 1 g at frequencies above 200-300 Hz. Instruments with features that meet such requirements are commercially available. In addition, vibration calibrators are available that may be used to calibrate the system by providing a known vibration (acceleration) input.

Instructions for the use of accelerometers as set forth in the literature and by manufacturers should be closely followed (7-10). Accelerometers can be used to measure vibration over wide frequency and dynamic ranges, but particular attention must be paid to the location and placement or mounting of the accelerometer. If possible, the unit should be mounted on a rigid and smooth surface that experiences the vibration that is to be measured. The axis of the unit will designate the direction of the component of vibration being measured, and consequently, this information should be recorded. Triaxial accelerometers are available that combine three separate units oriented in mutually orthogonal directions such that the resultant acceleration vector may be fully determined from the magnitudes of the orthogonal components. However, a single unit may be utilized to obtain this same information either by taking data for three mutually orthogonal directions or by measuring the acceleration magnitude along the major axis of vibration.

The accelerometer may be mounted by any of several methods. Generally, a threaded hole or a bolt is provided in the base of the accelerometer that permits mounting the unit directly to a surface, to a special adaptor that may then be cemented to a surface, or to a magnetic base that will attach readily and securely to surfaces of ferro-magnetic materials. The accelerometer may also be mounted by means of double-sided tapes, cements (for permanent type installations), or greases. In all cases, the mating surfaces should be smooth and free of dirt. A light coating of oil or grease is recommended between metallic mating surfaces that will be in direct contact.

Measurements are to be performed at locations that correspond to the point or points of complaint with complainant in place, and should be carried out upon that surface which is affecting the input of vibration to the complainant. Examples are flat surfaces of floors, desk or table tops, chair seats, etc. whereon the accelerometer is mounted directly. The measurement system of accelerometer and instrumentation should be calibrated prior to and after measurements and at any time during measurements whenever the operation of the system may become suspect, for example, whenever the transducer suffers a severe shock such as from an accidental fall. Acceleration magnitude (rms) should be measured in one-third-octave bandwiths and compared with those levels that correspond to vibration perception threshold at the center frequencies of the one-third-octave bandwiths (see Table B-1). The axis of the measurement should be recorded. In certain cases where this axis does not correspond to the major axis of the vibration stimulus, each of three orthogonal components should be measured and evaluated with regard to the perception criteria (Table B-1) along with the magnitude of the vector resultant. (The resultant is equal to the square root of the sum of the squares of the orthogonal components.) Whenever a measured level for any one-third-octave bandwidth exceeds a corresponding level of threshold of perception shown in Figure B-1 and in Table B-1, the vibration level may be out of compliance with ordinance requirements. It is appreciated that this method for the comparison of measured one-third-octave bandwidth levels with criteria that are based upon single frequency exposure data is an approximation and that circumstances may occur where such an application is inappropriate.

Table B-1

Vibration Threshold of Perception Criteria

Values are for the root-mean-square acceleration in units of g = 980.665 cm/sec^2 for the frequencies at the center of the one-third-octave bands beginning 1 Hz and ending 1000 Hz. Values have been determined from the curves of Figure B-1.

Center Frequency of One-Third-Octave Band, Hz	Acceleration (rms) For Threshold of Perception in g = 980.665 cm/sec^2	
	Whole-Body	Fingertip
1	1.8×10^{-3}	------
1.25	$(\sim 2.8 \times 10^{-3})$	------
1.6	3.2×10^{-3}	------
2	2.7×10^{-3}	------
2.5	2.3×10^{-3}	------
3.15	2.1×10^{-3}	------
4	1.9×10^{-3}	------
5	1.8×10^{-3}	8.3×10^{-4}
6.3	2.0×10^{-3}	1.2×10^{-3}
8	2.6×10^{-3}	1.9×10^{-3}
10	3.5×10^{-3}	2.7×10^{-3}
12.5	4.4×10^{-3}	3.9×10^{-3}
16	6.0×10^{-3}	5.9×10^{-3}
20	7.7×10^{-3}	8.3×10^{-3}
25	1.0×10^{-2}	9.2×10^{-3}
31.5	1.2×10^{-2}	9.0×10^{-3}
40	1.4×10^{-2}	8.0×10^{-3}
50	1.4×10^{-2}	6.9×10^{-3}
63	------	5.8×10^{-3}
80	------	4.9×10^{-3}
100	------	4.2×10^{-3}
125	------	3.6×10^{-3}
160	------	3.4×10^{-3}
200	------	3.6×10^{-3}
250	------	4.9×10^{-3}
315	------	8.8×10^{-3}
400	------	1.8×10^{-2}
500	------	4.6×10^{-2}
630	------	1.6×10^{-1}
800	------	1.0
1000	------	~ 8

REFERENCES

1. "Model Community Noise Control Ordinance," U.S. Environmetal Protection Agency, Public Information Center (PM215), Washington, D.C. 20460, EPA Document No. 550/9-76-003, September 1975.

2. Guignard, J. C., Chapter 28, "Introduction" and Chapter 29, "Vibration," in A Textbook of Aviation Physiology, edited by J.A. Gillies, Pergamon Press, New York, pp. 807-894, 1965.

3. Goldman, D.E. and H.E. von Gierke, Chapter 44, "Effects of Shock and Vibration on Man," in Shock and Vibration Handbook, Vol. 3, edited by C. M. Harris and C.E. Crede, McGraw-Hill Book Company, New York, pp 44-1 to 44-51, 1961.

4. ISO Standard, Publication ISO 2631-1974, Guide for the Evaluation of Human Exposure to Whole-Body Vibration, 1974.

5. Goldman, D.E., "A Review of Subjective Responses to Vibratory Motion of the Human Body in the Frequency Range 1 to 70 Cycles per Second," Report No. 1, Project NM 004 001, Naval Medical Research Institute, National Naval Medical Center, Bethesda, MD, 16 March 1948.

6. von Békésy, G., "Über die Vibrationsempfindung," Akust. Z. 4, 316-334 (1939).

7. B&K Instruments, Inc., 5111 West 164th Street, Cleveland, OH 44142, Mechanical Vibration and Shock Measurements, by J.T. Broch, 311 pp., Rev. Edition, May 1972.

8. Endevco Corporation, Pasadena, CA, Piezoelectric Accelerometer Manual, by D. Pennington, 119 pp., 1965.

9. Gen Rad, 300 Baker Avenue, Concord, MA 01742, Handbook of Noise Measurement, 7th Edition, by A.P.G. Peterson and E.E. Gross, Jr., 322 pp., 1972.

10. Wilcoxon Research, P.O. Box 5798, Bethesda, MD 20014, Catalog of instrumentation specification sheets, current.

BIBLIOGRAPHY OF
SOURCE MATERIAL ON COMMUNITY NOISE

Government Documents - Many of the following documents can be purchased through the U.S. Government Printing Office (GPO), Washington, DC 20402, Phone: 202/783-3238 or the National Technical Information Service (NTIS), U.S. Department of Commerce, 425 13th Street, N.W., Room 620, Washington, DC 20004, Phone: 202/296-4348. A GPO or NTIS document number will be included with the reference in such cases.

Report to the President and Congress on Noise, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, DC 20460, EPA Document No. NCR 500.1, December 31, 1971. (GPO Stock No. 5500-0040) (NTIS No. PB-206-716).

Noise Control Act of 1972, Public Law 92-574, 92nd Congress, H.R. 11021, October 27, 1972, 86 Stat. 1234.

EPA Noise Control Program Progress to Date, U.S. Environmental Protection Agency, Office of Noise Abatement and Control (AW471), Washington, DC 20460, March, 1977.

Toward a National Strategy for Noise Control, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, DC 20460, April, 1977.

Public Health and Welfare Criteria for Noise, U.S. Environmental Protection Agency, Office of Noise obatement and Control, Washington, DC 20460, EPA Document No. 550/9-73-002, July 27, 1973. (GPO Stock No. 5500-00103) (NTIS No. PB-241 000/AS).

Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, DC 20460, EPA Document No. 550/9-74-004, March, 1974. (NTIS No. PB-239 429/AS).

Report on Aircraft/Airport Noise, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, DC 20460, EPA Document No. Senate 93-8, August 1973. (GPO Stock No. 5270-01936).

Effects of Noise on People, NTID 300.7, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Technical Document, December 1971. (GPO Stock No. 5500-0050) (NTIS No. PB-206 723).

Community Noise, NTID 300.3, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Technical Document, December 1971. (GPO Stock No. 5500-0041) (NTIS No. PB-207 124).

Fundamentals of Noise; Measurement, Rating Schemes and Standards, NTID 300.15, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Technical Document, December 1971. (GPO Stock No. 5500-0054) (NTIS No. PB-206 727).

Model Community Noise Control Ordinance, U.S. Environmental Protection Agency, Public Information Center, (PM215), Washington, DC 20460, EPA Document No. 550/9-76-003, September, 1975.

Guidelines for Developing a Training Program in Noise Survey Techniques, U.S. Environmental Protection Agency, Office of Noise Abatement and Control, EPA Document No. 550/9-75-021. (NTIS No. AD-A01667).

Noise Control - Any one of the following publications offers information on noise control techniques.

- Guidelines on Noise, American Petroleum Institute, Committee on Medicine and Environmental Health, 1801 K St., N.W., Washington, DC 20006, Medical Research Report EA 7301, 1973.

- Industrial Noise Manual, 3rd edition, American Industrial Hygiene Association, 66 Miller Road, Akron, Ohio 44313, 1975.

- Industrial Noise Control Manual, U.S. Department of Health, Education, and Welfare, National Institute for Occupational Safety and Health, Cincinnati, OH 45202. HEW Publication No. (NIOSH) 75-183, June 1975. (For sale by GPO.)

- Berendt, R.D., Corliss, E.L.R., and Ojalvo, M.S. "Quieting: A Practical Guide to Noise Control," National Bureau of Standards, Washington, DC 20234, NBS Handbook 119, July 1976. (GPO Stock No. 003-003-01646-2.)

- Harris, C.M., Handbook of Noise Control, McGraw-Hill Book Co., New York 1957.

Periodicals - Community noise abatement program personnel should also consider subscribing to the following periodic publications:

- Sound and Vibration, a monthly magazine published by Sound and Vibration, 2701 E. Oviatt Road, Bay Village, OH 44140.

- Noise/News, a bimonthly newsletter of the Institute of Noise Control Engineering, published by Noise Control Foundation, P.O. Box 3460, Arlington Branch, Poughkeepsie, NY 12603.

- Noise Regulation Reporter, The Bureau of National Affairs, Inc. 1231 25th Street, N.W., Washington, DC 20037.

- Noise Control Report, Business Publishers, Inc., P.O.Box 1067, Blair Station, Silver Spring, MD 20910.

Books - The following list of source books is provided with a brief comment on the specific application of each book.

Acoustic Noise Measurements, J.T. Broch, Bruel & Kjaer, Denmark (1971). Intended as a guide for the application of B and K equipment in sound measurement, this text provides reliable technical background in physics of sound.

Fundamentals of Acoustics, L.E. Kinsler and A.R. Frey, Wiley & Sons, Ind., New York (1962). Detailed text for the advanced acoustics student: requires knowledge of physics and calculus.

Handbook of Noise Measurement, A.P.G. Peterson and E.E. Gross, Jr., General Radio Co., Concord, Mass. (1972). Basic overview of physics of sound and sound measurement techniques for the reader with limited physical science background.

Hearing Conservation, J. Sataloff and P.L. Michael, C.C. Thomas, Springfield, Illinois, (1973). Basic text on the physics of sound and the effect of sound on people that is well suited to a beginning learner in science of sound.

Introduction to Audiology, Fredrick W. Martin, Prentice-Hall, Inc., Englewood Cliffs, NJ (1975). A basic overview of the hearing mechanism and of hearing disorders and measurement techniques.

Sound and Hearing, S.S. Stevens and F. Warshofsky, Time-Life Books, New York (1970). Very basic and simplified overview of the physics of sound and the phenomenon of hearing; this book is especially useful because of the exceptional photographs and drawings used to illustrate various acoustic phenomena.

GLOSSARY

A-Weighting -- A-weighting refers to a particular processing of sound signals in which low frequencies are de-emphasized. This weighting has been found to correspond fairly well to subjective human response to sound signals. See also L_A.

Absorption -- Absorption is the removal of a portion of the original sound energy when sound is reflected from a surface.

Absorption Coefficient -- The absorption coefficient of a given surface is the ratio of the sound energy absorbed by the surface to the sound energy incident upon the surface.

Accelerometer -- An accelerometer is a device used to measure acceleration.

Acoustics -- Acoustics is the name of the scientific study of sound.

Acoustic Trauma -- Acoustic trauma refers to a permanent elevation in hearing threshold which follows a one-time exposure to high level sound.

Ambient Noise -- The ambient noise of an environment is the average sound level due to the combined effect of all the sound sources in that environment. It is sometimes identified as the sound level that is exceeded 90% of the time (L_{90}).

Amplitude -- The amplitude of a sound is a measure of the amount of energy (i.e., pressure, power, intensity) of that sound.

Anvil -- The anvil is one of the three bones of the middle ear. See Ossicles.

Attenuation -- Attenuation is the loss of a portion of sound energy as a result of passing through matter (through a wall, for example).

Attitude Survey -- An attitude survey is a process that seeks to determine how people feel about any matter of interest by asking them about it.

Audiogram -- An audiogram is a record of hearing threshold levels of a particular individual at various frequencies. These threshold levels are referenced to statistically normal hearing levels.

Audiometer -- An audiometer is a device for measuring hearing threshold levels.

Audition -- Audition is the process of hearing.

Auditory Nerve -- The auditory nerve carries neural impulses from the hair cells of the inner ear toward the brain, and from the brain to the inner ear.

Auditory Sensitivity -- Auditory sensitivity is a term that describes the ability of the human ear to respond to sounds.

Auricle -- See Pinna.

B-Weighting -- B-weighting is an infrequently used processing of sound signals in which there is a slight de-emphasis of the low frequencies.

C-Weighting -- C-weighting is a processing of sound signals that treats all frequencies from about 30 Hz to about 8000 Hz with equal emphasis.

Calibration -- Calibration is the process by which the accuracy of a measuring instrument is certified.

Calibrator -- A calibrator is any standard device used to calibrate other devices; in acoustics this commonly refers to a device used to certify the accuracy of sound level meters.

Community -- As used in this manual, a community is any jurisdiction that is smaller than a state (usually a city or a county).

Compression -- A compression is that portion of a cycle during which, or the portion of space within which, the molecules are crowded closer together than normal.

Continuous -- A continuous signal is a signal that is always present over the interval of observation although the level of the signal may vary considerably over this interval.

Cycle -- A cycle of a periodic occurrence is the complete sequence of values that occur during a period.

Decibel -- The decibel (abbreviated dB) is a convenient unit used to express the magnitude of sound as a logarithmic ratio of variables. The level of an acoustical quantity is usually expressed in decibels. (See Level, L_A, and also Chapter 1, Section 1.3.2.)

Decrement -- A decrement is a decrease in a quantity.

Demographic -- Demographic is a term referring to any characteristic of a person or population that may be relevant to behavior and attitudes.

Descriptor -- A descriptor is any number used to describe a situation. Some descriptors used to describe sound level are L_A, L_{eq}, L_{dn}, etc.

Diffraction -- Diffraction is the bending of waves when they encounter an obstacle.

Direct Interview -- A direct interview is one in which the respondent is aware of the central concern of the interview.

Eardrum -- The eardrum is a membrane which separates the outer ear and the middle ear, and which vibrates in response to sound pressure.

Etiology -- The etiology of a process is the set of related events leading to it.

Fast Response -- A setting of one of the controls of a sound level meter that allows the indicator to follow the variations in sound level as closely as possible.

Fixed-Alternative Questions -- Fixed-alternative questions are those for which the respondent must choose from the responses provided by the survey instrument.

Fluctuating -- A fluctuating sound is one that varies in pressure level during the period of observation, but remains above the ambient noise level most of the time (it may descend to the ambient level no more than once during the period of observation).

Frequency -- The frequency of a sound is the number of complete cycles of that sound occurring in one second. Most sound sources produce more than one frequency at a given moment.

Frequency Band -- A frequency band is a range of frequencies. Examples of frequency bands are octave bands, broad bands, critical bands, etc.

Frequency Spectrum -- The frequency spectrum of a sound is a representation of the frequencies present and their amplitudes.

Hair Cell -- A hair cell is one of the sensory cells in the inner ear that can respond to sound by initiating neural impulses in the auditory nerve.

Hammer -- The hammer is one of the three bones of the middle ear. See Ossicles.

Hearing Handicap -- Hearing handicap is defined as the existence of an average hearing threshold level of more than 25 dB in the better ear; this average is based on measurements at 500, 1000, and 2000 Hz.

Hearing Loss -- Hearing loss is any measureable difference for which the hearing of the subject is poorer than that of the population used to define normal hearing.

Hearing Threshold -- Hearing threshold is the minimum signal level (in dB) that can be detected by a subject during a hearing test. This level may be different at different frequencies.

Hearing Threshold Level -- Hearing threshold level is a scale for reporting the level of a sound (in dB) referred to average, normal hearing thresholds (see above). The zero level for this scale is based upon a statistically determined normal hearing population. This is the scale generally used for reporting hearing threshold results in the clinical audiogram.

Intermittent -- An intermittent sound is one that switches off and on two or more times during the period of observation.

Incus -- See Anvil.

Impedance -- Impedance is that property of a medium which determines the extent of its response to an external force and how well it will transfer energy to another medium.

Impedance Matching -- When the impedances of two media are equal, a condition of impedance matching exists, and maximum energy can be transferred from one medium to the other. The more the ratio of the impedances differs from one, the smaller is the fraction of energy transferred.

Infrasonic -- Infrasonic sounds are those with frequencies smaller than can be detected by persons of normal hearing.

L_A -- L_A is the A-weighted sound pressure level. It is the most commonly used descriptor of instantaneous sound pressure level. Many earlier documents state this level in units of dB(A).

L_{dn} -- L_{dn} is equivalent to the L_{eq} measured over a 24-hour period with a 10 dB penalty added for the nighttime hours.

$$L_{dn} = 10 \log_{10} \left[\frac{1}{24} \left(\sum_{7\ am}^{10\ pm} 10^{\frac{L_{eq}}{10}} + \sum_{10\ pm}^{7\ am} 10^{\frac{L_{eq}+10}{10}} \right) \right]$$

L_{eq} -- L_{eq} is a descriptor of the total noise exposure during a finite time interval. The equivalent sound level, L_{eq}, has the same total sound energy as the actual time varying A-weighted sound during the specified period.

$$L_{eq} = 10 \log_{10} \left[\frac{1}{T} \int_0^T \frac{\overline{p^2}}{p^2_{ref}} dt \right]$$ where T is normally 1 to 24 hours

Level -- The level of any quantity, described in decibels (dB) is proportional to the logarithm (base 10) of the ratio of that quantity to a reference value of the same quantity. Both the value and the reference value should be stated in the same units.

L_{10} -- L_{10} is that sound level that is exceeded in 10% of a set of observations. L_{10} is frequently close in numerical value to L_{eq}.

L_{50} -- L_{50} is that sound level that is exceeded in 50% of a set of observations.

L_{90} -- L_{90} is that sound level that is exceeded in 90% of a set of observations. This descriptor is often taken as the ambient sound level.

Loudness -- Loudness is that aspect of human perception of sound that corresponds most closely with the amplitude of the sound.

Malleus -- See Hammer.

Manual Sampling -- Manual sampling requires the presence of a human observer, usually to record the data.

Masking -- Masking is the obscuring (partial or total) of one or more sound signals by the presence of other sound signals.

Neural Impulse -- A neural impulse is a signal within the nervous system.

Noise -- Noise is any unwanted sound. Objective measurements of noise are made with instruments, most often with a sound level meter.

Noise Abatement -- Noise abatement is the reduction of existing noise through corrective measures.

Noise Control -- Noise control is the reduction of noise through preventive measures.

Noise Dose -- A noise dose is the ratio of the duration of exposure to the duration permitted for exposure at a specific sound level based on a damage risk criterion. The total noise dose is the sum of the individual noise doses at each exposure level.

Noise Emission Standard -- A noise emission standard is a limit, set by government regulations, on the output of sound measured at a specified distance from regulated operating devices.

Noise Exposure Limit -- The noise exposure limit is a figure established by the OSHA Act. It is designed to limit the hearing loss associated with work.

Noise-Induced Hearing Loss -- Noise-induced hearing loss is the hearing loss that results from exposure to noise. The total hearing loss is the result of noise plus other factors such as aging and disease.

Noise-Induced Permanent Threshold Shift (NIPTS, also PTS) -- Noise-induced permanent threshold shift is the irreversible elevation in the threshold of hearing (quietest sound a person can hear) which follows chronic immersion in high level noise.

Noise-Induced Temporary Threshold Shift (NITTS, also TTS) -- Noise-induced temporary threshold shift is a reversible elevation in the threshold of hearing (quietest sound a person can hear) which follows immersion in high level noise. In cases of TTS, the hearing threshold of the exposed listener will return to pre-noise-exposure levels if the listener is placed in a quiet environment for a period of time. Subscript numbers following "TTS" indicate the duration in minutes between noise cessation and hearing threshold testing (e.g., TTS_2 = hearing test 2 minutes after noise cessation).

Noise Map -- A noise map is a set of contours of equal noise exposure (such as equal L_{eq}) based upon measurements of noise in the region of interest.

Noise Survey -- A noise survey is a set of measurements of the sound levels or sound exposures in an environment of interest. In some surveys octave band (or even narrower band) analysis may be included.

Octave Band -- An octave band is a frequency band with its upper band edge equal to twice its lower band edge. Octave bands are usually named by their center frequencies. An example of an octave band is the one that has a center frequency of 1000 Hz: its lower band edge is at 707 Hz and its upper band edge at 1414 Hz.

Ordinance -- An ordinance is a municipal regulation set forth by a government authority.

Ossicles -- The ossicles are the three bones located in the middle ear. The hammer (or malleus) is attached directly to the eardrum at one end and to the anvil (or incus) at the other. The stirrup (or stapes) is attached to the anvil at one end and to the oval window (entrance to the inner ear) at the other.

Performance Standard -- A performance standard is a quantitative statement of the requirements that a particular product must meet to be acceptable.

Permanent Threshold Shift -- See Noise-Induced Permanent Threshold Shift.

Pink Noise -- Pink noise is a form of broad band sound in which each octave band has the same total energy.

Pinna -- The pinna (or auricle) is that portion of the ear that extends outward from the head.

Pitch -- Pitch is that aspect of an observer's perception of sound that corresponds most closely to the frequency of the sound.

Presbycusis -- Presbycusis is the loss of hearing that is associated with the aging process.

Pressure -- Pressure is force per unit area. In acoustics the variation in pressure associated with a sound signal, called the sound pressure, is the variable of primary interest.

Probability Sample -- A probability sample is one for which the individuals sampled are accurately representative of the population being studied.

Propagation -- Propagation is the passage of a signal from its source to a receiver. Some of the processes involved in propagation are absorption, reflection, and transmission.

Psychosocial -- Psychosocial refers to the interactive combination of psychological and social factors in the situation under consideration.

PTS -- See Noise-Induced Permanent Threshold Shift.

Pure Tone -- A pure tone is a sound signal whose instantaneous sound pressure can be represented by a simple sine wave. A pure tone has a single frequency.

Quality -- Quality is that aspect of an observer's perception of sound that corresponds most closely to the frequency spectrum of the sound.

Random Sample -- A random sample is one for which every member of the population under study has an equal chance of being selected.

Rarefaction -- A rarefaction is that portion of a cycle during which, or the region of space in which, the molecules are spread further apart than normal.

Reflection -- Reflection is the process in which some portion of an incident wave, upon encountering a barrier, is returned back into the medium from which it came.

Regulation -- A regulation is a statement issued by a governmental agency specifying some required condition or behavior.

Resonance -- A resonance is a condition for which the response of a system to a stimulus is unusually large. In acoustics, resonance is associated with increased response at certain frequencies, which are therefore called resonance frequencies.

Sensor -- A sensor is any physical device or physiological structure that responds to stimuli. The term is most often applied to certain structures of the human sense organs and to certain devices that respond to same types of stimuli as do the human senses.

Slow Response -- Slow response is a setting of one of the controls of a sound level meter that slows the movement of the level indicator (usually a meter movement) so that rms pressure variations occurring more rapidly than 0.5 seconds can be observed as a relatively steady value.

Sociocusis -- Sociocusis refers to those hearing losses associated with non-work exposures to noise.

Sound -- Sound, as used in this manual, refers to oscillations in pressure, particle position, and particle velocity.

Sound Analyzer -- A sound analyzer is a device that measures the sound pressure level in narrow bands (usually in octave or 1/3-octave bands).

Sound Intensity -- The sound intensity at a particular location is the average rate at which sound energy is transmitted through a unit area perpendicular to the direction of propagation.

Sound Level Meter -- A sound level meter is a device for measuring rms sound pressure level. Such meters fall into three types, called types 1, 2, and 3. Type 1 meters are the most accurate; Type 3 are the least accurate. Type 1 and Type 2 meters normally are used for measurement of community noise.

Sound Pressure -- Sound pressure is the variation in pressure that occurs when a sound signal is propagated through a medium. Sound pressure is expressed mathematically as: $p = p(t)$ where pressure changes as a function of time. It is the instantaneous difference between the actual pressure and the static or barometric pressure at a given time. The value that is usually measured is the root-mean-square (rms) sound pressure. The rms sound pressure at a measurement point is the square root of the mean-square value of the instantaneous sound pressure over a time interval. Expressed mathematically;

$$p_{rms} = \sqrt{\overline{p^2}} = \sqrt{\frac{1}{T}\int_0^T p^2\,(t)dt.}$$

Sound Pressure Level -- The sound pressure level, L_p, expressed in decibels (dB) is 20 times the logarithm to the base 10 of the ratio of the rms sound pressure to the rms reference pressure of 20 micropascals (newtons per square meter), or 20 μPa. The mathematical expression for sound pressure level is:

$$L_p = 10 \log_{10} \left[\frac{\overline{p^2}}{p_{ref}^2}\right] = 20 \log_{10} \left[\frac{p_{rms}}{p_{ref}}\right]$$

Sound Wave -- A sound wave is a variation in sound pressure associated with the propagation of a periodic sound signal.

Standard -- A standard is a set of specifications drawn up by a professional body that describes the required performance of a system, process, or device.

Stapes -- See Stirrup.

Stationary Source -- A stationary source is a source that remains within a pre-determined boundary line (for example, a property line) throughout a noise measurement.

Steady-State -- A steady-state noise is one whose sound pressure level is essentially constant throughout the period of observation.

Stirrup -- The stirrup is one of the three bones of the middle ear. See Ossicles.

Stratified Random Sample -- A stratified random sample is one for which two or more aspects of a population are sampled in proportion to their representation in the total population being studied.

Stressor -- A stressor is any stimulus that produces a condition of stress in the human body. Noise is an example of a stressor.

Structure-Borne Vibration -- Structure-borne vibration is any vibration propagated from a source at one location in a building to other locations through the structural elements (framework, floors, walls, etc.) of that building.

Structured Interview -- A structured interview is one in which the questions to be asked have been completely determined prior to the interview.

Survey -- A survey is any study of some aspect of a population or an environment that utilizes sampling techniques to obtain data.

Survey Instrument -- A survey instrument, as used in connection with social surveys, is a technique (such as an interview or questionnaire) for obtaining information.

Temporal Pattern -- The temporal pattern of a sound is the variation of sound pressure level with time.

Temporary Threshold Shift -- See Noise-Induced Temporary Threshold Shift.

Transducer -- A transducer is any device that receives an input signal in one form (e.g., mechanical) and puts out a signal in a different form (e.g., electrical).

Transmission -- Transmission is the passage of energy through a medium. The term often is used in connection with the sound energy that passes through a barrier.

Transmission Loss -- The transmission loss (TL) of a sound barrier is obtained by taking ten times the logarithm (base 10) of the ratio of the incident acoustic energy to the acoustic energy transmitted through the barrier.

TTS -- See Noise-Induced Temporary Threshold Shift.

Ultrasonic -- Ultrasonic sounds are those with frequencies greater than can be detected by persons of normal hearing.

Vibration -- Vibration is a back and forth motion of a system. The frequency of vibration can be either infrasonic, audible, or ultrasonic.

Vibration Perception Threshold -- The vibration perception threshold is reached when the vibrations can either be seen or felt by touch.

Wavelength -- One wavelength of a wave is the distance between two consecutive crests of the wave (more generally, the distance between any two consecutive points of identical phase).

White Noise -- White noise describes a sound source that has equal energy per unit frequency over a specified frequency range.