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IEEE Guide for
Power Station Noise Control

IEEE Guide for Power-Station Noise Control

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Foreword

(This Foreword is not a part of IEEE Std 640-1985, IEEE Guide for Power-Station Noise Control.)

Recognizing the need for guidance on various aspects of a comprehensive noise-control program for power generation plants, an IEEE Working Group on Power-Station Audible Noise Control was formed. Membership was composed of representatives from a cross section of utility companies, architect-engineering firms, and power-plant equipment suppliers. The working group held its organizational meeting in January 1972. Individual reports on power-station noise by the working group members became the basis for development of this guide. This guide reviews alternative noise-control methods for identifying and controlling noise-emission problems in existing and planned fossil and nuclear power plants.

Suggestions for improvement of this guide will be welcomed.

The IEEE wishes to acknowledge its indebtedness to those who have so freely given of their time and knowledge and have provided experimental or field-data work.

This guide was prepared by the Mechanical and Electrical Noise Working Group of the Station Design Subcommittee of the IEEE Power Generation Committee. At the time this guide was approved the working group had the following membership:

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Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments.

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IEEE Guide for Power-Station Noise Control

1. Introduction

Environmental noise and occupational noise exposure are a matter of increasing public concern. Legislation requiring assessment, control, and abatement of noise has been enacted on all governmental levels. This guide provides guidance to control electric power-plant noise emissions to acceptable limits.

There has been an increase in the noise emissions from power plants with the use of larger, more intensely used, machinery. To reduce this noise emission, power-plant engineers need to become familiar with noise-control principles. Noise control for new plants is usually expensive and may cost up to 4% of the total cost of the plant. It is necessary that noise-control planning be done prior to constructing a new plant or to modernizing an existing plant so as to eliminate or minimize excessive retrofit costs.

A typical noise-control program consists of the following subsections:

1.1 Establishment of Noise-Control-Design Objectives. Noise-control objectives are dictated by

(1) Community noise requirements

(2) The Occupational Safety and Health Administration (OSHA) limits inside the plant

(3) Speech interference levels in offices, control rooms, etc

These requirements are discussed in Section 3. The considerations in establishing these objectives are discussed in Section 8.

For new plants these objectives provide a starting point in specifying the equipment sound levels. For existing plants they help in determining the noise reduction necessary. Noise levels permitted inside the plant by OSHA are governed by the accumulated noise-exposure dose, not by the levels alone. Hence, the feasibility of administrative controls should be included in setting the permitted levels or the necessary noise reduction for hearing protection purposes.

1.2 Prediction/Determination of Power-Station Noise. Once the design objectives have been established, the next step is to predict for new plants or determine for existing plants the power-station noise.

In the case of an existing plant this means a sound survey inside the plant and in the surrounding community. The sound survey is discussed in Section 7.

There are two ways of predicting the noise from a new plant. If a similar plant is operating, one can conduct a sound survey and then modify the sound levels obtained for any differences which may exist between the two plants, such as topography of the surroundings and location, and orientation of the plant with respect to the nearby community. In the absence of a similar operating plant one can extrapolate the noise levels of a plant of smaller size but of a similar nature. There are no definite rules available for such an extrapolation. The manufacturers of the new plant equipment should provide sound data, measured or predicted, which will help in the extrapolation. These ideas are discussed in detail in Sections 6 and 7. If the manufacturers offer any modifications to their equipment to lower the noise levels, these should be considered in predicting the plant noise levels. The option of retrofitting to reduce the noise should also be kept in mind. Both have their advantages and disadvantages.

1.3 Specifications of Equipment Sound Levels and Noise Reduction. Some of the inputs that should be considered in preparing equipment specifications are discussed in Section 7. Design approaches to meet the desired levels are also discussed in Section 7.

To achieve the amount of noise reduction that may be required inside and around an existing power plant, the major sources of noise should be identified. Section 7 discusses the identification of noise sources in detail. Examples of frequency spectra of power-plant noise sources are described in Section 5. These spectra provide the necessary information needed in the selection of noise-reduction schemes in relation to the characteristics of the noise source. Noise-reduction schemes are discussed in Section 7. A list of the possible sources of noise and methods of noise reduction are also included in Section 7.

1.4 Evaluation of the Noise-Control Measures. Once the new plant, designed with noise-control considerations, is in operation or the noise-control measures are installed in an existing plant, a follow-up sound survey should be made to evaluate the noise-control program. If the noise levels fail to meet the selected design objectives, the reasons should be traced and corrected. See Section 7. This guide supports the program and addresses alternate noise-control methods for noise-emission problems generally encountered in fossil and nuclear power plants.

The noise-control techniques reviewed in this guide are not intended to be applicable to other power generating facilities such as combined cycle, diesel, gas turbine, hydro-electric, and solar power plants.

Information presented in this guide was obtained from published national standards, technical papers, and the experience from the installation and evaluation of noise-control equipment. Terminology used conforms to ANSI S1.1-1960 (R1976) [2][1].

It is not the intent of this guide to adopt any noise compliance limits or to design a specific series of noise-control devices to solve individual power-plant noise problems. Such an underaking is somewhat impractical because of the numerous variations in regulation requirements, personnel exposure, plant siting, noise sources, equipment ratings, background levels, environmental conditions, and individual plant operational requirements. This guide provides the power-plant engineer with the tools necessary to identify potential noise problem areas and alternate control methods which may be required to comply with applicable limits.

1.5 Definitions. The following definitions apply to the subject matter presented in this guide.

absorption coefficient. The ratio of the energy absorbed by the surface to the energy incident upon it.

decibel. 10 times the logarithm to base 10 of a ratio of two powers.

sound intensity. The average rate of sound energy transmitted through a unit area normal to the direction of sound.

sound power. The total sound energy radiated by a source per unit time.

sound pressure. The instantaneous pressure measured in a sound wave, that is, the variation in atmospheric pressure.

1.6 References. When the following American National Standards referred to in this standard are superseded by a revision approved by the American National Standards Institute, the latest revision shall be used.

[1] AMCA STD 300-67, Test Code for Sound Rating—Air-Moving Devices.[2]

[2] ANSI S1.1-1960 (R 1976), American National Standard Acoustical Terminology (Including Mechanical Shock and Vibration).[3]

[3] ANSI S1.4-1983, American National Standard Specification for Sound Level Meters.

[4] ANSI S1.8-1969 (R 1974), American National Standard Preferred Reference Quantities for Acoustical Levels.

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[1] Numbers in brackets correspond to those of the references in 1.6 of this guide.

[2] AMCA publications are available from Air Movement and Control Association, 30 West University Drive, Arlington Heights, IL 60004.

[3] ANSI publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

[5] ANSI S1.11-1966 (R 1976), American National Standard Specifications for Octave, Half-Octave, and Third-Octave Band Filter Sets.

[6] ANSI S1.13-1971 (R 1976), American National Standard Methods for the Measurement of Sound Pressure Levels.

[7] ANSI/ASC S1.6-1984, American National Standard Preferred Frequencies, Frequency Levels, and Band Numbers for Acoustical Measurements.

[8] IEEE Std 85-1973 (R 1980), IEEE Test Procedure for Airborne Sound Measurements on Rotating Electric Machinery.[4]

[9] NEMA TR 1-1980, Transformers, Regulators, and Reactors.[5]

[10] NUREG 4.2, Nuclear Regulatory Guide for Preparation of Environmental Reports for Nuclear Plants.[6]

[11] Noise Ordinance of Chicago, 1971.[7]

[12] Rules of Procedure—Certification for Major Steam Electric Generating Noise, 1973, Part 75, New York State, Albany, NY.

[13] State and Local Noise Regulations, 1973, ch 8. Illinois Pollution Control Board.

[14] *Sound and Vibration* (Magazine).

[15] 24 CFR 51 HUD, Environmental Criteria and Standards for Housing and Urban Development.[8]

[16] 29 CFR 1910.95 OSHA, Occupational Noise Standards.[9]

[17] 29 CFR Bulletin 334, Guidelines to the Department of Labor's Occupational Noise Standards.[10]

[18] 40 CFR 1 POE, Environmental Protection Agency—Public Health and Welfare Criteria for Noise.

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[4] IEEE publications are available from IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854.

[5] NEMA publications are available from National Electrical Manufacturers Association, 2101 L Street, NW, Suite 300, Washington, DC 20037.

[6] NUREG publications are available from Superintendent of Documents, US Government Printing Office, Washington, DC 20402.

[7] This publication is available from Department of Environmental Control, Chicago, IL.

[8] HUD publications are available from Superintendent of Documents, US Government Printing Office, Washington, DC 20402.

[9] OSHA publications are available from Occupational Safety and Health Administration, US Department of Labor, Washington, DC 20210 or from the nearest regional or area office of the United States Department of Labor.

[10] CFR publications are available from Superintendent of Documents, US Government Printing Office, Washington, DC 20402.

[19] 40 CFR 1 POE, Environmental Protection Agency—Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety.

[20] US Department of Transportation, Federal Highway Administration Fundamentals in Abatement of Highway Traffic Lanes. Report on Contract no DOT-FH-11/7976, 1976.

2. Fundamentals

2.1 Introduction. Sound waves are a form of elastic waves that can be propagated through any medium exhibiting mass and elasticity. Mass, or inertia, enables displaced particles of the medium to transfer energy. Elasticity enables the disturbed particles to return to their original position, somewhat similar to a spring.

Air has mass and elasticity and therefore can transmit sound waves. A noise source sets adjacent air molecules in motion. This movement produces a variation in atmospheric pressure and this disturbance is propagated from molecule to molecule. The instantaneous variation in atmospheric pressure is called sound pressure. The speed of sound in a particular medium is defined as the product of frequency and wavelength

$$c = f\lambda \qquad \text{(Eq 1)}$$

where

c = speed of sound
f = frequency
λ = wavelength

In air the speed of sound is dependent only on the temperature of air. At 70 °F, the speed of sound in air is 1128 ft/s.

Sound may consist of a pure tone (a single frequency) where the instantaneous sound pressure is a sinusoidal function of time, or it may consist of a complex combination of many tones. The sound energy of a source may be distributed over a range of frequencies. The frequency distribution of sound is usually referred to as sound spectrum.

2.2 Characteristics of the Noise Source. A noise source is characterized by its frequency spectrum, variation of the spectrum with time, and the sound radiation pattern. Directivity, which is an index of the sound radiation pattern, is important in determining the number of measurement locations for the calculation of the sound power level of the source. The noises usually encountered in practice are classified as steady or nonsteady noise.

2.2.1 Steady Noise. The level of a steady noise remains essentially constant (that is, fluctuations are negligibly small) during the period of observation. The frequency spectrum can be broad band (prominent discrete components and narrow bands of noise are absent) or can have one or more discrete frequency components which have significantly greater amplitudes than those of the adjacent spectrum. The spectral distribution of sound, with or without discrete tones, remains constant.

2.2.2 Nonsteady Noise. If a noise level varies during the period of observation (as determined by listening), the noise is classified as nonsteady. This type may or may not contain audible discrete tones. Depending upon the variation in spectrum the noise is classified as fluctuating, intermittent, or impulse. See Table 1 for an example of different types of noise.

Table 1
Examples of Sources of Different Types of Noise

Steady	Nonsteady
Without audible discrete tones	Fluctuating
Distant city	Heavy traffic (nearby)
Waterfall	Pounding surf
Air-conditioning system	
With audible discrete tones	Intermittent
Circular saw	Aircraft fly-over
Transformer	Automobile passing by
Turbojet engine	Train passing by
Automobile horn	
Siren	
	Impulsive
	Isolated bursts
	Drop forge hammer
	Dog barking
	Pistol shots
	Door slamming
	Electrical circuit breaker
	Quasi-steady noise
	Riveting
	Pneumatic hammer
	Machine gun

2.2.3 Directivity. Directivity is a measure of the radial asymmetry, in three dimensions, of the sound radiation pattern of the source. A numerical measure of the directivity of a sound source is the directivity factor Q, a dimensionless quantity, defined in 2.4.2.2.

2.3 Sound Power, Sound Intensity, and Sound Pressure. Consider a point source of noise suspended in free space. Sound waves will emanate as spherical waves from this source. As the wave front progresses further from the source, its area increases as the square of the distance since the area of a sphere is $4\pi r^2$. If the energy of the noise source remains constant, it is evident that the sound power per unit area shall decrease. Thus, for a doubling of distance, the available energy is spread over four times the area, or the *sound intensity* is one fourth of its original value. This reduction in intensity with distance is known in physics as the *inverse square* law. See 1.5, **sound power** and **sound intensity.**

Measurements have shown that a soft whisper may produce a sound power of 10^{-9} W. A jet engine at its exhaust can develop 10^4 W. This indicates the wide range of sounds (10^{13} to 1) which can occur in our environment. To avoid use of such large numbers, acoustical engineers have borrowed a term from electrical engineering, that is, the decibel. See 1.5, **decibel.**

Electrical engineers have long used the decibel to describe the gain of amplifiers.

Thus, assume that an amplifier has an input of W_1 and an output of W_2. The gain of the amplifier can be expressed as shown in Eq 2.

$$\text{Gain} = 10 \log \frac{W_2}{W_1} \qquad \text{(Eq 2)}$$

where

$W_1 = 1$ mW

$W_2 = 10$ mW

$\text{Gain} = 10 \log \frac{10}{1} = 10$ dB

From Eq 2 it can be noted that the decibel is a relative quantity. When used to express noise level, a reference quantity is usually stated or implied.

In acoustics, the reference power is taken as 10^{-12} W. Thus, the term sound power level (PWL) can be defined as in Eq 3.

$$\text{PWL} = 10 \log \frac{W}{10^{-12}} \text{ dB (ref } 10^{-12} \text{ W)} \qquad \text{(Eq 3)}$$

where

PWL = sound-power level

W = sound power, watts

This power level is conveniently computed from Eq 4.

$$\text{PWL} = 10 \log W + 120 \qquad \text{(Eq 4)}$$

For example, if

$W = 10$ W

$\text{PWL} = 10 \log 10 + 120$

$= 10 + 120$

$= 130$ dB (ref 10^{-12} W)

It is also convenient to use the decibel scale to express the ratio between any two sound pressures. Sound-pressure level (SPL) is defined in Eq 5.

$$\text{SPL} = 10 \log \frac{P^2}{P^2_{ref}} = 20 \log \frac{P}{P_{ref}} \qquad \text{(Eq 5)}$$

For airborne sounds, the reference sound pressure P_{ref} is 20 μPa, where

$1\ \mu\text{Pa} = 1\ \mu\text{N/m}^2 = 10^{-5}\ \mu\text{bar}$

Therefore

$$\mathrm{SPL} = 20 \log \frac{P}{20\ \mu\mathrm{Pa}}\ \mathrm{dB}\ (\mathrm{ref}\ 20\ \mu\mathrm{Pa}) \qquad \text{(Eq 6)}$$

where

SPL = sound-pressure level
P = sound pressure, Pa

NOTE: See Figs 1 and 2 for typical sound power and sound-pressure levels for various acoustic sources.

The instrument used to measure sound-pressure level consists of a microphone, attenuator, amplifier, and indicating meter. This instrument shall have an overall response that is uniform (*flat*) as a function of frequency, and the instrument is calibrated in decibels according to Eq 6.

The position of the selector switch of the instrument for this measurement is often called *flat* or 20–20 000 kHz to indicate the wide frequency range that is covered. The result of a measurement of this type is also called the overall sound-pressure level.

2.3.1 Sound Level. The apparent loudness that we attribute to a sound varies not only with the sound-pressure level but also with the frequency (or pitch) of the sound. If this effect is taken into account to some extent for pure tones, by *weighting* networks included in an instrument designed to measure sound-pressure level, then the instrument is called a sound-level meter. ANSI S1.4-1983 [3] requires that three alternate frequency response characteristics be provided in instruments designed for general use (see Fig 3 and Table 2). These three responses are obtained by weighting networks designated as A, B, and C. Responses A, B, and C selectively discriminate against low and high frequencies.

Whenever one of these networks is used, the reading obtained should be described as

(1) The A-weighted sound level is 45 dB
(2) Sound level (A) = 45 dB
(3) SLA = 45 dB

In a table, the abbreviated form L_A with the unit dB is suggested, or where exceptional compactness is necessary, dB(A). The form dBA has also been used, but this notation implies that a new unit has been introduced and is therefore not recommended. Note that when a weighting characteristic is used, the reading obtained is said to be the *sound level.* Only when the overall frequency response of the instrument is flat are sound pressure levels measured. Since the reading obtained depends on the weighting characteristic used, the characteristic that was used shall be specified or the recorded level may be useless.

It is often recommended that readings on all noises be taken with all three weighting positions. The three readings provide some indication of the frequency distribution of the noise. If the level is essentially the same on all three networks, the frequencies of the predominate sounds are probably above 600 Hz. If the level is greater on the C network than on the A and B networks by several decibels, much of the noise is probably below 600 Hz.

POWER (WATTS)	ACOUSTIC POWER POWER LEVEL dB (ref 10^{-12} W)	SOURCE
25−40 MILLION	195	SATURN ROCKET
100 000	170	RAM JET TURBO-JET ENGINE WITH AFTERBURNER
10 000	160	TURBO-JET ENGINE, 7000 lb THRUST
1000	150	
		4-PROPELLER AIRLINER
100	140	
10	130	75-PIECE ORCHESTRA } PEAK RMS LEVELS IN PIPE ORGAN } $\frac{1}{8}$ SECOND INTERVALS
		SMALL AIRCRAFT
1	120	LARGE CHIPPING HAMMER
0.1	110	PIANO } PEAK RMS LEVELS IN TUBA } $\frac{1}{8}$ SECOND INTERVALS BLARING RADIO
0.01	100	CENTRIFUGAL VENTILATING FAN (13 000 ft^3/min) 4 ft LOOM AUTO ON HIGHWAY
0.001	90	VANEAXIAL VENTILATING FAN (1500 ft^3/min) VOICE-SHOUTING (AVERAGE LONG-TIME RMS)
0.0001	80	
0.00001	70	VOICE—CONVERSATIONAL LEVEL (AVERAGE LONG-TIME RMS)
0.000001	60	
0.0000001	50	
0.000 000 01	40	
0.000 000 001	30	VOICE—VERY SOFT WHISPER

NOTE: These levels bear no simple relation to the sound levels of Fig 2

Fig 1
Typical Power Levels for Various Acoustic Sources

AT A GIVEN DISTANCE FROM NOISE SOURCE	dB(A)	ENVIRONMENTAL
	dB (ref 20 μPa)	
	140	
50 HP SIREN (100 ft)	130	
JET TAKEOFF (200 ft)	120	
RIVETING MACHINE	110	CASTING SHAKEOUT AREA
CUTOFF SAW PNEUMATIC PEEN HAMMER	100	ELECTRIC FURNACE AREA
TEXTILE WEAVING PLANT SUBWAY TRAIN (20 ft)	90	BOILER ROOM PRINTING PRESS PLANT
PNEUMATIC DRILL (50 ft)	80	TABULATING ROOM INSIDE SPORT CAR (50 mi/h)
FREIGHT TRAIN (100 ft) VACUUM CLEANER (10 ft) SPEECH (1 ft)	70	
	60	NEAR FREEWAY (AUTO TRAFFIC) LARGE STORE ACCOUNTING OFFICE
	50	PRIVATE BUSINESS OFFICE LIGHT TRAFFIC (100 ft) AVERAGE RESIDENCE
	40	MIN LEVELS – RESIDENTIAL AREAS IN CHICAGO AT NIGHT
SOFT WHISPER (5 ft)	30	STUDIO (SPEECH)
	20	STUDIO FOR SOUND PICTURES
	10	
THRESHOLD OF HEARING YOUTHS — 1000 Hz – 4000 Hz	0	

NOTE: These values are taken from the literature. Sound-level measurements give only part of the information usually necessary to handle noise problems, and are often supplemented by analysis of the noise spectra.

Fig 2
Typical A-Weighted Sound Levels Measured with a Sound-Level Meter

Table 2
A, B, and C Electrical Weighting Networks for the Sound-Level Meter*

Frequency (Hz)	A-Weighting Relative Response (dB)	B-Weighting Relative Response (dB)	C-Weighting Relative Response (dB)
10	−70.4	−38.2	−14.3
12.5	−63.4	−33.2	−11.2
16	−56.7	−28.5	−8.5
20	−50.5	−24.2	−6.2
25	−44.7	−20.4	−4.4
31.5	−39.4	−17.1	−3.0
40	−34.6	−14.2	−2.0
50	−30.2	−11.6	−1.3
63	−26.2	−9.3	−0.8
80	−22.5	−7.4	−0.5
100	−19.1	−5.6	−0.3
125	−16.1	−4.2	−0.2
160	−13.4	−3.0	−0.1
200	−10.9	−2.0	0
250	−8.6	−1.3	0
315	−6.6	−0.8	0
400	−4.8	−0.5	0
500	−3.2	−0.3	0
630	−1.9	−0.1	0
800	−0.8	0	0
1000	0	0	0
1250	+0.6	0	0
1600	+1.0	0	−0.1
2000	+1.2	−0.1	−0.2
2500	+1.3	−0.2	−0.3
3150	+1.2	−0.4	−0.5
4000	+1.0	−0.7	−0.8
5000	+0.5	−1.2	−1.3
6300	−0.1	−1.9	−2.0
8000	−1.1	−2.9	−3.0
10 000	−2.5	−4.3	−4.4
12 500	−4.3	−6.1	−6.2
16 000	−6.6	−8.4	−8.5
20 000	−9.3	−11.1	−11.2

* These numbers assume a flat, diffuse-field (random-incidence) response for the sound-level meter and microphone.

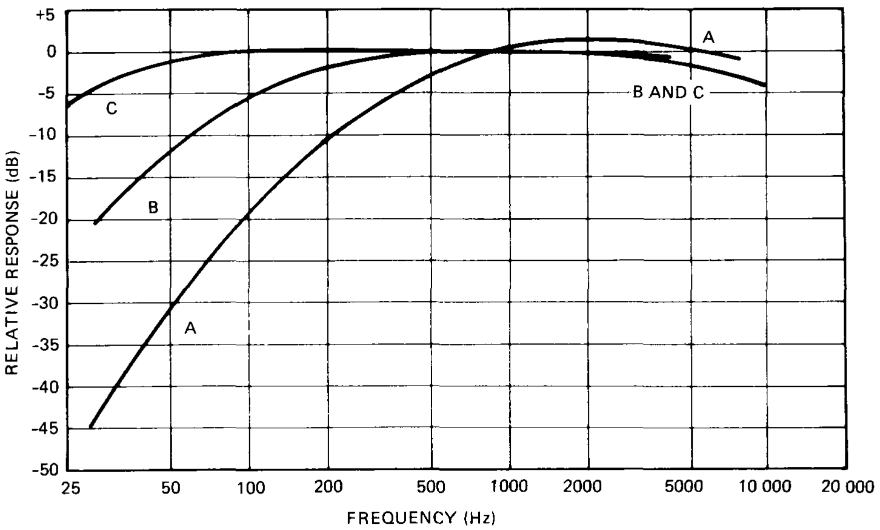


Fig 3
Frequency-Responses for SLM Weighting Characteristics
See ANSI S1.4-1983 [3]

2.3.2 A-Weighted Sound Level as a Single Number Rating. For simple ratings or screenings of similar devices, the A-weighted sound level at a specified distance is widely used. It is useful in preliminary ratings of similar noises for the human reactions that may occur. Measurement of the A-weighted sound level has been adopted for checking compliance with many ordinances and regulations, including the evaluation of personnel noise exposure.

2.3.3 Some Limitations of A-Weighted Sound Level. When only a single-weighted sound level is measured, the usefulness of the measurement is restricted.

The spectrum should almost always be measured, especially when noise control measures may be required. The spectrum is needed for efficient noise control, because the effects of sound isolation, acoustic treatment, vibration reduction, and other forms of noise control are frequency dependent. In addition, the reaction to the noise is frequency dependent, and the spectrum can show us the frequency region where the noise energy is most important in determining the effects. The source of an excessive noise and the spectrum often provide the most important clues for identifying and reducing the noise.

If a noisy machine is to be used in a room, the acoustic characteristics of the room as a function of frequency and the radiated sound-power level of the machine also as a function of frequency need to be known so as to estimate the noise level at some distance from the machine.

The spectra will help in providing data for later comparisons when conditions change or if better evaluation techniques are developed.

The limitations of the simple, weighted measurement should be recognized when plans for sound measurements are made.

2.3.4 Analysis in Frequency Bands. To make an analysis in the frequency domain, the signal energy is electrically separated into various frequency bands, for example, octave bands, each of which covers a 2:1 range of frequencies. The analysis yields a series of levels, one for each band, called *band levels*, or for octave bands, *octave band levels* or *octave band sound-pressure levels.* Here it is apparent that the band in which a reading of level is obtained shall be specified if the information is to be of value.

2.3.5 Octave Bands. The preferred series of octave bands for acoustic measurements [ANSI/ASC S1.6-1984 [7]] covers the audible range in ten bands. The center frequencies of these bands are 31.5 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, 8000 Hz, and 16 000 Hz. The actual nominal frequency range of any one of these bands is 2:1; for example, the effective band for the 1000 Hz octave band extends from 707 Hz to 1414 Hz (see Table 3).

Another series of octave bands has been widely used in the past. The older bands were a 75 Hz low-pass filter, and the octave bands of 75 Hz to 150 Hz, 150 Hz to 300 Hz, 300 Hz to 600 Hz, 600 Hz to 1200 Hz, 1200 Hz to 2400 Hz, 2400 Hz to 4800 Hz, and a 4800 Hz high-pass filter, but these are no longer preferred. This older series is still specified in a number of test codes and the published data obtained with this series is extensive.

NOTE: For a method of converting octave-band levels measured with this older series to levels for the new series, see ANSI S1.11-1966 (R 1976) [5] and Appendix A. It should be noted that this conversion method applies only to broadband noise.

When a graph is made of the results of octave-band pressure-level measurements, the frequency scale is commonly divided into equal percentage intervals (a logarithmic frequency scale). The level for each octave band is plotted as a point at the center frequency of the octave band. Adjacent points are then connected by straight lines. An example of a plot of this type is given in Fig 4. Graph paper conforming to ANSI S1.13-1971 (R 1976) [6] is available commercially.

2.3.6 Narrower Bands. For a more detailed analysis of the distribution of sound energy as a function of frequency, narrower frequency bands are used. For certain analyses involving steep sloped spectra, the octave bands are divided into three parts, called one-third octave bands (see Table 3). Still narrower bands called one-tenth octave bands are also in widespread use for detailed analysis.

Calculated dB(A) values obtained by using octave-band center-frequency weighting values (from Table 2 to 4) cannot be exact because the distribution of sound pressure within each octave band of frequency is not known and the actual weighting varies continuously with frequency. The error can become substantial with certain steeply-sloped spectra and spectra containing discrete tones; however, it can be minimized by using one-third octave-band resolution.

Table 3
Center and Approximate Cutoff Frequencies for Standard Set of Contiguous-Octave and One-Third Octave Bands Covering the Audio-Frequency Range

	Frequency (Hz)					
	Octave			One-Third Octave		
Band	Lower Band Limit	Center	Upper Band Limit	Lower Band Limit	Center	Upper Band Limit
12	11	16	22	14.1	16	17.8
13				17.8	20	22.4
14				22.4	25	28.2
15	22	31.5	44	28.2	31.5	35.5
16				35.5	40	44.7
17				44.7	50	56.2
18	44	63	88	56.2	63	70.8
19				70.8	80	89.1
20				89.1	100	112
21	88	125	177	112	125	141
22				141	160	178
23				178	200	224
24	177	250	355	224	250	282
25				282	315	355
26				355	400	447
27	355	500	710	447	500	562
28				562	630	708
29				708	800	891
30	710	1000	1420	891	1000	1122
31				1122	1250	1413
32				1413	1600	1778
33	1420	2000	2840	1778	2000	2239
34				2239	2500	2818
35				2818	3150	3548
36	2840	4000	5680	3548	4000	4467
37				4467	5000	5623
38				5623	6300	7079
39	5680	8000	11 360	7079	8000	8913
40				8913	10 000	11 220
41				11 220	12 500	14 130
42	11 360	16 000	22 720	14 130	16 000	17 780
43				17 780	20 000	22 390

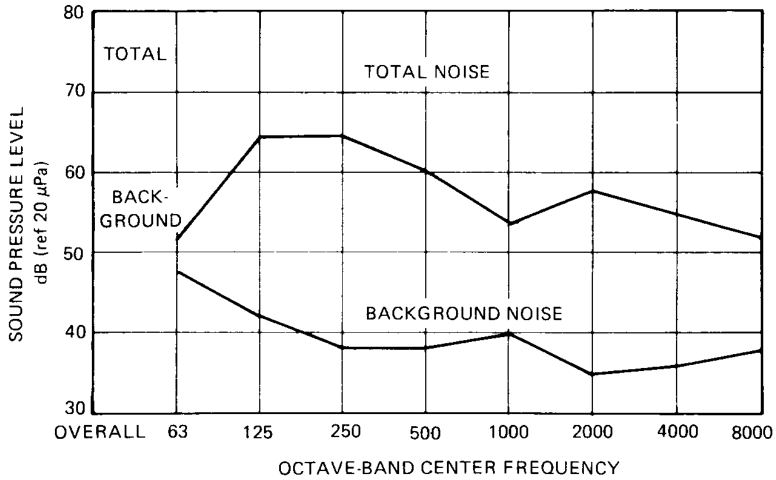


Fig 4
A Plot of the Octave-Band Analysis of Noise from a Calculating Machine

Also, in these cases, to minimize cumulative amplitude errors, values should be calculated to 0.1 dB resolution, with only final answers rounded to the nearest integral decibel (dB) values.

2.3.7 Combining Decibels. Assume that it is desired to combine three decibel readings to obtain a total sound-pressure level, for example, 90 dB(A), 88 dB(A), and 85 dB(A). The complete mathematical solution is

$$\begin{aligned}\text{Antilog } 90/10 &= 10.0\cdot 10^8\\ \text{Antilog } 88/10 &= 6.3\cdot 10^8\\ \text{Antilog } 85/10 &= \underline{3.16\cdot 10^8}\\ & 19.45\cdot 10^8\end{aligned}$$

$$\text{SPL total} = 10 \log 19.45\cdot 10^8 = 92.9 \text{ dB(A)} \qquad \text{(Eq 7)}$$

A much simpler method is to use the curve shown in Fig 5.

Difference(dB)	Increment	Interim Answer
90.0 − 88 = 2.0	2.1	90.0 + 2.1 = 92.1
92.1 − 85 = 7.1	0.8	92.1 + 0.8 = 92.9

Thus, the same answer, 92.9 dB(A), is obtained with much less work.

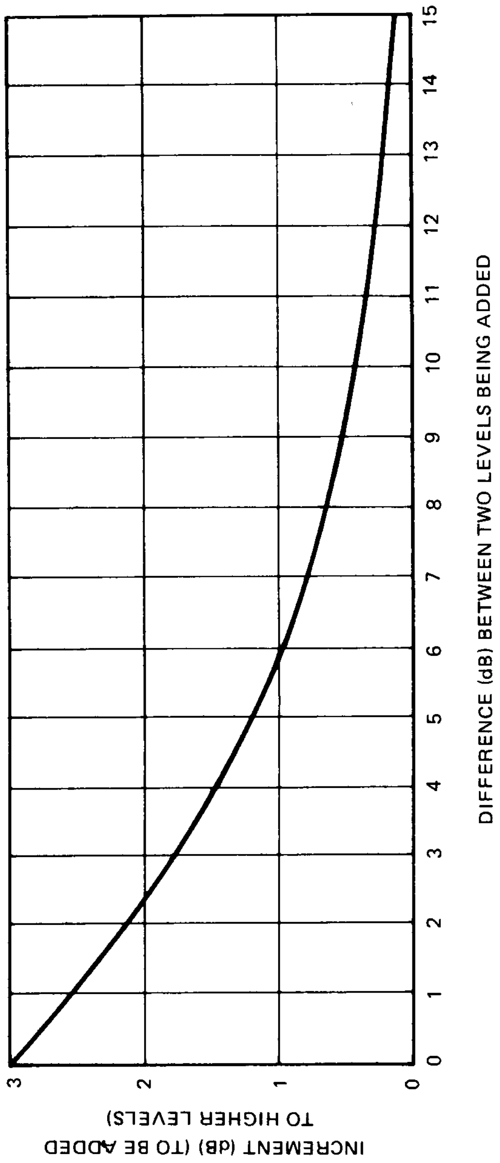


Fig 5
Chart for Combining Noise Levels

2.3.8 Combining Octave-Band Readings. Assume that an octave-band analysis in dB(C) is available, but no overall A-weighted reading was taken. The dB(A) value can be calculated as follows:

Octave Band	Band SPL dB(C)	Correction*	Corrected SPL dB(A)
31.5	88	−36	52
63.0	88	−26	62
125.0	88	−16	72
250.0	94	−9	85
500.0	96	−3	93
1000.0	96	0	96
2000.0	92	+1	93
4000.0	89	+2	91
8000.0	76	+2	78

*From Table 4

Difference(dB)	Increment*	Interim Answer
62.0 − 52.0 = 10.0	0.4	62.0 + 0.4 = 62.4
72.0 − 62.4 = 9.6	0.5	72.0 + 0.5 = 72.5
85.0 − 72.5 = 12.5	0.3	85.0 + 0.3 = 85.3
93.0 − 85.3 = 7.7	0.7	93.0 + 0.7 = 93.7
96.0 − 93.7 = 2.3	2.1	96.0 + 2.1 = 98.1
98.1 − 93.0 = 5.1	1.2	98.1 + 1.2 = 99.3
99.3 − 91.0 = 8.3	0.6	99.3 + 0.6 = 99.9
99.9 − 78.0 = 21.9	0.0	99.9 + 0.0 = 99.9

*From Fig 5

If these values are combined by the more rigorous method, the answer will also be 99.9 dB(A).

As a practical consideration, sufficient accuracy can be obtained by dropping any correction due to a difference of 10 dB or more. A similar procedure may be used to convert *flat* octave-band data to equivalent A-weighted values. See Table 4.

Table 4
Conversion to Equivalent A-Weighted Values

	Center Frequency (Hz)								
	31.5	63	125	250	500	1000	2000	4000	8000
Correction (dB) (C-to-A)	−36	−26	−16	−9	−3	0	+1	+2	+2
Correction (dB) (Flat-to-A)	−39	−26	−16	−9	−3	0	+1	+1	−1

Frequently, reference is made to A-weighted octave bands. The weighting networks and octave-band filter sets on some older instruments are arranged so that the input signal is passed through the weighting network and subsequently through the filter set. This will allow A-weighted octave-band sound levels to be measured. Alternatively, octave-band sound-pressure levels may be adjusted by the factors given in Table 4 to obtain the equivalent A-weighted values.

Care shall be taken when analyzing octave- (or narrower) band readings to ascertain whether they were first passed through a flat network or a weighted network. As will be noted from Fig 6, serious errors in interpretation can occur if an incorrect assumption is made.

2.4 Sound Fields. To better understand the propagation characteristics of sound waves it is necessary to investigate their behavior in various environments.

2.4.1 Free Field

2.4.1.1 Point Source. The simplest form of source is a sphere that vibrates uniformly over its entire surface. We can think of this source as a round balloon with air in it. This source radiates sound equally in all directions from an apparent center, which is the center of the balloon. It is a *point source* insofar as sound radiation is concerned.

If such a point (or spherical) source is in the air far from other objects, including the ground, the sound pressure produced by the source is the same in every direction at equal distances from the point source. Furthermore, the sound pressure is halved for each doubling of distance from the point. This change is usually expressed as a decrease in sound-pressure level of 6 dB. The sound field produced under these idealized conditions is called a free sound field or a free field because it is uniform, it is free from all bounding surfaces, and it is undisturbed by other sources of sound.

2.4.1.2 Power Level in Free Field. Under free-field conditions, a single measurement of the sound-pressure level at a known distance from a point source is enough to tell us all about the sound field radiated by the source. For example, we can predict the level at any other point, since the sound pressure varies inversely as the distance from the source. We can also compute the total sound power radiated by the point source as shown in Eq 8.

$$\mathrm{PWL} = \mathrm{SPL} + 20 \log r + 11 \text{ dB} \qquad \text{(Eq 8)}$$

where

PWL = sound power, dB (ref 10^{-12} W)
SPL = sound pressure (ref 20 μPa)
r = distance (meters) from the point source to the point where the sound-pressure level is measured

For example, measure a sound-pressure level of 73.5 dB (ref 20 μPa) at a distance of 20 m from a point source; then

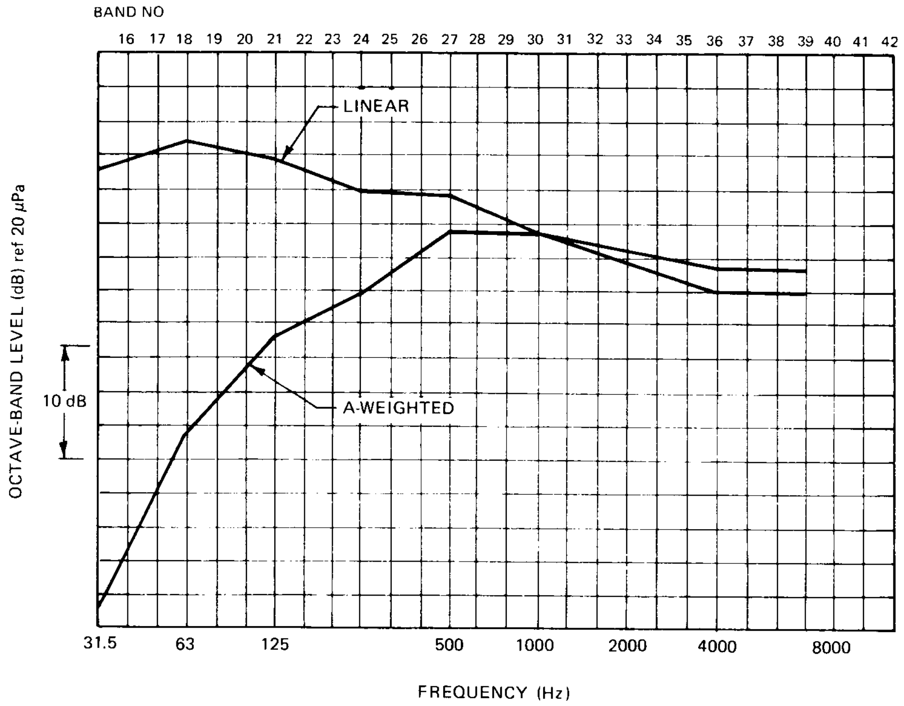


Fig 6
Comparison of Linear Versus A-Weighted
Octave Bands for Pulverizers—Bowl Mills

$$\begin{aligned} \text{PWL} &= 73.5+20 \log 20+11 \text{ dB} \\ &= 73.5+26+11 \\ &= 110.5 \text{ dB (ref } 10^{-12} \text{ W)} \end{aligned}$$

NOTE: The concept of a point source is an idealized one. It is unreasonable to assume that an actual source is a true point source, so that one should never be content with a single measurement.

2.4.1.3 Power Level in Hemispherical Space. For the more usual case, the source may be located far from other objects but close to the ground or floor. In this case, the sound source will radiate into hemispherical space as defined by the area above the ground plane. Since the intensity of the sound source radiating into a hemisphere is twice as great as that radiating into a sphere (see 2.4.1.2), the SPL measurement will be greater by 3 dB. In this idealized case, the sound-power level for hemispherical space is given by Eq 9.

$$\mathrm{PWL} = \mathrm{SPL} + 20 \log r + 8 \qquad \text{(Eq 9)}$$

where

PWL = sound power, dB (ref 10^{-12} W)
SPL = sound pressure (ref 20 μPa)
r = distance (meters) from the point source to the point where the sound-pressure level is measured.

2.4.2 Directional Source. In actual practice, noise sources are not as simple as point sources. The sound is not radiated uniformly in all directions, either because the shape of the sound source is not spherical, or because the amplitude and time phase of the vibrations of the different parts are not uniform, or both. The net result is that more sound is radiated in some directions than in others. In other words, the sound-pressure level for a given distance is different in different directions.

When such a directional sound source is far from any other object it behaves in some ways like a point source. For example, the sound-pressure level decreases 6 dB for each doubling of distance, provided measurements are started at a distance away from the source that is several times the largest dimension of the source, and moved directly away from the source. In actual practice this idealized behavior is upset by the effects of variation in terrain, atmospheric conditions, and the interference of nearby objects.

2.4.2.1 Near Field and Far Field. At locations close to a directional source equal sound-level contours are different in shape from those at a distance. Furthermore, there is no apparent center from which the 6 dB drop for each doubling of distance is found. Consequently, this *near-field* behavior cannot readily be used to predict the behavior at a distance. For the near-field effect to be minimized, the location should be at least one wavelength away from the source. This dimension should be determined on the basis of the lowest frequency of interest. For example, if the lowest frequency of sound of interest is 120 Hz, the wavelength is approximately 10 ft.

Another factor that enters into the differences between the near-field and far-field behavior is the way the sound waves spread out from a source. The sound waves from a large source vary with distance differently from waves produced by a small source. But at a distance of several (three to four) times the largest dimension of the radiating source, *spherical spreading* is said to exist, and the behavior is then nearly independent of the size of the source.

2.4.2.2 Directivity Factor. When we are interested in sound-pressure levels beyond the immediate vicinity of the source, any sound can be treated as a point source, provided we introduce a directivity factor. This factor takes into account the variation in sound-pressure level with direction to the source. This directivity factor, which is a function of direction and frequency, is usually labeled Q. It can be expressed as

$$Q = \text{antilog} \frac{DI}{10} \qquad \text{(Eq 10)}$$

where

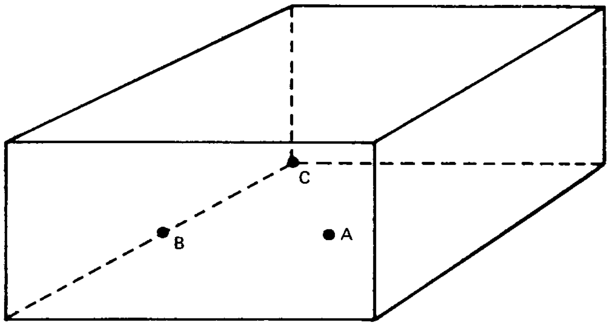
Q = directivity factor

DI = directivity index

For a point source located in the center of a large room, $Q = 1$ since the sound radiates uniformly in all directions. For other typical values of Q, refer to Fig 7.

Fig 7
Typical Values of Directivity Factor Q for Different Locations of a Sound Source in a Large Room

Location	Q
Center	1
A	2
B	4
C	8



Directivity index in any particular direction is defined as the sound-pressure level in that direction minus the mean sound-pressure level around the source. All these measurements are assumed to have been taken at a fixed distance r from the source.

$$DI = \mathrm{SPL} - \overline{\mathrm{SPL}} \ \mathrm{dB} \qquad \text{(Eq 11)}$$

where

DI = directivity index
SPL = sound-pressure level at a distance r in the desired direction
$\overline{\mathrm{SPL}}$ = mean sound-pressure level around the source at distance r

2.4.2.3 Directivity in Hemispherical Space. The directivity index of a sound source on a rigid plane in a given direction from the source is given by

$$DI_{\mathrm{H}} = \mathrm{SPL} - \overline{\mathrm{SPL}_{\mathrm{H}}} + 3 \ \mathrm{dB} \qquad \text{(Eq 12)}$$

where

SPL = octave-band sound-pressure level at a distance r in the desired direction

$\overline{\mathrm{SPL}_{\mathrm{H}}}$ = average octave-band sound-pressure level measured on a test hemisphere around a source at distance r

The 3 dB in Eq 12 is added to the $\overline{\mathrm{SPL}_{\mathrm{H}}}$ because the measurement was made over a hemisphere instead of a full sphere.

2.4.2.4 Mean Sound-Pressure Level. The accurate method for obtaining the mean sound-pressure level requires making a set of measurements uniformly distributed on the hemisphere (sphere in the true free field) centered about the acoustic center of the source. The mean sound-pressure level is then determined from Eq 13.

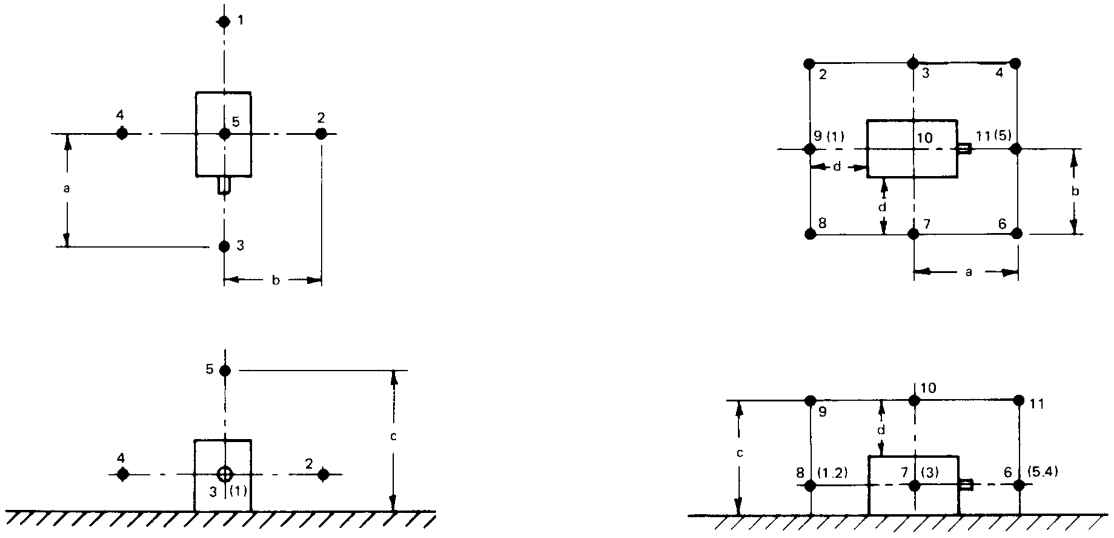
$$\overline{\mathrm{SPL}} = 10 \log \frac{1}{n} \left(\mathrm{antilog} \frac{\mathrm{SPL}_1}{10} + \mathrm{antilog} \frac{\mathrm{SPL}_2}{10} + \ldots + \mathrm{antilog} \frac{\mathrm{SPL}_{\mathrm{M}}}{10} \right) \ \mathrm{dB} \qquad \text{(Eq 13)}$$

where

$\overline{\mathrm{SPL}}$ = mean sound-pressure level
$\mathrm{SPL}_1 \ldots \mathrm{SPL}_{\mathrm{M}}$ = level in dB of each measurement
n = number of measurements

A simple, though not precise, method to approximate the mean of a number of decibel readings is to take an arithmetic average. The following rules should be observed:

(1) For summing decibels which differ by 5 dB or less, take the arithmetic average directly



All points of measurement (1 through 5) shall be located at a distance of 0.3 m or greater from the major machine surfaces.

(a)

All points of measurement shall be located on the rectilinear planes prescribed where $d = 1$ m or greater.

(b)

Fig 8
(a) Prescribed Points, Small Machines (b) Prescribed Points, Medium Machines

(2) For summing decibels which differ by 5 dB to 10 dB, take the arithmetic average and add 1 dB

2.4.2.5 Equivalent Radius. Instead of making measurements on a true hemispherical surface, see IEEE Std 85-1973 (R 1980) [8], 2.6 and 2.7, which proposes that measurements be made on a *prescribed surface* surrounding the machine. Also see Figs 8(a), (b), and (c) which show the prescribed measurement points.

2.4.2.6 Sound-Pressure Level for a Directional Source. When we know the directivity factor for the direction of interest, we can use it as a multiplying factor on the power. Expressed in terms of level, Eq 14 is as follows:

$$\text{SPL} = \text{PWL} + 10 \log Q - 20 \log r - 11 \text{ dB} \qquad \text{(Eq 14)}$$

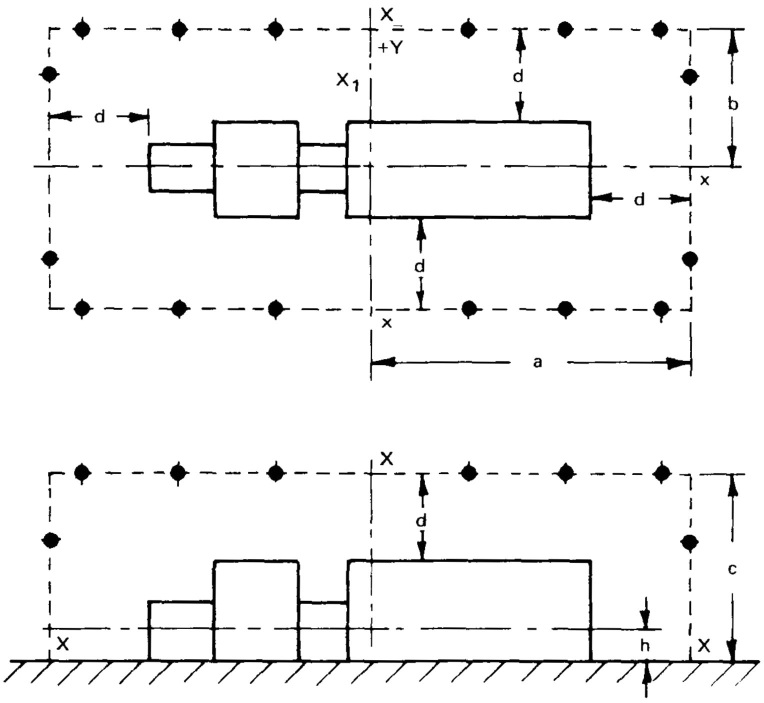
In terms of the directivity index Eq 15 is as follows:

$$\text{SPL}_H = \text{PWL} + DI - 20 \log r - 11 \text{ dB} \qquad \text{(Eq 15)}$$

Fig 8
(c) Prescribed Points, Large Horizontal Machines

h = shaft height or 0.3 m, whichever is greater
X = key measuring points
O = measuring points marked off at intervals of 1 m ± 0.25 m from key points
d = 1 m or greater from major machine surfaces

(c)



Equation 15 relates the power level of the source, the sound-pressure level in a given direction at a distance r meters from the source, and the directivity index for that direction.

2.4.3 Effect of Reflections in a Room. The sound that a noise source radiates in a room is reflected by the walls, floor, and ceiling. The reflected sound will again be reflected when it strikes another boundary, with some absorption of energy at each reflection. The result of these reflections is that the sound-pressure level measured at a distance from the source is different from that predicted by Eqs 8 and 9.

Close to the source of sound there is little effect from these reflections, since the direct sound dominates. But far from the source, unless the boundaries are very absorbing, the reflected sound dominates, and this region is called the reverberant field. The sound-pressure level in this region depends on the acoustic power radiated, the size of the room, and the acoustic absorption characteristics of the materials in the room. These factors and the directivity characteristics of the source also determine the region over which the transition between reverberant and direct sound occurs.

A second effect of reflected sound is that measured sound does not necessarily decrease steadily as the measuring position is moved away from the source. At certain frequencies in a room with hard walls, marked patterns of variations of sound pressure with position can be observed. These patterns are called standing waves. They are noticeable mainly when the sound source has strong frequency components in the vicinity of one of the very many possible resonances of the room. They also are more likely to be observed when a frequency analysis is made; and the narrower the bandwidth of the analyzer, the more marked these variations will be.

The acoustical boundary conditions of ordinary rooms are extraordinarily complicated, and most sound sources are also complicated. The result of this complexity is that without advanced computer methods, only an average type of description can be used. Even a rough approximation can be useful, however, and we shall review briefly some of the work on room characteristics as it applies to the sound produced by a source in a room.

2.4.4 Effective Room Absorption and Absorption Coefficient. To simplify the analysis of the effect of the room, it is assumed that enough measurements are made so that any standing wave patterns can be averaged. A number of other assumptions are made, and then a relation of the form shown can be developed.

$$\mathrm{SPL} = \mathrm{PWL} + 10 \log \left(\frac{Q}{4\pi \, r^2} + \frac{4}{R} \right) \quad \mathrm{dB} \qquad \text{(Eq 16)}$$

where

Q = directivity factor

r = distance from the sound source, m

R = effective room absorption (room constant), square meters or metric sabins and defined by Eq 17.

$$R = \frac{S\,\bar{\alpha}}{1 - \bar{\alpha}} \qquad \text{(Eq 17)}$$

where

S = room area (m^2)

$\bar{\alpha}$ = average absorption coefficient

The average absorption coefficient is given by Eq 18.

$$\bar{\alpha} = \frac{\alpha_1 S_1 + \alpha 2\, S_2 + \ldots\ldots\ldots\ldots\ \alpha_n S_n}{S_1 + S_2 + \quad \ldots\ldots\ldots\ldots\ S_n} \qquad \text{(Eq 18)}$$

where

$\alpha_1, \alpha_2, \alpha_n$ = absorption coefficients of all materials in the room

S_1, S_2, S_n = corresponding areas of various materials

When a sound wave strikes a surface, a certain portion of the incident energy is absorbed. The sound-absorbing ability of a material is called the absorption coefficient. By definition true absorption coefficients range from 0 to 1. When $\alpha = 0$ all the energy is reflected, when $\alpha = 1$ all the energy is absorbed.

Absorption coefficients vary with material, frequency, and angle of incidence of the sound. Typical values are shown in Table 5. At frequencies above approximately 2000 Hz, the sound absorption in the air in a very large room is often

Table 5
Absorption Coefficients of Various Materials Used in Acoustical Wall Treatment

Wall Treatment		Center Frequency (Hz)						
Facing*	Core**	125	250	500	1000	2000	4000	NRC***
None	1 in FW	0.06	0.20	0.65	0.90	0.95	0.98	0.70
None	3 in FW	0.53	0.99	0.99	0.99	0.99	0.99	0.95
None	1 in TIW	0.11	0.33	0.70	0.80	0.86	0.85	0.65
None	3 in TIW	0.46	0.99	0.99	0.99	0.99	0.99	0.95
¼ in pegboard	1 in FW	0.08	0.32	0.99	0.76	0.34	0.12	0.60
¼ in pegboard	1 in TIW	0.08	0.41	0.99	0.82	0.26	0.32	0.60
Perforated Metal (24 ga, 13% open)	2 in FW	0.18	0.73	0.99	0.99	0.97	0.93	0.95
	4 in Soundblox	0.19	0.83	0.41	0.38	0.42	0.40	0.50
Spray-on—¼ in thick		0.04	0.04	0.20	0.39	0.60	0.81	0.30
Spray-on—½ in thick		0.26	0.51	0.98	0.99	0.95	0.86	0.85

* ¼ in pegboard = perforated holes 1 in oc

**FW = Owens-Corning Fiberglass Wool

TIW = Thermal Insulating Wool

***NRC = Noise reduction coefficient = average of 250 Hz, 500 Hz, 1000 Hz, and 2000 Hz absorption coefficients to the nearest 0.05 Hz enough to affect the room constant appreciably. This absorption increases with frequency, and it varies markedly with humidity and temperature. The absorption at normal room temperatures is a maximum at relative humidities in the range of 10%–30%.

Another item that affects the absorption properties of a material is the method of mounting. For a porous-type absorber, the space between it and the wall will increase the absorption as the space is increased.

If the absorption coefficients of the materials in the room are not known, the room constant can be determined from measurements of the reverberation time of the room. The reverberation time is the time for the sound-pressure level in a room to deteriorate by 60 dB or $\frac{1}{1000}$ of its original value. The value of R is given by Eq 19.

$$R = 0.16\ (V/T)$$

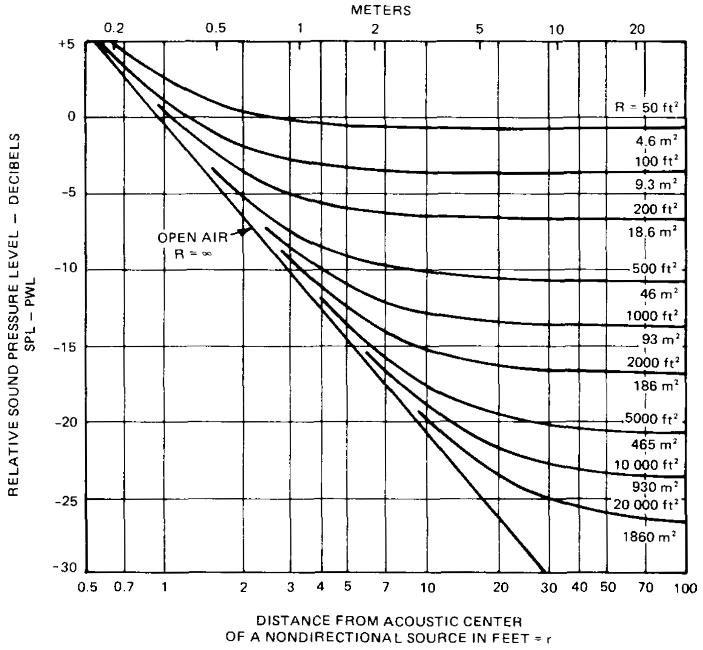
where

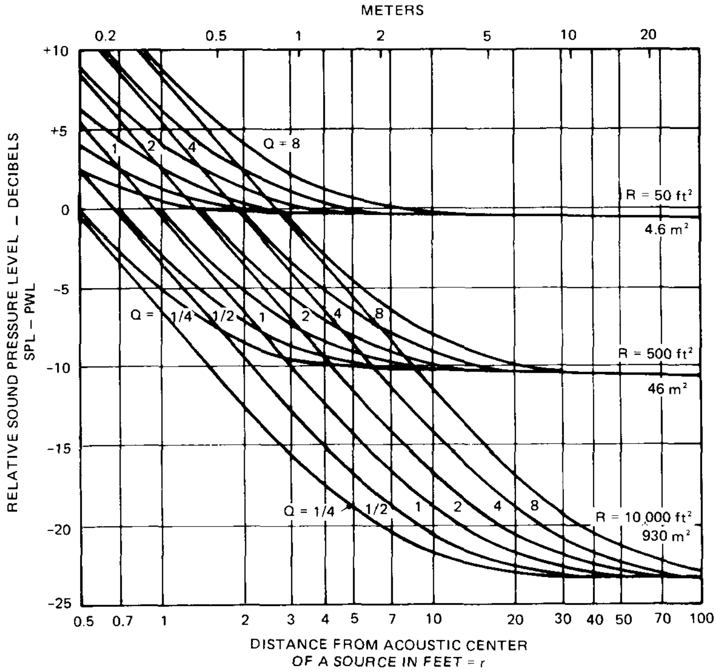
V = volume of the test room, m^3

T = reverberation time of the test room, s

The relation given in Eq 16 can be shown graphically in Fig 9 for the non-

Fig 9
Sound-Pressure Level (SPL) Relative to the Power Level (PWL) for a Nondirectional Source for Different Values of the Room Constant *R*, as a Function of the Distance from the Source





NOTE: The relation is shown for three different values of the room constant R, and for the six different values of the directivity factor Q.

Fig 10
Sound-Pressure Level (SPL) Relative to the Power Level (PWL) for a Directional Source as a Function of the Distance from the Source

directional source and in Fig 10 for the directions having the labeled values of directivity factor.

2.4.5 Reverberant Field. The graphs of Figs 9 and 10 show that close to the source the sound-pressure level tends to vary with the distance from the source as it does under free-field conditions ($R = \infty$). But far from the source the sound-pressure level becomes independent of the directivity of, and the distance to, the source. This region is called the reverberant field. Here, the level is determined by the acoustic power radiated by the source and the acoustic characteristics of the room. The region through which the transition between the free field and the reverberant field gradient occurs is determined by the directivity factor and the effective room absorption.

In terms of Eq 16 in the reverberant field, far from the source, r is large and therefore the directivity term can be neglected; Eq 16 becomes, for such a field

$$\mathrm{SPL} = \mathrm{PWL} + 10 \log \frac{4}{R} \quad \mathrm{dB} \tag{Eq 19}$$

Solving for the power level

$$\mathrm{PWL} = \mathrm{SPL} + 10 \log R - 6 \tag{Eq 20}$$

Equations 19 and 20 are useful in calculating the sound-power level of a single source based on sound-pressure level measurements taken in a reverberant room.

2.4.6 Actual Room Behavior. In a highly reverberant room, the behavior on the average is similar to that shown in Figs 9 and 10. Most other rooms have characteristics that, on the average, fall between the reverberant behavior and the free-field sound-pressure level decrease of 6 dB for each doubling of the distance.

The calculations from the simple formula tend to over-estimate the level at a considerable distance from the source. Much more complicated formulas can yield values in closer agreement but are tedious unless they are programmed on a computer. The simple formula is useful for a preliminary estimate of the expected behavior, particularly if the absorption is small and if no one room dimension is markedly different from the others.

2.4.7 Reverberation Measurements. See Section 4.

2.5 Sound Propagation Outdoors. Sound waves travel from source to receiver outdoors through an atmosphere that is in constant motion. Turbulence, temperature and wind gradients, viscous and molecular absorption, and reflection from the earth's surface all affect the amplitude and create fluctuations in the sound received. The longer the transmission path through the atmosphere, the less certain the average amplitude and the greater the fluctuations in the sound received.

In addition to the effect of hemispherical divergence (see Eq 9), the excess attenuation owing to environmental and other conditions may include the following topics given in 2.5.1 through 2.5.5.

NOTE: Frequently it may be difficult to obtain the information needed to determine these excess attenuation effects. In such cases, it is always conservative practice not to include such effects.

2.5.1 Air Absorption. Air absorption is caused when energy is extracted from a sound wave by rotational and vibrational relaxation of the oxygen molecules in the air. The vapor content of the air determines the time constant of the vibration relaxation, which is more important than rotational relaxation. In addition, the *molecular absorption* depends, in a major way, on temperature. See Fig 11.

2.5.2 Fog, Rain, or Snow. There is evidence that absorption due to such particulate matter in the atmosphere is negligible. The subjective impressions that one occasionally has of such effects can generally be explained by other atmospheric properties which accompany the occurrence of precipitation. For

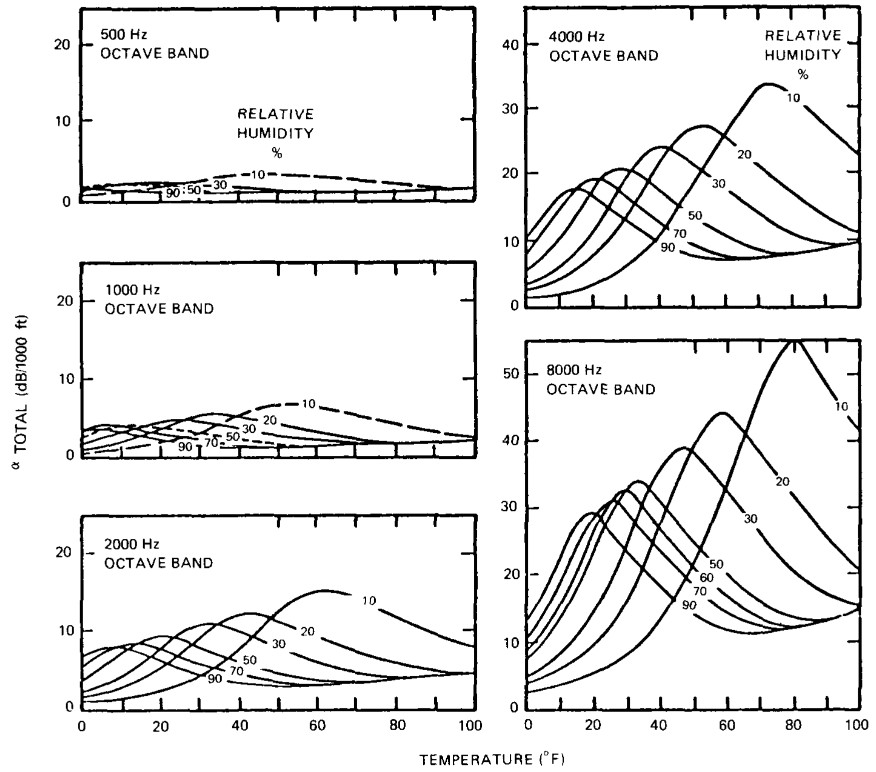


Fig 11
Atmospheric Absorption Coefficients for Octave Bands of Noise for Different Temperatures and Humidities

example, temperature and wind gradients during light precipitation tend to be small so that sound *carries* farther outdoors than on a sunny day. Temperature inversions cause sound to travel farther than when isotropic conditions are present.

2.5.3 **Barriers.** Nonporous walls of sufficient mass (at least 20 kg/m^2), if interposed between source and receiver, can result in appreciable noise reduction, because sound can reach the receiver only by diffraction around the boundaries of the obstacle. Barrier effects may be caused by either natural elevations (earth berm) or man-made obstacles (buildings).

2.5.4 **Foliage.** There have been large differences reported in the literature regarding excess attenuation due to foliage. Generally, any consideration of this excess attenuation is neglected unless the sound-wave path is through a significant distance of foliage (a minimum of 100 ft). In addition, there is wide variation depending on the nature and density of the vegetation.

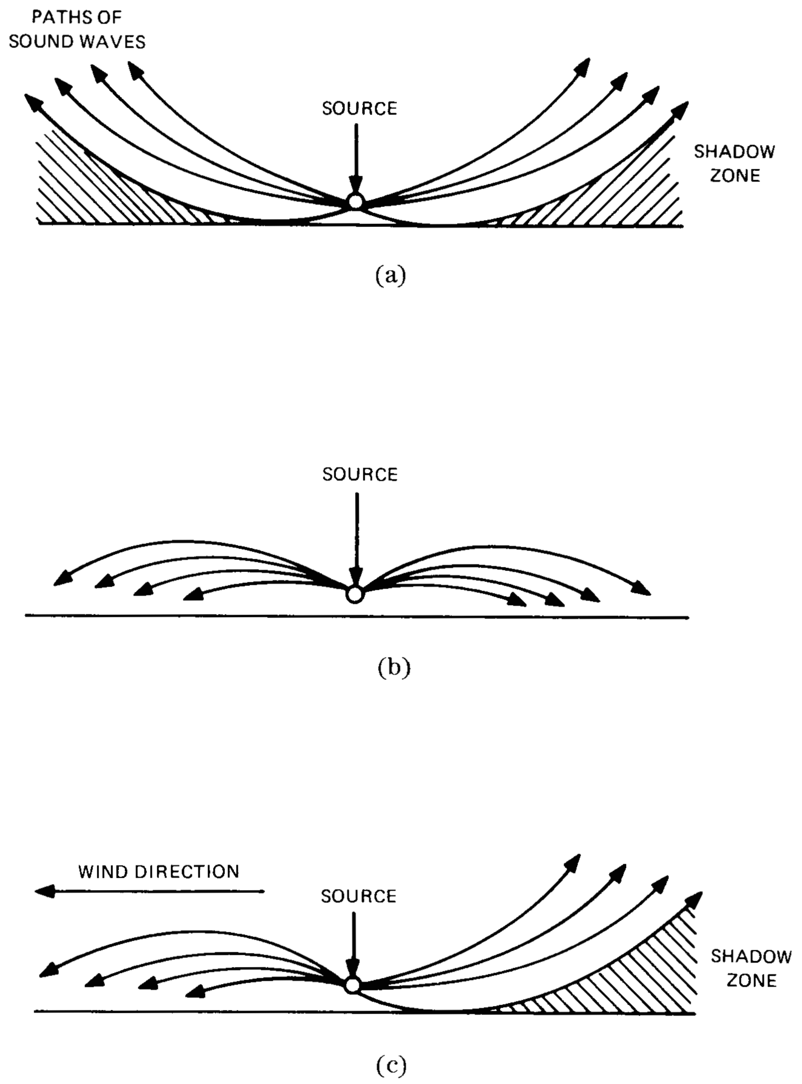


Fig 12
(a) Influence of Negative Temperature Gradient (Cooler Air Above) on Bending of Sound Waves Upward (b) Influence of Positive Temperature Gradient (cooler air below) on Bending of Sound Waves Downward (c) Influence of Wind Direction on Bending of Sound Waves, Assuming Typical Wind Speed Increase with Height Above the Ground

2.5.5 Atmospheric Inhomogeneities. The speed of sound in air increases with the square root of the absolute temperature. When the atmosphere is in motion, the speed of sound is the vector sum of its speed in still air and the wind speed. The temperature and the wind in the atmosphere near the ground are almost never uniform. This atmospheric nonuniformity produces gradients of the speed of sound, and thus refraction of sound-wave paths. Near the ground, this refraction can have a major effect on the apparent attenuation of sound propagated through the atmosphere.

A simplifying assumption is a horizontally stratified atmosphere in which temperature and wind speed vary only with height above the ground. During the daytime, temperature normally decreases with height (lapse), so that sound waves from a source near the ground are refracted upwards. In the absence of wind, an *acoustic shadow* forms around the source [see Fig 12(a)] in which sound from the source is attenuated. Marked attenuations are observed at receiving points well into the shadow zone—it is just as if a solid barrier had been built around the source.

At night a temperature increase with height (inversion) is common near the ground and our *barrier* disappears as in Fig 12(b). Under severe inversions, increases of 5 dB − 15 dB can occur at distances of 1 mi from the source.

Near the ground, wind speed almost always increases with height. Because the speed of sound is the vector sum of its speed in still air and the wind vector, a shadow zone can form upwind of the source, but is suppressed downwind [See Fig 12(c)].

The combined effects of wind and temperature are usually such as to create acoustic shadows upwind of a source, but not downwind. Only under rare circumstances will a temperature lapse be sufficient to overpower wind effects and create a shadow surrounding a source. It is less rare, but still uncommon for a surface inversion to be sufficiently strong to entirely overcome an upwind shadow.

To determine the amount of excess attenuation due to wind and temperature, it is necessary to obtain somewhat detailed meteorological data in the area of interest. Such data may not be available and may require special study.

Environmental impact requirements for new plant construction frequently require the erection of meteorological towers to monitor various air quality parameters. Such an installation is an ideal source for the data required in computing excess attenuation factors. Depending upon the data available, various simplifying assumptions may have to be applied to existing procedures for determining the excess attenuation effects.

3. Laws and Regulations

3.1 Introduction Environmental noise problems can include a wide variety of noise sources and noise environments. One of the first steps in the evaluation of such problems is to determine compliance with existing laws. This section provides a summary of the laws as they exist today and which are significant to power-plant design. Representative state and local regulations are examined.

3.2 Federal Laws

3.2.1 Occupational Noise Exposure Regulations of OSHA. Recognizing the harmful effects excessive noise can have on the sense of hearing, the federal government has adopted regulations for limiting occupational noise exposure. Permissible noise exposures are defined based upon an 8 h workday and exposure to steady sound levels of 90 dB(A) and higher (see [16]). When the noise exposure consists of a combination of exposures at different levels and for different durations, a method to calculate a cumulative exposure is also presented. The regulation further requires that when employee exposure exceeds permissible limits, feasible administrative or engineering controls should be utilized to reduce exposure within permissible limits. If such controls are unsuccessful, personal protective equipment should be provided for, and used by, employees to reduce exposure to permissible limits. A hearing conservation program is required whenever noise exposure equals or exceeds an 8 h time weighted average sound level of 85 dB measured on the A-scale slow response.

3.2.2 29 CFR Bulletin 334, Guidelines to the Department of Labor's Occupational Noise Standards [17]. This bulletin explains the terms used in federal occupational noise regulations and what is expected of an employer to comply with regulations, and describes certain instruments, equipment, and procedures which will be acceptable as a basis for judging compliance. These guidelines help overcome some of the confusion in interpreting the Occupational Noise Regulations of OSHA. They emphasize that the use of personal protective equipment is considered by the Department of Labor to be an interim measure while engineering and administrative controls are developed. In addition, the characteristics of a continuing effective hearing conservation program are described.

3.2.3 Noise-Control Act of 1972. This act gives the Environmental Protection Agency responsibility to establish national noise standards for products that have been identified as major sources of noise. These include construction equipment, transportation equipment, motors and engines, and electrical and electronic equipment. Some noise-emission standards for railroads, trucks, and construction equipment have been promulgated under this act.

3.2.4 Regulatory Guide. NUREG 4.2, Nuclear Regulatory Guide for Preparation of Environmental Reports for Nuclear Plants [10] describes procedures and criteria for use in the preparation of an environmental report for a nuclear power plant prior to the issuance of a construction permit or an operating license. For information on audible noise see [10], Section 3.9, p 4.2–14, ch 3, par 2; Section 4.1, p 4.2 − 15, ch 4, par 2; and Table 3, p 4.2 − 55, 4.2.1 and 4.3.1. These sections require an examination of the local population and an identification of the impact on their environment due to noise.

3.2.5 Department of Housing and Urban Development Environmental Criteria and Standards [15]. This department provides environmental standards, criteria, and guidelines for determining project acceptability and for necessary mitigating measures to ensure suitable noise environments. See [15].

3.2.6 Environmental Protection Agency [18]. Guidelines to rate the noise in various receiving areas are provided by the Public Health and Welfare Criteria for Noise. Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety is also provided.

3.3 Representative State and Local Regulations

3.3.1 State of Illinois [13]. In 1973, the Illinois Pollution Control Board adopted rules and regulations pertaining to audible noise under [13], Ch 8, Noise Regulations. Permissible octave-band noise levels at the boundary lines of property are specified according to land use. In some cases, daytime and nighttime levels are specified. Also included are regulations for impulsive sound and for *so-called* prominent discrete tones. A-scale sound levels corresponding to the octave-band pressure levels range from 45 dB to 70 dB depending upon source land use and adjacent land use. It is interesting to note that for some cases the State Code is more restrictive than the City of Chicago ordinance. See 3.4.2.

3.3.2 State of New York [12]. In 1973, the State of New York adopted Rules of Procedure regarding certification for Major Steam Electric Generating Noise, [12], Part 75. These rules basically require

(1) Measurement and documentation of ambient noise levels around the site

(2) Estimates of the effects of site construction and plant operation on ambient noise levels with particular attention to areas of adjacent land use

(3) An evaluation of the impact of site construction on ambient noise levels

(4) An evaluation of the effects of plant operation and maintenance on ambient sound levels

The format of the information to meet these requirements will include tabulated data, graphic data, and overlays of the area showing ambient and projected sound-level contours.

3.4 Local Ordinances

3.4.1 City Noise Ordinances. The magazine, *Sound and Vibration,* [14] periodically updates a listing of municipal noise regulations covering various categories from emission sources to land use.

3.4.2 Chicago Noise Ordinance [11]. The most publicized municipal ordinance is probably the Chicago ordinance. For over 20 years, this ordinance specified permissible octave-band pressure levels at the boundary lines of zoned districts. In 1971, a new ordinance was passed and included noise-emission limits for motor vehicles, construction equipment, recreational vehicles, and other noise producing devices. A condensed summary of the regulations has been prepared by the Department of Environmental Control, City of Chicago.

3.5 Summary. For the construction and operation of power generating stations, there are two types of noise regulations with which the designer should become familiar

(1) In-plant or occupational noise regulations to prevent noise-induced hearing loss

(2) Out-plant or community regulations to limit the effects of site noise on the noise environs of the surrounding community

Occupational noise regulations specify limits of exposure to A-weighted sound levels, require reduction of noise exposure by engineering controls (reduce level) or administrative controls (reduce exposure time), and allow provision and use of hearing protection devices. Community regulations limit noise emissions from a building or site, specify C-weighted/A-weighted or octave-band levels, and can include provisions for various types of noise such as impulse, tonal, and steady. The trend in community regulations is toward more restrictive levels and more detailed measurements. In addition to the specification of permissible levels at the plant boundaries, some provisions are made to examine the existing ambient levels, to determine the statistical distribution of these levels with frequency of occurrence, and to predict the effects of plant operation on ambient environmental noise. Conformance with these regulations does not guarantee freedom from complaints, especially where noise sources exhibit strong tonal characteristics. The first step in developing noise-control procedures for a power station should be an examination of applicable noise regulations.

4. Measurement of Sound

4.1 Introduction

4.1.1 Audible sound data in and around power stations are obtained primarily

(1) To determine if sound levels are excessive for employees' hearing and comfort
(2) To control exterior noise to avoid community annoyance
(3) To identify the sources of noise in a given acoustic environment

4.1.2 The basic considerations when measurements of sound are made are as follows:

(1) Sound level and its frequency
(2) Characteristics of the noise source, steady or nonsteady; directivity of the source
(3) Acoustic environment and measurement locations

In outdoor measurements, wind is an additional factor to be considered. The measurements should be made while the source is operating at its normal operating condition. The normal operating condition may vary with the time of day and night and also the time of year (summer — winter).

4.2 Power-Plant Environments. The sound pressure observed in the vicinity of a source is influenced by the acoustic environment in which the source is operating. Hence an understanding of the environment is essential to meaningful sound measurements. There are three basic acoustical environments (see Section 2).

(1) Free
(2) Reverberant
(3) Semireverberant

In the following subsections the characteristics of these three fields are presented briefly for continuity.

4.2.1 **Free Field and Free Field above a Reflecting Floor.** These environments, also called the direct field, are free of undesirable reflection and therefore allow for direct interpretation of data. Under ideal conditions, the sound-pressure level varies inversely with the distance from the source in the free field, that is, a decrease of 6 dB each time the distance from the acoustic center of the source is doubled. Due to nonideal conditions, the actual decrease in level may be lower.

4.2.2 **Reverberant Field.** This condition is one in which the sound intensity is predominantly due to reflected sound energy. If the sound energy density is uniform throughout the field, the reverberant field is called a diffuse field. In power plants, the field near the walls of the turbine hall and other enclosed spaces may resemble the reverberant field.

4.2.3 **Semireverberant Field.** At any point within this field, the sound-pressure level may be considered to be the resultant of two coincident sound fields: the direct field and the reverberant field.

Most of the indoor measurements in power plants are made in the semireverberant environment. Hence, environmental corrections may be needed to determine the sound radiated by the equipment.

4.3 Types of Measurements. Power-plant noise measurements can be categorized as follows:

(1) Measurements related to ambient and source noise
(2) Measurements related to personnel exposure
(3) Measurements related to community annoyance

The environment affects each of these types of measurements in a different fashion. Hence, the techniques and precautions vary with the type of measurement.

4.3.1 Measurements Related to Ambient and Source Noise

4.3.1.1 Measurements of Ambient Noise. Measurements of ambient noise are commonly made outdoors and indoors. The observed sound pressure is usually a superposition of the sound pressures generated by many sources at different locations. In this type of measurement, it is the total sound pressure that is of interest rather than the sound pressure generated by any of the individual sources. While measuring the sound radiated by a source, the background noise level should be subtracted from the sound level measured near the source.

If the difference is 3 dB or less, the sound-pressure level due to the source cannot be properly separated from the background noise. In such a case, reducing the background noise by the use of temporary barriers or partitions should be considered. Barriers are generally not practical for large-volume rooms such as the main turbine deck or for large sources such as boilers.

When the noise source is operating in a room with hard surfaces, the sound-pressure level measured around the source may have a significant contribution from the reverberant sound. There are two practical choices to reduce the reverberant contribution

(1) Increase surface absorption
(2) Near-field measurement

The relation between surface absorption and the buildup of reverberant sound is discussed thoroughly in Section 2. The free-field region around the source that is ideal for source measurement increases with absorption. It is difficult to specify exactly how much the absorption should be increased or how it can be increased. After the surface treatment, one should traverse the sound field to determine the variation of sound level with distance. In a power plant, even after increasing the wall absorption, ideal free-field conditions may not be attained because different sources in close proximity are simultaneously radiating sound in the confined spaces. It is advisable to make reverberation time measurements so that the measured sound levels can be corrected, if necessary, for any reverberant contribution.

4.3.1.2 Near Field of the Source. See Section 2. Near field of the source is that region in its immediate vicinity where the resemblance to the free-field behavior, that is, the decrease of sound level with distance away from the source, is not evident. The contribution of the reverberant sound in this region is negligible. Though the measurements in the near field do not give a true sound-power level of the source, they still provide very useful sound-level data. The sound levels measured within a distance of 0.25 m from the major surfaces of the source can be considered as near-field measurements.

Another technique to reduce the contribution of reverberant noise and at the same time minimize the influence of nearby noise sources is to use directional microphones. A directional microphone has the same response as the conventional, omnidirectional microphone for sound waves which are incident perpendicular to its diaphragm. Its response falls off for oblique incidences. Thus even for measuring locations in the semireverberant field, the microphone will essentially sense the direct sound field if it is pointed at the acoustic center of the source.

Such a microphone however needs to be used with some degree of caution. The frequency response of directional microphones is typically not as good as that of conventional microphones. Therefore, some low- and high-frequency sounds may not be accurately sensed. The user shall be aware of the frequency-response limitations of any unit used so as to judge its adequacy for the intended applications. Also, there are no convenient on-site calibrators that can be used to adjust the microphone amplifiers to read out absolute sound levels. A correction chart, tailored to each microphone system, can be used to facilitate determination of these levels. The greatest utility of directional microphones is, thus, for the identification of noise sources and relative measurements of the noise levels of several sources.

4.3.1.3 Measurement Locations. Measurement locations depend on the reasons for obtaining the data, which usually are

(1) To determine compliance with a purchase specification

(2) To determine the contributions of the equipment to the overall noise level

To determine the compliance with a purchase specification, the measurements should be made according to the appropriate noise standard. In a case when an existing standard is not suitable for equipment operating in a power-plant noise environment, or there is no suitable standard for the equipment, the measurement locations and the operating conditions should be agreed upon beforehand. Near-field in-situ measurements under normal operating conditions will suffice in these conditions.

In general, measurements to determine the contribution of the equipment to the overall noise level will depend upon the equipment itself, the overall noise level, and the ability to determine the background noise. Equipment noise should be measured in its direct field, if possible, at meaningful locations. For example, for rotating machinery, measurements are recommended on its axis level, at the shaft ends, on top of the machine, and on both sides of the machine on its center line perpendicular to the axis. A series of sound-level contours are also recommended around the machine by recording levels at various distances in all directions. If these contours exhibit a directional pattern, some additional measurements should be taken to understand the cause of directionality. On large equipment, for example, turbine generators and boilers, some additional measurements may be needed near the couplings, burners, steam leaks, etc.

Hence, the measurement locations vary with the sources and their environment. There are published standards that can serve as a guide to determine the number of key measuring positions around a piece of equipment, microphone location, and its height above the floor. In most cases, the maximum sound level of the machinery has to be determined. This can be done by walking around the equipment holding the microphone at approximately 1.5 m above the ground, and observing the scale for the maximum reading. Caution shall be exercised when measuring equipment, such as boiler feed pumps, which produces audible discrete tones. Standing-wave interferences or large spatial variations in sound pressure are frequently produced by sound sources that radiate audible tones, and these are particularly pronounced in indoor locations. To reduce the influence of localized interferences, the microphone may be moved rapidly (a minimum of 1 cycle per second) in a vertical plane approximately ±0.3 m from each location.

4.3.2 **Noise Exposure Measurements Related to Personnel.** The measurements are made primarily to determine the noise exposure of plant personnel and therefore should concentrate on the major noisy areas which are critical, that is, 90 dB(A) and higher. According to current OSHA regulations, the guiding factor in establishing the noise exposure measuring locations in the plant area should be the path traveled most frequently by the personnel who get most noise exposure in the plant.

4.3.3 **Measurements Related to Community Annoyance.** Sound will usually be measured at the power-plant property boundaries or at the points of complaint or annoyance. There are no set rules established to determine how many measuring locations are required around the plant perimeter, although four locations are considered the minimum. The number depends upon the location and orientation of the plant, local regulations, and the proximity of the residential areas.

The purpose of the measurements is to characterize the noise at the selected locations. Measurements shall be made over a period of time sufficient to reflect the true time variation of the noise level. Statistical distribution noise measurements may be made manually or by using automatic equipment. A manual method of statistical noise measurement is described in [20]. Automatic monitoring equipment is available on the market.

The following descriptors are used to describe the temporal distribution of noise with time:

(1) Decile $L_{\%}$ is a noise level exceeded a given percentage of time with the percentage indicated by the subscript

(2) Equivalent sound L_{EQ} is the continuous noise energy average of a fluctuating noise level

(3) Day-night sound L_{DN} is the L_{EQ} level over a 24 h period with a weighting factor applied for nighttime levels between the hours of 10 pm and 7 am

(4) Community noise equivalent level (CNEL) is the L_{EQ} level over a 24 h period with a weighting factor applied for evening hours from 7 pm to 10 pm and another weighting factor applied for the period from 10 pm to 7 am

The L_{EQ} and L_{DN} descriptors are recommended by the EPA to assess long-term effects on the health and welfare of the public.

4.4 Recording the Acoustic Environment and Test Equipment Characteristics. When making sound-pressure level measurements, the acoustic environment should be noted so that the measured levels can be corrected for the influence of the environment. The mechanical characteristics of the source should be noted so that noise generation mechanisms can be determined from the analysis of the acoustic data. Some of the important parameters which describe the acoustic environment and test equipment characteristics are listed in the following subsections:

4.4.1 Acoustic Environment. The location of machinery; dimensions and description of the test area; location of the reflecting surfaces; room constant of the test area; and presence of standing waves. Site descriptions for outdoor sites (that is, wind speed direction, relative humidity, temperature, topography of the surroundings, etc); background noise, presence of nearby sources, and normal ambient.

4.4.2 Equipment Characteristics. The description of the machine; mounting of the machine; operating conditions (rotating speed, flow velocity); variation of the operating conditions with the output of the equipment; and add-on-noise control features, if any.

If the subject equipment is a component of another equipment system, the above characteristics of the latter should also be noted, for example, boiler feed pump and its drive, turbine, and generator.

4.4.3 Acoustic Instrumentation and Measurement Locations. The instrumentation used in the measurement of noise should be described and also their calibration and attenuator settings. The quality of the data obtained depends upon the precision of the instrumentation and its proper operation. Microphone location and orientation with respect to some reference on the equipment, acoustic center, and geometric center should be noted for each measurement.

The type of measuring equipment used and the detail of the data obtained should be adequate for their intended use. It should be remembered that detailed data (such as octave bands rather than sound level) can be obtained quite easily and prove quite useful.

4.5 Instrumentation for the Measurement and Analysis of Sound. Two basic instrumentation schemes are described below. Scheme A is for direct on-the-site readout. Scheme B records the data for detailed laboratory analysis.

Scheme A

Microphone		
Sound level meter or its equivalent	Octave band or one-third octave-band filter set	Readout

Scheme B

Microphone
Sound-level meter
or its equivalent　Tape recorder
Frequency analyzer　Display

The instrumentation should meet the requirements of the latest edition of applicable ANSI or ASA standards.

4.5.1 Sound-Level Meter. The sound-level meter is the basic instrument for measuring sound levels. It consists of a microphone, an amplifier, an attenuator, and an indicating meter. Most sound-level meters provide filter networks so that the A-, B-, and C-weighted levels can be read off the meter. Some sound-level meters have data analyzing capacity in one or one-third octave bands, can measure impulse noise, and can be used in conjunction with a tape recorder to store the data.

Various degrees of precision and accuracy are required in practical measurement of sounds of various kinds for different purposes. There are three basic types of sound-level meters

Type 1 — Precision
Type 2 — General purpose
Type 3 — Survey

Their performance requirements become progressively less stringent, proceeding from Type 1 to Type 3. The sound-level meters should meet the requirements of ANSI S1.4-1983 [3].

The microphone should be carefully selected to suit the acoustic environment. Consideration should be given to the environment, the expected range of sound-pressure levels, the desired frequency response, directional characteristics of the microphone, and its physical size and shape. For most of the acoustic measurements in power plants, a $\frac{1}{2}$ inch condenser microphone or equivalent is suitable. Sometimes it is impossible or impractical for an observer to be near the microphone. In such cases, an extension cable is used to connect the microphone to the instrument. To minimize the cable effects, the microphone should be mounted directly on a preamplifier, and the sound-level meter should be calibrated as a system, including the cables.

4.5.2 Frequency Analyzers. The distribution of sound energy versus frequency is needed for identifying the noise-generation mechanism, or for prescribing the noise-control treatment and to evaluate its effectiveness, or both. Instruments performing this function are known as analyzers. Analyzers determine the sound-pressure levels in different frequency bands covering the audio range. The bands are usually identified by their center frequencies. Most common-frequency analyzers are of the constant percentage bandwidth type. These include octave, one-half octave, and one-third octave band analyzers, the bandwidth decreasing progressively from octave to one-third octave bands. If further detailed analysis of the data is required, a constant bandwidth can be selected between 2 Hz and 200 Hz, and the whole audio range traversed. The choice of the analyzer used depends upon the information required. For example, if the sound spectrum is essentially flat, not much is gained by resorting to a one-third octave band or a narrow band analysis.

4.5.3 **Tape Recorders.** A tape recorder is an important tool in the acquisition and analysis of data. The data are stored on magnetic tapes which can be analyzed in detail in the laboratory. The data-storing aspect can be especially convenient for the measurement and analysis of single-occurrence events such as sound from the blow-off valves.

A tape recorder is also convenient to analyze the transient noise, for example, to understand how the noise spectrum of a control valve varies with load on the turbine.

It is important that the tape recorder does not distort the original noise data during playback. It should also have low electrical noise so that low sound-pressure levels can be recorded and reproduced. The accuracy of the recorder should be within the specifications of the sound-level meter, or its equivalent, used in conjunction with it. The attenuator settings on the tape recorder should be noted while recording the data. Some recorders have a voice track separate from the data track. This is very desirable because voice notes can be recorded without interrupting the data recording.

4.5.4 **Graphic Level Recorder.** A graphic level recorder can make a continuous record of the sound level measured by the sound-level meter or by a frequency analyzer. Thus, the variation of the sound with time can be monitored. A special case of monitoring the time variation of sound-pressure level is the measurement of reverberation time. The graphic recorder can also be used to obtain the frequency spectrum of a steady sound signal when used in conjunction with a frequency analyzer.

5. Sources of Noise and Spectra Examples

5.1 Introduction. The basic mechanism by which noise is generated is the formation of a sound wave when the volume of air or gas or a solid body occupying a given region is changed very rapidly. Noise and vibration sources are forms of mechanical energy which creates this basic mechanism.

Noise-producing mechanisms may be categorized into one of four classifications

(1) Aerodynamic (moving gases and liquids)
(2) Dynamic (rotating, oscillating, or vibrating mechanisms)
(3) Force (impact)
(4) Explosion (combustion processes)

With mechanical equipment, some noise is essentially unavoidable. Table 6 presents common mechanical equipment and the characteristics of their sound or vibration.

5.2 Plant Noise Sources. Sound sources in and around power stations contribute to the overall plant noise level with different energy levels, spectra, and radiation characteristics. Power-plant noise sources can be produced in some instances and locations within the plant by a single piece of equipment or any array of different pieces or multiple pieces of essentially identical equipment. Table 7 lists sound producing equipment which make up a power station and attempts to identify the major noise-producing components, their internal and external contribution to the plant, sound producing mechanisms, and operational period of significant sound contribution.

Specific sources of noise and the contribution of these sources to the A-weighted sound level require extensive engineering noise surveys using frequency selective instruments which include octave, one-third octave, and narrow-band analyzers. The octave-band analysis may describe the inherent sound characteristics of a single piece of equipment. However, when multiple pieces of equipment, pure tones, or widely varying levels are involved, the preferred method is the use of one-third octave band analysis or narrower-band analysis. An example of different types of analyses for the same sound source is provided in Fig 31.

The most significant contributors to overall power-plant noise and personnel noise exposure are coal mills, boiler feed pumps, forced draft fans, induced draft fans, seal air fans, primary air fans, air compressors, pressure-reducing stations, turbine-generators with accessories, and in some cases auxiliary equipment drives such as motors and turbines. In any plant survey and noise-control program, it is important to isolate and identify the noise sources and significant noise problem contributors. Identification and an understanding of the noise-producing mechanism in the various equipment will be beneficial.

5.3 Rotating Turbo-Machinery. This equipment category includes forced draft fans (backward-curved airfoil), induced draft fans (backward-curved airfoil or

Table 6
Mechanical Equipment Noise Characteristics

Source and Type of Noise	Characteristics of Sound or Vibration	
	Inherent	Incidental
Rotating: Fans Blowers Turbines Centrifugal pumps Centrifugal compressors Centrifugal chillers	A tone of frequency: $f = (\text{r/min})/60 \cdot$ number of blades on wheel or impeller, and higher harmonics	Acrodynamic *roar* (broadband). Dynamic imbalance with vibration frequency: $f = (\text{r/min})/60$, and higher harmonics
Cooling Towers	Fan Noise and Water Splash	Same
Motors Generators	*Whine* of frequency $f = (\text{r/min})/60$, or some multiple	Same, and cooling fan noise
Gears	*Whine* of frequency $f = (\text{r/min})/60 \cdot$ number of teeth or some multiple	Vibration with frequency similar to inherent noise. High speed impact and sliding noise; broadband *grinding* and *screeching*.
Bearings	*Squeal* of frequency: $f = (\text{r/min})/60 \cdot$ a multiple	Same
Grinders	Grinding noise, essentially broadband, often with a relatively strong pure tone of frequency: $f = (\text{r/min})/60 \cdot$ a multiple	Same
Reciprocating: Internal combustion engines	A *roar* of frequency of firing rate: $f = (\text{r/min})/60 \cdot$ multiple of number of cylinders (1 if two-cycle engine, $\frac{1}{2}$ if four-cycle) Exhaust noise	Cooling fan and pump noise; valve *clatter*; air noise. Dynamic imbalance with vibration frequency: $f = (\text{r/min})/60$, and higher harmonics

(Continued on Page 61)

Table 6 (*Continued*)
Mechanical Equipment Noise Characteristics

Source and Type of Noise	Characteristics of Sound or Vibration	
	Inherent	Incidental
Compressors	Same: $f = (\text{r/min})/60 \cdot$ number of cylinders	Same
Pumps	Intake and exhaust noise	Pressure pulses in gas and fluid lines; frequency related to inherent sound frequency
Vibrating Transformers Ballasts Rectifiers Light filaments	Relatively pure tones of frequency: $f = 2 \cdot$ Hz of ac, or some harmonic	Sympathetic vibration of housings, casings, and attachments; some multiple of inherent sound
High-speed vibrators	*Vibration*, *buzz*, or *rattling*, essentially broadband	Same
High-speed shakers		
Impact: Presses Hammers Shears Low speed vibrators Office machines	*Hammering*, *rattling*, *pounding*, *thumping*, *banging*, etc essentially broadband	Vibration, broadband in frequency
Flow: Air-flow in ducts Fluid-flow in pipes	*Rushing*, or *flow* sound, relatively broadband	Same. Cavitating pumps or supply-return imbalance create squeals and pulsations.
Valves and meters Throttling devices Dampers Flash tanks Orifices Nozzles	*Rushing*, *whooshing*, *swishing* type of sound. Often a strong, almost pure *tone* or *scream* or *screech*. Often very high frequency.	Same. Sound often travels long distances down ducts or pipes by way of walls or by way of fluid or gas. Strong pulsation or hammering when valves or throttling devices close or open.

Table 7
Base Load Power-Plant Sources

Noise Producing Equipment	Major Noise Producing Component	Principal Noise Contribution to Plant		Principal Noise Source				Period of Significant Noise Contribution			
		*		**				***			
		Int	Ext	A	D	I	E	S	P	F	I
1. Turbine Generators		Int									
	a. Turbine			A	D					F	
	b. Generator			A	D					F	
	c. Extractions			A						F	
	d. Exhaust			A						F	
	e. Governing valves			A	D			S	P		
	f. Gland steam exhauster			A	D					F	
	g. Exciter			A	D					F	
	h. Couplings			A					P	F	
	i. EHC power unit			A	D			S	P	F	
	j. Lube system			A	D			S	P	F	
2. Steam Generator		Int									
	a. Combustors (cyclone)			A			E			F	
	b. Combustors (furnace burners)			A			E			F	
	c. Coal feeders				D			S	P	F	
	d. Pulverizers			A	D					F	
	e. Air heaters			A	D					F	
	f. Shot cleaning system for air heaters				D	I				F	
	g. Clinker grinders				D	I				F	
	h. Blowdown tank			A						F	
	i. Lagging (sound radiating)				D					F	
	j. Soot blowers (steam or air)			A						F	
	k. Coal scales				D	I				F	
3. Auxiliary Drives		Int and Ext									
	a. Turbine drives			A	D					F	
	b. Motor drives (4 kV and larger)			A	D					F	

(Continued on Page 63)

Table 7 (*Continued*)
Base Load Power-Plant Sources

Noise Producing Equipment	Major Noise Producing Component	Principal Noise Contribution to Plant	Principal Noise Source	Period of Significant Noise Contribution
		*	**	***
		Int Ext	A D I E	S P F I
4. Auxiliary Equipment		Int and Ext		
	a. Fans		A D	S P F
	i. Forced draft			
	ii. Induced draft			
	iii. Gas recirculation			
	iv. Primary air			
	v. Ducts			
	b. Pumps		A D	S P F
	i. Boiler feed and hydraulic couplings			
	ii. Boiler feed booster			
	iii. Condensate booster			
	iv. Hotwell			
	v. Condenser circulating water			
	vi. Boiler circulating			
	vii. Ash sluice			
	viii. Jet pulsion ash			
	ix. Service water			
	x. Stator cooling water			
	xi. Heater drain			
	xii. Cooling tower circulating			
	c. Compressors		A D	S P F
	i. Service air			
	ii. Control air			
	iii. Soot blowing air			
	d. Condensers		A D	S P F
	i. Main			
	ii. Auxiliary			
	iii. Air ejector			
	iv. Vacuum pump			

(*Continued on Page 64*)

Table 7 (*Continued*)
Base Load Power-Plant Sources

Noise Producing Equipment	Major Noise Producing Component	Principal Noise Contribution to Plant *		Principal Noise Source **				Period of Significant Noise Contribution ***			
		Int	Ext	A	D	I	E	S	P	F	I
	e. Heaters			A	D					F	
	i. Closed										
	ii. Open (deaerator)										
	f. Valves			A	D			S	P	F	I
	i. Safety										I
	ii. Relief										I
	iii. Condensate regulating							S	P	F	
	iv. Turbine control							S	P		
	v. Power control										I
	vi. Gas regulators							S	P	F	
	vii. Heater drains								P	F	
	viii. Steam dumps (turbine bypasses or flash tank dumps)							S			
	ix. Feed pump recirculation										
	x. Air comp, antisurge bypass							S	P	F	
	g. Precipitators				D						
	i. Rappers								P	F	I
	ii. Plate vibrators								P	F	I
	h. Piping			A	D						
	i. Main steam									F	
	ii. Boiler feed									F	
	iii. Condensate									F	
	iv. Extraction									F	
	v. Ash sluice										
	vi. Raw water cooling							S	P	F	
	vii. Fuel (gas or oil)								P	F	
	i. Startup boilers			A	D		E				
	i. FD fans							S	P	F	
	ii. BF pumps							S	P	F	
	iii. Other auxiliaries										
	iv. Stacks									F	

(*Continued on Page 65*)

Table 7 (*Continued*)
Base Load Power-Plant Sources

		Principal Noise Contribution to Plant	Principal Noise Source				Period of Significant Noise Contribution			
		*	**				***			
Noise Producing Equipment	Major Noise Producing Component	Int Ext	A	D	I	E	S	P	F	I
5. Coal Handling		Ext								
	a. Coal breakers or conditioners			D	I				F	
	b. Conveyors system			D					F	
	c. Car unloaders			D	I				F	
	d. Barge unloaders			D	I				F	
	e. Transfer stations			D					F	
	f. Tractors					E			F	
6. Electrical Distribution		Int and Ext								
	a. Transformers		A	D					F	
	b. Circuit breakers		A		I					I
7. Heat Dissipation Systems		Ext								
	a. Mechanical draft towers		A	D	I				F	
	b. Natural draft towers				I				F	
	c. Spray canals			D	I				F	

*	
Int	Intenal to plant
Ext	External to plant

**	
A	Aerodynamic (moving gas or liquid)
D	Dynamic (rotating, oscillating, and vibrating)
I	Impact (force)
E	explosion (combustion process)

***	
S	Starting
P	Part load
F	Full load
I	Intermittent

radial), axial forced draft fans, steam turbines, boiler feed pumps, air compressors, and various pumps. Generally, the forced draft fans and boiler feed pumps are the noisiest pieces of equipment in the power plant although the main turbo-generator contributes significantly to the overall indoor plant noise environment and air compressors and pumps influence more localized areas in the plant.

5.3.1 Fans. Fan noise occurs when blades exert fluctuating forces on the air. Each time a blade passes a point on its rotational path, an impulse is delivered to the air at that point. The repetitive rate of this impulse called the blade passing frequency determines the fundamental tone of this type of noise. This rotation, or blade noise, is basic to all types of fans. Fan blades are also a major source of vortex noise. When a blade moves through the air, a pressure gradient is built up across the blade causing separation and giving rise to eddy formation and vortex shedding. The first mechanism forms a discrete noise related to revolutions per minute (r/min) and the second forms a more random noise which is primarily associated with turbulence and a resultant broadband noise spectrum. The same mechanisms apply to all centrifugal fans; however, radial blade fans are generally noisier and exert a predominant blade frequency tone that can be extremely objectionable. The fundamental tone or 1st harmonic of the axial flow fan is usually twice the frequency of an equivalent centrifugal fan.

Airborne noise generated by the fan impeller radiates through the intake and discharge openings and the fan housing. Noise may also be radiated as a result of resonance of fan housings and ducts since the aerodynamic noise from the fan contains all possible frequencies in the audible range with which to excite any mechanical resonant system at its natural frequencies of vibration.

5.3.2 Steam Turbine-Generator. The steam turbine is a significant noise contributor in the power plant. Due to its size, operating environment, and multitude of potential sources, its generated noise is particularly difficult to assess.

Identification of major sources of sound produced by fossil or nuclear steam turbine-generator units can be found within the steam admission valves, steam piping, turbines, couplings, generator, and exciter.

Most steam turbine-generator noise is created by friction, impact, turbulence, imbalanced rotating parts, pressure drops, mass flow, magnetic attraction, or other motions related to the change in velocity of moving parts. Flow-related sources account for the majority of middle-to-high frequency noise emitted by a turbine-generator. Low-frequency noise is created by rotor imbalance and fluctuating electromagnetic forces.

The sound-pressure levels near the low-pressure turbine and generator vary only a few decibels with load. Near the high-pressure turbines larger variations are possible.

High-pressure ratios across the turbine-control valves will produce very high sound levels near the high-pressure turbine. As the load on the unit increases, the pressure ratio across the valve decreases until, at some point, the steam noise produced is primarily the result of flow noise instead of valve noise in the piping system.

Near the low-pressure turbine and generator, the sound levels remain fairly constant with load. The constant volumetric steam-flow through the crossover pipes (if used) across the entire load range sets the sound level in these areas.

Valves and piping systems radiate sound in the most sensitive frequency ranges of 250 Hz – 4000 Hz. Steam-turbine control valves of fossil turbines generally have not proven to be a dominant noise source, although noise problems have existed, such as valve instabilities leading to chattering and mechanically generated noise. The first generation nuclear turbine control valves produced high noise levels when the valves were operating under choked conditions and have become more prominent than fossil turbines. This is due partly to differences between partial-load characteristics of fossil and nuclear turbines and their respective operating procedures. Largely, it is due to differences between fossil and nuclear control-valve construction.

The typical fossil turbine with partial arc admission has two steam chests, each containing three or four control valves. Each valve feeds one segment of the nozzle chamber in the turbine. The throat diameter of these valves is typically in the range of 100 mm – 150 mm. Structural walls are very thick. Full arc admission, throttle control valves on the larger supercritical fossil turbines are similar to nuclear turbine valve arrangements but still exhibit the thicker wall characteristics of fossil turbines.

The first generation nuclear turbines, with their much lower steam pressures, require approximately five times as much volumetric flow as fossil turbines of the same power output. Because of this increased flow rate, a completely different configuration had to be chosen. The nuclear turbines have four individual control valves and comparatively their walls are much thinner than fossil valves. The throat diameter of these valves presently ranges up to approximately 500 mm.

Turbine-control valve noise is a function of the velocity immediately downstream from its throat and the mass flow. The noise generated within the valve propagates down the pipe toward the turbine, and exhibits essentially a line source of sound power per unit length.

Steam piping is one of the major sources of turbine-generator system noise. Piping systems not only radiate sound produced by valves, they also radiate the hydrodynamic pressure fluctuations impinging on their walls due to the turbulent fluid. Steam flow through a complex piping system involving joints, bends, constrictions, etc, may result in fluid excitation that can cause structural resonances in the piping system.

The moisture separator-reheater is also a possible source of noise in nuclear units. This stationary device mechanically separates moisture from the steam and then reheats and discharges it to the low-pressure turbine inlet. Airborne sound is generated by the flow of steam through this device.

The basic generators of noise inside the steam turbine are rotor imbalance and the interaction between rotating and stationary blades. As the rotating blades in a turbine pass the upstream stationary blades, they are acted upon by a periodic steam force at the stationary blade passing frequency. This force may excite various modes of vibration in the rotating blades. Similarly, stationary blades are subjected to pulsations from the passing of the rotating blades, and can be excited into vibration.

In isolated cases, turbine blade passing frequencies have been detected; however, they do not contribute significantly to the overall noise level.

Fluctuating electromagnetic forces are the main contributors to noise in a generator. Magnetic forces result from the interactions between magnetic fields and electrical current, and every rotating electrical machine has some vibration due to magnetic forces. Most of these forces originate in, or near, the air gap of the machine. Magnetic forces exist only at twice line-frequency in an ideal machine.

Aerodynamic noise resulting from the high-surface velocity of the rotor or ventilation noise from the exciters sometimes reaches unacceptable noise levels. Consequently, the dB(A) sound level of the steam turbo-generators is flow-related noise with control valves and piping as major contributors.

5.3.3 Centrifugal Pumps and Compressors. High-speed centrifugal boiler feed pumps and soot-blowing air compressors (axial type) are significant contributors to the power-plant noise environment since their capacities and speeds may be very high compared to other types of pumps or compressors. Their most important source of noise is turbulence. This turbulence is actually a combination of two effects, that is, vortex shedding and upstream turbulence.

Vortex shedding is explained here. The boundary layer over each blade is turbulent by the time it reaches the trailing edge. The turbulent layers on the top and bottom surfaces produce a fluctuation in the lift and this turbulence has a broad frequency spectrum. The application of a fluctuating force to a fluid generates sound at the same frequency; therefore, broadband noise is radiated, which explains the broadband nature of these centrifugal machines. The frequency of the vortices is proportional to the fluid velocity and inversely proportional to the thickness of the trailing edge. For a particular blade design, the vortex shedding establishes a lower limit to the broadband noise produced.

When upstream turbulence is present due to improper design, obstructions, or off-design condition operation, fluctuations are produced which create greater turbulence and higher noise levels. Turbulence within a centrifugal pump or compressor casing is at a minimum when the pump is operating in its best efficiency region, since in this region, flow angles are properly aligned to coincide with wave angles and passageway orientation.

Of the frequencies usually encountered in centrifugal machines, those related to the basic rotational speed of the pump and the number of impellers (blade-passing frequency) are identifiable, although very often it is not the major component and is partially or completely overshadowed by the sounds due to fluid turbulence.

High-speed machines are noisier than low-speed units; however, high-speed compressor noise increases at a greater rate due to speed increases than high-speed pumps. This is probably because high speed for pumps is usually fairly low speed for compressors and because compressors are usually more efficient noise generators than pumps.

5.4 Flow or Aerodynamic Action. Control valves, pressure-reducing valves, and other similar devices produce high-intensity noise. Flow-induced noise may also be generated in pipelines and duct systems and contain mostly middle- and high-frequency energy.

High-velocity steam or gas which is blown off to the open air or to the condenser through blow-off valves, safety valves, or other pressure-relief devices creates a free jet effect and results in very high noise levels.

5.4.1 Valves. Throttling-type control valves used for flow control and pressure-reduction applications are generally the primary sources of noise radiated by piping systems. Noise generation by valves is caused by any of the following distinct and different noise phenomena emanating from a control valve:

(1) Noise induced by mechanical vibration
(2) Noise produced by cavitating liquids
(3) Noise caused during aerodynamic throttling

These noise sources should be understood so far as their generating mechanism is concerned. Only then can effective evaluation be made of a noisy valve problem. Mechanical vibration noise seldom happens simultaneously with cavitation and aerodynamic noise. If this does occur, the cure of one is usually the cure of the other.

Noise produced by mechanical vibration involves two mechanisms. The first is mechanical vibration induced by pulsation of the fluid passing through the valve. The frequency is usually low, that is, between 50 Hz and 500 Hz. If this turbulence-induced vibration of the valve trim approaches the natural frequency of the plug-stem combination, the second mechanism of valve component part resonance can be initiated. This resonance occurs at frequencies between 2000 Hz and 7000 Hz.

Cavitation noise is associated with separation of the fluid from the valve surfaces and is caused by the flashing of liquid into the gaseous state due to the reduction in pressure below the vapor pressure of the liquid. Laboratory investigation indicates noise to be a function of the amount of decrease in downstream pressure of the valve beyond the pressure that causes incipient cavitation and the difference between downstream pressure and the liquid vapor pressure. The peak in cavitation noise can be expected where these two variables are nearly equal. With present availability of good engineering data, it is possible to predict quite accurately whether or not a selected valve will cavitate under a given process condition.

Aerodynamic noise is the most important form of acoustical annoyance so far as control valves or pressure-reducing valves are concerned. Aerodynamic noise is a byproduct of the reconversion of kinetic energy through turbulence into heat downstream of the throttling orifice. There are two basic contributory factors. One is the terminating shock front of a supersonic jet generating from the vena contracta (narrowest point) of the valve orifice (at higher-than-critical pressure drop). The second comes from the general turbulence of the fluid boundary and is effective above and below choked flow in the valve orifice.

Regardless of the generating mechanism, the in-pipe valve-generated noise field is propagated downstream and upstream, and decays very slowly with distance from the valve. Generally, the mass of the valve wall tends to attenuate noise generated in the valve. As a result, the piping system itself often becomes the prime source of externally radiated noise.

5.4.2 Piping. Excluding valve, orifice, or equipment noise the most common pipeline noise source is the fluid flow itself, particularly with compressible fluids such as steam and air. The higher the fluid or gas velocity and the lower its viscosity, the louder the noise. From a system approach, velocity in valves and piping are contributing factors and lack of design consideration in one area can negate efforts in the other. Also, contributing to noise sources in piping systems but usually to a lesser extent are

(1) Water hammer
(2) Valve cavitation
(3) Mechanical vibration

Within the fluid itself, noise originates from either pulsating flow, fluid-wall interaction, fluid mixing, or shock waves.

Pulsating flow causes the pipe wall to radically expand and contract and thus generate noise when the pulse cycling falls in the audible range. Common causes of the pulsations are reciprocating compressors, unstable valves, or similar devices.

Fluid-wall interaction occurs when a turbulent steam or gas flow strikes a pipe or fitting wall and creates a fluctuating force that causes the pipe to vibrate. This force is usually minor in long, straight pipe runs. Projections or discontinuities can produce turbulent wakes leading to serious noise conditions. Fan noise is an example of fluid interaction with a solid surface.

Turbulent mixing of fluids creates a sound that travels outward to the pipe wall, causing it to vibrate and generate noise. Usually, this occurs downstream of an orifice or valve where a high-velocity jet mixes with a lower-velocity fluid.

Shock waves, other than those resulting from valves and orifices, can occur in steam or gas lines when the pressure drop across a restriction exceeds a limit known as critical pressure drop. Under this so-called *choked flow* condition, flow at the *vena contracta* is sonic and shall inevitably slow down and mix with the normal-velocity fluid somewhere downstream. This takes place in a short space, creating a shock wave. Normally, the shock wave fluctuates in intensity and position, giving rise to vibrations that carry through the pipe wall in the form of noise.

5.5 Electric Machinery. Noise in electric machinery such as transformers, motors, and generators is caused by electromagnetic force, mechanical vibration, and windage.

5.5.1 Motors. Large electric-motor noise has all three basic sources, that is, windage, electromagnetic field, and mechanical parts.

Windage can be divided into three categories

(1) Fundamental fan blade frequency and other fundamental frequencies of rotating parts

(2) Duct noise (mainly a concern with large induction motors)

(3) Broadband noise

The first category is a single-frequency noise produced when a rotating, air-moving member rotates near stationary obstructions in an otherwise smooth contour. In the case of a rotor fan, for example, the flow from each blade is modified as it passes the obstruction, thereby producing a noise frequency equal to the number of fan blades times running speed. Another example involves the salient poles of a synchronous machine where the frequency equals the number of poles times the running speed.

The second category of windage noise is duct noise. This is a pure tone sound usually in the range of 1000 Hz – 2000 Hz produced by induction motors that have radial ventilating passages in the rotor and stator. This includes nearly all open and weather-protected motors larger than 200 hp with the exception of 3600 r/min machines which normally do not have passages in the rotor. The siren sound is produced by the chopping action of the rotor bars on the ventilating air that passes through the rotor and is exhausted from the stator.

Broadband windage noise is the characteristic air-movement sound produced by rotating electric machinery. It is generally in the frequency range of 150 Hz – 1200 Hz. Broadband windage noise is caused by air turbulence produced as a machine's fan circulates air through the complex path of rotor, air gap, coil end turns, stator, and enclosure.

Since windage noise varies approximately as the 5th power of the peripheral velocity, broadband windage is the major noise source in high-speed machines. Totally enclosed, fan-cooled motor noise level is also a particular problem because a large external fan with high peripheral velocity is required to provide adequate cooling.

A second basic source of noise in motors is the electromagnetic field. Forces are generated that act across the air gap of a machine to produce cyclic distortion or vibration of the stator core. These forces have single-tone frequencies and generally occur at twice line frequency in ac machines and, in all types of machines, at frequencies determined by interaction of parameters, such as the number of rotor and stator slots, number of poles, and flux density. These forces can be particularly troublesome if they are coincident with resonant frequencies of the stator core or other parts of the motor. Modern technology has also created solid-state power supplies for dc motors and special controls for adjustable ac machines. These may contain harmonics of the fundamental frequency that result in more force frequencies than considered in the past. It shall be remembered that if the machine works there are electromagnetic forces present that can cause a noise problem.

The last noise source is mechanical. This includes bearings, brushes, imbalance, etc. Rotor imbalance as a noise-producing element has been virtually eliminated by modern balancing equipment and techniques. Sleeve-journal type bearings are not a noise contributor, but antifriction bearings may be. The contact between the rolling parts and the stationary parts generates noise at generally predictable frequencies. The condition of the bearing parts and the clearances between them are very important considerations. Brush noise is another mechanical sound determined by the condition and quality of the brush, its holder, and the rotating contact surface. This may be the prime noise source in dc motors because of their slotted commutators. Brush noise in large motors and generators may also be a factor in synchronous machines, but usually it is of secondary importance.

Typically, the higher speed motors have higher noise levels. This is an effect of higher peripheral velocities of rotating parts and thus, more windage noise. In slower speed machines, the noise level is more electromagnetic in origin.

Motor noise level is a function of basic machine parameters. With all other parameters constant — a higher speed motor will have a higher noise level, a larger machine will be noisier than a smaller one, and a more enclosed machine will be quieter than an open noise source.

The type of machine enclosure has a significant influence on the radiated sound. A totally enclosed fan-cooled motor is the noisiest enclosure because it utilizes a large external fan for cooling. The dripproof enclosure ranks second because of the generally exposed parts. The weather protected Type II enclosure is quite effective in providing a quieter machine because its air paths can be effectively treated.

The driven equipment should be a part of the consideration in evaluating the noise sources present in a power train. In the power-station environment, the driven equipment includes small generators, pumps, compressors, fans, and in some cases, a gear box.

Gears tend to produce pure-tone noise in the 500 and 1000 octaves. Friction is one of the major sources of gear noise. Gear frequency noise consists of the tooth-passing frequency and a number of higher harmonics, plus other components associated with the impacts and structural resonances.

Sound produced by small generators is similar to that of motors and the same criteria generally apply.

5.5.2 **Tranformers.** Transformer noise is created principally in the transformer core where alternating electromagnetic forces are generated in voltage transformation which can produce vibration of the core steel. The resultant vibrations in the core occur at a fundamental frequency of twice the line frequency or 120 Hz for 60 Hz transformers. This is the characteristic *hum* of a transformer. Mechanical resonance of the core can further magnify relatively high levels of harmonics of the initial values of core strain produced by electromagnetic forces. Oil-filled core-type transformers may allow their core vibrations to be transmitted to the container or tanks by direct transmission at points where the core is attached to the tank and through the oil. Since the oil has a high acoustic impedance, the amplitude of the vibration of the tank wall is almost the same as that of the core. The efficiency of the tank as a radiator of sound depends on the pattern of vibration on its surface at the frequency concerned.

The cooling system on large transformers also produces some noise; however, it is of low magnitude and normally not a problem.

5.6 Combustion Processes. The noise emitted from combustion systems is of a complex nature and is determined by the interaction between the energy conversion mechanism of the flame and the combined acoustic and aerodynamic character of the installation. The flame-generated noise in a free field has shown that the acoustic output is essentially broadband in form. Noise generated by flames and turbulent gas jets can be considered as originating from separate sources. Generally, flame noise created by firing in a furnace is not a continuous constant pressure process but a pulsating process which fills the lower part of the audible frequency spectrum and is one of the forms of energy accompanying the principal conversion of chemical energy to heat. The extent to which noise is created is, among other things, dependent on the specific rate of energy release. Interaction between enclosures and flames also occurs due to combustion instability and the amplitude of the discrete frequency peaks which make a major contribution to the generated noise.

Furnace noise, apart from burner noise, results from fluctuations in volume of the burning gas or oil droplets. If a uniform rate of burning can be achieved, the noise becomes significantly smaller. This fluctuation in the rate of burning can be aggravated by pressure changes near the burner due to acoustic wave reflection from the farthest surface. Thus, a very low-frequency rumble can occur.

Any attempt to reduce noise output from a combustion system shall be coupled with some assessment of the noise-generating mechanism. It is essential to identify whether the noise is combustion generated and whether discrete frequencies due to instability are identifiable in the sound spectrum.

A pulverizer, although not directly associated with the combustion process noise, is a major part of the fuel delivery system and a significant contributor of power-plant noise in coal-fired units. Noise generated from the pulverizer system is generally produced by the motor driver, ball or bowl grinding and crushing action, couplings, and exhauster or fan. Unbalanced and pyrite interference within the pulverizer will add significant noise level to the system.

The most significant noise is the low-frequency grinding and crushing action.

5.7 Cooling Towers. The power industry commonly uses hyperbolic natural draft (counterflow or crossflow) and rectangular multicell or round multifan mechanical draft cooling towers of the wet evaporative type for the power-plant condenser cooling. The high degree of splashing inherent in cooling-tower operation is an important source of noise and is reminiscent of a waterfall. The air induction fans used in mechanical draft towers are also a potential source of noise.

In a natural draft crossflow, tower noise is generated by water cascading through the packing which is similar in style and arrangement to that of the mechanical draft tower packing.

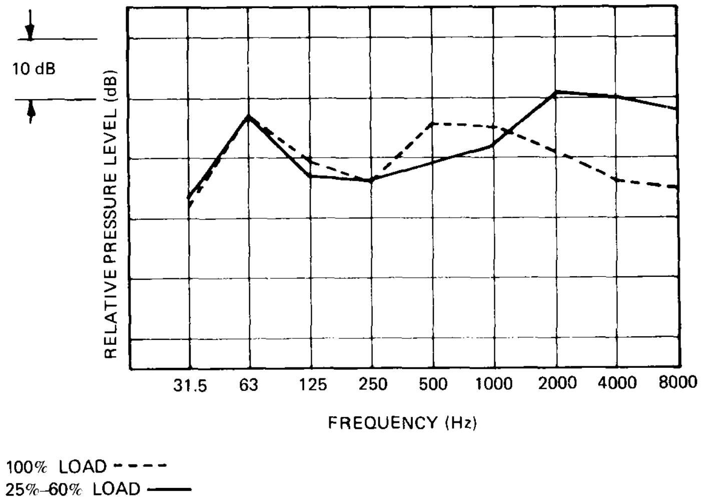
In the counterflow natural draft tower, the packing or fill is contained within the shell of the tower and most of the noise is generated by the water falling from the bottom of the packing into the basin of the tower.

The tower water-splash noise is generally composed of high-frequency sounds and increases with increasing water-flow rates. Typical operation of cooling towers at power stations is at a constant flow rate; therefore, the tower presents a very constant source of noise. The overall sound power radiated by a mechanical induced-draft cooling tower is determined almost entirely by fan noise and is related to the power of the tower fans. Total noise radiated by these types of towers is therefore composed of fan noise at low frequencies and water-splash noise at high frequencies. For a propeller fan used on cooling towers, the peak noise level should occur in the frequency band containing the blade passing frequency which is typically in the lower frequency bands. Round mechanical draft towers have a concentration of fans at the center that may tend to have a greater low-frequency influence on the sound spectrum than the fans of a mechanical rectangular tower.

5.8 **Noise-Spectra Examples.** Sound-spectra examples of major power-plant equipment are given in Figs 13 through 30. Inherent sound-spectra char-

Fig 13
Turbine Admission Valves

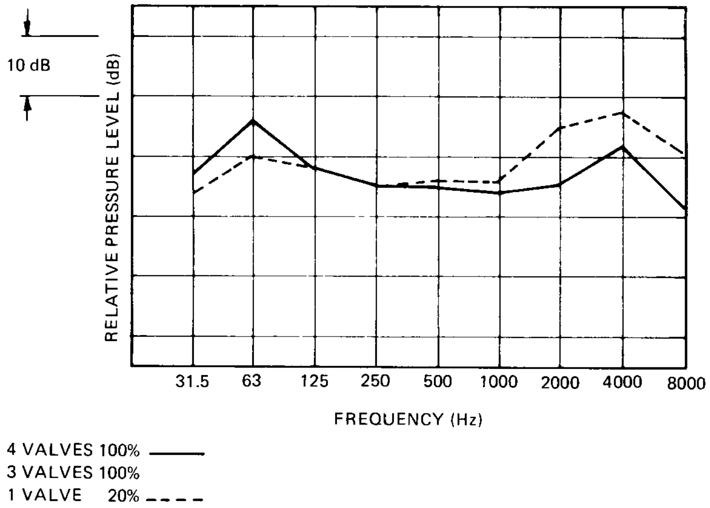
NOTE: *The changing frequency characteristic of the noise from turbine admission valves is illustrated as a function of load or valve position. Lowest sound levels are produced at full open valves.*

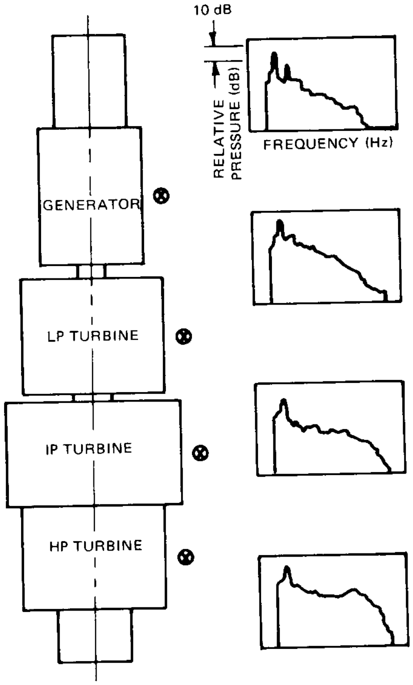


acteristics of the equipment can be identified in some of the examples; however, the relative contributions of individual sources in power plants are very difficult to determine. Sound levels measured close to a piece of equipment or noise source in the near field can sometimes distinguish its characteristics. The examples exhibited are taken from many different sources and are in some cases influenced by other adjacent or close-proximity equipment or noise sources. Where these characteristics and influences can be identified in spectra presented, we have attempted to provide an explanation on the exhibited example. Some of the sound-spectra discontinuities however are unexplainable due to lack of sufficient data.

Fig 14
Turbine Admission Valves

NOTE: The increase in noise levels near the valve is illustrated after one valve is closed to a 20% throttling position.

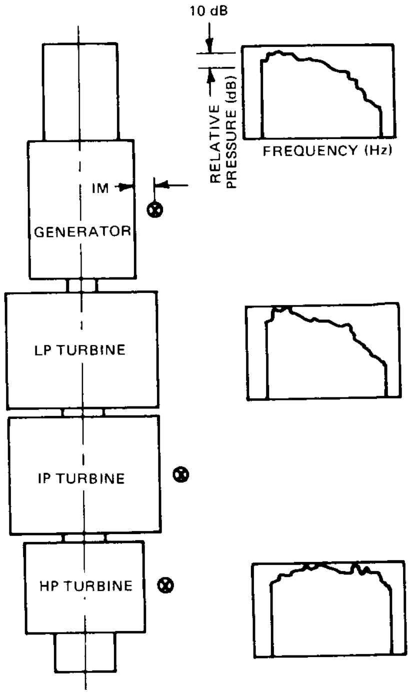




⊗ MEASURING POINTS STEAM TURBINE-GENERATORS

NOTE: The noise is generally broadband for turbine-generators with some characteristic peak at running speed of unit, at power frequency and at excitation frequency. The data is illustrated in ⅓ octave since octave-band data would drop out rotational and excitation frequency peak.

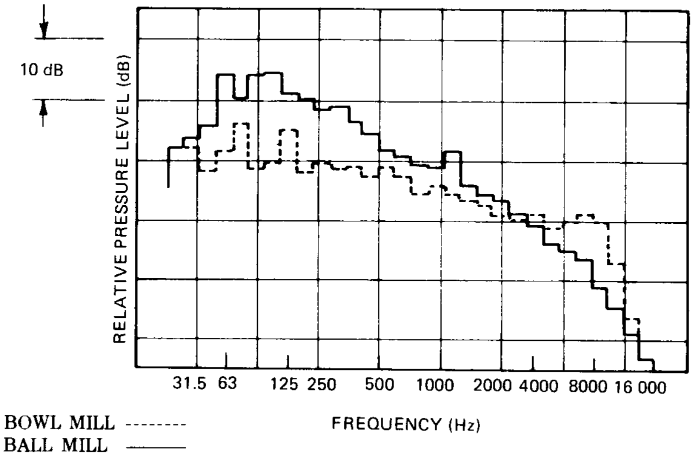
Fig 15
Steam Turbine-Generator
Fossil-Fired Plant



⊗ MEASURING POINTS STEAM TURBINE-GENERATORS

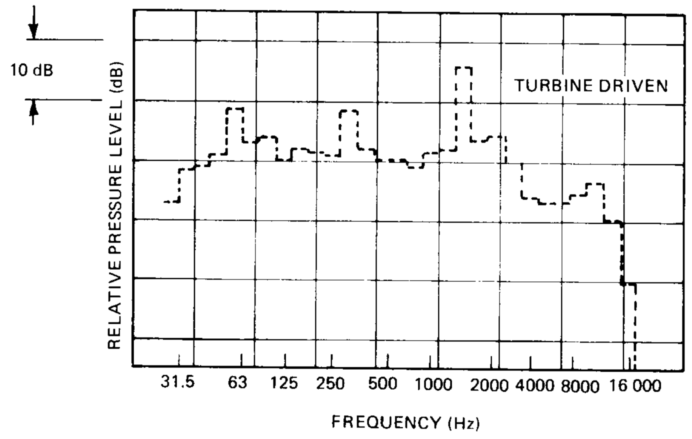
NOTE: The noise is generally broadband for turbine-generators with some characteristic peak at running speed of unit, at power frequency and at excitation frequency. The data is illustrated in ⅓ octave since octave-band data would drop out rotational and excitation frequency peak.

Fig 16
Steam Turbine-Generator
Nuclear Plant



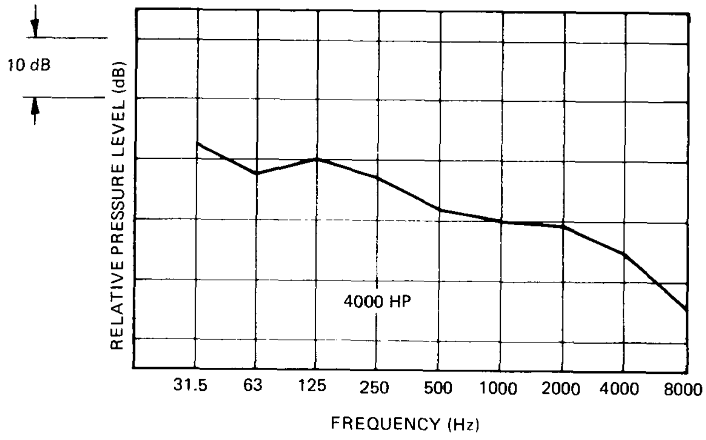
NOTE: Two different types of coal pulverizer spectra in ⅓ octave is illustrated. Noise from the ball mill has considerable low-frequency content and is higher in level than noise from comparable sized bowl mill.

Fig 17
Pulverizers



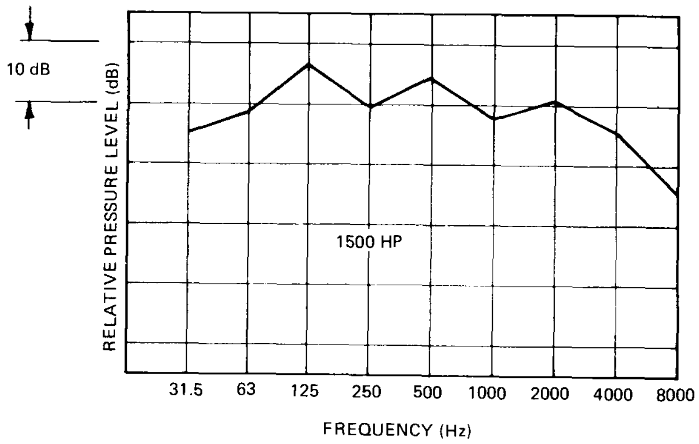
NOTE: ⅓ octave-band spectra illustrates pumping frequency peak between 1 kHz and 2 kHz. Peak at 300 Hz nearby heater feed pump.

Fig 18
Boiler Feed Pump



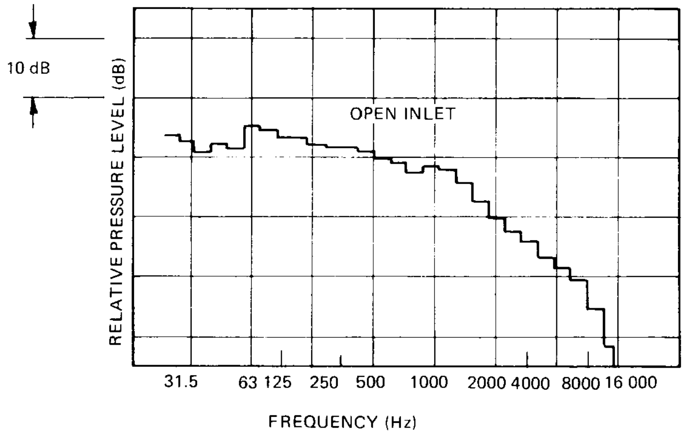
NOTE: The variation in noise spectra from two different motor drives. The small unit actually produced higher sound levels and several pure tones are evidenced by the sawtooth spectra.

Fig 19
Boiler Feed Pump



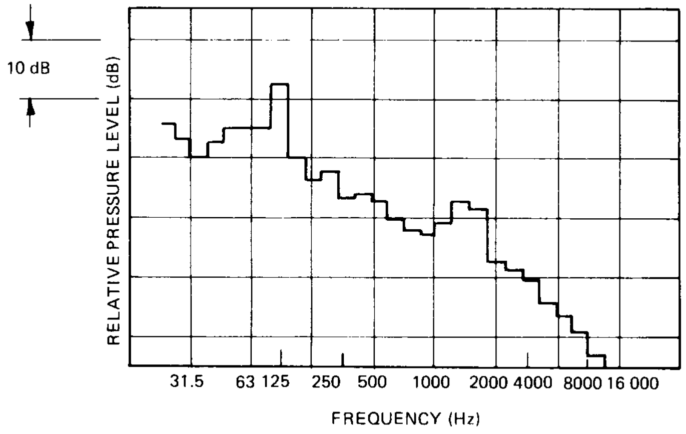
NOTE: The variation in noise spectra from two different motor drives. The small unit actually produced higher sound levels and several pure tones are evidenced by the sawtooth spectra.

Fig 20
Boiler Feed Pump



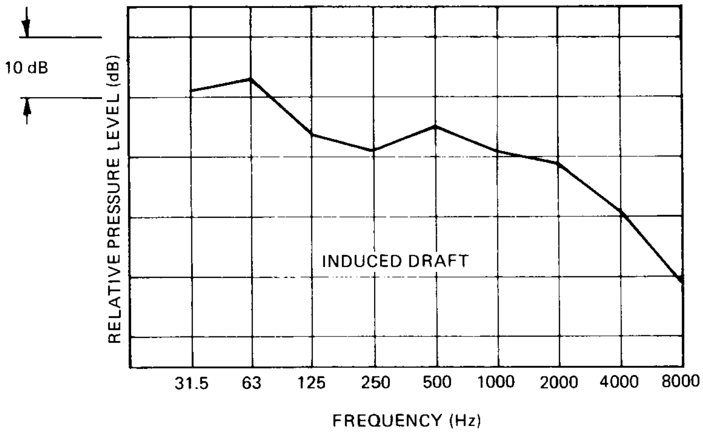
NOTE: The relatively broadband spectrum on noise at the inlet to this type fan is illustrated with the somewhat tonal spectrum of noise from the motor in the 1 kHz and 2 kHz octave.

Fig 21
Forced Draft Fan



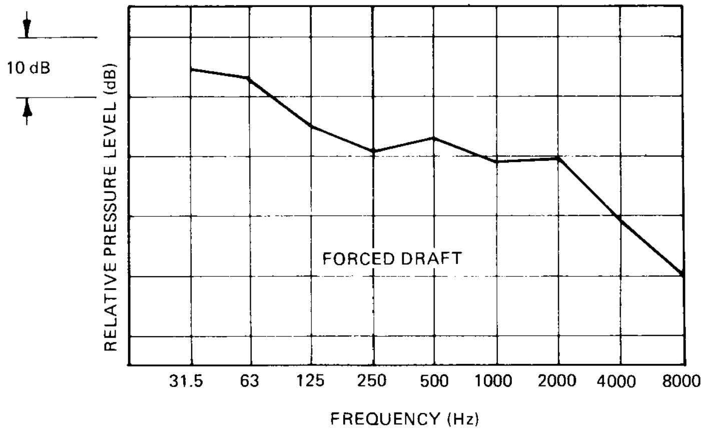
NOTE: $\frac{1}{3}$ octave band spectra illustrates blade passage frequency peak at 125 Hz. Peaks between 1 kHz and 2 kHz is noise from drive motor.

Fig 22
Induced Draft Fan



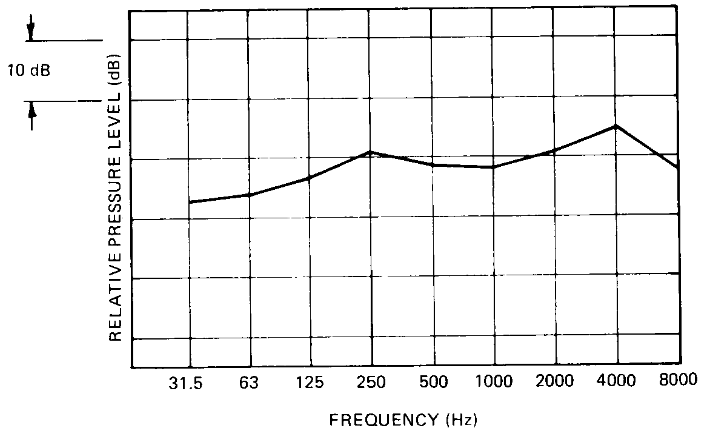
NOTE: Octave-band spectrum is illustrated from two different axial fans. The peak in the 500 Hz octave is a result of the blade passage frequency.

Fig 23
Axial Flow Fan



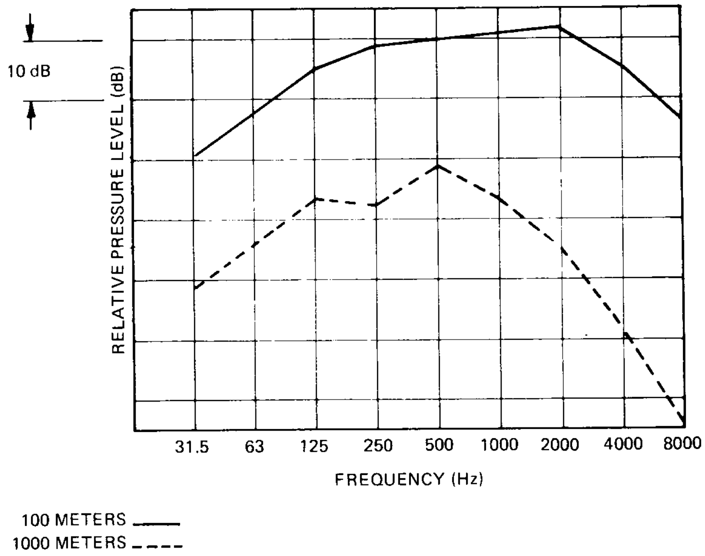
NOTE: Octave-band spectrum is illustrated from two different axial fans. The peak in the 500 Hz octave is a result of the blade passage frequency.

Fig 24
Axial Flow Fan



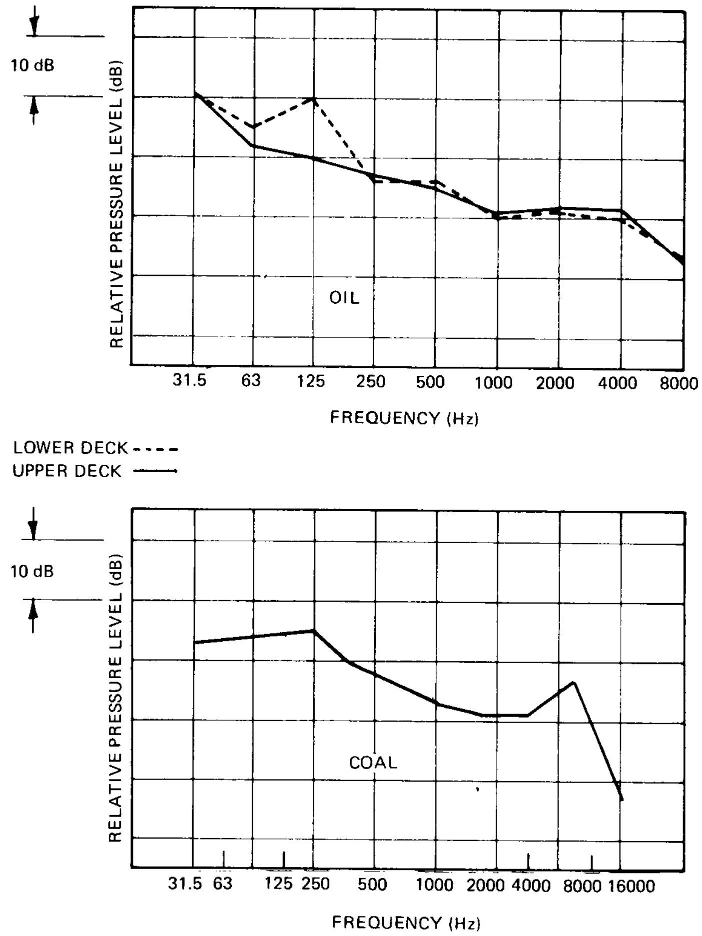
NOTE: Octave-band data on this centrifugal motor-driven unit illustrates the somewhat broadband spectrum but contains significant pure tones at blower frequency at 4 kHz and gear frequency at 250 Hz.

Fig 25
Soot-Blowing Air Compressor



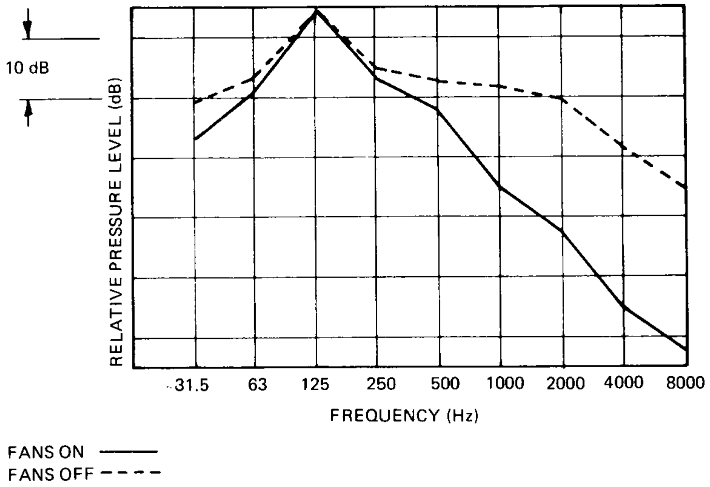
NOTE: Octave-band spectrum illustrated during a venting or relief condition. The effect on spectrum due to excess atmospheric attenuation at frequencies above 500 Hz is very evident at remote measured location.

Fig 26
Boiler Drum Safety Valves



NOTE: Burner noise for two different fuels is illustrated. The low-frequency rumble of the oil-fired burner is quite evident. The coal-fired burner does not exhibit such low-frequency peak characteristics. The peak at 8 kHz is the result of nearby steam or air leak.

Fig 27
Furnace Burners

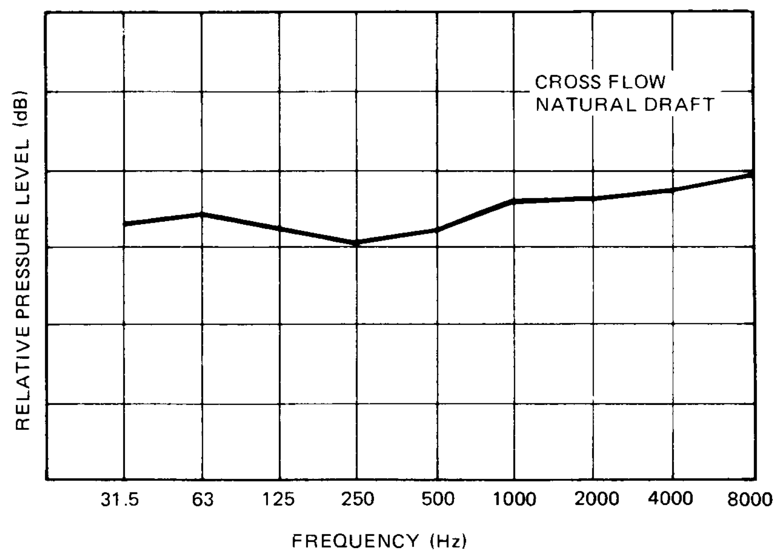


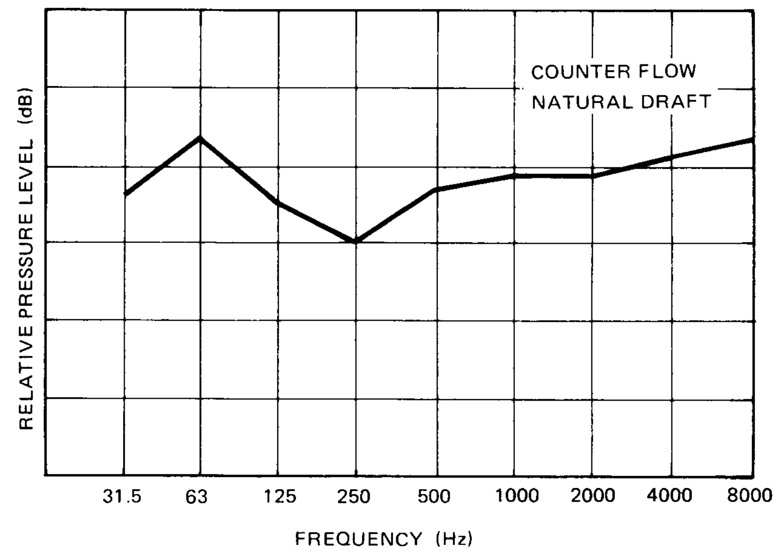
NOTE: Octave-band illustrates the predominant noise in the 125 Hz octave. The effect of noise from fans is most evident above 500 Hz.

Fig 28
Transformer

5.9 Conclusions. Isolation or identification of noisy or potentially noise sound sources in a power station is essential for a meaningful noise-control program. Plant sound-producing equipment can be characterized and its sound-producing mechanism explained and categorized. Relative contributions of individual noise sources are difficult to assess and sometimes unachievable even by prudent analysis methods. However, sound-level measurements taken in near field of equipment with appropriate band analysis can distinguish its characteristic or discrete influence on the noise environment.

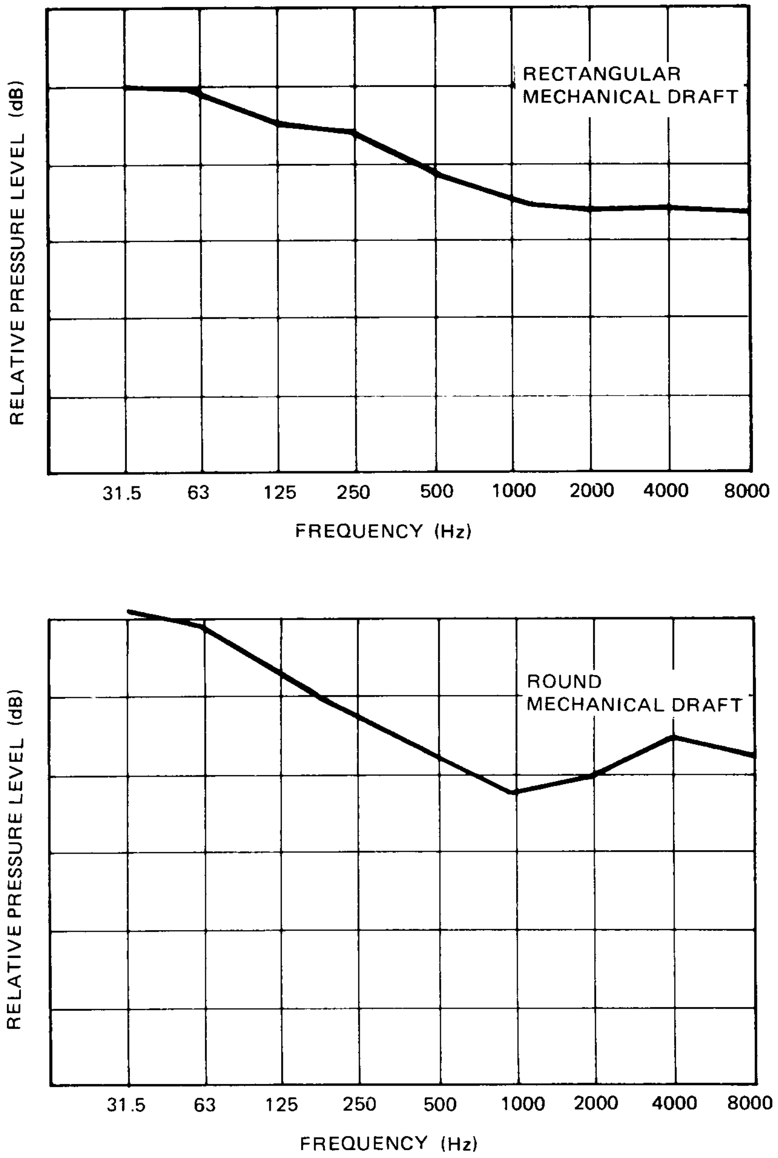
The noise spectra presented provide examples of noise measurement data which have been obtained in existing power stations and should not be construed as typical for all such equipment. Differences in equipment design, plant layout, and noise-control features can drastically change the spectra which influences plant environment.





NOTE: Towers handling approximately 250 000 g/m at a measurement distance of 24 m. The high-frequency characteristic of the water splash is evident in the spectra.

Fig 29
N D Cooling Towers



NOTE: Rectangular tower of 5 cells handling 90 000 g/m. Round towers handling 172 000 g/m with 16 fans in tower center. Measurements at a distance of 24 m. Fan noise is quite evident at the low frequencies.

Fig 30
M D Cooling Towers

6. Noise Control in Power-Plant Design

6.1 Introduction. Since retrofit measures are often expensive, inconvenient, and sometimes impractical, noise-control features should be incorporated in the initial design of all future power plants. This section provides the design engineer with guidelines for applying noise controls in the design of new power plants.

6.2 Criteria for Noise-Control Planning. Fundamental concerns in the planning for noise control in power plants are

(1) Sound levels in the nearby community
(2) Existing or projected in-plant personnel exposure
(3) Speech interference levels

The sound transmitted to the surrounding community from a power plant depends on its location and orientation with respect to the community. The potential levels inside and outside also depend on

(1) Whether the plant uses fossil or nuclear fuel
(2) Whether it is open, partially closed, or completely closed
(3) The arrangement of the equipment
(4) Sound power of the equipment and its directivity
(5) Architectural features and acoustical treatments

The sound transmission loss required for the walls of the control and other offices depends on the level outside these areas and the interior noise-control criteria.

6.3 Typical Plant Configuration. A power plant can be characterized, from a noise viewpoint, by

(1) The type of fuel used; coal, gas, or oil or any combination of these, or nuclear
(2) The type of enclosure; complete, partial, or open
(3) The cooling-water system; forced or natural draft cooling towers or once through

A typical plant layout can be selected for the power plant under consideration.

6.4 Generalized Noise-Control Model. Using a preliminary plant layout, a generalized noise-control model can be constructed as a design aid. Inputs for such a model include

(1) Community noise requirements
(2) Topography of the plant site
(3) General orientation of the plant
(4) Spatial constraints/flexibility of the general arrangement
(5) Noise exposure in an eight-hour shift of the plant maintenance and operating personnel during normal plant operation; OSHA requirements for personnel noise exposure (see 29 CFR 1910.95 OSHA [16])

(6) Sound radiation from the equipment. These data may be obtained from manufacturers or measurements on similar installations

(7) Absorption on interior surfaces and transmission loss of plant construction

(8) Possibility of using noise-control measures such as mufflers, enclosures, design, and supplier options

(9) Economic considerations, including

(a) Cost of buying low-noise machinery

(b) Administrative controls

(c) Economic feasibility of acquiring enough land surrounding the plant site, if needed, for required noise attenuation

Though construction of such a model is outside the scope of this guide, the participation of the inputs and their interactions are discussed in the following subsections to present their influence on the optimum solutions.

6.4.1 Plant Location. After the general location of the plant site has been decided, the specific location of the facilities on the site shall be considered and also the noise emission of the plant. The community requirements and the sensitive noise receptors of the community shall be identified. The location of the plant on the site should be selected so that the noise impact on the surrounding community is minimized.

If a power plant is located within a few hundred feet of a residential area, it can meet some current noise limits only by building it entirely inside a building using only acoustically controlled openings. On the other hand, many plants are located on large plots to provide for cooling towers or lakes, coal and ash storage, and large extra-high voltage (EHV) switchyards. A totally outdoor plant may meet community requirements if located 3000 ft to 4000 ft from the property line. Between these extremes, the ability of a plant to meet the applicable neighborhood noise criteria can only be determined by design calculations.

6.4.2 General Arrangement of Plant. The boiler side of the plant should be located away from the closest property line, if practical, because large fans and their ductwork are major sources of noise. Other sources of noise, such as cooling towers, transformers, gas regulating stations, and car dumpers should be located as far from property lines as practical.

If offices and shops cannot be located remote from the main plant, transmission of noise into these areas should be controlled. Airborne noise transmission may be controlled adequately by using masonry walls between the quieter and noisier parts of the plant. Major process pipes and ducts should not penetrate the walls or be supported on structural elements common to the offices. Any penetration that does exist shall be sealed airtight to prevent a noise leakage between the opening and the pipe. Mechanical equipment should not be located on the roof of a noise-sensitive area or immediately adjacent to the walls.

6.4.3 Building Design. Conventional masonry and double-panel metal siding generally provide adequate noise reduction properties for the control of exterior noise. However, openings such as windows, roof vents, and overhead doors transmit noise to the outside; therefore, if the plant is located close to the property line, the noise emanating from these openings may have to be controlled to achieve the required noise level at the property line. Ventilating louvers with sound-attenuating properties are available. For the control of interior noise, sound-absorption material on the interior surfaces should be considered.

6.4.4 **Design Approaches.** Some items of mechanical and electrical equipment can be specified with regard to sound level performance by referring to industry standard test codes. There are economic considerations in buying quieter equipment.

There are two primary approaches for designing a power plant to meet the desired indoor noise levels. The first could best be described as a single noise-level approach. Here, the increase in sound-pressure levels due to reverberation and multiple sources is estimated. The maximum free-field sound-pressure level from any specific equipment is so specified that the combined sound level does not exceed the OSHA requirement (see [16]). The current eight-hour limit of 90 dB(A) is often specified for all areas of the plant.

The second approach is described as a multinoise-level approach. From the OSHA noise requirement [16], the maximum permissible levels in various areas of the power plant are determined. Allowing for reverberation, the relative contribution of the major sources to the existing/projected noise levels in these areas is estimated. With this information, an individual noise level is specified for each of the major sources. With this approach, some retrofit noise-control measures may be needed, but the total cost of power-plant noise control is minimized.

It is difficult to outline a specific procedure for designing a power plant to meet the exterior noise requirements. The sound field around a power plant depends on its layout (that is, its location and orientation with respect to the surrounding community). The exterior levels may depend on the type of fuel the plant uses, which governs the choice of some of the auxiliaries, and whether or not the plant is fully or partially enclosed. Each plant has to be designed individually.

6.5 Considerations in Equipment Specifications. Sound radiation from most power-plant equipment is complex. Care should be exercised in specifying their sound output to achieve the desired sound criteria. There are some specific items of the equipment which require special consideration.

6.5.1 Forced-Draft Fans. Forced-draft fans are often of such size that testing is difficult. Test conditions and procedures should be discussed and agreed upon with manufacturers during the design phase.

Most centrifugal forced-draft fans operate at constant speed, and output is regulated by means of variable pitch inlet vanes. Axial fans use variable blade pitch for load control. The noise is pronounced at all loads because at low flow the turbulence at the vanes makes up for the reduced noise produced by the fan blades. Since the fan seldom operates at maximum rating, very effective quieting may be achieved by using a variable speed fluid drive.

The noise generated by the fans radiates from the inlet, casing, and duct system. All three sources shall be given consideration for effective noise control.

Depending on the type of building and the fan location, it is sometimes possible to provide a separate fan room with muffled inlets to the room. Reverberant sound buildup inside the room can be reduced by using sound-absorbing material on its walls and ceilings. Provisions have to be made for relieving pressures and maneuvering and transporting the equipment.

An alternate noise-control procedure is to use insulation and lagging, and to install inlet and ducting silencers.

6.5.2 **Primary Air Fans.** If the primary air fans have open inlets, they may have to be enclosed or the housing changed to accommodate inlet ducting and mufflers. An acceptable sound level should be specified by the purchaser since most fan manufacturers can now predict the sound-power level of their equipment for its noisiest operating mode. With this information, the acoustical engineers can determine the dynamic insertion loss (DIL) required for the inlet silencer and whether or not the inlet, outlet, and fan housing require normal thermal insulation or the addition of acoustical insulation. An alternate approach is to enclose an open inlet fan and use silencers with the enclosure.

6.5.3 **Induced-Draft Fans.** Induced-draft fans and boiler gas recirculation fans have ducted inlets and outlets with thermal insulation on the ducts and fan casings. They may however produce excessive noise levels. The specification should state the intent of having the sound-pressure levels no greater than specified at some designated distance from the fan, including the attenuating effect of the duct wall and insulation. Octave-band sound power or pressure levels should be specified in the manufacturers' proposal so the design engineer can evaluate the resulting sound-pressure level.

In addition to the near-field noise the induced-draft fan system may radiate noise from the top of the stack. To control this noise a specification should be adopted that defines either the allowable sound power radiating from the stack or acceptable noise level at some far field such as a distance of 1000 ft.

If the sound-pressure level is specified, an acceptable measurement procedure shall be agreed upon to check compliance.

6.5.4 **Roof and Wall Vent Fans.** Roof and wall vent fans should be specified to meet the octave-band sound-power levels necessary to meet the neighborhood and OSHA criteria. They can be tested in accordance with AMCA STD 300-67 [1].

6.5.5 **Air Conditioning and Ventilating Fans.** Air conditioning and ventilating fans should be specified to meet octave-band sound-power levels that will limit the noise in the occupied area to the noise-control criteria selected for the particular area. They can be tested in accordance with AMCA STD 300-67 [1]. Some sound attentuation is provided by the ductwork, filters, and coils in the ducts.

6.5.6 **Motors.** The free-field sound-pressure levels from electric motors can be specified in accordance with IEEE Std 85-1973 (R 1980) [8].

6.5.7 **Control Valves.** Control valves can produce excessive noise under some operating conditions. Quieter valves with special *quiet* trim can be obtained, or the valve body and adjacent piping can be covered with acoustical insulation to reduce noise. However, the cost of doing this is expensive if it is done for all control valves. A better procedure is to ask the valve supplier for the sound level and spectra of the valves and then provide quieter valves or covering for only those valves and their adjacent piping which are likely to produce excessive sound levels.

6.5.8 **Boiler Feed Pumps.** Boiler feed pumps and their drives can be housed in enclosures. These enclosures may be modules or permanent construction. The many appurtenances on the equipment can make the application of enclosures difficult. Enclosures around each pump and its drive allow maintenance work on one unit without noise exposure from the other pump.

6.5.9 **Main Turbine Generators.** The main turbine generators are well covered with metal enclosures and generally produce noise levels of approximately 95 dB(A) or less in conventional turbine rooms for medium-size turbine generators, without any sound-absorbing materials on the walls or ceiling.

6.5.10 **Burners.** The noise levels due to the burners and the boiler are not excessive because the normal insulation and metal lagging on the boiler walls provide reduction in noise.

6.5.11 **Piping.** Noise associated with fluid flow may be transmitted through pipe walls. Fuel gas piping can be covered with acoustical insulation in addition to the usual antisweat insulation, if it is found to be a noise problem after the plant is in service. The same is true of condensate piping. A high-temperature, high-pressure pipe has heavier walls and heavier thermal insulation but may need acoustical treatment if the velocity and pressure drops are high.

6.5.12 **Cooling Towers.** Blower fans and falling water are the main sources of noise in cooling towers. The manufacturer can provide representative values of sound levels which should be reviewed with regard for neighborhood criteria. Relocating the cooling towers is one of the solutions if a problem exists. Two-speed fan motors can be provided and operated at lower speed under low-load conditions at night where the criteria are more stringent.

6.5.13 **Soot Blowers.** Soot blowers will usually produce noise levels above 90 dB(A). However, their intermittent operation prevents them from overexposing plant personnel. If need be, some attentuation of noise can be achieved through quiet valves, larger piping, and better fitting wall boxes.

6.5.14 **Pulverizers.** Pulverizers and their motors can be noisy. To date, the only noise control that has been applied has been to enclose the pulverizers as a group in one room. It may not be practical to acoustically insulate them.

6.5.15 **Aspirators.** The airflow through opened aspirator doors will usually produce excessive noise levels. The only practical solution is personal hearing protection.

6.5.16 **Safety Valves.** Unmuffled safety valves when operated can produce excessive noise levels in the surrounding community. While their operation is infrequent, in some installations it may still be advisable to provide muffling. Muffling may also be provided for steam blow-off operations.

6.5.17 Transformers. Transformers can be specified with a standard A-weighted sound-level rating, in accordance with NEMA TR1-1980 [9], or have sound levels lower than standard. These lower sound levels are provided at extra cost by the manufacturer by providing larger than normal cores or by double-wall construction. An alternative is to accept the standard sound level for the size and style of the transformer, and then to place the transformer in a full or partial enclosure with or without interior sound-absorptive treatment.

7. Noise-Control Techniques

7.1 Introduction. The selection and application of appropriate noise-control measures for equipment in an existing power plant are a very broad and complex problem. Instrumentation, measurement techniques, analysis of sound spectrum to pinpoint the noise source, matching of the sound spectrum with the sound transmission loss of an acoustical device so that maximum attenuation may be gained, and theoretical analysis of sound in a power plant are discussed in this section.

The extent of noise reduction needed in a power plant is determined from a noise survey of the plant and a comparison of the results with the allowable sound levels. A more detailed survey may be required in the problem areas to determine the cause(s) of excessive noise. General approaches to noise reduction in existing power plants and known engineering or administrative techniques for each are presented in this section. The scientific principles involved and the three major categories of acoustical treatment—source, path, and receiver—are also discussed.

7.2 The Noise Survey

7.2.1 Determination of the Noise-Survey Objective. To develop a proper plant noise-control program, it is essential to determine the noise-control objective. This will generally include two aspects

(1) In-plant noise exposure of plant personnel

(2) Community exposure to plant noise or the noise produced by the plant at the property line.

The present regulations for in-plant personnel exposure follow the guidelines of 90 dB(A) for 8 h of exposure and for higher levels progressively lower exposure time is allowed to the maximum limit of 115 dB(A) for 15 min or less. When the daily noise exposure is composed of two or more periods of noise exposure at different levels, their combined effect shall be considered, rather than the individual effect of each. The use of an equation to determine whether the mixed exposure exceeds the limit value is explained in the Occupational Safety and Health Standards [16], Section 1910.95, Table G.16.

A plant noise-control program will depend very much on the ability to compare plant personnel exposure with equipment noise source sound levels. A combination of both values will determine the plant equipment which is critical for the operators and needs noise control.

Time and motion studies can be made to determine exposure to specific job tasks; by computation the accumulative exposure of the employee to any combination of tasks can be determined.

By examining the actual exposure-time chart in a particular plant, one can select the most economical approach for attenuating various noise sources. In a hypothetical case where the auxiliary operator is overexposed according to the

Table 8
Case I, Cumulative Overexposure

Work Location	Hours/Day C_n	Noise Level at Work Location dB(A)	Allowable Exposure Time Hours/Day T_n	C_n/T_n Noise Rating
Control room	3	< 90	> 8	0
Operating floor	1	96	3.5 min	$\frac{1}{3.5} = 0.286$
Mezzanine floor	1	100	2	$= 0.5$
Boiler area	1	< 90	> 8	0
Ground floor	1	97	3	$= 0.33$
Yard	1	< 90	> 8	0
				Σ 1.12

regulations, it is observed that the turbine-generator and two air compressors (combined) produce the same level of 95 dB(A). If the operator spends the same amount of time inspecting the turbine-generator and the compressors, the most economical step is to attenuate the noise from the two air compressors due to their ease of modification. A similar approach can be taken for other cases where different equipment has approximately the same sound level and the same operator's exposure.

7.2.1.1 Case Histories. Two case histories that illustrate the application of [16], Table G.16 are as follows:

7.2.1.1.1 Case I, Overexposure. This case shows the cumulative exposure of an operator who works throughout the plant and consequently is exposed to various noise levels. See Table 8.

Since the noise rating exceeds unity, the daily exposure is above the permissible limit, although the total exposure at each sound level is below the permissible duration for that level.

7.2.1.1.2 Case II, Underexposure. This case shows the cumulative exposure of an operator who roves in the plant and is exposed to various noise intensities. See Table 9.

Since the noise rating is less than unity, the daily exposure of the operator is within the OSHA permissible limit [16].

7.2.1.2 Community Noise Exposure. Community exposure to plant noise presents a more complex problem than plant personnel exposure. Here the pertinent noise criterion is established by the state or community annoyance criteria.

In any case, before implementing a sound-control program for an existing

Table 9
Case 11, Cumulative Underexposure

Work Location	Hours/Day C_n	Noise Level at Work Location dB(A)	Allowable Exposure Time Hours/Day T_n	C_n/T_n Noise Rating
Control room	7	< 90	> 8	0
Ground floor	20 min	97	3	$\frac{0.333}{3} = 0.111$
Mezzanine floor	20 min	100	2	$\frac{0.333}{2} = 0.167$
Operating floor	20 min	96	3.5 min	$\frac{0.333}{3.5} = 0.095$
				Σ 0.373

station, it is preferable to take daytime and nighttime measurements along the plant perimeter and in the nearest community for weekdays and weekends. These values can be used to check the expected results and to make corrections if necessary.

Some states have promulgated noise codes that require a one-third octave-band analysis to detect prominent discrete tones. An octave-band analysis may not be sufficient for a noise survey in these states.

7.2.2 Selection of the Team and Equipment Required for the Survey. Experience with sound surveys in various plants reveals that a team composed of two is appropriate for conducting a sound survey. While one person takes measurements, the other can record them. Sometimes more information is required, such as taking pictures of the various pieces of equipment, and a third person may be of assistance.

If the time of survey is limited or there is more than one plant to be surveyed, two or three teams can operate simultaneously.

The minimum equipment needed for a thorough plant sound survey consists of

(1) Sound-level meter
(2) Octave-band analyzer
(3) Microphone wind screen
(4) Calibrator for the analyzer and sound-level meter
(5) Sound-level data forms to record measurements

The equipment may be supplemented by a recorder for a detailed study of the critical noise sources. Also, in certain areas there is a need for a narrow-band analyzer to detect prominent discrete tones.

7.2.3 Selection of Measuring Locations and Time of Survey Inside and Around the Plant. The sound survey is based on the exposure of plant personnel, and should concentrate on the major noise sources which are critical. This includes noise sources which may have noise levels of 90 dB(A) and above, such as

(1) Forced draft fans and motors
(2) Boiler feed pumps
(3) Steam dump valves
(4) Pulverizers and turbine-generators

In addition, it is useful to measure noisy areas where plant operators move around and are consequently exposed to noise, such as: compressor building, demineralizer building, and ground floor elevation. The guiding factor in establishing the noise-exposure measuring locations in the plant area should be the path traveled most frequently by one or more persons in the plant, such as the auxiliary operators and the yard persons.

A very critical noise source is the steam dump to the atmosphere which can be released unexpectedly and create a severe noise hazard to plant personnel. This type of noise is particularly offensive in nuclear plants where the discharge to the atmosphere can last for long periods of time and may pose a community annoyance problem. Thus, near-field and far-field sound measurements should be taken from this noise source.

The two most difficult problems in obtaining true sound readings during a plant survey are the isolation of individual pieces of machinery from the other plant equipment and the determination of the influence of room acoustical characteristics on the measured sound levels.

The first problem can be resolved by taking sound measurements during outages. Equipment such as forced-draft fans, compressors, and pumps should be operated alone and can be measured with a good degree of isolation.

During normal plant operation, sound measurements taken at various distances from equipment with a one-third octave-band analyzer will help reveal tones that are often the most predominant noise sources in the area. Acoustical treatment of these tones will contribute much towards an effective sound-control program.

The influence of room acoustics will be evident at higher sound levels in highly reverberant rooms. This fact should be kept in mind when correlating a manufacturer's noise rating of equipment and measurements taken during a field survey. It indicates that any noise-reduction effort shall consider the building acoustics, particularly where a sheet metal or concrete building is used.

Some standards recommend four key-measuring positions in a rectangular array around the plant equipment for sources which are not highly directional. When the source is highly directional, measurements at more than 20 different locations may be required. The preferred height of the microphone above the floor is approximately 1.5 m.

7.2.4 Selection of Measuring Locations and Time of Survey at the Plant Property Line. Measuring points should be established around the plant property and measurements should be taken, preferably during the day and at night.

There are no set rules which establish how many measuring locations are required around the plant perimeter. This depends upon the location and orientation of the plant, local regulations, and the proximity of residential areas. Since wind can upset the sound-level readings, it is good practice to take measurements when there is minimum wind. Wind screens have been devised to reduce microphone sensitivity to wind noise, but their usefulness is limited to velocities below 20 mi/h. A good practice is to carry an anemometer when taking outdoor measurements, thus eliminating the need to estimate wind velocity.

The sound level is affected by atmospheric pressure; therefore, if the atmospheric pressure at the site is significantly different from 760 mm of mercury a correction shall be made to the measurements.

A minimum of A-weighted network and octave-band readings are recommended for indoor and outdoor plant measurements. For most cases a range of 63 Hz−8000 Hz center frequencies for the octave-band spectra will be sufficient. The 16 Hz and 31.5 Hz bands have received attention due to complaints about low-frequency noise from residents bordering industrial sites and should be considered when residents are located close to the plant.

7.2.5 Selection of the Plant Load. Some noise sources produce their highest noise level at a high load and other sources at a low load. For example, a boiler feed pump coupling produced a 4 dB(A) higher sound level at a station load of 550 MW than at 350 MW. Conversely, the turbine control valves produced a 4 dB(A) higher sound level at a load of 350 MW than at a station load of 550 MW.

A sound survey should include measurements taken at different loads, both in-plant and at the boundary line, to pinpoint the highest noise level emanating from a particular piece of equipment. This is important for base load plants that may operate at a variable output because of maintenance problems.

Subsequent acoustical treatment of plant equipment will be based on the most frequently occurring high noise level found during the variable load operation.

7.3 Data Interpretation. Proper interpretation of the measured sound-level data is a significant part of the overall noise-reduction program in an existing power plant. Misinterpretation of the sound-level data can result in an unnecessary expenditure of time and money.

To determine the sound-radiation characteristics of the equipment, its acoustic environment shall be properly understood. See Section 4. Once the sound-level data and the relevant equipment and environment information are obtained, the next step is interpretation of the data.

7.3.1 Data Reduction. Sound data has to be processed and displayed in a manner suitable for interpretation. For source identification and noise-control work, it is advantageous to express the noise-measurement signal in the form of a frequency spectrum because the effect of applying acoustical treatment, vibration reduction, and other kinds of noise control are frequency dependent. The octave-band analysis is a convenient form of a frequency spectrum. See Section 2.

Octave-band analysis is often insufficient for specific noise-source identification and noise-control work because it can only provide a general indication of

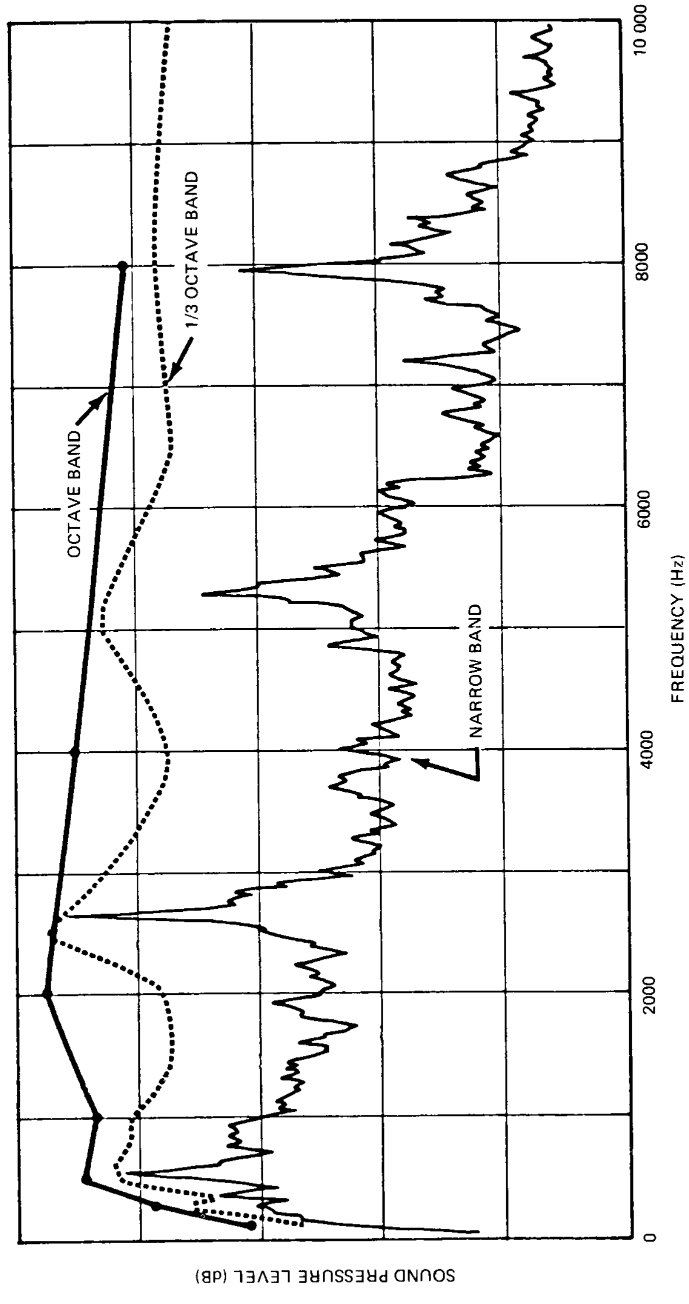


Fig 31
Comparison of Acoustical Data Analyzed with Octave Band, One-Third Octave-Band and Narrow-Band Filters

whether measured noise is a high or low frequency. For specific noise-source identification, narrow-band techniques are available and prove to be more effective. In Fig 31 an example that compares full octave, one-third octave, and narrow-band frequency spectrums analysis is illustrated showing a noise measurement recorded on tape in the vicinity of a power-plant noise source. The signal is compared using octave-band filters, one-third octave-band filters, and a narrow-band filter (15 Hz constant bandwidth).

As the narrow-band analysis illustrates, the noise is made of a small number of pure-tone frequencies. By using a one-third octave-band analyzer there is only a broad indication of high-frequency tones. Octave bands yield no information in this case regarding the presence of pure tones.

Octave band and one-third octave-band spectra can be useful in noise-control work because a broad range of frequencies that need attenuation is easily discernable. In Fig 31, attention should be directed towards attenuation of the noise levels of the frequencies in the range of 500 Hz – 8000 Hz. An enclosure around this noise source should be designed to emphasize midrange and high-frequency noise attenuation.

If one objective is an investigation into the mechanism by which the noise is generated, then the narrow-band spectrum is necessary. By using the appropriate analyzing techniques, pure-tone frequencies can be pinpointed to within 2 Hz.

7.3.2 Corrections to the Measured Sound-Level Background Noise. During a noise survey around an operating machine, it is often difficult to determine the true sound level of the machine because of the background noise in the room. Accurate sound-level measurements can be obtained around a source if the ambient noise can be reduced to a level at which it will not contribute to the measurement. Sound measurements should be made with and without the source operating, if possible (see 4.3). If the difference between these two measurements is 4 dB or greater, the actual sound level of the source alone can be approximated by applying the correction given in Table 10.

Often, station design precludes the isolation of background noise because it is impossible to carry out a steady-state operation of certain noisy power-plant apparatus independent of the operation of other noise sources located in the

Table 10
Correction for Ambient Sound-Pressure Levels

Difference	Decibels (dB)						
Between SPL measured with sound source operating and ambient SPL alone (dB)	4.0	5.0	6.0	7.0	8.0	9.0	10.0
Correction Subtracted from source operating to obtain SPL due to sound source alone (dB)	2.2	1.7	1.3	1.0	0.8	0.6	0.4

vicinity. In such an environment, it is more difficult to interpret sound-level measurements.

There are several techniques which can be used to help identify noise sources in this type of an environment and to provide useful data for noise control studies in the plant.

7.3.2.1 **Near-Field Measurements.** Near-field noise measurements can be very useful in source identification. For free-field measurements the microphone locations should be no closer than the wavelength of the lowest frequency of interest. For 120 Hz, the measurement distance is approximately 10 ft distance from the area. For most noise sources located indoors in a power plant, it is impossible to obtain meaningful data at such a distance from a machine. This is due to the reverberation effects of the room and the proximity of other equipment. One way to reduce the reverberation effect is to make the measurement location close enough so the noise is due to direct radiation from the source. This can be checked by scanning the noise levels while backing straight away from the source. Ideally, the sound level should drop 6 dB for each doubling of distance from the acoustic center of the source. Realistically, this sound-level drop-off may not exceed 3 dB because of the proximity of the floor and vagueness concerning the acoustic center of larger noise sources. For some power-plant sources, measurement locations will be required as close as 0.25 m to 1 m from the surface of the source to reduce the influence of the reverberant field.

7.3.2.2 **Barriers and Partitions.** For smaller rooms or station lower decking where the height is less than 5 m, the background noise can be reduced by the use of temporary portable barriers. A lead curtain, placed between a background noise source and the measurement location, will block the direct transmission path of the external source and improve measurement accuracy. This technique will be most effective where the curtain spans the entire height of the room since reflections around the curtain, by way of the floor and ceiling, will be reduced.

7.3.2.3 **Sound-Level Contours.** In most cases the ultimate goal of a plant noise study is compliance with personnel noise-exposure regulations. To facilitate identifying noisy areas and correlating them with plant personnel exposure, it is often useful to display the data as sound contours using a grid network technique as shown in Fig 32. These contours can also be useful in determining whether administrative controls (rotating plant personnel) are a feasible alternative to engineering controls.

7.3.2.4 **A-Weighted Network.** Another effective tool when considering personnel exposure in data interpretation is the A-weighted network, because personnel exposure levels are based on an A-weighting system. As an example, measurements are taken on the turbine deck of a 350 MW unit, with machinery located as shown in Fig 33. Octave-band analyses of measurements taken at three locations are compared in Fig 34. It is evident that there is a predominant peak at 63 Hz, which dominates the operating floor area, and it appears to be generated from the boiler feed pump and from the turbine-generator.

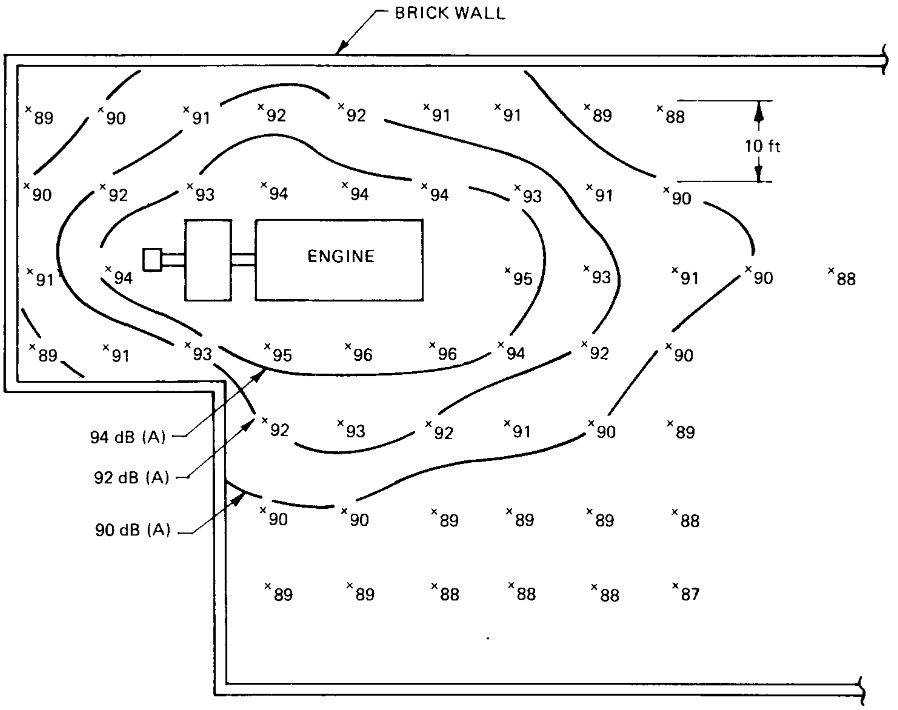


Fig 32
Sound Contours

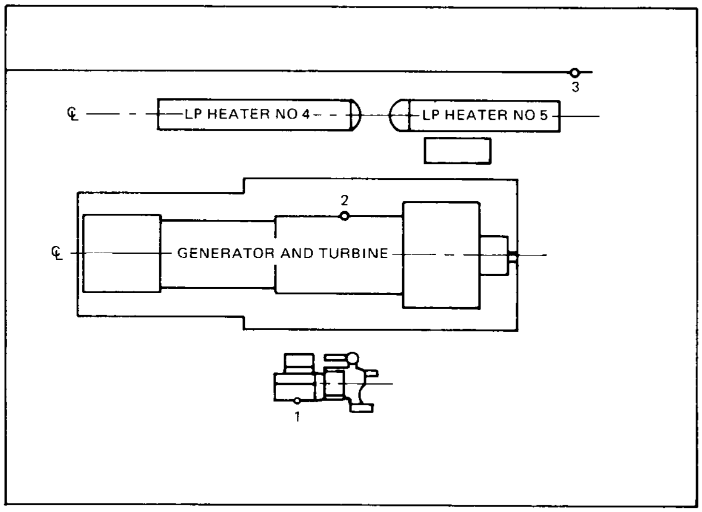
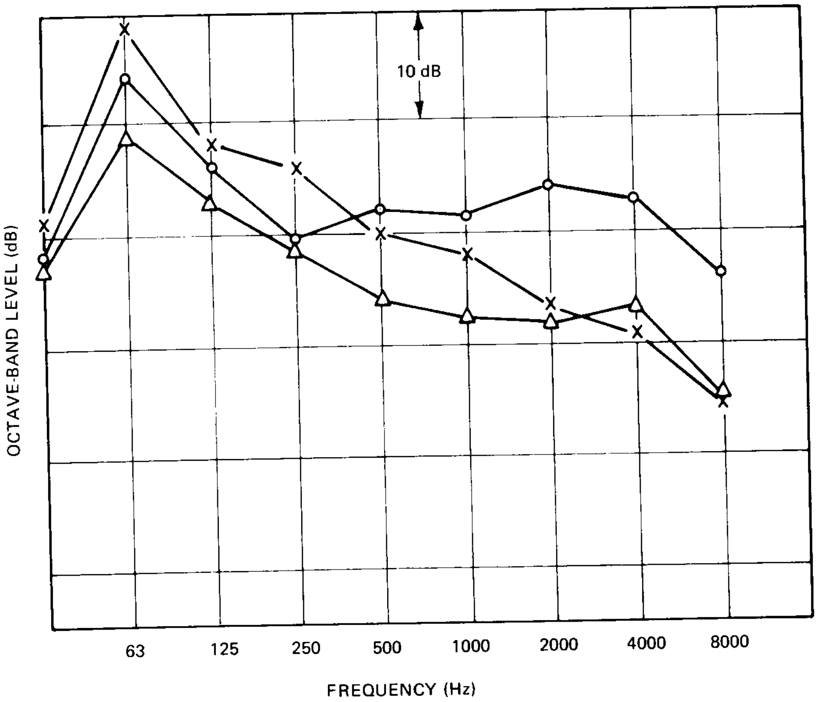


Fig 33
Turbine-Generator and Boiler Feed Pump
Measurements Locations



○ NEAR BOILER FEED PUMP (1)
x NEAR TURBINE-GENERATOR (2)
△ AMBIENT (3)

Fig 34
Octave-Band Analyses at Three Locations on Turbine Deck

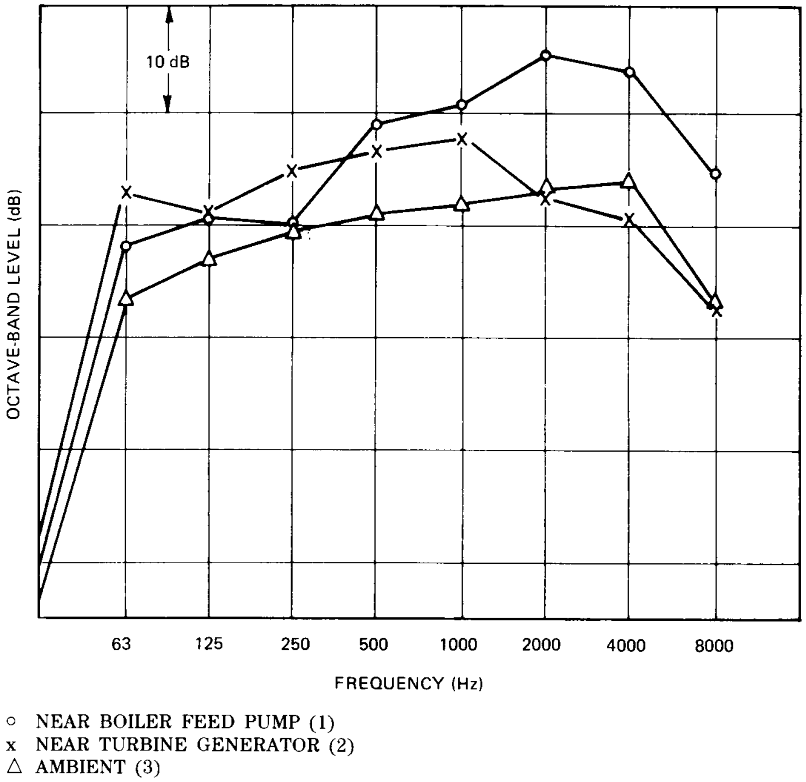


Fig 35
A-Weighted Octave-Band Analyses at Three Locations on Turbine Deck

A closer look at the data however shows that this peak is not of primary concern when the goal is in compliance with personnel noise-exposure regulations. These regulations are concerned with the A-weighting scheme applied at each octave band. Under these criteria it is seen in Fig 35 that high-frequency noise from the boiler feed pump (1000 Hz–8000 Hz) is pushing up the overall A-weighted sound level in the room. To reduce the A-weighted sound level, the boiler feed pump is considered first even though the initial inclination may be to work on the main turbine because of its size.

7.3.2.5 Load Dependent Noise Sources. Noise levels can vary with the load on the unit. Some noise sources produce their highest noise level at a high load and other sources at a low load. For example, a boiler feed pump produced a 4 dB higher sound level at a station load of 550 MW than it did at a

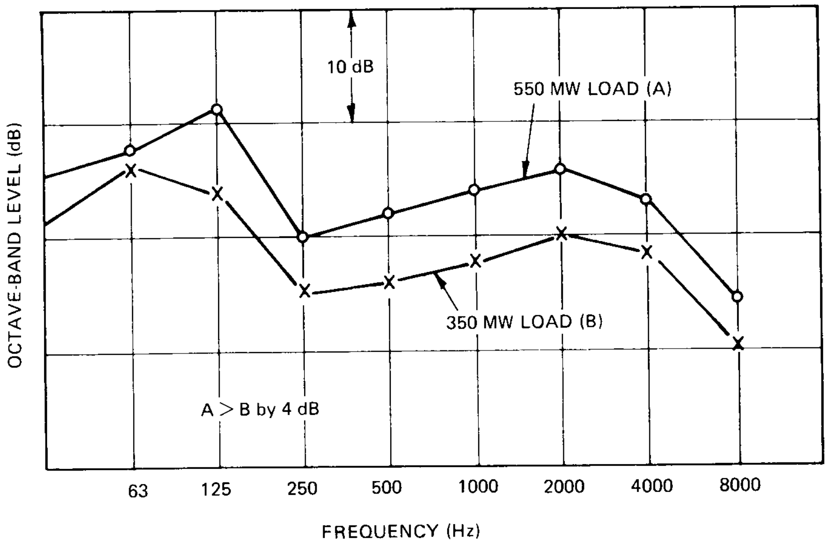


Fig 36
Boiler Feed Pump

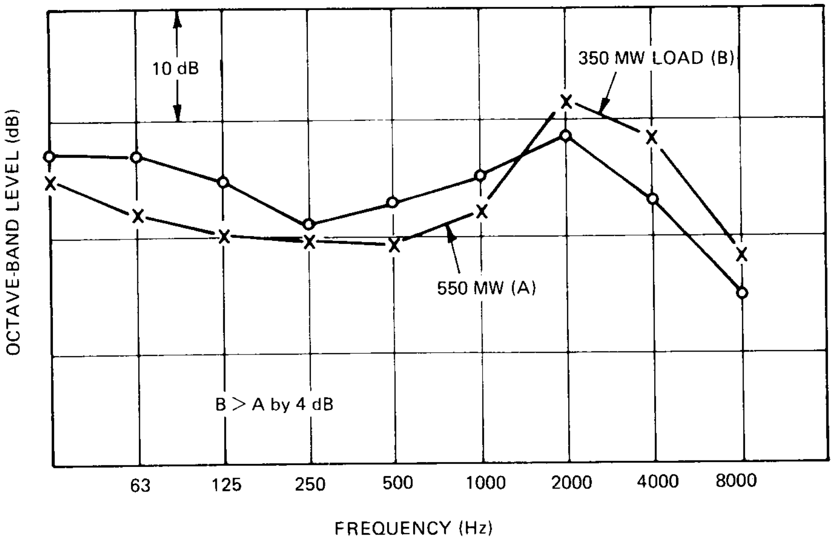


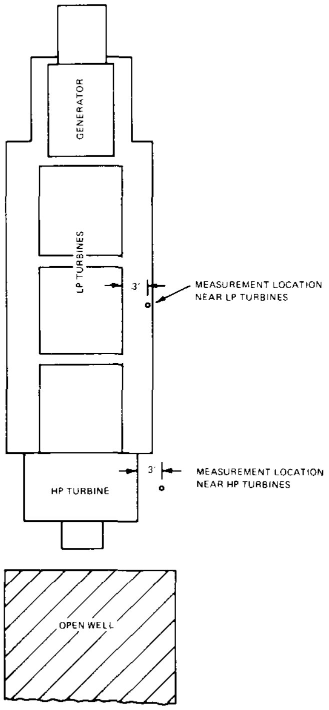
Fig 37
Turbine Control Valve Chest

station load of 350 MW, as shown in Fig 36. Conversely, the turbine-control valve chest produced a 4 dB higher sound level at a load of 350 MW than at a station load of 550 MW, as shown in Fig 37. Thus, a sound survey should include measurements taken at different plant loads to pinpoint the highest noise level emanating from a particular piece of equipment.

7.3.2.6 Narrow-Band Analysis. Since a noise measurement taken in an operational power plant can contain contributions from a number of sources, it is important to be able to locate the source of discrete frequency noise. Narrow-band analysis can be a useful tool in identifying noise sources.

As an example, this technique is used inside a 750 MW plant. An extensive sound survey is conducted on the turbine deck and on lower levels. One measurement location is 3 ft from a valve on a lower plant level. Two other points are on the turbine deck, 3 ft from the turbine, as illustrated in Fig 38. Figure 39 shows data from these three points displayed as narrow-band spectrum plots.

Fig 38
Location of Measuring Points on Turbine Deck



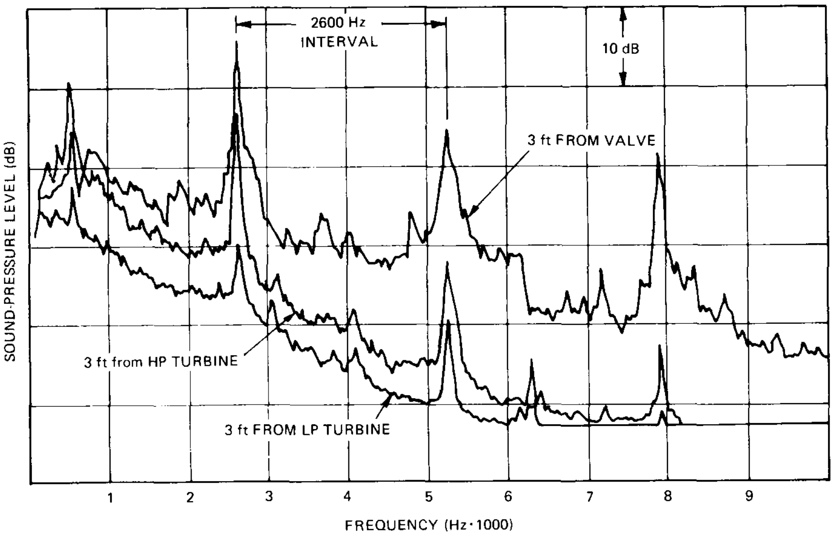


Fig 39
Narrow-Band Spectrum Plots

As can be seen in Fig 39, all three measurement locations show significant peaks at 2600 Hz intervals. For each of these peaks the valve shows consistently higher sound levels. For example, at the 2600 Hz peak, the valve sound level is approximately 9 dB higher than the level associated with the low-pressure turbine.

Since the peaks are of the greatest magnitude in the vicinity of the valve, it is a good indication that the peaks are characteristic of the valve. Even though the valve is located on a lower level, it has a significant influence on the sound levels associated with the main turbine-generator on the turbine deck. This can be accounted for because an open well is located on the high-pressure end of the machine which permits valve noise to emanate up into the turbine hall. The sound spectrum recorded near the low-pressure turbine then shows the smallest peaks at 2600 Hz intervals because it is farthest away from the well. Noise traversing from floor to floor will tend to be a universal problem when attempting to obtain accurate noise measurements because open wells are rather common in power plants.

7.3.3 Data Interpretation of Community Noise. Power-plant noise sources that influence community ambient-noise levels shall be identified. The first step in this process is the collection of noise data at the complaint location or at a position prescribed by local code for the accurate measurement of ambient-noise levels. The next step is the interpretation of this data.

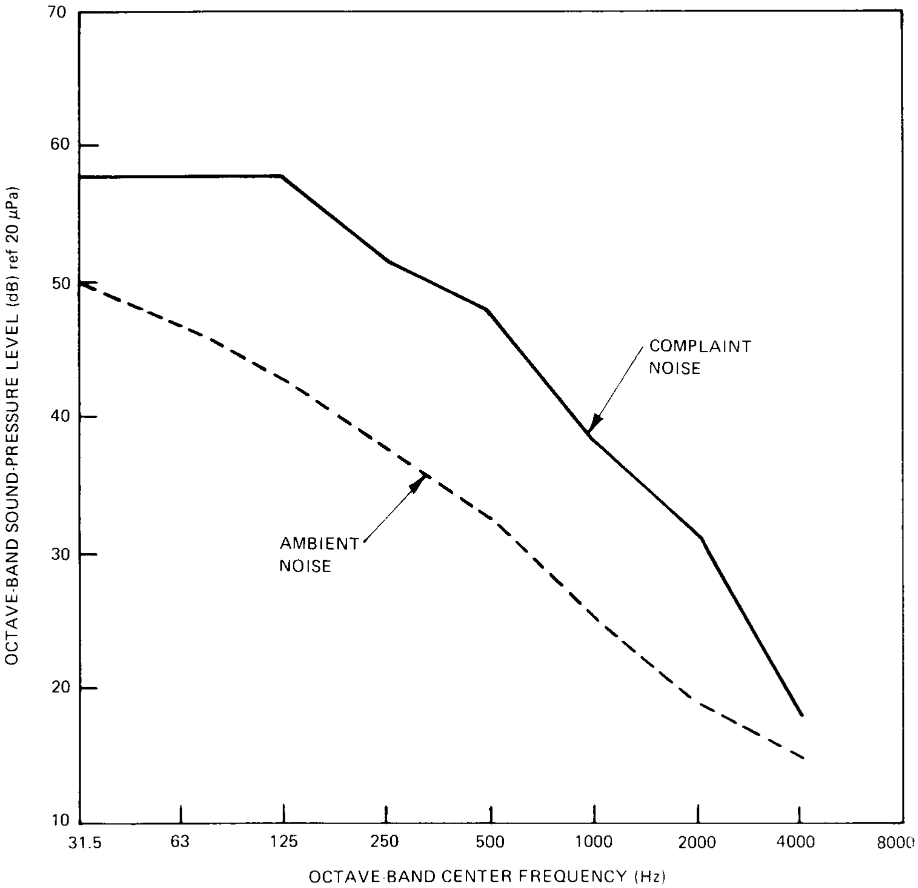


Fig 40
Sound-Pressure Level of Complaint and Residual Ambient Noise as a Function of Frequency in Octave Bands
(Distance from Plant is 2000 ft)

Narrow-band analysis can be a very powerful tool for analyzing community noise. By comparing the results of narrow-band analysis with the sound spectrum of the residual (excluding plant noise source) ambient-noise level, one can pinpoint the major sources. As an example, we will examine the influence of noise generated by induced-draft fans on the ambient-noise level. Figure 40 compares, as a function of frequency in octave bands, the sound-pressure level of the residual ambient level to the sound spectrum during emission of the

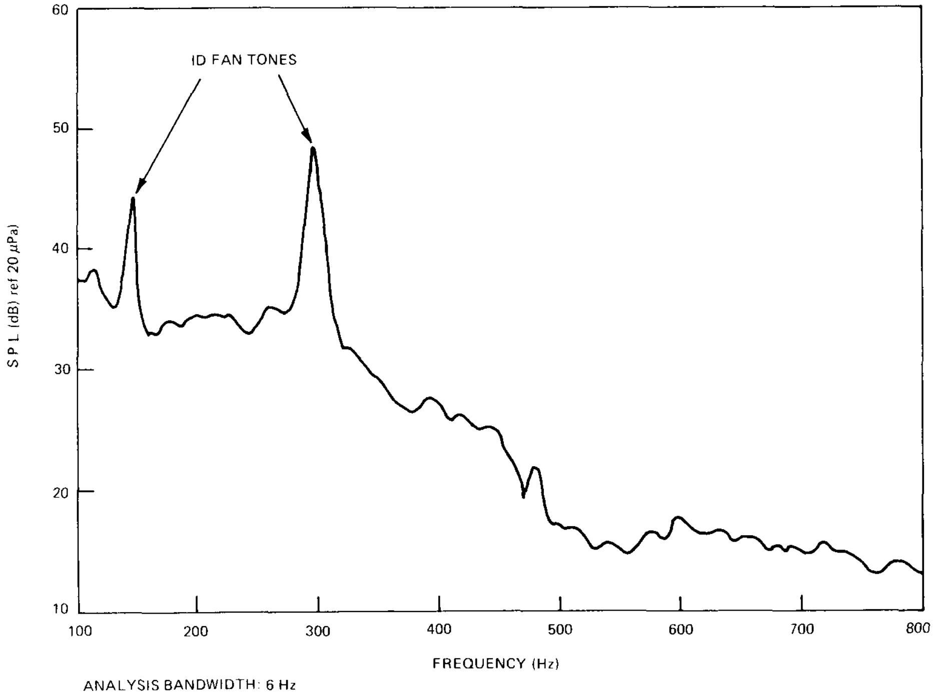


Fig 41
Narrow-Band Analysis of Complaint Noise with Sound-Pressure Level Plotted as a Function of Frequency

objectionable noise. In this example, a complaint was registered at a distance of 2000 ft from the plant. Although one can easily perceive the increase in noise level due to the plant, it is rather difficult to pinpoint the exact source. Figure 41 illustrates a narrow-band analysis (6 Hz bandwidth) of the noise recorded at the location of the complaint during emission of the offensive noise. Prominent tones appear at 150 Hz and 300 Hz indicating the presence of a discrete noise source. Calculations show that the blade-passing frequency of the induced-draft fans matches these tones. Consequently, the fan system shall be acoustically treated.

Studies have shown that power-plant noise levels measured in a community at a distance from the plant may vary even though the noise emission from the plant is steady. These noise levels may vary by as much as 20 dB due to the effects of weather conditions. Wind speed and direction, and snowy or rainy conditions influence noise levels. The variation of background noise caused by

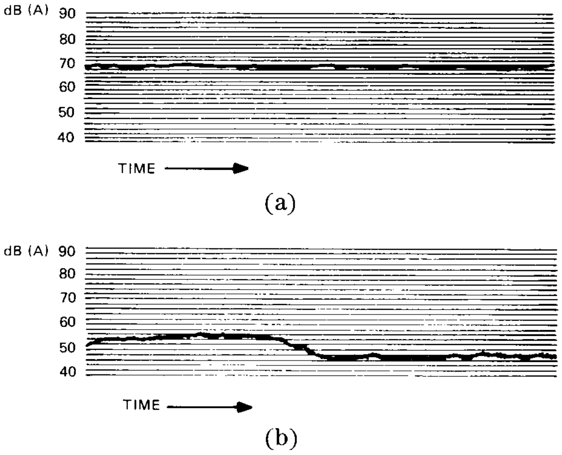


Fig 42
Variation of Background Noise Caused by Meteorological Conditions
(a) Noise Recorded Near Power Plant
(b) Noise Recorded During Same Time Span but in a Residential Area Some Distance from the Plant

meteorological conditions is illustrated in Fig 42(a) and (b). In Fig 42(a) the noise recorded close to the plant is plotted as a function of time, while in Fig 42(b) the noise level is recorded in a nearby residential area as a function of time. Note that while the plant noise is steady, the residential recorded noise varies significantly.

The load level of the power plant can also affect community noise levels. Normally the plant's contribution to community noise levels is greater at higher loads: During nighttime operation, load demands are usually less than daytime output requiring the throttling of valves. Consequently, more pronounced pure tones may be generated.

The type and magnitude of noise on which a complaint is lodged is important. Whether it is a pure tone or a pulsating noise may be indicative of the source. The time and date of the initial complaint should also be noted. Knowing whether the noise repeats at the same time every night or occurs only on weekends is very important in determining the source. The geographical relationship between the power plant and the complaint location is also of importance. For example, a transformer was determined to be the source of complaint even though it was 10 000 ft from the lone complaining resident. The noise emanating from the transformer funneled through valleys, was reflected by the atmosphere, and finally propagated to the general location of the complaint.

If the noise data is statistically analyzed, the percentage of pulsating, tonal, and prominent tone characters should be evaluated as a function of time. Such an analysis can help determine the time during which a narrow-band analysis should be made.

The human ear can play an important role when interpreting community noise. One who is familiar with plant machinery noise may be able to detect a prominent noise generator by listening to the noise at the location of the complaint. This technique should always be supplemented by narrow-band analysis of the noise.

7.4 General Approaches to Noise Reduction. General approaches to noise reduction in existing power plants, known engineering or administrative techniques for each, and the scientific principles involved are presented in this subsection. The three major categories of acoustical treatment, that is, source, path, and receiver are also discussed. As background information, probable sources of noise in a power plant and possible methods of reduction for each are listed. Once the attenuation device has been installed, experience has taught that a follow-up sound survey should be conducted to determine if the selected noise criteria have been met or if rearrangement of the work schedule, an administrative control, shall be invoked to reduce the overall noise exposure of employees.

It is not the intent of this guide to offer a specific solution to a particular noise problem. The methods, procedures, and techniques for this are adequately presented in instruction manuals for the equipment used to measure, record, and plot the noise spectrum or in handbooks and textbooks on noise control. This literature should be consulted for assistance in any theoretical analysis. Furthermore, the determination of the economic feasibility of any stated or implied engineering or administrative control or technique can only be determined by a detailed analysis of each specific noise problem.

7.4.1 Noise-Reduction Methods. Four basic methods are generally employed to reduce noise.

7.4.1.1 Sound Absorption. When sound waves strike soft, porous surfaces, air flows in and out of the minute pores in the material because of the pressure fluctuations produced by sound. Frictional force converts sound energy into heat and tends to reduce the sound level. By definition, the sound-absorbing ability of a surface can be expressed in terms of its absorption coefficient.

The absorbent material on the active side of an enclosure absorbs some of the incident energy and provides a barrier effect without increasing the sound pressures in surrounding areas.

7.4.1.2 Sound Isolation. Sound isolation is the technique of preventing the transmission of sound from a source to a receiver by means of a barrier. The sound attenuation of nonporous materials used in barriers is quite difficult to calculate since it depends on mass, stiffness, and the manner in which a barrier is constructed. The parameter used to define the acoustical power reduction through a nonporous material is the sound transmission loss (TL) measured in decibels. The transmission-loss response of a panel, for example, can be separated into three frequency regions.

7.4.1.2.1 Region 1, Stiffness Controlled and Resonances. At very low frequencies, sound transmission is controlled primarily by panel stiffness. As the frequency increases, a fundamental resonance or damping-controlled region is observed where a number of panel resonances requiring mass and stiffness occur.

7.4.1.2.2 Region 2, Mass Controlled. Above the first few resonances, transmission loss results from the inertia of the panel opposing incident waves and is controlled by panel mass. In the mass-controlled frequency range of a panel, the transmission loss is proportional to the mass of the panel and increases at approximately 6 dB per octave. Doubling the surface weight (weight per unit of thickness) of the panel material can increase the sound transmission loss from 5 dB to 6 dB.

7.4.1.2.3 Region 3, Wave Coincidence Controlled. The mass controlled region of the panel may extend from two or three times the lowest resonance frequency to the *critical frequency*. The critical frequency is the frequency at which the bending wavelength of the panel and the acoustical wavelength of the radiated sound wave from the panel are identical. Above the critical frequency, the panel stiffness is again important in determining the transmission loss. Ribbed panels are often used to construct large ducts. The analysis of the transmission loss of such panels is complicated by the fact that both the bending stiffness and the average mass of the composite panel are affected. In general, the resonant frequencies are shifted, and if the ribs occupy a significant area of the panel, the transmission loss of the ribbed panel is higher.

7.4.1.3 Vibration Isolation. Vibration isolation is a reduction in the capacity of a system to respond to an excitation and is attained by the use of a resilient support. Relative to audible noise control, vibration isolation is useful for reducing the transmission of energy from sources of vibration, such as pumps or motors, into attached structures which reradiate the energy as airborne noise.

An isolation system usually consists of several vibration isolators (resilient supports) installed between a vibration source and the attached structures. The isolators may be constructed of metallic springs, elastomeric elements (for example, rubber, silicone, and urethane), pad-type elements (for example, cork, felt, and fiberglass), or flexible structure elements (for example, cantilever beams acting in flexure).

Care should be exercised in the design and installation of vibration-isolated equipment. Rigid connections for piping and electrical conduits shall be avoided to prevent energy transmission through secondary paths. Isolation of sources having the center of gravity higher than the isolation support system may require stabilizers to prevent rocking, or possibly overturning, due to horizontal forces.

7.4.1.4 Vibration Damping. Vibration damping can be used to reduce the amplitude of the offending frequency and should be considered prior to installing the equipment.

Vibration damping is the dissipation of energy with time or distance. Relative to audible noise control, damping may be useful for reducing noise radiated from vibrating structures by reducing the vibration amplitude of forced resonances, speeding up the decay of free vibrations produced by impacts on the structure, and attenuating structure-borne waves propagated throughout the structure.

The most effective use of damping for controlling audible noise is in its application to large, thin metallic panels which are easily excited and are efficient radiators of airborne noise. There are three basic methods of applying damping treatments to such panels: surface damping, constrained layer damping, and spaced layer damping. In all three cases, damping is achieved through cyclic deformation of a high-loss *viscoelastic* material whose performance depends critically on its temperature and the frequency of the vibration.

7.4.1.4.1 Surface damping utilizes the viscoelastic material applied directly to the surface of the vibrating panel. These materials are available in solid sheet form, which may be applied with an adhesive, and in liquid form, which may be applied with a brush, trowel, spray gun, or roller. A near-optimum thickness for the viscoelastic layer is approximately 1.5 times the thickness of the panel to be damped. If vibrational amplitudes are still high after the use of this thickness, other noise-control procedures should be investigated.

7.4.1.4.2 Constrained layer damping utilizes the viscoelastic material sandwiched between the panel to be treated and an added rigid sheet. Constrained layer damping dissipates energy primarily through shear deformation of the material, whereas surface damping dissipates energy primarily through extensional deformation of the viscoelastic material.

Spaced layer damping utilizes the viscoelastic material spaced away from the surface to be damped by a spacing layer. The spacing layer should ideally not store any energy, be rigid and shear, and be constructed so that elements in the spacing layer normal to the panel to be damped remain normal during panel vibration (honeycomb structures tend to behave in this manner when used as spacing layers). The spaced viscoelastic layer dissipates energy primarily through extensional deformation similar to the surface-damping treatment. However, the spacing layer tends to increase the energy dissipation due to increased extensional deformation. Spaced layer damping is more applicable to heavier and stiffer structures than the other methods.

7.4.2 Categories for Noise-Reduction Treatments. Noise abatement techniques may be categorized as source, path, or receiver treatments. Any treatment for sound attenuation may employ one or more of the four basic methods for noise reduction.

7.4.2.1 Source Treatment. As a general rule, it is best to quiet equipment by some form of source treatment. In some cases, the actual sound level generated by a piece of equipment can be reduced by internal design. For example, power transformers are designed to meet noise-level criteria specified by

NEMA TR1-1980[9] but lower noise-level transformers can be obtained from the manufacturer at a higher initial price. In many control valve applications, the valve body can be designed to accommodate various forms of special trim which reduce noise by controlled multipath expansion and therefore reduce velocity and noise.

Treatment of internal equipment noise generated by friction, impact, turbulence, imbalance of rotating parts, fluid cavitation, pressure drops, mass flow, magnetic attraction, or other motions due to change in velocity of moving parts is most effectively done and generally more economical during preliminary design, before the new or modified machine leaves the drawing board. For existing power-plant equipment, changing to a quieter design by modification or retrofit, or by replacing partially depreciated equipment with new *quiet* equipment, if available, is often very expensive, inconvenient, and sometimes impossible from a practical viewpoint.

7.4.2.2 Path Treatment. Sometimes it is impossible to reduce sound levels of high horsepower and high-speed machinery to acceptable levels by internal design changes alone. Compromises on size, weight, accessibility for maintenance, and convenience in operation may also fail to reduce noise to acceptable levels. In this case, additional sound control will be necessary after the machine has been built. In general, any method which is prescribed to reduce noise between the origin or source and a microphone or the ear of the listener (receiver) is defined as *path* treatment.

Some of the main devices which are being used for path treatment are

(1) Acoustical enclosures
(2) Mufflers
(3) Plenums
(4) Lagging
(5) Acoustical shields or barriers
(6) Absorbent coatings and ceiling septums
(7) Vibration isolation
(8) Vibration damping
(9) Various combinations of these devices

Selection and usage of a particular type of path treatment is often a difficult task and depends on the sound spectrum being radiated from the source and the nature of the path it takes to the ear of the receiver.

7.4.2.2.1 Acoustical Enclosures. An acoustical enclosure may consist of a single solid, laminated, multilayer, or sandwich-type panel which has a solid outer *shell,* space for one or more fibrous or *limp mass* inner fillers, and an absorbent liner with a *retainer* for holding the liner or filler in place. The liner may consist of a perforated inner sheet which has sufficient strength to be self-supporting or it may be a soft, porous material which adheres to or is attached to the existing structure.

For maximum attenuation, the shell that blocks the transmission of noise shall be nearly airtight with a sealant or flexible material used around all piping, electrical, or other penetrations to minimize noise leaks. Thinner shells may be used, particularly on attached enclosures, provided they are sufficiently damped and stiffened so that they will not reradiate noise as the result of mechanical or airborne excitations. Internal damping materials are particularly useful in the fundamental resonance frequency range.

Acoustical enclosures often have fair insulating characteristics and tend to trap heat which shall be dissipated by some mechanism to prevent overheating. Since they are nearly airtight, or should be, to be effective sound attenuators, some form of ventilation, forced or natural, shall be provided. This is accomplished with fans, coupled with mufflers, and acoustical louvers.

7.4.2.2.2 Mufflers (Silencers). Mufflers permit the flow of the fluid while confining noise within the enclosure or piece of equipment. Mufflers are usually divided into two major categories, reactive (reflective) and dissipative (absorptive). A purely reactive muffler does not depend on the presence of sound-absorbing material but utilizes reflective characteristics and the attenuation properties of conical connectors, expansion chambers, side-branch resonators, and tail pipes to accomplish sound reduction. The purely reactive muffler is seldom applied in broad-band noise applications due to its inherent narrow-band performance and the inherent pass-band characteristics of the design. Where relative broad-band performance is obtained, as with the snubber-type muffler, the category is best described as low reactive.

Dissipative mufflers have relatively broad-band noise-reduction characteristics and are usually applied to noise-control problems associated with wide-band noise spectra such as fans, centrifugal compressors, jet engines, and gas turbines. They are also used where a narrow-band noise predominates, but the frequency varies because of a wide range of operating conditions.

Acoustical features of reactive and absorptive mufflers may be combined to cover the entire audible frequency range of 20 Hz–20 000 Hz.

Mufflers are available from several suppliers who can be of valuable assistance in the selection of the most suitable muffler type and size for a given application, if provided with the following parameters:

(1) Type of application and service
(2) Noise spectrum
(3) Required insertion loss, dB
(4) Properties of fluid (mass flow rate, temperature, and density)
(5) Allowable pressure drop
(6) Maximum size and weight

After a muffler is sized, it shall be incorporated in the overall system design in such a manner as to prevent regeneration of noise by excessive velocity or turbulence.

7.4.2.2.3 Plenums. A plenum chamber is a combination muffler and enclosure generally used to admit low-velocity cooling and combustion air without leaking excessive noise.

An unlined duct or pipe is an almost perfect wave guide and there is no attenuation due to spherical divergence since the wave cannot spread. A perfect acoustical transmission line has a constant cross section and therefore has the same acoustical impedance throughout its length. To block the transmission of waves, the acoustical impedance of a pipe shall be changed. This can be done by changing the cross-sectional area, inserting a perforated screen, branching into a tank, or using a plenum chamber.

7.4.2.2.4 **Lagging.** Lagging is the action of covering something with a material. In power-plant equipment, the main purpose of this covering is to reduce the transmission of heat or sound waves, or both, from piping, ducting, furnaces, equipment boundaries, etc. Lagging is quite useful in reducing the noise radiated from piping and ducting. It differs from an enclosure in that it is applied directly to the radiating surface. Acoustical lagging usually consists of one or more layers of a porous material combined with a nonporous outer shell. Porous fillers such as glass, fiber, or mineral wool support the protective outer shell, damp it, and isolate it from direct contact with the vibrating source. A layer of lead or lead-coated vinyl may be used as the protective outer shell or beneath the outer shell to provide a *limp-mass* layer and increase the lagging's inertia opposing incident sound waves. The thickness of the outer metal shell becomes a trade-off between the sound transmission loss attained and the problems encountered during field fabrication.

7.4.2.2.5 **Acoustical Shields or Barriers.** The propagation of noise between a source and the receiver can also be reduced by using an acoustical shield or barrier. Noise reduction is limited by diffraction of sound waves around the barrier, with its effect being greater at lower frequencies. The basic reduction attained from a barrier depends on its height, the distance from source to barrier and barrier to receiver, the wave length of sound at a particular frequency, and the presence of other reflecting surfaces.

The distance from the barrier to the receiver should be much greater than the distance from the source to the barrier. The general rule used in placing barriers is to put them as close to the source or the receiver as possible and to make them as wide and high as possible to provide the longest possible path.

Baffles, curtains, and three-sided partial enclosures—with or without a top—tend to redirect sound and are most effective in reducing high-frequency, short wavelength sound.

Barriers without absorbent material on the source side should be used with caution. They serve the function of changing the radiation pattern of sound which may have the undesirable by-product of increasing the sound-pressure level at some other point.

7.4.2.2.6 **Absorbent Coatings and Ceiling Septums.** Absorbent coatings and the soft, porous active layer of a paneled enclosure reduce reverberant noise within a room. Absorbents convert to heat only the energy that reaches them. They may reduce sound levels as much as 3 dB–5 dB.

A ceiling septum reduces the reverberant noise and the noise transmitted to the floor above.

7.4.2.2.7 **Receiver Treatment.** Reducing noise by receiver treatment or personal protection is generally not considered to be an engineering method of noise control, but it is a very important part of an overall noise-control program.

For existing power plants, it may be the only economically feasible method of employee protection from intermittent exposure to high noise levels.

Personal protection devices consist of ear plugs of various types, ear muffs, or earphones. Properly fitted ear plugs and muffs can provide up to 25 dB attenuation in some frequency bands.

Another personal protection measure which may infringe on path treatment instead of receiver treatment is to enclose the operator(s) of a piece of equipment in an air-conditioned enclosure, such as a cab or booth. A three-sided partial enclosure with a top and windows for viewing is an effective technique.

After source and path treatment, the two major categories for the engineering methods of noise control, have proven to be unfeasible or unpracticable, the next step in a noise-control program is administrative controls. See 7.7.

7.5 Selection of Noise Reduction Schemes for Different Noise Sources. The acoustical engineer selects the most appropriate attenuation device for a specific area, room, or individual piece of equipment after identifying the noise source by analysis of data obtained during a sound-level survey, determining acceptable noise criteria, and reviewing probable attenuation techniques. The most logical device from a noise-reduction viewpoint may not be economically feasible or practical from a field-erection standpoint. The space available in an existing plant, multiple penetrations (such as pipes, conduits, and cable trays) that cannot be sealed airtight, the risk of overheating existing equipment, and any acoustical device shall be partly removed or disassembled for inspection and periodic maintenance of equipment are a few of the design parameters that often prevent use of the most logical acoustical device. All of the design parameters should be considered in the selection of any noise attenuation device.

The attenuation techniques listed in Table 11 may be used as a guide in selecting a device for the reduction of noise from equipment of like size and type, and similarly located and mounted in a system where projected field use is the same.

Table 11
Possible Sources of Noise and Possible Methods of Noise Reduction

1. Air Equipment
    a. Compressors — acoustical block or paneled enclosure
        Air intake and discharge — mufflers
        Intake and discharge piping — lagging
        Relief valves and vents — quiet trim or in-line silencers
    b. Ejectors — lagging, mufflers
    c. Open-air jets — quiet trim valves or mufflers
2. Boilers
    a. Aspirated doors — wear hearing protectors when doors are opened
3. Coal Handling Equipment
    a. Car shakers — provide acoustical booth for operator
    b. Coal crushers — enclosure and vibration isolators
    c. Feeder vibrators — enclosure
    d. Mills or pulverizers — enclosure

(Continued on Page 117)

Table 11 (*Continued*)
Possible Sources of Noise and Possible Methods of Noise Reduction

4. Engines
   a. Emergency power diesel generator — enclosure
      Intake and exhaust — muffler
      Cooling fan — shroud intake or exhaust, or both
   b. Fire pump diesel — same as above (This is an intermittent duty item.)

5. Electrical Equipment
   a. Circuit breakers — mufflers
   b. Motors (large) — enclosure and mufflers
   c. Transformers — barrier or enclosure (Install in vault with sound absorption.)

6. Fans
   a. Forced draft — enclosure, lagging, or duct silencers
      i. *Open Inlet.* Enclosure or acoustical plenum with or without inlet silencers. Configuration with fans on base slab and inlet ducted from opening near top of boiler may not require inlet silencers. Air preheater and boiler act as noise sink for airborne noise traversing the length of the duct. Lagging reduces radiated noise.
      ii. *Closed Inlet.* Lagging or lagging and duct silencers, or both
   b. Induced draft — lagging (A silencer may be required to reduce tonal noise.)
   c. Gas recirculating — lagging
   d. Primary air — lagging and inlet and discharge silencers (Use enclosure if inlets are open.)
   e. Ventilating air — louvers and silencers

7. Precipitators
   a. Rapper and vibrators — lagging and enclosures

8. Pumps
   a. Ash sluice — lagging and enclosure
   b. Boiler feed — located operating floor — enclosure
      Located base slab — numerous penetrations and maintenance costs affect economic feasibility of an enclosure in this case.
   c. Condensate — lagging and enclosure
   d. Condensate booster — lagging and enclosure
   e. Fire — lagging and enclosure

9. Soot Blowers
   a. Air flow — redesign of some of piping and valves which contribute to noise. Closer fitting wall box on furnace.
   b. Steam flow — same as above
   c. Air motor drive — exhaust mufflers

10. Turbogenerators
    a. Bearings — walk-in lagging and enclosure
    b. Exciter brushes — lagging and enclosure
    c. Exciter gears — enclosure
    d. Exciter vent fans — install silencers in air inlet and discharge
    e. LP turbine casing — seal openings in existing housing
    f. Steam control valves — insulate with fiberglass and impervious covering
    g. Reduction gearing — enclosure
    h. Steam piping — reduce velocity, reduce number of bends and install acoustical/thermal insulation.

11. Vacuum System
    a. Cleaners — lagging and enclosure
    b. Ejectors — lagging
    c. Pumps — lagging and enclosure

(Continued on Page 118)

Table 11 (*Continued*)
Possible Sources of Noise and Possible Methods of Noise Reduction

12. Valves

NOTE: Quiet trim is usually limited to replacement items or new facilities.

- a. Pressure reducing — quiet trim, multiple step pressure reduction, in-line silencers, lagging, heavier wall pipe, enclosures
- b. Pressure relief — quiet trim, silencers, bell mouth, or tapered exit
- c. Steam dump — quiet trim, silencer, heavier wall pipe, and lagging
- d. Vent — quiet trim and silencers and plenums

13. Miscellaneous

- a. Piping — heavier wall and lagging. Delete discontinuities such as sharp bends, and large divergent sections. Provide quiet valves or silencers for atmospheric releases. Lower velocity.
- b. Ducting — lagging, turning vanes, addition of stiffeners, and heavier wall thickness
- c. Intakes — silencer and louvers
- d. Vents — silencers, quiet trim valves, and plenums
- e. Housing and panels — lag or damp emitting housing and panels
- f. Air and steam leaks — improve maintenance to minimize leaks

7.6 Follow-Up Sound Survey to Evaluate Noise-Control Measures. When installation or field erection of the attenuation device has been completed, a follow-up sound survey should be made to determine if the selected criteria have been met. If noise levels are still excessive, reexamine the methods of noise analysis and the attenuation device to determine if excessive noise levels can be traced to

(1) Failure to identify the true noise source in the original or detailed survey

(2) Presence of a secondary source originally masked by the louder source

(3) Inferior materials, improper fabrication or installation of the noise-control device, or a combination of these

(4) Failure to use the noisiest operating mode as the design basis

(5) Improper selection or design of the attenuation device

Based on this evaluation, modify the existing device or add additional attenuation to achieve the selected criteria.

It shall be remembered that two noise problems will rarely be exactly the same, since each piece of equipment has its own noise signature. Comparison of the data obtained during a follow-up survey and a previous survey will show that measured noise reduction usually reflects the untreated noise from untreated portions of the same source or from adjacent sources rather than the absolute performance of the control measure. However, the experience and knowledge gained by this evaluation may be used to improve the performance and reduce the cost of future ambient noise projects, particularly in the design of new plants.

7.7 Administrative Control. Administrative control involves rearrangement of work schedules to reduce the overall noise exposure of employees. The implementation of administrative control can prove to be as costly as the application of engineering control. In some cases, labor union contracts may have to be rewritten before applying administrative control.

For newer power plants, where most employees are not stationed at a particular operator location, the actual noise exposure of employees may be difficult to estimate. The determination of typical daily exposures requires

(1) Knowledge of the industry

(2) Interviews with plant personnel to determine their work patterns and stations

(3) A time and motion study using a sound-level meter and timing device or personal noise dosimeter

Taking into account the mixed exposure times, it will be found that it is not essential to reduce all equipment noise levels to 90 dB(A) to comply with current OSHA exposure criteria.

7.8 Summary. The basic methods and techniques for noise reduction (see 7.4) may be used not only in and around power plants, but also in and around other industrial plants to produce a quieter environment.

Under engineering control for noise abatement, the two major categories of treatment, *source* and *path*, have been discussed and the conclusion drawn that source treatment is generally the most economical approach to noise reduction. However, from the standpoint of an overall noise-control program, *receiver* treatment through the application of administrative control is quite important and shall be considered.

Numerous probable sources of noise and known attenuation techniques for each have been listed and discussed. Experience has shown that once a noise attenuation method has been employed, a follow-up sound-level survey should be made to ascertain its effectiveness. Analysis of the follow-up data will aid in the continuing search for more economical methods, techniques, and devices for noise reduction in power plants.

The application of known techniques, the analysis and study of the results achieved, and the reapplication of modified or improved methods to similar noise problems is a process which shall be continued if the noise problems are to be resolved effectively.

8. Noise-Control Design Approach

8.1 Introduction. The noise-emission characteristics of various power-plant equipment and possible noise-control procedures that can be utilized to reduce these emissions have been discussed in Sections 5, 6, and 7. Although most of the techniques can be applied as retrofit solutions to noise problems after the plant becomes operational, it will generally be found that such retrofit will be more expensive, more difficult to install, interfere more with equipment operation and maintenance, and be less effective acoustically than if planned and implemented in the original plant design. Planning for noise control in the design stages rather than attempting retrofit solutions to problems also allows for the important options of either purchasing equipment that incorporates available low noise design features or using alternate lower noise equipment types.

An effective design noise-control program that will also be as economical as possible requires much initial planning and coordination of many interrelated design aspects throughout the design process. It should not be attempted without first establishing noise-control design objectives. These should not only define any numerical noise limits that are not to be exceeded but should also set forth a general policy to be followed for making noise-control decisions in situations where numerical limits cannot logically be defined. For example, firm numerical design limits apply in the presence of environmental noise regulations that set maximum permissible noise levels. In other instances, it may be more desirable to establish a general design policy instead of setting firm limits on noise levels. For example, the OSHA regulations are not based on the actual noise level to which employees may be exposed, but are based on the accumulated noise exposure dose. OSHA does however limit the maximum permissible continuous noise level to 115 dB(A) for any length of exposure and the maximum permissible impulse noise level to 140 dB(A). It may therefore be a more desirable design approach to establish a general policy regarding compliance with these regulations which takes into account design cost and the influence of employee exposure durations in certain plant locations rather than establishing a firm design limit, such as 90 dB(A).

This section, while suggesting general considerations to be included in developing noise-control design objectives, does not recommend specific numerical limits. Legal limits are addressed in Section 3. In the absence of legal restrictions, subjective evaluations of noise on people and the influence of noise on human activity (for example, sleep and speech) shall be relied upon in determining desirable noise-control design goals. Considerable work is left to be done in correlating these effects with power-plant noise. Until this work advances further, it is advisable to maintain contact with the open literature in trying to rate acceptable power-plant noise levels against these effects.

8.2 A Process for Establishing Practical Noise-Control Design Objectives. Noise-control design objectives should address the two major categories of environmental noise (that is, noise emitted beyond the plant property line) and in-plant noise (that is, noise within the property line). For either of these two concerns, the development of realistic design objectives can follow a logical four-step process

(1) Establish *ideal* noise-control objectives

(2) Determine conceptual noise-control procedures that are probable to achieve the ideal noise-control objectives

(3) Evaluate the conceptual noise-control procedures and determine those procedures that are feasible and, if required, will be implemented

(4) Determine realistic design noise-control objectives based upon the limitations established by design procedures considered not feasible

The following subsections outline what is involved in each of the four steps:

8.2.1 Ideal Noise-Control Design Objectives. The purpose of developing *ideal* noise-control design objectives is to generate a baseline for preliminary evaluation of the impact of designing for noise control. These objectives set forth numerical values with which to compare expected equipment noise emissions and determine probable design noise-control procedures. The required design procedures are conceptual in nature at this point and generally do not consider feasibility from aspects other than acoustical. They do however serve the important functions of allowing those responsible for making design decisions to grasp the potential impact of noise control on the project and providing the basis for evaluating the feasibility of potential noise-control/design features from other aspects, such as cost, safety, maintenance, and operations.

Ideal noise-control design objectives are numerical limits that are selected to ensure that the new power plant will not experience any noise problems at all; neither from the standpoint of legal requirements nor from the standpoint of annoyance. Ideal environmental design objectives should consider

8.2.1.1 Legal Requirements. The status of noise regulations that may affect the new plant should be thoroughly investigated at federal, state, county, and municipal levels (see Section 3). Ideal design goals should be based upon existing noise regulations and on regulations that either have been proposed or are likely to be proposed by governmental bodies.

8.2.1.2 Interference with Activities. Plant noise emissions should not interfere with activities of surrounding neighbors. Major consideration should be given to noise-sensitive activities such as sleeping, conversing, or activities requiring concentration (for example, studying). In determining normal activities which will be conducted around the new site, possible land use changes around the site should be considered.

8.2.1.3 Ambient Noise Increases. Neighbors, particularly those in residential areas, will look upon excessive increases in ambient noise levels as a pollutant that degrades the value and full enjoyment of their property. Ambient noise surveys should always be taken around a new plant site that has existing neighbors and these results should be weighed in setting ideal noise design objectives. This is also important if there is a possibility of new neighbors moving in prior to the completion and operation of the plant.

Ideal in-plant noise design objectives should consider

(1) *OSHA Regulations*. These regulations set limits on employee noise-exposure doses and not on the actual noise-exposure level. Ideal noise design goals should establish design levels so that these regulations are met without the use of work scheduling for compliance. Under the existing regulations, the design level is 90 dB(A); however, there are indications that this may be reduced to at least 85 dB(A) and will apply, retroactively, to all plants.

(2) *Office Comfort and Speech Communication*. Offices, control rooms, and some plant areas such as workshops should have ideal design levels established from the standpoint of comfort and good speech communication. Many references address these goals such as noise criteria (NC) curves.

8.2.2 Conceptual Noise-Control Design Procedures. Having established noise-control design objectives that will ensure no noise problems with the completed plant (that is, the *ideal* objectives), the design procedures required to achieve these goals should be determined. This will require a comparison between anticipated noise emission levels of major plant equipment and the ideal design noise-control objectives. At this point, these procedures should be conceptual in nature but should be accurate enough to reflect probable major design impacts based upon realistic expectations of the noise emissions of the equipment and the effectiveness of design procedures in reducing these emissions. The design noise-control procedures which should be considered are given in Section 6. Conservative estimates of the noise emissions of major equipment should be used based on past experience with similar or identical equipment and on manufacturers' information, if available.

8.2.3 Feasible Noise-Control Design Procedures. The ideal noise-control design objectives and the conceptual design procedures described in 8.2.2 are developed without concern for design aspects other than acoustical. With the exception of applicable legal limits that specify maximum permissible noise levels, these objectives should be tempered by consideration of other design aspects. This consideration should involve individuals responsible for management, safety, operations, maintenance, and engineering aspects of the project to ensure that noise-control design procedures implemented are feasible and compatible in all respects with the new plant.

The cost aspects of noise control will be of particular significance. In evaluating the cost feasibility of implementing noise-control procedures, it is important to consider that there are also costs associated with not using noise control to reduce the noise levels. Some of these costs may include hearing loss compensation claims, possible increased insurance rates, and lower employee productivity due to higher noise levels. The costs of not reducing noise levels in the design will continue throughout the life of the new plant and are impossible to estimate at this time.

8.2.4 Practical Noise-Control Design Objectives. Some of the design procedures required to achieve the ideal noise-control objectives will not be feasible from the standpoint of cost, difficulty of maintenance, or other important considerations. This will establish limitations on the noise levels that can be achieved. Because of the total absence of any benefits gained by reducing levels due to secondary noise sources much below these limits, it is important to determine these limitations. Those design procedures judged to be unfeasible will determine the practical noise-control design objectives to be used for the project.

8.3 Applications of Noise-Control Design Objectives. The four-step process described in 8.2.4 for developing noise-control design objectives results in objectives that

(1) Satisfy all legal requirements
(2) Weigh cost, safety, operations, and maintenance aspects
(3) Weigh potential noise problems not governed by legal requirements
(4) Prevent expensive and ineffective oversilencing of individual equipment by considering the plant as an entire system in establishing the design objectives

It is significant to note that, in the development of the design objectives, a considerable amount of the overall noise-control effort will have been accomplished. The development of design objectives using the four-step approach defines the scope of noise-control effort. The individual responsible for noise control is expected to ensure that the implemented design procedures are compatible with the practical noise-control design objectives that are established.

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Appendixes

(These Appendixes are not a part of IEEE Std 640-1985, IEEE Guide for Power-Station Noise Control.)

Appendix A
Noise Legislation

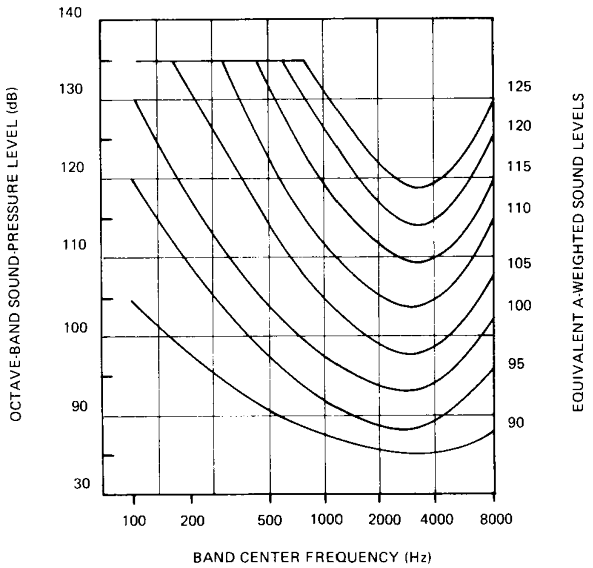
A1. Federal Legislation

A1.1. Federal Register 1910.95 Occupational Noise Exposure [B6].[11]

"(a) Protection against the effects of noise exposure shall be provided when the sound levels exceed those shown in Table A-1 when measured on the A scale of a standard sound level meter at slow response. When noise levels are determined by octave band analysis, the equivalent A-weighted sound level may be determined as follows:

"Equivalent sound level contours. Octave band sound pressure levels may be converted to the equivalent A-weighted sound level by plotting them on this

Fig A1 (OSHA Fig G.9)
Band Center Frequency (Hz)



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[11] The numbers in brackets preceded by the letter B correspond to those of the References listed in A4. of Appendix A.

graph and noting the A-weighted sound level corresponding to the point of highest penetration into the sound level contours. This equivalent A-weighted sound level, which may differ from the actual A-weighted sound level of the noise, is used to determine exposure limits from Table A-1.

"(b) (1) When employees are subjected to sound levels exceeding those listed in Table A-1, feasible administrative or engineering controls shall be utilized. If such controls fail to reduce sound levels within the levels of Table A-1, personal protective equipment shall be provided and used to reduce sound levels within the levels of the table.

"(2) If the variations in noise level involve maxima at intervals of 1 second or less, it is to be considered continuous.

Table A-1 (OSHA Table G.16)

Duration per day, hours	Sound level db(A) slow response
8	90
6	92
4	95
3	97
2	100
1½	102
1	105
½	110
¼ or less	115

"When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered rather than the individual effect of each. If the sum of the following fractions: C1/T1 + C2/T2 .... Cn/Tn exceeds unity, then, the mixed exposure should be considered to exceed the limit value. Cn indicates the total time of exposure at a specified noise level, and Tn indicates the total time of exposure permitted at that level.

"Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level."

"NOTE: Section 1910.95(c) through (s) and Appendixes A through I describe the hearing conservation program. These amendments are still under administrative review prior to final issuance."

A1.2. Guidelines to the Department of Labor Occupational Noise Standards, Bulletin 334, Rev 1971 [B7]

(1) *Introduction.* Noise has long been recognized as an occupational cause of hearing loss. Some companies have for many years taken steps to reduce noise levels and the exposure of their employees to them. In promulgating noise standards under the Walsh-Healey Public Contracts Act, the Department of Labor merely made mandatory minimum standards which have proved practical and effective in preventing hearing loss in many plants.

Measurement, control, and protection against noise is a somewhat technical subject and one with which plant management, which is responsible for the enforcement of safety regulations, may not be familiar. Therefore, this bulletin: First, explains the terms used in Sections 50−204.10 and 1910.95 [B6] of the Occupational Safety and Health Standards, as amended and first published in the *Federal Register* on May 20, 1969.

Second, explains what is expected of the employer to be in compliance with the requirements.

Third, specifies certain instruments, equipment, and procedures which will be acceptable as a basis for judging compliance.

These latter points are of particular interest to technical personnel, either at the plant or engaged on a consultative basis, to assist them in developing and carrying out the required controls and procedures.

This bulletin is equally applicable to employers currently covered by the McNamara-O'Hara Service Contract Act and by the Williams-Steiger Occupational Safety and Health Act of 1970.

(2) *Determining Sound-Level Exposures and Permissible Limits.* Basically, Sections 50−204.10 [B6] and 1910.95 [B6] set maximum permissible noise levels and exposures and explain the types of corrective action which shall be taken if these noise levels are exceeded.

A1.1 (a) states:

"(a) Protection against the effects of noise exposure shall be provided when the sound levels exceed those shown in Table 1 of this section when measured on the A scale of a standard sound level meter at slow response. . . ."

Loss of hearing occurs as a result of the cumulative effect of exposure to sound above a maximum intensity and over a maximum duration in a given period of time. For the purpose of this guide, the basic permissible intensity is 90 dB(A) for a duration of 8 h a day. The amount of sound energy absorbed during such an exposure is considered to be the upper limit of a daily dose which will not produce disabling loss of hearing in more than 20% of the exposed population.

Table 1 indicates the duration of exposure to higher sound intensities which will result in no more damage to hearing than produced by 8 h at 90 dB(A). Employees shall not be exposed to steady sound levels above 115 dB(A), regardless of the duration.

The A scale is one of several on the sound-level meter, a measuring instrument used to determine sound intensity. On this scale, the instrument reacts in much the same way as does the human ear in that it is much less responsive to low-pitched tones than to those of higher pitch. The *slow* response is another setting of the instrument that causes it to average out high-level noises of brief duration (such as hammering), rather than responding to the individual impact noises.

It is important to note that decibels are measured on a logarithmic rather than a linear scale. Every increase of 10 dB represents an increase of approximately 300% in sound pressure. A 100 dB noise is therefore 3 times as intense as a 90 dB noise, rather than approximately 10% more intense, as might be expected. Illustrated another way, if one machine produces a sound level of

Table 1
Permissible Noise Exposures[1]

Duration per day, hours	Sound level db(A) slow response
8	90
6	92
4	95
3	97
2	100
1½	102
1	105
½	110
¼ or less	115

[1] When the daily noise exposure is composed of two or more periods of noise exposure at different levels, their combined effect should be considered, rather than the individual effect of each. If the sum of the following fractions: C1/T1 + C2/T2 .... Cn/Tn exceeds unity, then, the mixed exposure should be considered to exceed the limit value. Cn indicates the total time of exposure at a specified noise level, and Tn indicates the total time of exposure permitted at that level.

90 dB, a second machine of the same kind placed next to it will result in a combined noise level of 93 dB, rather than 180 dB, which might be expected.

(3) *Exposures at Different Sound Levels.* Table 1 describes the method by which several separate exposures to different sound levels during a day are to be treated in determining whether or not the combined exposure is within permissible limits.

For example, assume that an employee works most of the day in an area in which the sound level is 90 dB(A), but for 105 min out of each of 8 h, he is in an area of 100 dB(A), and for one 15 min period each day, he is in an area of 105 dB(A).

This adds up to 6 at 90 dB(A): permissible duration of exposure, 8 h; $1\frac{3}{4}$ h at 100 dB(A): permissible exposure 2 h; and $\frac{1}{4}$ h at 105 dB(A): permissible exposure, 1 h. Tabulating it, we have:

dB(A)	Actual Time C (h)	Permissible Time T (h)
90	6	8
100	$1\frac{3}{4}$	2
105	$\frac{1}{4}$	1

These values expressed as an equation is as follows:

$$\frac{6}{8} + \frac{1.75}{2} + \frac{0.25}{1} = \frac{6}{8} + \frac{7}{8} + \frac{2}{8} = \frac{15}{8} = 1.87 \qquad \text{(Eq A1)}$$

This is greater than unity and therefore not permissible. Either the exposure to the 100 dB(A) levels have to be eliminated or the exposure to 105 dB(A) eliminated and the exposure to 100 dB(A) reduced to 0.5 h or 30 min so as not to exceed the permissible total exposure. In addition; no further exposure at the 90 dB(A) level is allowed.

$$\frac{6}{8} + \frac{0.25}{1} = \frac{2.0}{2} = 1 \text{ or } \frac{6}{8} + \frac{0.50}{2} = \frac{2.0}{2} = 1 \qquad \text{(Eq A2)}$$

(4) *Impulse or Impact Noise.* The last sentence of Sections 50−204.10 [B6] and 1910.95 [B6] states

"Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level."

This sets the upper limit of sound level to which a person should be exposed, regardless of the brevity of the exposure.

In contrast with the 115 dB(A) upper limit for steady noise, the higher intensity for impact noise is permissible because the noise impulse resulting from impacts, such as hammer blows or explosive processes, is past before the ear has time to react fully. Impact noise levels are to be measured only with an impact meter or an oscilloscope.

(5) *Converting Octave-Band Analyzer Readings.* Many plants have done much noise-control work based on measurements taken with the type of instrument that measures the sound level at each of a number of frequencies, or pitches, of the sounds produced rather than the overall total noise, as measured by the sound-level meter. A chart is provided in the regulations to permit readings obtained from an octave-band analyzer to be converted to corresponding values as indicated in Table 1.

Sections 50−204.10 [B6] and 1910.95 [B6] (a) state

"When noise levels are determined by octave-band analysis, the equivalent A-weighted sound level may be determined as follows:

"Equivalent sound level contours. Octave band sound pressure levels may be converted to the equivalent A-weighted sound level by plotting them on this graph and noting the A-weighted sound level corresponding to the point of highest penetration into the sound level contours. This equivalent A-weighted sound level, which may differ from the actual A-weighted sound level of the noise, is used to determine exposure limits from Table 1."

Figure A2 illustrates, in a general way, the response of a sound-level meter working on the A scale. It minimizes, as does the ear, the low-frequency sounds and emphasizes, as does the ear, the high-frequency sounds. Thus, a 90 dB reading on the A scale may include as high as 103 dB at 125 Hz, but will not accept more than 85 dB at 2000 Hz and 4000 Hz.

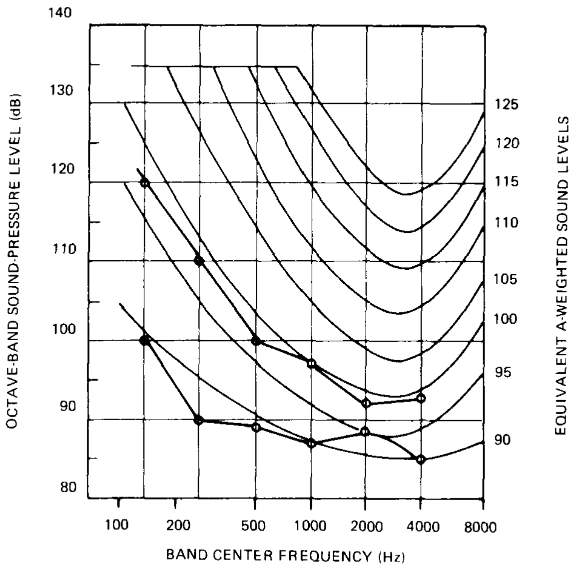

Fig A2
Band Center Frequency (Hz)

To illustrate the use of Fig A2 in converting octave-band readings into A-scale sound-level-meter readings, two sets of values of octave-band readings have been plotted. Series 1 shows readings at or below the 90 dB(A) curve, except at 2000 Hz, where the reading falls on the 95 dB(A) curve. In this case, the sound level for use of Table A1 should be taken as 95 dB(A). In Series 2, all the readings are below the 100 dB(A) curve, except at 1000 Hz, where the reading is just on the curve. The value to be used in Table 1 would therefore be 100 dB(A).

As noted in Fig A2, the actual sound levels measured with a sound-level meter on the A scale may differ somewhat from the values determined by plotting the readings from an octave-band analyzer on the graph. These differences, for most sounds, are of the same order of magnitude as the errors to be expected in the measurement and are not important. The intention is to provide a simple and relatively accurate means of conversion from one system of measurement to another to accommodate existing, effective plantwide programs.

(6) *Variable Noises.* Sections 50–204.10 [B6] and 1910.95 [B6] state the final consideration in determining whether or not a permissible sound level is being exceeded.

"If the variations in noise level involve maxima at intervals of 1 second or less, it is to be considered continuous."

Where the sound-level meter on the A scale, at slow response, moves up from a generally steady reading, for example, from 88 dB to 92 dB, at intervals of 1 s or less, the high reading shall be taken as that to be used in Table 1.

As a corollary, intermittent sounds of brief duration at intervals greater than 1 s should, as far as practical, be measured as to intensity and duration, and the total duration over a day be ascertained. This total should be entered in the equation given in Table 1, Footnote 1, to determine the permissible limit. These intermittent sounds, which can be measured with a sound-level meter, should not be confused with impulse sounds of very short duration resulting from impacts or explosions.

(7) *Control Measures.* Sections 50−204.10(b) [B6] and 1910.95 (b) [B6] refer to control measures to be taken:

"(b) When employees are subjected to sound exceeding those listed in the Table of Permissible Noise Exposures, feasible administrative or engineering controls shall be utilized...."

The Department of Labor considers *feasible* to mean "Capable of being done, accomplished or carried out; capable of being dealt with successfully" [B8].

(8) *Engineering Noise-Control Measures.* Engineering controls are those which reduce the sound intensity either at the source of the noise or in the hearing zone of the workers. For example,

(a) Maintenance
  (i) Replacement or adjustment of worn and loose or imbalanced parts of machines
  (ii) Lubrication of machine parts and use of cutting oils
  (iii) Properly shaped and sharpened cutting tools
(b) Substitution of machines
  (i) Larger, slower machines for smaller, faster ones
  (ii) Step dies for single operation dies
  (iii) Presses for hammers
  (iv) Rotating shears for square shears
  (v) Hydraulic for mechanical presses
  (vi) Belt drives for gears
(c) Substitution of processes
  (i) Compression for impact riveting
  (ii) Welding for riveting
  (iii) Hot for cold working
  (iv) Pressing for rolling or forging
(d) Vibration dampening
  (i) Increase mass
  (ii) Increase stiffness
  (iii) Use rubber or plastic bumpers or cushions
  (iv) Change size to change resonance frequency
(e) Reducing sound transmission through solids
  (i) Flexible mountings
  (ii) Flexible sections in pipe runs

(iii) Flexible shaft couplings
(iv) Fabric sections in ducts
(v) Resilient flooring

(f) Reducing sound produced by fluid flow
(i) Intake and exhaust mufflers
(ii) Fan blades designed to reduce turbulence
(iii) Large, low-speed fans for smaller, high-speed fans

(g) Include noise level specifications when ordering new equipment

(h) Isolating noise sources
(i) Completely enclose individual machines
(ii) Use baffles
(iii) Confine high noise machines to insulated rooms

(i) Isolating operator. Provide a relatively soundproof booth for the operator or attendant of one or more machines.

Controlling noise at the source [see (8) (a)–(i)] is the ideal means of preventing noise-induced hearing loss. The results are relatively long lasting; the operator of the individual machine is protected, and the employees at a distance from it, and there is no need for wearing protective equipment or following prescribed schedules of exposure. The measures listed in (h) (ii), (h) (iii), and (i) will, if effective, limit the number of persons exposed to high noise levels, but are unlikely to protect operators and those close to the noise sources.

A number of the listed controls can be accomplished quite inexpensively by plant personnel. Others require considerable expense and highly specialized technical knowledge to ensure the expected results. It is therefore strongly recommended that plants avail themselves of the services of competent acoustical engineers in planning and carrying out their noise-control programs.

The Department of Labor expects employers to explore the possibility and practicability of controlling noise by engineering and to take all feasible measures before resorting to use of administrative controls or of personal protective equipment.

(9) *Administrative Controls.* If noise cannot be reduced to permissible intensities through engineering controls, administrative controls should be developed so as to limit the duration of workers' exposure to noise levels above 90 dB(A) to the times shown in Table A1. For example:

(a) Arrange work schedules so that employees working the major portion of a day at, or very close to, the 90 dB(A) limit are not exposed to higher noise levels.

(b) Ensure that employees who have reached the upper limit of duration for a high noise level, in accordance with Table 1, work the remainder of the day in an environment with a noise level less than 90 dB(A).

(c) Where the workhours required for a job exceed the permissible time for one employee in one day for the existing sound level, divide the work among two, three, or as many employees as are needed, either successively or together, to keep individual noise exposure within permissible time limits.

(d) If less than full-time production of a noisy machine is needed, arrange to run it a portion of each day, rather than all day for part of the week.

(e) Perform occasional high-level noise-producing operations at night or at other times when a minimum number of employees will be exposed.

Measures such as these can often be instituted at little cost or effort, simply by introducing noise exposure as a factor in production planning. While not as satisfactory as controlling noise at its sources, administrative control measures are more easily enforced than is the requirement to wear personal protective equipment. For this reason it is preferred.

(10) *Personal Protective Equipment.* When engineering and administrative controls fail to bring noise levels or duration of exposure to them below permissible levels, the use of personal protective equipment is required, as stated in Sections 50–204.10(b) [B6] and 1910.95 (b) [B6]

"If such controls fail to reduce sound levels within the levels of the table, personal protective equipment shall be provided and used to reduce sound levels within the levels of the table."

The use of personal protective equipment is considered by the Department of Labor to be an interim measure while engineering and administrative controls are being perfected. There will be very few cases in which the use of this equipment will be acceptable as a permanent solution to noise problems.

Some methods of control, such as providing an isolation booth for operators or conducting noisy operations when few employees are in the plant, may require use of personal protective equipment by the operator when he must emerge from his booth to make adjustments, or by those few employees who carry on the noisy operation.

In addition, the regulations require *both the provision and use* of personal protective equipment. It is up to the employer how to accomplish the latter. The Department of Labor recommends however that an educational and promotional program precede initiation of required use of such equipment, and continue as long as necessary to achieve 100% acceptance by employees. In the absence of an observable high proportion of use, the Department of Labor will consider the lack of a training and promotional program as constituting a violation of the regulation.

(11) *Selection of Personal Protective Equipment.* Cotton stuffed in the ears has little value and will not be accepted by the Department of Labor because of the relatively small attenuation (reduction of noise level) and the care that shall be taken in using it.

Fine glass wool can be used instead of cotton because the attenuation that can be achieved is very good. It is an acceptable protective device.

Wax impregnated cotton, when properly inserted in the ear, provides protection equivalent to that provided by plugs or muffs. If supervisors can ensure that this material is properly used and fresh material is provided daily, then this type of ear protection will be acceptable.

Properly fitted earplugs are essentially equal in attenuating ability to ear muffs; either is acceptable to the Department of Labor. Plugs are inexpensive but shall be fitted to the individual. In addition, plugs, and any other type of protector inserted into the ear, shall be issued by a physician or by a trained person under the direction of a physician. Frequent checks shall be made to see that the plugs are being properly inserted.

Ear muffs, though relatively expensive, may be issued by any designated person in the plant, as the only fitting required is adjustment of the headband. This makes it very easy for the supervisor to check on proper use of the muffs. Long hair and spectacle or goggle temples will interfere with the seal made by the cushioned edges of the muffs and will correspondingly reduce the actual attenuation as stated by the manufacturer.

Regardless of the type of ear protector decided upon, its attenuation, as stated by the manufacturer, shall be sufficient to reduce the noise level in the worker's ear to the level and for the duration prescribed in Table 1. The manufacturer's stated values are determined under ideal conditions and therefore, as a precaution, it is wise to assume that the attenuation actually attained in use in the shop will be at least 5 dB less than the stated value.

The Department of Labor strongly recommends that any employee who is exposed to high sound levels and requests ear protection be provided with it, even if the duration of exposure is within the limits prescribed by Table 1.

(12) *Hearing Conservation Program.* Sections 50–204.10 [B6] and 1910.95 [B6] conclude

"In all cases where the sound levels exceed the values shown herein, a continuing, effective hearing conservation program shall be administered."

Where the sound level in a working area has not been reduced to 90 dB(A) or below by engineering means, and reliance must be placed on administrative controls to limit duration of exposure, or on ear protection to reduce the sound level actually reaching the ear, a hearing conservation program is required. The program will be applied to all those employees whose work brings them either steadily or infrequently into areas in which sound levels exceed 90 dB(A).

(13) *Definitions.*

continuing. A program will be in effect and in use for the duration that noise levels above 90 dB(A) occur in the plant.

effective. Employees exposed to those noise levels above 90 dB(A) will not suffer continuing deterioration of hearing acuity because of the exposure, and incipient loss of hearing will be detected and necessary steps taken to prevent further deterioration before serious hearing loss has occurred.

hearing conservation. Refers to audiometry; periodic checks of the noise level in the areas in which employees are working.

NOTE: The entire range of actions required by Sections 50–204.10 [B6] and 1910.95 [B6] are applicable.

(14) *Audiometry.* Audiometric tests will be made of all individuals whose exposure to noise levels equals or exceeds an 8 h time-weighted average of 85 dB. The purpose of these tests is to ensure that administrative controls in use or ear protection devices provided are being adhered to or properly used and are effective in preventing loss of hearing from the noise levels encountered.

At least annually after obtaining the baseline audiogram, the employer shall obtain a new audiogram for each employee exposed at or above a time-weighted average of 85 dB.

An audiologist, otolaryngologist, or qualified physician shall review the audiograms to determine whether any significant threshold shift is work related or whether there is need for further evaluation.

(a) *Test Facilities and Procedures.* The test booth or room shall meet the criteria of ANSI S3.1-1977 [B2] for testing to a minimum level of 10 dB on the ISO 1964 audiometric scale [B5].

The booth or room may be either prefabricated or locally built. Doors, gaskets, and other parts of the room or booth that may deteriorate, warp, or crack shall be carefully inspected periodically and necessary repairs or replacements made at once to ensure that successive audiometric tests of each individual are directly comparable and will give a true evaluation of the individual's hearing ability.

The operator of the audiometer should be positioned outside the room or booth but able to see the interior through a window. The person being tested shall face away from the operator and the audiometer to ensure that all his responses are based on sound signals alone.

The test shall consist of an air conduction octave-band analysis, as described in ANSI S3.1 1977 [B2] and shall include, at least, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 6000 Hz.

The audiometric tests shall be made by a person trained and skilled in audiometric testing.

(b) *Audiometers.* The audiometer used to make these tests shall meet the specifications of ANSI S3.6-1969 (R1973) [B3] for limited range and pure tone audiometers.

The audiometer shall have a certificate of calibration before it is placed in use, and shall be recalibrated each year thereafter. This calibration shall check both frequency and intensity at each setting, rise time and overshoot, and electrical and mechanical integrity. A current certificate attesting to such calibration shall be readily available for inspection by the Department of Labor.

There shall be a statement on the audiometer indicating whether it is calibrated to the values of ANSI S2.45-1983/ASA 51 [B4] which is identical to ISO R389-1964 [B5].

The audiometer shall be subjected to a biological check, preferably once a week but at least once a month, or before each use of the instrument if it is used less than once a month. The check shall be made by testing a person with a known and stable audiometric curve. The monthly check should include movement and bending of cord, wire, and lead; knob turning, switch actuating, and button pushing to ensure that there are no sounds other than the test tones. A log of these checks shall be maintained and available for inspection.

(c) *Records.* In addition to the certificates and logs referred to in (13) (b), a record of each audiogram made on each individual tested shall be available for inspection. Records of audiometric tests shall indicate whether readings are based on ANSI S2.45-1983/ASA 51 [B4] (ISO R389-1964 [B5]). The complete records on each employee required to be tested shall be retained for 1 year following termination of employment or transfer to an area in which noise levels above 90 dB(A) do not exist.

The records will be examined for evidence of any deterioration of hearing acuity and of action taken to prevent further deterioration in those employees found to suffer some loss of acuity. Conclusions as to the effectiveness of control measures taken will be based on examination of a significant number of audiograms and not upon the basis of one or two cases.

(d) *Audiometric Tests Outside of the Plant.* If audiometric tests are done outside the plant, the Department of Labor representative will also inspect the facilities and test records and the same standards will apply.

Plant management will make arrangements for such inspection with the person conducting the audiometric tests and may accompany the representative in the inspection and review of records.

(15) *Noise Surveys.* A noise survey of each area in the plant in which sound levels exceed 90 dB(A) shall be made at least once each year to ensure that sound levels have not increased above those originally existing. The survey may also establish that noise levels in some areas have been reduced to levels below 90 dB(A) and thereby justify discontinuing application of requirements for administrative controls, ear protection, and audiometric tests of individuals in such areas.

A noise survey of an area is recommended whenever a change is made in either equipment or type of operations, so that significant changes in noise level will be acted upon immediately.

Tests of noise levels will be made with a sound-level meter on the A-scale, slow response. The use of octave-band analyzers or impact meters for control or other purposes shall be in addition to, not in place of, tests made with the sound-level meter.

The sound-level meter used will be one meeting the specifications in ANSI S1.4-1983 [B1].

Records will be made of such surveys showing

(a) The instrument used
(b) Date
(c) The time and location of such tests
(d) The machinery or equipment generating the noise
(e) The name of the person making the test

Test records shall be kept readily available for inspection for 1 year or until a subsequent survey is made, if done more frequently.

The noise survey will be made by an insurance carrier, a consultant, a representative of a state health or labor department, or by a qualified individual designated by the company.

(16) *Compliance Plan.* Whenever a noise survey shows noise levels in excess of those listed in Table 1, necessary steps to reduce the noise exposure to or below those levels shall be ascertained and a detailed plan, with completion dates for individual steps, shall be prepared.

Following the original survey that shows the existence of overexposures, the steps in a typical compliance plan might include the following steps (not necessarily in this order and some usually going on simultaneously):

(a) A detailed survey of sound levels and sound spectra to determine the sources of excessive sound levels

(b) Initiation of engineering studies to determine methods for reducing the sources of excessive sound levels

(c) Planning and initiation of feasible administrative controls, such as modifying production schedules to divide noisy jobs among a number of people to bring each below the permissible limit or spreading part-time noisy operations

(d) Initial audiograms for personnel excessively exposed

(e) Installation of a personal protective equipment program

(f) Follow-up audiograms at appropriate intervals to assess effectiveness of the personal protective equipment program and administrative controls

(g) Installation of engineering controls, or process changes to reduce noises at their source

(h) Repeated noise surveys to measure effectiveness of the engineering changes

When the compliance plan involves long-term engineering projects (for example, one or two years), it may be revised from time to time as conditions change. The orderly completion, on schedule, of the various phases of the compliance plan, together with other components of the hearing conservation program, will be considered in compliance with the regulation.

A1.3. Highlights of the Noise-Control Act of 1972

(1) *Background of Legislation.* Recognition of the fact that noise is an environmental problem that affects people other than workers has been late in coming.

Federal noise legislation first appeared in 1968 when Congress directed the Federal Aviation Administration (FAA) to establish rules and regulations to control aircraft noise.

At the state and local levels, laws tended to treat noise as a public nuisance, and enforcement was difficult and spotty. More recently, some jurisdictions, notably in California, Chicago, and New York City, have established new laws and ordinances that are based on noise-generating characteristics of specific equipment and therefore are easier to enforce.

The Clean Air Amendments of 1970 called for the establishment of an Office of Noise Abatement and Control in the United States Environmental Protection

Agency (EPA). The legislation also called for public hearings of environmental noise and a special report to the Congress on the problem, incorporating the results of the public hearings and other special studies. Information from this EPA report and extensive Congressional hearings formed the basis of the Noise-Control Act of 1972.

(2) *The Effects of Noise.* Half of the some 80 million people significantly affected by noise (from transportation, construction activities, and other engine-powered equipment and devices) are exposed to levels that can damage their hearing or otherwise affect their health. Noise also interferes with communication and interrupts sleep—generally adding to the stress of modern life—with some of the resulting physiological responses apparently chronic. For the average urban dweller, the fact that noise impinges upon the quality of the environment is probably the most impelling reason for quieting things.

(3) *The Noise-Control Act of 1972.* The Noise-Control Act of 1972 represents the first major federal attempt to eliminate excess noise at the design stage of a wide variety of new consumer products.

The administrator of the EPA is required to develop and publish information regarding permissible levels of noise, and then to set noise standards for products that have been identified as major sources of noise.

While aircraft noise control remains under the administration of the FAA, the law gives the EPA an advisory role in formulating criteria and standards for controlling this source of noise.

(4) *Major Provisions.* The EPA is directed to develop and publish information on the noise limits required for protecting the public health and welfare and a series of reports to identify products that are major sources of noise and to give information on the techniques for controlling noise from such products.

Using the criteria thus developed, the EPA administrator is required to set noise-emission standards for products that have been identified as major sources of noise and for which standards are deemed feasible. The law requires such standards to be set for products in the categories of construction equipment, transportation equipment (except aircraft), all motors and engines, and electrical and electronic equipment. It also grants authority to set standards deemed feasible and necessary to protect public health and safety for other products.

The EPA has authority to require the labeling of domestic or imported consumer products as to their noise-generating characteristics or their effectiveness in reducing noise. Manufacturers or importers of nonconforming or mislabeled products are subject to fines of up to $25 000 per day for each violation and to imprisonment for up to one year. Manufacturers must issue warrants that at the time of sale their regulated products comply with federal standards. They are also required to maintain records and provide information, including production samples, if requested by the EPA.

The EPA administrator also is to prescribe noise-emission standards for the operation of equipment and facilities of interstate railroads, trucks, and buses.

All federal agencies are directed to use the full extent of their authority to ensure that purchasing and operating procedures conform to the intent of the law. The EPA may certify low-noise emission products for purchase by the federal government.

(5) *Some of the Common Noisemakers.* Aircraft, transportation equipment (most notably trucks), and construction equipment are major sources of environmental noise. Recently, the booming recreation industry has added a new dimension to the problem as snowmobiles, trailbikes, and other engine-powered devices have become more and more popular. By the end of 1970, there were approximately two and one-half million motorcycles in the United States, five times the number in use in 1960. The growing number of power tools and devices in use in the home (manufacturers of power lawn-mowing equipment have shipped nearly 89 million units since 1946) are also adding to the din. It is not surprising, then, that from 22 to 44 million people have lost part of the use of their homes because of aircraft and transportation noise.

(6) *Aircraft Noise.* Under the Noise-Control Act of 1972, the EPA administrator was required by mid-1973 to make a comprehensive study of aircraft noise and cumulative noise exposure around airports. Using this information, the EPA is to submit to the FAA proposed regulations to control aircraft noise and sonic booms. After a hearing and further consultation with the EPA, the FAA may adopt or modify the proposed regulations. The FAA may reject the proposals if it believes they are unsafe, technologically or economically infeasible, or not applicable to certain aircraft. However, it must publicly explain its specific reasons for rejection. A continuing review and consultation role is provided for the EPA.

(7) *Citizen Suits.* Any person may start a civil action on his/her own behalf against any person or the United States and any other governmental agency for violation of this act. Similarly, civil action may be brought against the administrator of the EPA or the FAA for failure to perform any nondiscretionary duty under this law. Rights which a person may have under different statutes or the common law to enforce a noise-control requirement are not restricted by this law.

(8) *An End to Noise Pollution.* The comprehensive nature of the Noise-Control Act of 1972 brings under federal regulation, for the first time, nearly all of the major new sources of noise. An incentive now exists for the full employment of noise-control technology that is already available, and the day when quiet is restored appears closer.

A2. State Legislation

A2.1. Illinois Pollution Control Board Rules and Regulations, ch 8, Noise Regulations, Aug 3, 1973, pt 1, General Provisions

"**Rule 101: Definitions.** Except as hereinafter stated and unless a different meaning of a term is clear from its context, the definitions of terms used in this chapter shall be the same as those used in the Environmental Protection Act.

"All definitions of acoustical terminology shall be in conformance with those contained in ANSI S1.1-1960 (R1976), Acoustical Terminology.

"(a) *ANSI:* American National Standards Institute or its successor bodies.

"(b) *Construction:* On-site erection, fabrication, installation, alteration, demolition or removal of any structure, facility, or addition thereto, including all related activities, including, but not restricted to, clearing of land, earth moving, blasting, and landscaping.

"(c) *Daytime hours:* 7:00 am to 10:00 pm, local time.

"(d) *dB(A):* Sound level in decibels determined by the A-weighting of a sound-level meter.

"(e) *Decibel (dB):* A unit of measure, on a logarithmic scale to the base 10, of the ratio of the magnitude of a particular sound pressure to a standard reference pressure, which, for purposes of this Chapter, shall be 20 micronewtons per square meter ($\mu N/m^2$).

"(f) *Existing property-line-noise-source:* Any property-line-noise-source, the construction or establishment of which commenced prior to the effective date of this Chapter. For the purposes of this subsection, any property-line-noise-source whose A, B, or C land use classification changes, on or after the effective date of this Chapter, shall not be considered an existing property-line-noise-source.

"(g) *Impulsive sound:* Either a single pressure peak or a single burst (multiple pressure peaks) for a duration less than one second.

"(h) *New property-line-noise-source:* Any property-line-noise-source, the establishment of which commenced on or after the effective date of this Chapter.

"(i) *Nighttime hours:* 10:00 pm to 7:00 am, local time.

"(j) *Noise pollution:* The emission of sound that unreasonably interferes with the enjoyment of life or with any lawful business or activity.

"(k) *Octave-band sound-pressure level:* The sound-pressure level for the sound being measured contained within the specified octave band. The reference pressure is 20 micronewtons per square meter.

"(l) *Person:* Any individual, corporation, partnership, firm, association, trust, estate, public or private institution, group, agency, political subdivision of this State, any other State of political subdivision or agency thereof or any legal successor, representative, agent or agency of the foregoing.

"(m) *Preferred frequencies:* Those frequencies in Hertz preferred for acoustical measurements which, for the purposes of this Chapter, consist of the following set of values: 20, 25, 31.5, 40, 50, 63, 80, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, 5000, 6300, 8000, 10000, 12500.

"(n) *Prominent discrete tone:* Sound, having a one-third octave-band sound-pressure level which, when measured in a one-third octave band at the preferred frequencies, exceeds the arithmetic average of the sound-pressure levels of the two adjacent one-third octave bands on either side of such one-third octave band by:

"(1) 5 dB for such one-third octave band with a center frequency from 500 Hz to 10 000 Hz, inclusive. Provided: such one-third octave-band sound-pressure level exceeds the sound-pressure level of each adjacent one-third octave band, or;

"(2) 8 dB for such one-third octave band with a center frequency from 160 Hz to 400 Hz, inclusive. Provided: such one-third octave-band sound-pressure level exceeds the sound-pressure level of each adjacent one-third octave band, or;

"(3) 15 dB for such one-third octave band with a center frequency from 25 Hz to 125 Hz, inclusive. Provided: such one-third octave-band sound-pressure level exceeds the sound-pressure level of each adjacent one-third octave band.

"(o) *Property-line-noise-source:* Any equipment or facility, or combination thereof, which operates within any land used as specified by Rule 201 of this Chapter. Such equipment or facility, or combination thereof, must be capable of emitting sound beyond the property line of the land on which operated.

"(p) *SLUCM:* The Standard Land Use Coding Manual (1969, United States Government Printing Office) which designates land activities by means of numerical codes.

"(q) *Sound:* An oscillation in pressure in air.

"(r) *Sound level:* In decibels, a weighted sound-pressure level, determined by the use of metering characteristics and frequency weightings specified in ANSI S1.4-1983, Specification for Sound-Level Meters."

"(s) *Sound-pressure level:* In decibels, 20 times the logarithm to the base 10 of the ratio of the magnitude of a particular sound pressure to the standard reference pressure. The standard reference pressure is 20 micronewtons per square meter.

"(t) *Unregulated safety relief valve:* A safety relief valve used and designed to be actuated by high pressure in the pipe or vessel to which it is connected and which is used and designed to prevent explosion or other hazardous reaction from pressure buildup, rather than being used and designed as a process pressure blowdown.

"Rule 102: Prohibition of Noise Pollution. No person shall cause or allow the emission of sound beyond the boundaries of his property so as to cause noise pollution in Illinois, or so as to violate any provision of this Chapter of the Illinois Environmental Protection Act.

"**Rule 103: Measurement Techniques.** Test procedures to determine whether emission of sound is in conformance with this Chapter shall be in substantial conformity with Standards and Recommended practices established by the American National Standards Institute, Inc (ANSI) and the Society of Automotive Engineers, Inc (SAE), and the latest revisions thereof, including ANSI S1.1-1960 (R 1976), ANSI S1.4-1983, ANSI S1.8-1969 (R 1974),—Type 1 Precision, ANSI S1.11-1966 (R 1976), ANSI S1.13-1971 (R 1976) Field Method, SAE J-184.

The Agency may adopt procedures which set forth criteria for the measurement of sound. Such procedures shall be revised from time to time to reflect current engineering judgment and advances in noise measurement techniques. Such procedures, and the revisions thereto, shall not become effective until filed with the Index Division of the Office of the Secretary of State as required by "An Act concerning administrative rules," approved June 14, 1951, as amended.

"**Rule 104: Burden of Persuasion Regarding Exceptions.** In any proceeding pursuant to this Chapter, if an exception stated in this Chapter would limit an obligation, limit a liability, or eliminate either an obligation or a liability, the person who would benefit from the application of the exception shall have the burden of persuasion that the exception applies and that the terms of the exception have been met. The Agency shall cooperate with and assist persons in determining the application of the provisions of this Chapter.

"**Rule 105: Severability.** If any provision of these rules or regulations is adjudged invalid, or if the application thereof to any person or in any circumstance is adjudged invalid, such invalidity shall not affect the validity of this Chapter as a whole or of any part, subpart, sentence or clause thereof not adjudged invalid."

"**Part 2, Sound Emission Standards and Limitations for Property-Line-Noise-Sources.** All terms defined in Part 1 of this Chapter which appear in Part 2 of this Chapter have the same definitions specified by Rule 101 of Part 1 of this Chapter.

"**Rule 201: Classification of Land According to Use**

"(a) *Class A Land.* Class A land shall include all land used as specified by SLUCM Codes 110 through 190 inclusive, 651, 674, 681, through 683 inclusive, 691, 711, 762, 7121, 7122, 7123 and 921.

"(b) *Class B Land.* Class B land shall include all land used as specified by SLUCM Codes 397, 471 through 479 inclusive, 511 through 599 inclusive, 611 through 649 inclusive, 652 through 673 inclusive, 675, 692, 699, 7124, 7129, 719, 721, 722 except 7223 used for automobile and motorcycle racing, 723 through 761 inclusive except 7311 used for automobile and motorcycle racing, 769 through 790 inclusive, and 922.

"(c) *Class C Land.* Class C land shall include all land used as specified by SLUCM Codes 211 through 299 inclusive, 311 through 396 inclusive, 399, 411 except 4111, 412 except 4121, 421, 422, 429, 441, 449, 460, 481 through 499 inclusive, 7223 and 7311 used for automobile and motorcycle racing and 811 through 890 inclusive.

"(d) A parcel or tract of land used as specified by SLUCM Code 81, 83, 91 or 922, when adjacent to Class B or C land may be classified similarly by action of a municipal government having zoning jurisdiction over such land. Notwithstanding any subsequent changes in actual land use, land so classified shall retain such B or C classification until the municipal government removes the classification adopted by it.

"**Rule 202: Sound Emitted to Class A Land During Daytime Hours.** Except as elsewhere in this Part 2 provided, no person shall cause or allow the emission of sound during daytime hours from any property-line-noise-source located on any Class A, B or C land to any receiving Class A land which exceeds any allowable octave band sound pressure level specified in Table 1, when measured at any point within such receiving Class A land, provided, however, that no measurement of sound pressure levels shall be made less than 25 feet from such property-line-noise-source.

Table 1

Octave Band Center Frequency (Hertz)	Allowable Octave Band Sound Pressure Levels (dB) of Sound Emitted to any Receiving Class A Land from		
	Class C Land	Class B Land	Class A Land
31.5	75	72	72
63	74	71	71
125	69	65	65
250	64	57	57
500	58	51	51
1000	52	45	45
2000	47	39	39
4000	43	34	34
8000	40	32	32

"**Rule 203: Sound Emitted to Class A Land During Nighttime Hours.** Except as elsewhere in this Part 2 provided, no person shall cause or allow the emission of sound during nighttime hours from any property-line-noise-source located on any Class A, B or C land to any receiving Class A land which exceeds any allowable octave band sound pressure level specified in Table 2, when measured at any point within such receiving Class A land, provided however, that no measurement of sound pressure levels shall be made less than 25 feet from such property-line-noise-source.

Table 2

Octave Band Center Frequency (Hertz)	Allowable Octave Band Sound Pressure Levels (dB) of Sound Emitted to any Receiving Class A Land from		
	Class C Land	Class B Land	Class A Land
31.5	69	63	63
63	67	61	61
125	62	55	55
250	54	47	47
500	47	40	40
1000	41	35	35
2000	36	30	30
4000	32	25	25
8000	32	25	25

"**Rule 204: Sound Emitted to Class B Land.** Except as elsewhere in this Part 2 provided, no person shall cause or allow the emission of sound from any property-line-noise-source located on any Class A, B or C land to any receiving Class B land which exceeds any allowable octave band sound pressure level specified in Table 3, when measured at any point within such receiving Class B land, provided, however, that no measurement of sound pressure levels shall be made less than 25 feet from such property-line-noise-source.

Table 3

Octave Band Center Frequency (Hertz)	Allowable Octave Band Sound Pressure Levels (dB) of Sound Emitted to any Receiving Class B Land from		
	Class C Land	Class B Land	Class A Land
31.5	80	79	72
63	79	78	71
125	74	72	65
250	69	64	57
500	63	58	51
1000	57	52	45
2000	52	46	39
4000	48	41	34
8000	45	39	32

"**Rule 205: Sound Emitted to Class C Land.** Except as elsewhere in this Part 2 provided, no person shall cause or allow the emission of sound from any property-line-noise-source located on any Class A, B, or C land to any receiving Class C land which exceeds any allowable octave band sound pressure level specified in Table 4, when measured at any point within such receiving Class C land, provided however, that no measurement of sound pressure levels shall be made less than 25 feet from such property-line-noise-source.

Table 4

Octave Band Center Frequency (Hertz)	Allowable Octave Band Sound Pressure Levels (dB) of Sound Emitted to any Receiving Class C Land from	
	Class C Land	Class B Land and Class A Land
31.5	88	79
63	83	78
125	78	72
250	73	64
500	67	58
1000	60	52
2000	54	46
4000	50	41
8000	47	39

"**Rule 206: Impulsive Sound.** No person shall cause or allow the emission of impulsive sound from any property-line-noise-source located on any Class A, B, or C land to any receiving Class A, B or C land which exceeds the allowable dB(A) sound level specified in Table 5, when measured at any point within such receiving Class A, B, or C land, provided however, that no measurement of sound levels shall be made less than 25 feet from the property-line-noise-source.

Table 5

Classification of Land on Which Property-Line-Noise-Source is Located	Allowable db(A) Sound Levels of Impulsive Sound Emitted to Designated Classes of Receiving Land			
	Class C Land	Class B Land	Class A Land	
			Daytime	Nighttime
Class A Land	57	50	50	45
Class B Land	57	57	50	45
Class C Land	65	61	56	46

"**Rule 207: Prominent Discrete Tones**

(a) No person shall cause or allow the emission of any prominent discrete tone from any property-line-noise-source located on any Class A, B, or C land to any receiving Class A, B, or C land, provided however, that no measurement of one-third octave band sound pressure levels shall be made less than 25 feet from such property-line-noise-source.

"(b) This rule shall not apply to prominent discrete tones having a one-third octave band sound pressure level 10 or more dB below the allowable octave band sound pressure level specified in the applicable table in Rules 202 through 205 for the octave band which contains such one-third octave band. In the application of this sub-section, the applicable table for sound emitted from any existing property line noise source to receiving Class A land, for both daytime and nighttime operations, shall be Table 1 (Rule 202).

"Rule 208: Exceptions

(a) Rules 202 through 207 inclusive shall not apply to sound emitted from land used as specified by SLUCM Codes 110, 140, 190, 691, 7311 except as used for automobile and motorcycle racing, and 742 except 7424 and 7425.

"(b) Rules 202 through 207 inclusive shall not apply to sound emitted from emergency warning devices and unregulated safety relief valves.

"(c) Rules 202 through 207 inclusive shall not apply to sound emitted from lawn care maintenance equipment and agricultural field machinery used during daytime hours. For the purposes of this sub-section, grain dryers operated off the farm shall not be considered agricultural field machinery.

"(d) Rules 202 through 207 inclusive shall not apply to sound emitted from equipment being used for construction.

"(e) Rule 203 shall not apply to sound emitted from existing property-line-noise-sources during nighttime hours, provided, however, that sound emitted from such existing property-line-noise-sources shall be governed during nighttime hours by the limits specified in Rule 202.

"Rule 209: Compliance Dates for Part 2

(a) Except as provided in Rules 209(f), 209(g), 209(i) and 209(j), every owner or operator of a new property-line-noise-source shall comply with the standards and limitations of Part 2 of this Chapter on and after the effective date of this Chapter.

"(b) Except as otherwise provided in this Rule 209, every owner or operator of an existing property-line-noise-source shall comply with the standards and limitations of Part 2 of this Chapter on and after twelve months from the effective date of this Chapter.

"(c) Every owner or operator of an existing property-line-noise-source who emits sound which exceeds any allowable octave band sound pressure level of Rules 202, 203, 204, or 205 by 10 dB or more in any octave band with a center frequency of 31.5 Hertz, 63 Hertz or 125 Hertz shall comply with the standards and limitations of Part 2 of this Chapter on and after eighteen months from the effective date of this Chapter.

"(d) Except as provided in Rules 209(f), 209(g), and 209(h) every owner or operator of an existing property-line-noise-source required to comply with Rule 206 of this Chapter shall comply with the standards and limitations of Part 2 of this Chapter on and after eighteen months from the effective date of this Chapter.

"(e) Every owner or operator of an existing property-line-noise-source required to comply with Rule 207 of this Chapter shall comply with the standards and limitations of Part 2 of this Chapter on and after eighteen months from the effective date of this Chapter.

"(f) Every owner or operator of Class C land now or hereafter used as specified by SLUCM Codes 852 and 854 shall have three years from the effective date of this Chapter to bring the sound from necessary explosive blasting activities in compliance with Rule 206, provided that such blasting activities are conducted between 8:00 am and 5:00 pm local time, at specified hours previously announced to the local public.

"(g) Every owner or operator of Class C land now and hereafter used as specified by SLUCM Code 4112 shall have three years from the effective date of this Chapter to bring the sound from railroad car coupling in compliance with Rule 206.

"(h) Every owner or operator of Class C land on which forging operations are now conducted shall have three years from the effective date of this Chapter to bring sound from the impact of forging hammers into full compliance with the limits specified in Rule 206 for emissions to any receiving land.

"(i) Every owner or operator of Class C land now and hereafter used as specified by SLUCM Code 291 shall comply with the standards and limitations of Part 2 of this Chapter on and after two years from the effective date of this Chapter.

"(j) Every owner or operator of Class C land now and hereafter used as specified by SLUCM Code 7223 and 7311 when used for automobile and motorcycle racing shall comply with the standards and limitations of Part 2 of this Chapter on and after two years from the effective date of this Chapter."

A2.2. State of New York Adopted Rules of Procedure Regarding Certification of Major Steam Electric Generating Station Noise, Part 75.

"Section
75.1 General Requirements
75.2 Exhibit K: Present Environmental Sound Levels
75.3 Exhibit L: Facility Conceptual Design, Construction, Operation, and Maintenance Characteristics Affecting Environmental Sound Levels

75.4 Exhibit M: Impact of Facility Construction, Operation and Maintenance on Environmental Sound Levels

"Section 75.1 General Requirements. (a) As used in this Part:

"(1) The term *daytime* means the period from 7:00 am to 7:00 pm

"(2) The term *evening* means the period from 7:00 pm to 10:00 pm

"(3) The term *nighttime* means the period from 10:00 pm to 7:00 am

"(4) The term *noise sampling time period* means one of the 12 time periods shown on Table L-1.

"(5) The term *area of noise impact* means that area in which the on-site construction, operation, or maintenance of a proposed facility during any noise sampling time period would probably cause an ambient sound level increase of five or more decibels on the A weighted scale.

"(6) The term *noise sampling area* means the area within the area of impact plus one-quarter mile beyond the boundary of the area of noise impact.

"(7) The term *noise sensitive land use* means any land use which may be adversely affected by an increase in the ambient sound level and includes a hospital, house of worship, outdoor amphitheater, auditorium, nursing home, library, residential structure or area, and educational institution.

"(8) The term *noise sampling location* means the general area containing the specific sampling points at which measurements are taken.

"(b) The information on present environmental sound required by subdivisions (a) and (b) of section 75.2 shall:

"(1) Include data collected during noise sampling time periods within 18 months prior to the date on which the application is filed;

"(2) Be based upon generally accepted measuring and recording techniques;

"(3) Contain a statement of the bases for determining the number and location of noise sampling points adequate to determine that the measurements taken are representative of the site and area of noise impact;

"(4) Contain a statement of the bases for determining the number of observations made at each sampling location adequate to determine that the data is statistically reliable;

"(5) Be based upon data collected in weather conditions which do not create a bias in the data, such as winds, rain, sleet, hail, falling snow, or thunder;

"(6) Be based upon field measurements made during normal ambient conditions when significant temporary changes in sound patterns have not occurred, such as transportation strikes and closed streets, except that this restriction shall not apply if there is a generally acceptable method for adjusting data to reflect any temporary change in sound patterns; and

"(7) Unless circumstances indicate or require that measurements should be made at a greater height or closer to a vertical reflecting surface, be based upon measurements taken four to five feet above the ground and at least 12 feet from a vertical sound reflecting surface.

"(c) In providing the information on present environmental sound levels required by subdivision (b) of section 75.2, the applicant shall indicate:

"(1) The time, location and date of measurement;

"(2) Appropriate meteorological data, including air temperature, relative humidity, and wind speed and direction; and

"(3) The name and pertinent training and experience of the persons responsible for the measurement.

"(d) (1) For each instrument and microphone combination used to measure sound level or frequency, the applicant shall state the:

(i) Name;
(ii) Make;
(iii) Type; and
(iv) Method and date of calibration.

"(2) Only measurements from sound measuring equipment that meets the Type 1 specifications of the American National Standards Institute (S1.4-1971) may be used to satisfy the requirements of this Part.

"**75.2 Exhibit K: Present Environmental Sound Levels.** (a) The applicant shall submit overlays for the ambient noise sampling area showing ambient sound contours for each note sampling time period at intervals of five decibels on the A weighted scale.

"(b) For the noise sampling area for each noise sampling time period at each location, the applicant shall submit, in tabular form and, with the exception of the information required by paragraph (3), graphic form, a summary of the results of observations showing:

"(1) The frequency occurrence distribution, with a class interval or cell size of five decibels or less;

"(2) A cumulative percentage curve;

"(3) The peak sound measured in decibels on the A weighted scale, slow response; and

"(4) The frequency, duration, and octave band pressure level of any pure tone.

"(c) The applicant shall submit an overlay or overlays showing each noise sampling location and each noise sensitive land use within the noise sampling area.

"75.3 Exhibit L: Facility Conceptual Design, Construction, Operation and Maintenance Characteristics Affecting Environmental Sound Levels. For each:

"(1) Major source of construction related noise during the period of facility construction, and

"(2) Facility component which will be a major source of noise during facility operation or maintenance, the applicant shall estimate, based upon the manufacturer's specifications, if available, or experience at a comparable plant, or technical literature, the average and maximum sound levels in decibels on the A weighted scale and, in the case of a pure tone sound, the octave band sound level in decibels and the frequency. In presenting the information required by the preceding sentence, the applicant shall, for each sound level, state the associated distance from the sound source. Additionally, the applicant shall state the times of the year, week, and day each such noise would be generated and any measure or measures proposed to minimize such noise, including the use of low noise producing equipment or components.

"75.4 Exhibit M: Impact of Facility Construction, Operation, and Maintenance on Environmental Sound Levels. (a) The applicant shall evaluate the noise impact associated with the construction of a facility. The applicant shall:

"(1) Provide such overlays as may be necessary to show any projected shift, resulting from facility construction, in any ambient sound level contour shown on the overlays required by subdivision (a) of section 75.2; and

"(2) Submit a statement evaluating any such shift in ambient sound levels and the effect of such shift on any noise sensitive land use, including an estimate of the number of people affected within the area of noise impact.

"(b) The applicant shall evaluate the noise impact associated with the operation and maintenance of a facility. The applicant shall:

"(1) Provide such overlays as may be necessary to show any projected shift, resulting from facility operation at full load and from facility maintenance, in any ambient sound level contour shown on the overlays required by subdivision

(a) of section 75.2; and

"(2) Submit a statement evaluating any shift in ambient sound levels and the effect of any such shift on noise sensitive land uses, including an estimate of the number of people to be affected within the area of noise impact.

Table L-1

	Noise Sampling Periods	
Season	Day	Time
Winter	Monday through Friday [1]	Daytime
Winter	Monday through Friday [1]	Evening
Winter	Monday through Friday [1]	Nighttime
Winter	Saturday or Sunday	Daytime
Winter	Saturday or Sunday	Evening
Winter	Saturday or Sunday	Nighttime
Summer	Monday through Friday [1]	Daytime
Summer	Monday through Friday [1]	Evening
Summer	Monday through Friday [1]	Nighttime
Summer	Saturday or Sunday	Daytime
Summer	Saturday or Sunday	Evening
Summer	Saturday or Sunday	Nighttime

[1] "The requirement is for any of the five weekdays

A3. City Noise Ordinances

A3.1. Communities with Noise Legislation

"**Municipal Noise Ordinances: 1975.** The enactment of city noise ordinances continues to grow in the United States. Compiled below is the current list of 539 municipalities with noise regulations, up 23% over the 1974 figure of 440. These ordinances now affect a combined population of over 66 million people.

"There is a continuing interest in enacting legislation with quantitative noise emission limits which replace nonquantitative or general nuisance provisions.

"The ordinances are organized by category: Nuisance, Zoning (land use), Vehicles, Recreation Vehicles, Railroads, Aircraft, Construction and Building. New categories this year are Recreational Vehicles, Railroads, and Construction. Regulations containing acoustical criteria are referred to as performance type regulations, while those without noise emission limits are nonquantitative and difficult to enforce. Land use regulation through the zoning process is still the largest single category of noise control, with a 41% increase over 1974. All categories have grown significantly in the number of acoustical criteria enactments.

	Nuisance	Zoning	Vehicle	Recreational Vehicle	Railroad	Aircraft	Construction	Building
■ Regulation includes acoustical criteria	113	188	117	43	12	26	42	22
□ Regulation does not include acoustical criteria	359	18	93	17	6	5	55	8
– No regulation	67	333	329	479	521	508	442	509

Jurisdiction	1970 Population	Nuisance	Zoning	Vehicle	Rec/Vehicle	Railroad	Aircraft	Construction	Building
ALABAMA									
Anniston	31,533	□	–	□	–	–	–	□	–
Birmingham	300,910	□	–	–	–	–	–	–	–
Irondale	3,166	■	□	–	–	–	–	–	–
Madison	3,086	–	■	–	–	–	■	–	■
Mobile	190,026	□	–	–	–	–	–	–	–
Montgomery	133,386	□	–	–	–	–	–	–	–
ALASKA									
Anchorage	48,081	□	–	■	■	–	–	–	–
Juneau	6,050	□	–	–	–	–	–	–	–
ARIZONA									
Flagstaff	26,177	□	–	□	–	–	–	–	–
Phoenix	581,562	□	–	□	□	–	–	–	–
Tempe	62,907	■	■	■	–	–	■	–	–
Tucson	262,933	■	■	–	–	–	–	–	–
ARKANSAS									
Little Rock	132,125	□	–	–	–	–	–	–	–
Pine Bluff	57,389	□	–	–	–	–	–	–	–
CALIFORNIA									
Alhambra	62,125	■	–	–	–	–	–	–	–
Anaheim	166,704	■	■	■	–	–	–	■	■
Arcadia	43,867	■	–	–	–	–	–	–	–
Berkeley	166,716	□	–	–	–	–	–	–	–
Beverly Hills	33,416	■	–	■	–	–	–	■	■
Buena Park	63,646	■	■	–	–	–	–	–	–
Burbank	88,871	■	■	□	□	–	–	□	–
Chico	19,580	■	–	–	–	–	–	■	–
Costa Mesa	72,660	■	■	■	–	–	■	■	–
Cotati	2,081	■	■	–	–	–	–	–	–
Cupertino	18,216	□	–	–	–	–	–	–	–
Downey	88,442	■	–	■	■	–	–	□	–
El Cajon	52,273	–	■	–	–	–	–	–	–
El Segundo	15,620	■	■	□	–	–	–	□	–
Escalon	1,834	■	–	■	■	–	–	–	–
Fountain Valley	31,826	■	■	–	–	–	–	■	–
Fresno	165,972	■	■	–	–	–	–	■	–
Fremont	100,869	–	■	□	–	–	–	–	–
Gardena	41,021	■	■	■	■	–	–	■	■
Garden Grove	121,371	–	–	–	–	–	–	–	□
Glendale	132,752	■	■	□	–	–	–	□	–
Glendora	31,349	■	■	□	–	–	–	□	–
Hayward	93,058	□	–	–	–	–	■	–	■
Hemet	12,252	□	■	–	–	–	–	–	–
Hermosa Beach	17,412	□	■	□	–	■	–	–	■
Inglewood	89,385	■	■	–	–	■	■	–	–
Larkspur	10,487	■	–	■	■	–	–	–	–
Lakewood	82,973	□	■	–	–	■	■	■	–
Lodi	28,691	–	■	–	–	■	–	–	–
Lomita	19,784	■	■	–	–	–	–	–	–
Long Beach	358,633	■	–	■	–	–	■	■	–
Los Altos Hills	6,853	–	■	□	–	–	–	–	■
Los Angeles	2,816,061	□	■	■	–	–	–	□	■
Los Banos	9,188	■	–	■	■	–	–	–	–
Lynwood	43,353	–	■	□	–	–	–	–	–
Manteca	13,845	–	■	–	–	–	–	–	–
Menlo Park	26,826	□	–	–	–	–	–	–	–
Monterey	26,302	■	■	–	–	–	–	–	–
Newark	27,153	■	■	–	–	–	–	–	–
Newport Beach	49,422	■	–	■	■	–	–	–	–
Novato	31,006	■	–	■	■	–	■	■	–
Oakland	361,561	□	■	–	–	–	–	–	–
Orange	77,365	■	■	–	–	–	–	■	–
Pacifica	36,020	□	–	–	–	–	–	–	–
Palo Alto	55,966	■	■	–	–	–	–	–	–
Pasadena	112,951	■	■	□	–	–	–	■	–
Pleasant Hill	24,610	■	–	■	–	–	–	□	–
Redding	16,659	■	–	■	■	–	–	–	–
Red Bluff	7,676	□	–	–	–	–	–	–	–
Richmond	79,043	–	■	■	–	■	■	–	–
Ross	2,742	■	–	■	■	–	–	–	–
Sacramento	254,413	□	–	–	–	–	–	–	–
Salinas	58,693	□	–	□	□	–	–	–	–
San Anselmo	13,031	■	■	■	–	–	–	–	–
San Bernardino	104,251	□	–	–	–	–	–	–	–
San Clemente	17,063	□	–	–	–	–	–	–	–
San Diego	696,769	■	■	■	■	–	–	■	■
San Francisco	715,674	■	■	■	■	–	–	■	–
San Marcos	3,896	■	–	■	■	–	–	–	–
San Jose	445,779	–	–	–	–	–	□	–	–
San Leandro	68,698	□	–	–	–	–	–	–	–
San Mateo	78,991	□	■	–	–	–	–	–	■
San Rafael	38,977	□	–	–	–	–	–	–	–
Santa Barbara	70,215	□	■	–	–	–	■	–	–
Santa Clara	67,717	□	–	–	–	–	■	–	■
Santa Fe Springs	14,750	–	■	–	–	–	–	–	–
Santa Maria	32,749	–	■	–	–	–	–	–	–
Santa Monica	88,289	–	–	–	–	–	□	–	–
Santa Rosa	50,006	■	■	■	–	–	–	–	–
Sausalito	6,158	■	–	□	–	–	–	–	–

Jurisdiction	1970 Population	Nuisance	Zoning	Vehicle	Rec/Vehicle	Railroad	Aircraft	Construction	Building
Simi Valley	59,832	■	–	–	–	–	–	–	–
South El Monte	13,442	■	–	–	–	–	–	–	–
South Gate	56,909	■	–	–	–	–	–	–	–
Sunnyvale	95,403	□	■	–	–	–	–	–	–
Tracy	14,724	–	■	–	–	–	–	–	■
Torrance	134,564	■	■	■	–	–	–	□	–
Victorville	10,845	□	–	–	–	–	–	–	–
COLORADO									
Arvada	49,083	□	■	■	–	–	–	–	–
Aspen	2,404	□	■	■	–	–	–	–	–
Aurora	74,974	–	■	–	–	–	–	–	–
Boulder	66,870	□	–	■	■	–	–	–	–
Colorado Springs	135,060	□	■	■	–	■	■	–	–
Denver	514,678	□	■	■	–	–	–	–	–
Dillon	182	–	–	□	–	–	–	–	–
Englewood	33,695	□	■	■	–	–	–	–	–
Fort Collins	43,337	□	■	■	■	–	–	■	–
Lakewood	92,787	■	■	■	■	–	–	■	–
Littleton	26,466	□	■	■	■	–	–	■	–
Wheat Ridge	29,795	□	–	–	–	–	–	–	–
CONNECTICUT									
Berlin	14,149	□	■	–	–	–	–	–	–
Bridgeport	156,542	■	■	■	–	–	–	■	■
Farmington	14,390	■	■	■	–	–	–	–	–
Hartford	158,017	□	–	–	–	–	–	–	□
New Haven	137,707	□	■	–	–	–	–	–	–
Stonington	15,590	□	■	–	–	–	–	–	–
Westport	27,414	–	■	–	–	–	–	–	–
DELAWARE									
Wilmington	80,386	□	■	■	–	–	–	–	–
DISTRICT OF COLUMBIA									
District of Columbia	756,510	□	■	■	–	–	–	–	–
FLORIDA									
Anna Maria	1,400	□	–	–	–	–	–	–	–
Atlantis	844	■	■	–	–	–	–	–	–
Bal Harbor Village	2,104	□	–	–	–	–	–	–	–
Bay Harbor	4,723	□	–	–	–	–	–	–	–
Bay Lake	18	■	–	–	–	–	–	–	–
Boca Raton	28,506	■	–	–	–	–	–	□	–
Cape Canaveral	5,131	■	■	–	–	–	–	–	–
Clearwater	52,074	□	–	–	–	–	–	□	–
Cocoa Beach	11,555	–	■	–	–	–	–	–	–
Coral Gables	42,494	■	■	–	–	–	–	□	■
Dania	9,819	□	–	–	–	–	–	–	–
Daytona Beach	47,682	■	–	–	–	–	–	–	–
Deerfield Beach	19,577	■	■	–	–	–	–	–	–
Deland	11,641	–	–	■	–	–	–	–	–
Delray Beach	19,915	□	–	□	□	–	–	□	–
Edgewater	3,348	■	■	■	–	–	–	–	–
Fort Lauderdale	139,590	■	–	■	–	–	–	■	–
1 Myers	32,563	□	–	–	–	–	–	–	–
l Pierce	31,752	□	–	–	–	–	–	–	–
Gainesville	64,510	■	■	■	–	–	–	–	–
Hallandale	32,292	■	–	–	–	–	–	–	–
Hialeah	102,452	□	□	–	–	–	–	–	–
Hialeah Gardens	1,076	■	–	–	–	–	–	–	–
Hollywood	106,873	□	–	□	–	–	–	□	–
Homestead	19,022	□	–	–	–	–	–	–	–
Indian Shores	891	□	–	–	–	–	–	–	–
Jacksonville	528,865	■	■	□	–	–	–	–	–
Lake Buena Vista	22	■	–	–	–	–	–	–	–
Lakeland	45,091	□	–	–	–	–	–	–	–
Lake Park	7,927	■	■	■	■	–	–	■	–
Lake Worth	25,934	□	–	–	–	–	–	–	–
Lauderdale by the Sea	2,941	□	–	–	–	–	–	–	–
Lighthouse Point	11,760	□	–	–	–	–	–	–	–
Madiera	4,769	■	■	–	–	–	–	–	–
Margate	17,153	□	–	–	–	–	–	–	–
Melbourne	40,236	–	■	■	–	–	–	–	–
Miami	334,859	–	■	–	–	–	–	–	–
Miami Beach	89,741	■	■	–	–	–	–	–	–
Miami Shores	9,541	□	–	–	–	–	–	–	–
Miami Springs	13,384	□	–	–	–	–	–	–	–
Miramar	27,132	□	–	–	–	–	–	–	–
North Lauderdale	5,648	□	–	–	–	–	–	–	–
North Miami	42,970	■	–	–	–	–	–	–	–
North Palm Beach	12,056	■	–	–	–	–	–	–	–
Oakland Park	19,700	□	–	–	–	–	–	–	–
Oldsmar	2,090	□	■	–	–	–	–	–	–
Opa Locka	12,924	□	–	–	–	–	–	–	–
Orlando	97,565	□	■	–	–	–	■	–	–
Plantation	29,512	□	–	–	–	–	–	–	–
Plant City	15,781	□	–	–	–	–	–	–	–
Pinellas Park	28,525	□	–	–	–	–	–	–	–
Palm Beach Gardens	8,315	■	■	–	–	–	–	–	–
Pompano Beach	38,544	■	■	■	■	–	■	–	–
Riviera Beach	21,401	□	■	□	–	–	–	–	–
Redington Shores	2,111	□	–	–	–	–	–	–	–
St. Petersburg	216,232	■	■	■	–	–	–	–	–
Sarasota	44,638	□	–	–	–	–	–	–	–
South Daytona	7,825	–	■	–	–	–	–	–	–
Surfside	3,649	□	–	–	–	–	–	–	–
Tallahassee	72,586	–	–	■	–	–	–	–	–
Tampa	298,740	□	–	–	–	–	–	–	–
avares	3,673	□	–	–	–	–	–	–	–
reasure Island	6,878	□	–	–	–	–	–	–	–
Vero Beach	14,211	■	■	■	■	–	–	–	–
Virginia Gardens	2,592	□	–	–	–	–	–	–	–
West Miami	5,989	□	–	–	–	–	–	–	–
West Palm Beach	27,132	■	–	■	■	–	–	■	–
Winter Haven	16,136	■	■	■	–	–	–	–	–
GEORGIA									
Alma	3,756	□	–	□	–	–	–	–	–
Atlanta	497,421	□	–	–	–	–	–	–	–
Camilla	4,987	□	■	–	–	–	–	–	–
Carrollton	13,520	□	–	□	–	–	–	–	–
Claxton	2,669	–	■	–	–	–	–	–	–
College Park	18,203	■	■	□	–	–	■	■	–
Columbus	154,168	□	–	□	–	–	–	–	–
Cordele	10,733	–	□	–	–	–	–	–	–
Dacula	782	–	–	□	–	–	–	–	–
Danielsville	370	□	–	–	–	–	–	–	–
Decatur	21,943	□	–	–	–	–	–	–	–
Dover	220	□	–	–	–	–	–	–	–
Flowery Branch	761	□	–	–	–	–	–	–	–
Forest Park	19,994	□	–	□	□	□	–	□	–
Griffin	22,734	□	–	–	–	–	–	–	–
Hapeville	9,567	□	–	–	–	–	–	–	–
Kingsland	1,631	□	–	□	–	–	–	–	–
Lake City	2,306	□	–	□	□	–	–	□	–
Louisville	2,691	□	–	–	–	–	–	–	–
Macon	122,423	□	–	□	–	–	–	–	–
Moultrie	14,400	■	■	–	–	–	–	–	–
Newnan	11,205	□	■	□	–	–	–	–	–
Peachtree City	793	–	–	□	–	–	–	–	–
Rincon	1,854	□	–	–	–	–	–	–	–
Riverdale	2,521	□	–	–	–	–	–	–	–
Savannah	118,345	■	■	■	■	–	–	■	–
Tyrone	136	□	–	–	–	–	–	–	–
Warner Robins	33,491	–	■	–	–	–	–	–	–
Waynesboro	5,530	□	–	–	–	–	–	–	–
HAWAII									
Honolulu	324,871	□	■	■	–	–	–	–	–
IDAHO									
Boise	74,990	□	□	□	–	–	–	–	–
Idaho Falls	35,776	–	–	■	–	–	–	–	–
Pocatello	40,036	□	–	■	–	–	–	–	–
ILLINOIS									
Arlington Heights	64,884	–	■	–	–	–	–	–	–
Chicago	3,369,359	■	■	■	■	–	–	■	–
Decatur	90,397	□	–	–	□	–	–	–	–
Des Plaines	57,239	□	■	■	■	–	■	■	–
Joliet	80,378	□	–	□	–	–	–	–	–
Marengo	4,235	■	–	■	–	–	–	–	–
Moline	46,237	–	–	■	–	–	–	–	–
Northbrook	27,297	–	–	–	–	–	–	–	■
Park Ridge	42,466	■	–	■	–	–	■	–	–
Peoria	126,963	■	–	■	–	–	–	–	–
Rockford	147,370	□	–	■	■	–	–	□	–
Savanna	4,942	□	–	□	–	–	–	–	–
Urbana	32,800	□	■	■	■	–	–	■	–
INDIANA									
Evansville	138,764	□	■	■	■	–	■	□	–
Gary	175,415	□	■	□	–	–	–	–	–
Hammond	107,888	□	■	■	■	–	■	–	–
Indianapolis	745,739	■	–	–	–	–	–	–	□
Ogden Dunes	992	–	■	–	–	–	–	–	–
South Bend	125,580	□	–	□	–	–	–	□	–
IOWA									
Cedar Falls	29,597	□	■	■	–	–	–	□	–
Council Bluffs	60,348	□	–	□	□	–	–	□	–
Davenport	98,459	□	–	□	–	–	–	□	–
Des Moines	200,587	□	–	□	–	–	–	□	–
Dubuque	62,309	□	■	■	–	–	–	–	–
Pella	6,668	–	–	■	–	–	–	–	–
Sioux City	82,925	□	□	□	–	–	–	–	–
Storm Lake	8,591	□	■	■	–	–	–	–	–
Waterloo	75,533	□	–	–	–	–	–	–	–
KANSAS									
Lawrence	45,698	□	–	□	–	–	–	–	–
Prairie Village	28,138	□	■	■	■	–	–	■	–
Wichita	276,534	□	–	□	–	–	–	–	□
KENTUCKY									
Covington	52,535	■	–	□	□	–	–	□	–
Lexington	108,137	□	–	–	–	–	–	–	–
Louisville	361,472	–	–	■	■	–	■	■	–
LOUISIANA									
Baton Rouge	165,963	□	–	□	□	–	–	□	–
New Orleans	593,471	□	□	–	–	–	–	–	–

Jurisdiction	1970 Population	Nuisance	Zoning	Vehicle	Rec/Vehicle	Railroad	Aircraft	Construction	Building
MARYLAND									
Baltimore	905,759	□	■	-	□	-	-	-	-
Cumberland	29,724	□	-	-	-	-	-	-	-
Rockville	41,564	□	-	-	-	-	-	-	-
MASSACHUSETTS									
Acton	14,770	-	□	-	-	-	-	-	-
Boston	641,070	■	■	■	-	-	-	-	-
Concord	16,148	□	-	□	□	-	-	□	-
Fall River	96,898	□	□	-	-	-	-	-	-
Milford	19,352	-	■	-	-	-	-	-	-
Newton	91,263	□	-	□	-	-	-	-	-
Pittsfield	57,020	■	-	■	-	-	-	-	-
Springfield	163,905	□	■	-	-	-	-	-	-
Worcester	176,572	□	-	-	-	-	-	-	-
MICHIGAN									
Ann Arbor	99,797	□	■	■	-	-	-	-	□
Augusta Township	1,016	□	-	-	-	-	-	-	-
Beverly Hills	13,598	□	-	-	-	-	-	-	-
Birmingham	26,170	□	-	■	-	-	-	-	-
Comstock	5,003	■	-	■	■	-	-	-	-
Dearborn	104,199	□	-	-	-	-	□	-	-
Detroit	1,512,893	□	-	-	-	-	-	-	-
Farmington	10,329	□	-	-	-	-	-	-	-
Grand Rapids	197,649	■	■	■	■	-	-	■	■
Kalamazoo	85,555	□	■	■	■	■	-	■	-
Meridian Township	23,817	■	■	■	■	-	-	-	-
Milford	4,699	-	■	-	-	-	-	-	■
Pontiac	85,279	□	■	-	-	-	-	-	-
Ravenna	851	□	-	-	-	-	-	-	-
Saginaw	91,849	□	□	□	-	□	-	□	-
Troy	39,419	□	-	-	-	-	-	-	-
Warren	179,260	□	■	□	-	-	-	-	-
Westland	86,749	■	■	-	-	-	-	-	-
Wyoming	56,560	□	-	-	-	-	-	-	-
MINNESOTA									
Bloomington	81,970	□	■	□	■	-	-	□	-
Cannon Falls	2,155	-	-	■	-	-	-	-	-
Columbia Heights	23,837	-	■	-	-	-	-	-	-
Minneapolis	434,400	□	■	■	-	-	-	■	□
Rochester	53,766	□	■	-	-	-	-	-	-
St. Paul	309,828	□	-	-	-	-	-	-	-
MISSISSIPPI									
Jackson	153,968	□	-	-	-	-	-	-	-
MISSOURI									
Bridgeton	19,992	□	-	-	-	-	-	-	-
Gladstone	23,422	□	-	■	-	-	-	■	-
Grandview	17,456	□	-	□	-	-	-	□	-
Independence	111,662	□	■	□	-	-	-	-	-
Kansas City	507,330	□	■	■	-	-	-	-	-
St. Louis	622,236	□	■	■	□	-	-	■	-
Springfield	120,096	□	-	□	-	-	-	-	-
Waynesville	3,376	□	-	□	-	-	-	-	-
NTANA									
ngs	61,581	□	-	-	-	-	-	-	-
Great Falls	60,091	□	■	■	■	■	■	■	-
Helena	22,730	□	■	■	■	■	-	■	-
Missoula	29,497	■	■	■	■	-	-	-	-
NEBRASKA									
Beatrice	12,787	□		-	-	-	-	-	-
Lincoln	149,518	-	-	■	-	-	-	-	-
McCook	8,285	□	■	■	-	■	-	-	-
Omaha	346,929	□	-	□	-	-	-	□	-
Scottsbluff	14,507	□	-	□	-	-	-	□	□
Sidney	6,258	□	-	□	-	-	-	-	-
NEVADA									
Las Vegas	125,787	□	■	□	-	-	-	-	-
NEW HAMPSHIRE									
Manchester	87,754	□	-	-	-	-	-	-	-
NEW JERSEY									
Absecon	6,094	□	-	-	-	-	-	-	-
Asbury Park	16,533	□	-	-	-	-	-	-	-
Bayonne	72,743	□	-	-	-	-	-	-	-
Belleville	34,643	■	■	-	-	-	-	-	-
Berkeley Heights	13,078	■	■	-	-	-	-	■	■
Bloomfield	52,059	□	-	-	-	■	-	-	-
Boonton	9,261	■	■	-	-	-	-	-	-
Bordentown	4,490	□	-	-	-	-	-	-	-
Brigantine	6,741	□	-	-	-	-	-	-	-
Burlington	11,991	□	-	-	-	-	-	-	-
Camden	102,551	□	-	-	-	-	-	-	-
Cape May	4,392	□	-	-	-	-	-	-	-
Clifton	82,437	■	■	-	-	-	-	-	-
Clinton	1,742	□	-	-	-	-	-	-	-
Corbin	258	□	-	-	-	-	-	-	-
Dover	15,039	□	-	-	-	-	-	-	-
East Orange	75,471	□	-	-	-	-	-	-	-
Elizabeth	112,654	□	■	-	-	-	-	-	-
Ewing	32,831	□	-	-	-	-	-	-	-
Fairlawn	37,975	□	■	-	-	-	-	-	-
Gloucester	14,707	□	■	-	-	-	-	-	-
Hackensack	36,008	□	-	-	-	-	-	-	-
mmonton	11,464	□	■	-	-	-	-	-	-
over	10,700	-	■	-	-	-	-	-	-
rison	11,811	□	-	-	-	-	-	-	-
Hasbrouck Heights	13,651	□	-	-	-	-	-	-	-
Hawthorne	9,173	-	■	-	-	-	-	-	-
Hightstown	5,431	□	-	-	-	-	-	-	-
Hoboken	45,380	-	■	-	-	-	-	-	-
Irvington	59,743	-	■	-	-	-	-	-	-
Jersey City	260,545	□	-	□	-	-	-	-	-
Lakewood	17,874	□	■	-	-	-	■	□	-
Linden	41,409	□	-	□	-	-	-	□	-
Long Branch	31,774	□	-	-	-	-	-	-	-
Margate	10,576	□	-	-	-	-	-	-	-
Maywood	11,087	■	-	-	-	-	-	-	-
Morristown	17,662	□	-	-	-	-	-	-	-
Newark	382,417	□	-	-	-	-	-	-	-
Newton	7,297	□	-	-	-	-	-	-	-
North Haledon	7,614	□	-	-	-	-	-	-	-
North Wildwood	3,914	□	-	-	-	-	-	-	-
Nutley	31,913	□	-	-	-	-	-	-	-
Ocean City	10,575	□	-	-	-	-	-	-	-
Orange City	32,566	□	-	-	-	-	-	-	-
Passaic	55,124	□	-	-	-	-	-	-	-
Paterson	144,824	□	-	-	-	-	-	-	-
Pemberton Borough	1,576	□	-	-	-	-	-	-	-
Perth Amboy	38,798	□	-	-	-	-	-	-	-
Plainfield	46,862	□	-	-	-	-	-	-	-
Pleasantville	13,778	□	■	-	-	-	-	-	-
Princeton	12,311	■	■	-	-	-	-	-	-
Rahway	29,114	□	■	-	-	-	-	-	-
Ridgefield Park	14,453	□	-	-	-	-	-	-	-
Salem	7,648	□	-	-	-	-	-	-	-
Secaucus	13,228	□	-	-	-	-	-	-	-
South Amboy	9,338	□	■	-	-	-	-	□	-
Sparta	10,919	■	-	■	-	-	-	□	□
Summit	23,620	□	-	-	-	-	-	-	-
Trenton	104,638	□	-	-	-	-	-	-	-
Vineland	47,399	□	-	-	-	-	-	-	-
Wayne	49,141	□	-	-	-	-	-	-	-
Westfield	33,720	□	-	-	-	-	-	-	-
West Orange	43,915	■	■	■	■	-	-	-	-
Wharton	11,105	-	■	-	-	-	-	-	-
Wildwood	4,110	□	-	-	-	-	-	-	-
Woodbridge	78,846	■	-	-	-	-	-	-	-
MEXICO									
querque	243,751	□	□	□	□	-	□	□	-
Gallup	13,779	□	-	□	-	-	-	-	-
Los Alamos	11,310	□	■	■	-	-	-	-	-
NEW YORK									
Albany	115,781	-	□	-	-	-	-	-	-
Binghamton	64,123	-	■	-	-	-	-	-	-
Buffalo	462,768	□	-	□	-	-	-	-	-
Freeport	40,374	□	-	-	-	-	-	-	-
Hempstead	39,411	□	-	-	-	-	■	-	-
Ithaca	26,226	□	-	-	-	-	-	-	-
Lake George	1,506	□	□	-	-	-	-	-	-
Lynbrook	23,776	□	-	-	-	-	-	-	-
Mamaroneck	18,909	□	-	■	-	-	-	-	-
New Rochelle	75,385	□	-	-	-	-	-	-	-
New York City	7,895,563	□	■	■	-	-	-	-	■
Niskayuna	6,155	-	■	-	-	-	-	-	-
Ossining	21,659	□	-	-	-	-	-	-	-
Rochester	296,233	□	-	-	-	-	-	-	-
Utica	91,611	□	-	-	-	-	-	-	-
White Plains	50,125	■	-	□	-	-	-	-	-
Yonkers	204,297	□	-	-	-	-	-	-	-
NORTH CAROLINA									
Aberdeen	1,592	□	-	-	-	-	-	-	-
Asheville	57,681	□	-	-	-	-	-	-	-
Aurora	620	□	-	-	-	-	-	-	-
Belmont	4,814	□	-	-	-	-	-	-	-
Benson	2,267	□	-	-	-	-	-	-	-
Boone	8,754	□	-	-	-	-	-	-	-
Burlington	35,930	□	-	-	-	-	-	-	-
Carolina Beach	1,663	□	-	-	-	-	-	-	-
Carrboro	3,472	□	-	-	-	-	-	-	-
Chapel Hill	25,537	■	-	□	-	-	-	□	-
Concord	18,464	□	-	-	-	-	-	-	-
Conetoe	160	□	-	-	-	-	-	-	-
Durham	95,438	□	-	□	-	-	-	□	-
Fayetteville	53,510	□	-	□	-	-	-	□	-
Forest City	7,179	□	-	-	-	-	-	-	-
Franklin	2,336	□	-	-	-	-	-	-	-
Fuquay-Varina	3,576	□	-	-	-	-	-	-	-
Gastonia	47,143	□	-	-	-	-	-	-	-
Gibsonville	2,019	□	-	-	-	-	-	-	-

Jurisdiction	1970 Population	Nuisance	Zoning	Vehicle	Rec/Vehicle	Railroad	Aircraft	Construction	Building
Goldsboro	26,810	□	–	–	–	–	–	–	–
Greensboro	144,076	□	–	□	–	–	–	–	–
Hickory	20,569	□	–	–	–	–	–	–	–
High Point	63,204	□	–	–	–	–	–	–	–
Kings Mountain	8,405	■	–	–	–	–	–	–	–
Kinston	22,309	□	–	–	–	–	–	–	–
Kure Beach	394	□	–	–	–	–	–	–	–
Laurinburg	8,859	□	–	–	–	–	–	–	–
Lumberton	16,961	□	–	–	–	–	–	–	–
Madison	2,081	□	–	–	–	–	–	–	–
Manteo	547	□	–	–	–	–	–	–	–
Marion	3,335	□	–	–	–	–	–	–	–
Monroe	11,282	□	–	–	–	–	–	–	–
Mt. Pleasant	1,174	□	–	–	–	–	–	–	–
New Bern	14,660	□	–	□	–	–	–	–	–
Newton	7,857	□	–	–	–	–	–	–	–
Raleigh	123,793	□	–	□	–	–	–	–	–
Red Springs	3,383	□	–	–	–	–	–	–	–
Roanoke Rapids	13,508	□	–	–	–	–	–	–	–
Rocky Mount	34,284	□	–	–	–	–	–	–	–
Roper	649	□	–	–	–	–	–	–	–
Salisburg	22,515	□	–	–	–	–	–	–	–
Seaboard	611	□	–	–	–	–	–	–	–
Silver City	4,689	□	–	–	–	–	–	–	–
Southern Pines	5,937	□	–	–	–	–	–	–	–
Statesville	19,996	□	–	–	–	–	–	–	–
Tarboro	9,425	□	■	–	–	–	–	–	–
Thomasville	15,230	□	–	–	–	–	–	–	–
Valdese	3,182	□	–	–	–	–	–	–	–
Wake Forest	3,148	□	–	–	–	–	–	–	–
Walnut Cove	1,213	□	–	–	–	–	–	–	–
Warsaw	2,701	□	–	–	–	–	–	–	–
Washington	8,961	□	–	–	–	–	–	–	–
Wilmington	46,169	□	–	–	–	–	–	–	–
Winston-Salem	132,913	□	■	■	–	–	–	–	–
Winton	917	□	–	–	–	–	–	–	–
NORTH DAKOTA									
Bismark	34,703	□	–	–	–	–	–	–	–
OHIO									
Akron	275,425	□	–	–	–	–	–	–	–
Amherst	9,902	□	–	–	□	–	–	–	–
Cincinnati	452,524	□	–	■	–	–	–	–	–
Cleveland	750,903	□	■	■	–	–	–	□	–
Columbus	540,025	□	■	–	–	–	–	–	–
Dayton	243,601	□	■	–	–	–	–	–	–
Middleburg Heights	12,367	–	■	■	–	–	–	–	–
Shaker Heights	36,306	□	–	■	–	–	–	–	–
Springfield	81,941	□	–	–	–	–	–	–	–
Toledo	383,818	□	■	■	■	–	–	■	–
University Heights	17,055	□	–	–	–	–	–	–	–
OKLAHOMA									
Oklahoma City	368,856	□	■	–	–	–	–	–	–
Tulsa	330,350	□	–	–	–	–	–	–	–
OREGON									
Coos Bay	13,466	□	–	□	–	–	–	□	–
Grants Pass	12,455	□	■	–	–	–	–	–	–
Medford	28,454	□	–	–	–	–	–	–	–
Portland	380,620	□	■	■	■	–	–	■	–
Silverton	4,301	–	■	–	–	–	–	–	–
PENNSYLVANIA									
Allentown	109,527	■	■	■	–	–	■	–	–
Bethlehem	72,686	□	■	–	–	–	–	–	–
Erie	129,231	□	–	–	–	–	–	–	–
Girard	2,631	–	■	–	–	–	–	–	–
Philadelphia	1,950,098	□	–	–	–	–	–	–	–
Pittsburgh	520,117	□	–	–	–	–	–	–	–
Scranton	103,564	□	–	–	–	–	–	–	–
West Mifflin	28,070	□	■	–	–	–	–	–	–
RHODE ISLAND									
Cranston	74,287	–	■	–	–	–	–	–	–
East Providence	48,151	–	■	–	–	–	–	–	–
Pawtucket	76,984	■	■	–	–	–	–	■	■
Providence	179,116	□	–	–	–	–	–	–	–
Warwick	83,694	–	■	–	–	–	–	–	–
SOUTH CAROLINA									
Columbia	113,542	–	■	■	–	–	■	–	–
Florence	25,997	–	■	–	–	–	–	–	–
SOUTH DAKOTA									
Lemmon	2,456	–	–	■	–	–	–	–	–
Sioux Falls	72,488	–	□	□	–	–	–	–	–
TENNESSEE									
Chattanooga	119,923	□	–	□	–	–	–	□	–
Kingsport	31,939	□	–	□	–	□	–	–	–
Knoxville	276,293	–	–	■	■	–	–	□	–
Memphis	623,530	□	–	□	–	–	–	□	–
Nashville	448,003	–	■	□	–	–	–	–	–
TEXAS									
Amarillo	127,010	□	■	■	–	–	–	–	–
Austin	193,862	□	–	–	–	–	–	–	–
Beaumont	117,548	□	–	–	–	–	–	□	–
Corpus Christi	204,525	□	–	□	–	–	–	–	–
Dallas	844,401	□	■	–	–	–	–	–	–
El Paso	322,261	□	–	□	–	–	–	–	–
Fort Worth	393,476	□	–	□	–	□	–	–	–
Garland	81,437	□	–	□	–	–	–	–	–
Houston	1,232,802	□	–	–	–	–	–	–	–
Irving	97,457	□	–	□	–	–	–	□	–
Killeen	35,507	□	–	□	–	–	–	–	–
Mineral Wells	18,411	□	–	□	–	–	–	–	–
Odessa	78,380	□	■	□	–	□	□	□	–
Saginaw	2,382	□	–	□	–	–	–	□	–
San Antonio	654,153	□	–	–	–	–	–	–	–
Texarkana	30,497	□	–	□	–	–	–	□	–
Wichita Falls	96,265	□	–	□	–	–	–	□	–
UTAH									
Ogden	69,478	■	■	■	–	–	–	■	–
Provo	53,131	■	–	■	–	–	–	■	■
Roosevelt	2,005	□	–	–	–	–	–	–	–
Salt Lake City	175,885	■	■	■	■	■	–	■	–
VIRGINIA									
Alexandria	110,927	□	–	□	–	–	–	–	–
Arlington	174,284	□	■	■	–	–	–	–	–
Chesapeake	89,580	□	□	–	–	–	–	–	–
Hampton	120,779	□	□	□	□	–	–	□	–
Newport News	136,177	■	■	–	–	–	–	–	–
Norfolk	307,951	□	–	□	–	–	–	□	–
Richmond	249,621	□	□	–	–	–	–	–	–
Virginia Beach	172,106	□	■	–	–	–	–	–	–
WASHINGTON									
Bellevue	61,102	–	■	–	–	–	–	–	–
College Place	4,510	□	–	■	–	–	–	–	–
Medina	3,455	■	–	■	–	–	–	■	–
Pullman	20,509	■	■	□	–	–	–	□	–
Richland	26,290	–	■	–	–	–	–	–	–
Seattle	530,831	□	–	■	–	–	–	–	–
Snohomish	5,174	■	■	■	–	–	■	–	–
Spokane	170,516	□	□	–	–	–	–	–	–
Tacoma	154,581	–	■	–	–	–	–	–	■
Walla Walla	23,619	□	–	□	□	□	–	□	–
Yakima	45,588	□	–	□	–	–	–	□	–
WISCONSIN									
Madison	173,258	■	■	□	–	–	–	–	–
Milwaukee	717,372	■	■	■	–	–	–	–	–
Racine	95,162	■	■	–	–	–	–	–	–
Sparta	6,258	□	–	□	–	–	–	–	–
WYOMING									
Casper	39,361	–	□	–	–	–	–	–	–
Cheyenne	40,914	■	–	■	–	–	–	–	–
Lander	7,112	□	–	■	–	–	–	–	–
Powell	4,807	□	–	■	–	–	–	–	–
Riverton	7,995	–	–	■	–	–	–	–	–
Worland	5,055	□	–	–	–	–	–	–	–
Total	[illegible]								

NOTE: The current list of municipalities with noise regulations are available at any public library in the United States. The listing has been reproduced here for the convenience of the users of this guide.

A3.2. Chicago Noise Regulations

"Department of Environmental Control, News on Noise in Chicago. A new ordinance, directed at urban noise sources, becomes effective July 1, 1971. The ordinance incorporates recommendations made by acoustical consultants in a report on urban noise submitted to the city.

"Extensive public hearings were conducted by the Environmental Committee of the Chicago City Council in which representatives from industry, conservation groups, environmental organizations, medical authorities and interested citizens presented their viewpoints. After weighing the testimony from the public hearings and the recommendations of the consultants, the City Council unanimously passed a comprehensive noise ordinance on March 10, 1971.

"*How Sound is Measured.* The most commonly used yardstick for measuring sound pressure on the ear is the decibel (dB) scale. The hearing threshold — the point where one begins to hear — starts at zero decibels. Leaves may rustle at 10 to 20 decibels, hardly an assault to the ear. A conversation overheard at three feet is around 60 decibels. Since the ear winces most at high pitch sounds, experts use sound level meters based on what is called an A scale. This A scale gives greater weight to high tones to measure noise likely to be annoying or harmful. A rock group might produce music which could run as high as 120 decibels A weighted dB(A).

"*New Restrictions.* Manufacturers must certify that the following vehicles, construction and industrial equipment, agricultural equipment, powered commercial equipment and other powered equipment for residential areas and recreational vehicles sold in Chicago meet the noise limitations of the ordinance. Noise from these products will be measured with instruments to find the dB(A) level at a distance of 50 feet from the vehicle.

"*Motorcycles*

Manufacture Date	Noise Limit by dB(A)
Before Jan 1, 1970	92
After Jan 1, 1970	88
After Jan 1, 1973	86
After Jan 1, 1975	84
After Jan 1, 1980	75

"*Vehicles with Gross Weight of 8000 lb or More*

Manufacture Date	Noise Limit by dB(A)
After Jan 1, 1968	88
After Jan 1, 1973	86
After Jan 1, 1975	84
After Jan 1, 1980	75

"*Cars, Other Motor Vehicles or Cycles*

Manufacture Date	Noise Limit by dB(A)
Before Jan 1, 1973	86
After Jan 1, 1973	84
After Jan 1, 1975	80
After Jan 1, 1980	75

"Construction and Industrial Equipment, including Tractors, Bulldozers, Drills, Loaders, Power Shovels, Cranes, Derricks, Motor Graders, Paving Machines, Off Highway Trucks, Ditchers, Trenchers, Compactors, Scrapers, Wagons, Pavement Breakers, Compressors and Pneumatic Powered Equipment — Pile Drivers are not Included

Manufacture Date	Noise Limit by dB(A)
After Jan 1, 1972	94
After Jan 1, 1973	88
After Jan 1, 1975	86
After Jan 1, 1980	80

"*Agricultural Tractors and Equipment*

Manufacture Date	Noise Limit by dB(A)
After Jan 1, 1972	88
After Jan 1, 1975	86
After Jan 1, 1980	80

"Powered Commercial Equipment Twenty Horsepower or Less for Occasional Use in Residential Areas includes Chain Saws, Pavement Breakers, Log Chippers, Powered Hand Tools and the Like

Manufacture Date	Noise Limit by dB(A)
After Jan 1, 1972	88
After Jan 1, 1973	84
After Jan 1, 1980	80

"Powered Equipment in Residential Areas for Repeated Use such as Lawnmowers, Small Lawn and Garden Tools, Riding Tractors, Snow Removal Equipment

Manufacture Date	Noise Limit by dB(A)
After Jan 1, 1972	74
After Jan 1, 1975	70
After Jan 1, 1978	65

"*Snowmobiles*

Manufacture Date	Noise Limit by dB(A)
After Jan 1, 1971	86
After June 1, 1972	82
After June 1, 1974	73

"*Dune Buggies, All Terrain Vehicles, Go-Carts, Mini Bikes*

Manufacture Date	Noise Limit by dB(A)
After Jan 1, 1971	86
After Jan 1, 1973	82
After Jan 1, 1975	73

"*Noise Responsibility Does Not End with Manufacturer.* Under the ordinance the manufacturer is required to turn out products that will meet prescribed noise levels. The user of these products is also subject to limitations. He must see that the product is kept in good working condition so that it will not give off more noise than the manufacturer intended. He cannot modify or change the product to make it louder, and in operating the following restrictions must be met. These restrictions apply to the total noise from a vehicle or any combination of vehicles. Noise limits will be measured at a distance of 50 feet from the following vehicles.

"Restrictions by Speed for Operation of Motor Vehicles with Manufacturer's Gross Volume Weight of 8000 lb or more, and Any Combination of Vehicles Towed by Same

	Noise Limit by dB(A)	
	For Posted Speed Limits	
Date	35 mi/h or Less	Over 35 mi/h
Before Jan 1, 1973	88	90
After Jan 1, 1973	86	90

"*Motorcycles*

	Noise Limit by dB(A)	
	For Posted Speed Limits	
Date	35 mi/h or Less	Over 35 mi/h
Before Jan 1, 1978	82	86
After Jan 1, 1978	78	82

"Any other Motor Vehicle and Any Combination of Vehicles Towed by Same

	Noise Limit by dB(A)	
	For Posted Speed Limits	
Date	35 mi/h or Less	Over 35 mi/h
After Jan 1, 1970	76	82
After Jan 1, 1978	70	79

"*Operational Standards for Recreational Vehicles.* On property zoned for business or residential use, the following limitations must be maintained during operation:

Date	Noise Limit by dB(A)
Before Jan 1, 1973	86
After Jan 1, 1973	82

"*Engine Powered Boats.* Engine powered pleasure vessels, engine powered crafts or motorboats operating in Chicago harbors or any waterway in the city or on Lake Michigan within two miles of the corporate limits of the city are subject to the following regulations:

Date	Noise Limit by dB(A)
Before Jan 1, 1975	85
After Jan 1, 1975	76

"*Noise from Buildings.* (In Business and Commercial Districts). Noise will be measured at the *boundaries of the lot.* This includes noise from such activities as production, processing, cleaning, servicing, testing and repair of materials, goods, or products. Noise levels from any of these functions cannot exceed 62 dB(A).

"(In Manufacturing Districts) In districts zoned as manufacturing (light to heavy), noise is measured at district boundaries. The noise limitations range from 55 dB(A) to 61 dB(A). Where manufacturing zoning boundaries meet business and commercial zoning boundaries, the noise limit is also measured at the boundary district and ranges from 62 to 66 dB(A).

"*Vibrations.* Any vibration that can be felt beyond the property line in any zoning district, whether manufacturing, business, commercial or residential, is in violation of the ordinance. Instruments are not needed to determine the vibration.

"*Horns or Audible Signal Devices.* Motor vehicles not in motion may not blow horns or sound audible signal devices. Moving vehicles may blow horns only in an emergency. Sounds coming from ice cream vendors would be subject to this part of the ordinance.

"*Public Performances.* Public performances, such as parades and concerts, are not subject to the operating performance standards of the ordinance. A city permit is necessary for such performances.

"*Other Restrictions of the Ordinance.* (Retained from 1957 Ordinance)

— No loud noises in public ways.
— No performance of musical instruments in public places.
— No blowing of steam whistles at factories or plants except for emergencies.
— No boisterous noise from buildings.
— No building construction operations between 9:30 p.m. and 8:00 a.m., except for public improvements.
— No standing on private property for vehicles in excess of four tons for more than two minutes (bus turn arounds exempted).

"*Penalties for Violations.* First offense — $15 to $300.

Second and subsequent offenses in any 180-day period — $50 to $500, or six months in County Jail, or both.

A4. References

[B1] ANSI S1.4-1983, American National Standard Specification for Sound-Level Meters.[12]

[B2] ANSI S3.1-1977, American National Standard Criteria for Permissible Ambient Noise During Audiometric Testing.

[B3] ANSI S3.6-1969 (R 1973), American National Standard Specifications for Audiometers.

[B4] ANSI S2.45-1983/ASA 51, American National Standard Electrodynamic Test Equipment for Generating Vibration — Methods for Describing Equipment Characteristics.[13]

[B5] ISO R389-1964, Standard Reference Zero for the Calibration of Pure-Tone Audiometers.[14]

[B6] 29 CFR 1910.95 OSHA, Occupational Noise Standards.[15]

[B7] 29 CFR Bulletin 334, Guidelines to the Department of Labor's Occupational Noise Standards.

[B8] Webster's New Collegiate Dictionary. Springfield, MA: G. and C. Merriam Company.

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[12] ANSI publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

[13] This publication is available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018. Copies are also available from the Acoustical Society of America, 335 East 45th Street, New York, NY 10017.

[14] ISO publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

[15] OSHA publications are available from Occupational Safety and Health Administration, US Department of Labor, Washington, DC 20210 or from the nearest regional or area office of the United States Department of Labor.

Appendix B

Publications Applicable to Power-Station Noise

ABMA Procedure for the Measurement of Sound from Large Field-Erected Steam Generators.[16] The purpose of this procedure is to set forth a method for the measurement and recording on data sheets of the sound-pressure levels of large field-erected steam generators and their immediate auxiliaries.

ABMA Procedure for the Measurement of Sound from Packaged Boiler Units. The purpose of this procedure is to provide a standard test for the measurement of airborne sound from packaged steam or hot water generators (boilers), using water or other fluids, and from liquid phase heaters.

AGMA 295.04-77, Specification for Measurement of Sound on High-Speed Helical and Gear Units.[17] The specifications and procedures apply to sound measurement, testing methods, and limiting values of direct air-borne sound generated by a gear unit, and the auxiliary equipment required for its operation, whose prime mover is not integral with the unit.

AGMA 297.02-83, Sound for Enclosed Helical, Herringbone, and Spiral Bevel Gear Drives. The purpose of this standard is to present the instrumentation and procedure to be used for sound measurements of enclosed helical, herringbone, and spiral bevel gear drives and to present typical maximum A-Weighted sound levels. This standard includes the instrumentation and procedure necessary for the determination of the gear unit sound level or octave-band sound-pressure levels.

AGMA 298.01-1975, Sound for Gearmotors and In-Line Reducers and Increasers. The purpose of this standard is to present the instrumentation and procedure to be used for sound measurements of gearmotors and in-line reducers and increasers and to present typical maximum A-weighted sound levels.

AMCA STANDARD 300-1967, Test Code for Sound Rating.[18] This code establishes a practical method of determining the sound-power level of an air-moving

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[16] ABMA publications are available from American Boiler Manufacturers Association, 950 N. Glebe Rd, Suite 160, Arlington, VA 22203.

[17] AGMA publications are available from American Gear Manufacturers Association, 1901 North Ft Myer Drive, Suite 1000, Arlington, VA 22209.

[18] AMCA publications are available from Air Movement and Control Association, 30 W. University Dr, Arlington Heights, IL 60004.

device (AMD). The test set-ups are designed to represent general usage of the AMDs tested.

AMCA BULLETIN 301-1965, Standard Method of Publishing Sound Ratings for Air-Moving Devices. This bulletin establishes a standard method of publishing sound ratings for air-moving devices. This bulletin applies to

(1) Centrifugal fans
(2) Axial and propeller fans
(3) Power roof and wall ventilators
(4) Steam and hot water unit heaters

It is intended that this bulletin shall also apply to central station heating, ventilating and air-conditioning units.

AMCA PUBLICATION 303-1973, Application of Sound-Power Ratings for Ducted Air-Moving Devices. AMCA sound-power level ratings are indicators of the sound generated by an air-moving device when operated at various points within its normal operating range. The ratings are obtained from tests conducted by the method described in AMCA STANDARD 300-1967, Test Code for Sound Rating, and are published in accordance with AMCA BULLETIN 301-1965, Standard Method of Publishing Sound Ratings for Air-Moving Devices.

AMCA PUBLICATION 311-67, Certified Sound-Ratings Program for Air-Moving Devices. The purpose of the certified sound-ratings program is to give the buyer, specifier, and user of air-moving equipment increased assurance that published sound ratings are reliable. At the same time, the program establishes standard testing and rating methods and ensures the manufacturer that competitive ratings have been checked by an impartial authority.

ANSI S1.1-1960 (R1976), American National Standard Acoustical Terminology.[19]

ANSI S1.2-1962 (R1976), American National Standard Method for the Physical Measurement of Sound (Partially Revised—see S1.13-1971 and S1.21-1972). This standard applies primarily to airborne sound produced by apparatus which normally operates in air. These sounds shall be nonimpulsive and of sufficient duration to be within the dynamic measuring capabilities of the instruments used.

ANSI S1.4-1983 (ASA 47-83), Specification for Sound-Level Meters. This standard provides the minimum requirements for three basic types of sound-level meters: Types 1, 2, and 3 with performance requirements that become progressively less stringent, proceeding from Types 1 to 3. Provision is made for a special purpose sound-level meter—type S.

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[19] ANSI publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

ANSI S1.6-1984 (ASA 53-84), Preferred Frequencies, Frequency Levels, and Band Numbers for Acoustical Measurements (Agrees with ISO 266-1975).

ANSI S1.7-1970, Method of Test for Sound Absorption of Acoustical Materials in Reverberation Rooms (see ASTM C423-77).

ANSI S1.8-1969 (R1974), American National Standard Preferred Reference Quantities for Acoustical Levels. Reference quantities are stated in units of the International System (Systeme International SI), and also in centimeter-gram-second (cgs) and British units.

ANSI S1.10-1966 (R1976), American National Standard Methods for the Calibration of Microphones (see also IEC 327-1971). In this standard, methods are described for performing absolute and comparison calibrations of laboratory standard microphones.

ANSI S1.11-1966 (R1976), American National Standard Specification for Octave, Half-Octave, and Third-Octave Band Filter Sets (see also IEC 225-1966).

ANSI S1.12-1967 (R1978), American National Standard Specifications for Laboratory Standard Microphones.

ANSI S1.13-1971 (R1976), American National Standard Methods for the Measurement of Sound-Pressure Levels. (Partial revision of S1.2-1962). The purpose of this standard is to provide uniform guidelines for measuring and reporting sound-pressure levels observed under different environmental conditions. This standard is intended to assist in the preparation of test codes for

(1) Determining compliance with a specification, ordinance, or acoustical criterion

(2) Obtaining information to assess the effects of noise on people or equipment.

ANSI S3.4-1980 (ASA 37-80), Procedure for the Computation of Loudness of Noise. This standard specifies a procedure for calculating the loudness experienced by a typical listener under the conditions of a diffuse field with a broadband spectrum which is essentially steady-state.

ANSI S5.1-1971, Test Code for the Measurement of Sound from Pneumatic Equipment (see CAGI Test Code 1969).

ANSI S6.1-1973, Qualifying a Sound Data Acquisition System (see SAE J184-1978).

ARI STANDARD 575-1979, Standard for Method of Measuring Machinery Sound

Within Equipment Rooms.[20] The purpose of this standard is to establish a uniform method of measuring, recording, and specifying the sound-pressure level of machinery installed in mechanical equipment spaces. This standard applies to water-chilling systems, pumps, and similar operating machines and parts thereof, which for reasons of size or operating problems cannot practically be evaluated by the procedure of ASHRAE 36-72, Methods of Testing for Sound Rating Heating, Refrigerating, and Air-Conditioning Equipment.

ASA STD 3-1975, Test-Site Measurement of Noise Emitted by Engine Powered Equipment.[21] This standard presents test-site measurement methods for determining the maximum noise emitted by motor vehicles, public conveyances, construction and industrial machinery, and residential and recreational devices powered by engines operating on petroleum-based fuels, coal, steam, electricity, or other source of energy.

ASHRAE 36-72, Methods of Testing for Sound Rating Heating, Refrigerating, and Air-Conditioning Equipment.[22] This standard establishes a method of testing heating, refrigerating, and air-conditioning equipment to determine the sound-power levels in frequency bands.

ASTM C423-84, Standard Test Method for Sound Absorption and Sound Absorption Coefficients by Reverberation Method.[23] This method covers the measurement of the sound absorption of acoustical materials in a diffuse sound field. When a material is in the form of an extended plane surface, such as an acoustical ceiling or wall treatment, the results shall be given as sound absorption coefficients.

ASTM E90-83, Standard Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions. This recommended practice covers the laboratory measurement of airborne sound transmission loss of building partitions such as walls of all kinds, floor—ceiling assemblies, doors, and other space-dividing elements. The sound transmission loss is defined in terms of a diffuse incident sound field, and this is intrinsic to the test procedure.

ASTM E336-77, Standard Recommended Practice for Measurement of Airborne Sound Insulation in Buildings. This recommended practice establishes uniform procedures for the determination of field transmission loss, that is, the airborne

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[20] ARI publications are available from Air Conditioning and Refrigeration Institute, 1501 Wilson Boulevard, Arlington, VA 22209.

[21] ASA publications are available from Acoustical Society of America, 335 East 45th Street, New York, NY 10017.

[22] ASHRAE publications are available from American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1799 Tullie Circle, NE, Atlanta, GA 30329.

[23] ASTM publications are available from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

sound insulation provided by a partition already installed in a building. This recommended practice gives measurement procedures for determining the field transmission loss in nearly all cases that may be encountered in the field—no limitation to room-to-room transmission is intended.

ASTM E477-84, Standard Method of Testing Duct Liner Materials and Prefabricated Silencers for Acoustical and Airflow Performance. This method covers the laboratory testing of duct liner materials, integral ducts, and in-duct absorptive silencers used in the ventilation systems of buildings.

CAGI TEST CODE (1969), CAGI-PNEUROP Test Code for the Measurement of Sound from Pneumatic Equipment.[24] (see ANSI S5.1-1979). The purpose of the code is to provide standard test procedures for the measurement of airborne sound from pneumatic equipment. This code applies to compressors and pneumatic equipment and specified procedures and operating conditions acceptable and expedient for use by nonspecialists and by acoustical engineers.

DEMA TEST CODE (1972), for the Measurement of Sound from Heavy-Duty Reciprocating Engines.[25] The purpose of this document is to establish a standard procedure for measuring, recording, and reporting data in acoustic surveys at engine installations. This code applies to heavy-duty internal combustion engines and driven equipment, such as generators, pumps, or compressors, and specifies procedures and operating conditions acceptable and expedient for use by nonspecialists and by acoustic engineers.

IEC 34-9 (1972), Rotating Electrical Machines, Part 9 Noise Limits.[26] A-weighted sound levels have been adopted for this standard. When the machine being tested emits one or more pure tones of significant intensity, the A-weighted level is not sufficient and the recommendation provides for the use of frequency band analysis in such cases. This recommendation covers rotating electrical machines in the following power and speed ranges: 1 kW – 400 kW and 600 r/min – 3750 r/min.

IEC 123 (1969), Recommendations for Sound-Level Meters.

IEC 179 (1973), Precision Sound-Level Meters. This recommendation applies to sound-level meters for high precision apparatus for laboratory use, or for accurate measurements in which stable, high-fidelity, and high-quality apparatus are

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[24] CAGI publications are available from Compressed Air and Gas Institute, 1230 Keith Blvd, Cleveland, OH 44115.

[25] DEMA publications are available from Diesel Engine Manufacturers Association, 14600 Detroit Avenue, Suite 712, Cleveland, OH 44107.

[26] IEC publications (International Electrotechnical Commission) are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

required. This recommendation does not apply to apparatus for measuring discontinuous sounds or sounds of very short duration.

IEC 179A (1973), First Supplement to Publication 179 (1973) Precision Sound Level Meters, Additional Characteristics for the Measurement of Impulsive Sounds. This recommmendation specifies the characteristics of an apparatus for measuring sounds of short duration, single impulses, and sequences of impulses (pulses).

IEC 225 (1966), Octave, Half-Octave and Third-Octave Band Filters Intended for the Analysis of Sounds and Vibrations. See ANSI S1.11-1966 (R1976).

IEC 327 (1971), Precision Method for the Pressure Calibration of One Inch Standard Condenser Microphones by the Reciprocity Technique. See ANSI S1.10-1966 (R1976).

IEC 402 (1972), Simplified Methods for Pressure Calibration of One-Inch Condenser Microphones by the Reciprocity Technique. The object of this recommendation is to specify a method of absolute pressure calibration of one-inch condenser microphones used in laboratories for conventional measuring purposes, without requiring the highest obtainable accuracy.

IEC 486 (1974), Precision Method for Free-Field Calibration of One Inch Standard Condenser Microphones by the Reciprocity Technique. The object of this recommendation is to specify methods of measuring certain characteristics of standard condenser microphones with high accuracy, so that discussions between testing authorities may be based on clearly expressed and reproducible results.

IEEE Std 85-1973, IEEE Test Procedure for Airborne Sound Measurements on Rotating Electric Machinery.[27] This test procedure defines approved methods for conducting tests and reporting results to effect the uniform determination of rotating electric machine sound under steady-state conditions with an accuracy of 3 dB tested in free field, reverberant field, and semireverberant field acoustical environments. This procedure assumes the presence of pure tones or the predominance of discrete frequencies in the sound spectrum.

ISO R31 PART VII-1965, Quantities and Units of Acoustics.[28]

ISO R131-1959, Expression of the Physical and Subjective Magnitudes of Sound or Noise.

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[27] IEEE publications are available from IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854.

[28] ISO publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

ISO 266-1975, Acoustics—Preferred Frequencies for Acoustical Measurements. See ANSI S1.6-1967 (R1976).

ISO R354-1963, Measurement of Absorption Coefficients in a Reverberation Room. This recommendation describes how a reverberation room should be used to measure, under specified conditions, the sound absorption coefficients of acoustical materials used as wall or ceiling treatments, or the sound absorption of separate objects, such as furniture, persons, or space absorbers.

ISO R357-1963, (Supplementary to ISO R131-1959) Expression of the Power and Intensity Levels of Sound or Noise.

ISO R495-1966, (Superseded by ISO 3740-3746) General Requirements for the Preparation of Test Codes for Measuring the Noise Emitted by Machines. This recommendation is concerned with the procedures to be followed in the objective measurement of the noise emitted by machines. The aim is to indicate the general principles by which specific test codes for noise measurements may be formulated.

ISO 532-1975, ACOUSTICS—Method for Calculating Loudness Level.

ISO R2151-1972, Measurement of Airborne Noise Emitted by Compressor/Prime-Mover Units Intended for Outdoor Use. This recommendation specifies a method of determining the airborne sound emitted by compressor/prime mover units intended for outdoor use and gives instructions for conducting the tests and reporting the results.

ISO R1680-1970, Test Code for the Measurement of the Airborne Noise Emitted by Rotating Electrical Machinery. This recommendation was drafted in accordance with ISO R495-1966, and gives the detailed instructions for conducting and reporting tests on rotating electrical machines, to determine the airborne noise characteristics under steady-state conditions. This test code for the measurement of noise applies to rotating electrical machines such as motors and generators of all sizes without limitation of output or voltage, when fitted with their normal auxiliaries.

NEMA MG1-78 (Rev 8, Nov 84, Motors and Generators, Methods of Measuring Machine Noise.[29] (See IEEE Std 85-1973).

NEMA MG3-1974 (R1979), Sound Level Prediction for Installed Rotating Electrical Machines. This document provides a method of predicting approximate sound-pressure levels in industrial and commercial areas. The method is

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[29] NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street, NW, Suite 300, Washington, DC 20037.

intended for estimating sound-pressure levels and should not be construed as a guarantee of results. It requires a knowledge of the sound levels, location of all sound sources, and room characteristics. For simplicity, emphasis is placed on the use of overall A-weighted sound levels.

NEMA TR1-80 (Rev 2, Apr 1983), Transformers, Regulators, and Reactors (Section 9-04 Audible Sound-Level Tests). This standard lists test conditions and measurement procedures for determining the audible sound level associated with transformers under field conditions.

NFP(A) T39.12-1970 (R1975), Method of Measuring Sound Generated by Hydraulic Fluid Power Pumps.[30] This standard considers only sound directly radiated from hydraulic fluid power pumps in terms of loudness, disregarding installation effects. Its purpose is to establish a uniform basis for measuring, reporting, and accurately comparing the sound levels of such pumps.

SAE ARP 866A (1975), SAE Aerospace Recommended Practice, Standard Values of Absorption as a Function of Temperature and Humidity for Use in Evaluating Aircraft Flyover Noise.[31] This document describes a method by which values can be obtained for the absorption of sound in air over a wide range of temperature and humidity conditions. The purpose here is to consider only the classical and molecular absorption of sound energy by the atmosphere.

SAE J184 (1978), SAE Recommended Practice, Qualifying a Sound Data Acquisition System. See ANSI S6.1-1973. Various SAE vehicle noise standards require use of a sound-level meter which meets the requirements of International Electrotechnical Commission, IEC 179 (1973), Precision Sound-Level Meters, and ANSI S1.4-1971 (R1976), American National Standard Sound-Level Meters. The purpose of this recommended practice is to provide a procedure for determining if an acoustical data acquisition system has performance equivalent to such a meter.

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[30] NFP(A) publications are available from the National Fluid Power Association, 3333 N. Mayfair Road, Milwaukee, WI 53222.

[31] SAE publications are available from the Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

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