**Bolt Beranek and Newman Inc.**

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# Outdoor Warning Systems Guide

## (Approved and Cleared Final Report)

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June 1979

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A practical guide has been developed to aid public officials in determining the requirements for outdoor warning systems. The guide is a replacement for DCPA Federal Guide, Part E, Chap. 1, Appendix 3, "Principles of Sound and Their Application to Outdoor Warning Systems," first issued in December 1966. The new guide is based upon a survey of the current literature, and upon discussions with Civil Preparedness personnel and vendors. No experimental work has been performed. (Over)

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by

David N. Keast

for

Defense Civil Preparedness Agency
Washington, DC 20301

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## DCPA Review Notice

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# OUTDOOR WARNING SYSTEMS GUIDE
(Approved and Cleared Final Report)

## Abstract

A practical guide has been developed to aid public officials in determining the requirements for outdoor warning systems. The guide is a replacement for DCPA Federal Guide, Part E, Chap. 1, Appendix 3, "Principles of Sound and Their Application to Outdoor Warning Systems," first issued in December 1966. The new guide is based upon a survey of the current literature, and upon discussions with Civil Preparedness personnel and vendors. No experimental work has been performed.

The guide, included as Sec. 3 of this report, covers in a simplified form the principles of sound, outdoor warning systems and devices, propagation and detection of sound out of doors, avoiding hazardous noise exposures, and warning system planning, testing, and use. Technical data in support of the Guide are given in Sec. 4 of this report, and conclusions and recommendations based upon the study are provided in Sec. 5.

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## 1. SUMMARY

This report contains a new Defense Civil Preparedness Guide entitled "Outdoor Warning Systems Using Sound." The new Guide, included as Sec. 3 of this report, is based upon a literature study and interviews with Civil Preparedness personnel and vendors. No experimental work has been done under this program.

The new Guide is simpler than its predecessor documents and is intended to be readily understandable by public officials who are not technically trained. It contains information on the types of acoustic outdoor warning devices, their siting, and their principles of operation. Consideration is given to siting details that will avoid excessive sound exposures to bystanders.

Section 4 of this report contains technical data from the literature to support the specific recommendations of the Guide concerning ranges of effectiveness of warning devices, siting details, and avoidance of exposures to excessive sound. Some conclusions and recommendations based upon this study are given in Sec. 5.

## 2. OBJECTIVES AND METHODS

The objective of this program has been to prepare a Guide for public officials who are not technically trained. The Guide covers the following subjects:

- Types of acoustic outdoor warning devices
- Basic facts on sound propagation out of doors
- Human detection of sounds, and avoiding exposure to excessive sound
- The planning, layout, and siting details of outdoor warning systems in a community
- Testing and operation of outdoor warning systems.

The intent has been to develop an updated version of the information contained in DCPA publication Federal Guide, Part E, Chap. 1, Appendix 3, "Principles of Sound and Their Application to Outdoor Warning Systems," first published in December of 1966; and Appendix 4, "Public Outdoor Warning Systems," of the same date. The new Guide is simplified, compared to the 1966 publications, and contains up-to-date information on avoiding hazardous exposures to sound.

The Guide has been completed and is included in Sec. 3 of this report. The new Guide is the principle accomplishment of the work described herein.

The method used to develop the Guide has been to review recent literature on the subject and to interview Civil Preparedness personnel and vendors of warning devices. No experimental work has been done under this program.

## 3. GUIDE: "OUTDOOR WARNING SYSTEMS USING SOUND"

The complete text of the Guide is reproduced in the following pages.

March, 1979

# OUTDOOR WARNING SYSTEMS USING SOUND

## I. Introduction

### A. The Role of Outdoor Warning Systems in Civil Preparedness

Audible outdoor warning systems (sirens, air horns, etc.) are an essential component of the Civil Defense Warning System (CDWS) established by the Federal Government to advise government agencies and the public of impending enemy attack or other disaster. Following the detection of an attack or other hazard, information is disseminated over the Defense Civil Preparedness Agency's (DCPA's) dedicated communication network -- The National Warning System (NAWAS) -- to more than 2000 locations throughout the United States. From these locations, the public can be informed of a potential hazard through the Emergency Broadcast System (EBS), TV stations, the news media, and other means.

Outdoor warning systems can advise people that a hazard exists and that they should determine the nature of the hazard by listening to the radio, etc. For more information on other aspects of the CDWS, see CPG 1-14, "Civil Preparedness, Principles of Warning," June 30, 1977.

This manual concentrates on the selection, siting, and operation of audible outdoor warning devices. Under certain circumstances, federal aid is available to assist communities in the purchase and installation of outdoor warning systems. (See CPG 1-3, "Federal Assistance Handbook," Chap. 3, Sec. 4, December 1976.) A community may also use outdoor warning systems purchased with federal aid for other purposes, such as local fire warning, provided the outdoor warning devices can produce a distinctive sound for those purposes. (See Sec. III below.)

## B. Purpose

The purpose of this manual is to set forth the basic principles of sound that are applicable to audible outdoor warning devices and to describe a method for planning and laying out an effective outdoor warning system.

## II. Principles of Sound

### A. Terminology

Since outdoor warning devices use sound to alert listeners to danger, this section starts with a brief introduction to the vocabulary and principles of sound.

*Sound* is a form of mechanical energy that moves from a *source* (a voice, a musical instrument, a siren) to a listener as tiny oscillations of pressure just above and below atmospheric pressure. When people hear sounds, they can distinguish their *loudness*, their *tone* or *pitch*, and variations of loudness and pitch with time. The loudness and pitch variations of some sounds are recognized as having certain meanings, such as with speech sounds.

Instruments used to measure sounds give the magnitudes of sounds in *decibels* [abbreviated here as *dB(C)*]. This magnitude is closely related to what we hear as loudness. Thus, an audible warning device that produces 110 dB(C) at 100 ft (30 m) away sounds louder than one that produces only 100 dB(C) at the same distance. All audible outdoor warning devices are rated in terms of their sound output at 100 ft, in dB(C).

Instruments can also measure the *frequency components* of a sound, in Hertz (Hz). They are closely related to what we hear as pitch. As discussed below, the frequency components of the sound from an audible outdoor warning device are important in determining how far that sound will carry through the air and how well it will be heard. Most audible outdoor warning devices produce sound within the frequency range from about 300 Hz to about 1000 Hz.

## B. Attenuation

It is well known that sound decreases in magnitude [in loudness and in dB(C)] at greater distances from its source. This decrease is called *attenuation with distance*, and it is caused by a number of factors described in Sec. IV-A below. The amount of sound available to warn a listener can be calculated simply with the following equation:

$$\begin{bmatrix}\text{Amount of Sound}\\ \text{Available to Warn,}\\ \text{in dB(C)}\end{bmatrix} = \begin{bmatrix}\text{Sound Output of}\\ \text{Audible Warning}\\ \text{device, in dB(C)}\end{bmatrix} \quad \text{minus} \quad \begin{bmatrix}\text{Attenuation}\\ \text{with Distance,}\\ \text{in dB(C)}\end{bmatrix}$$

Thus, if it is known that an audible outdoor warning device produces 110 dB(C) at 100 ft (30 m), and that the attenuation with distance is 25 dB(C), then the amount of sound left over to warn people is 110 - 25 dB(C), or 85 dB(C).

## C. Hearing

Whether the amount of sound available to warn people will indeed be sufficient to do the job depends upon several factors. First, the warning sound must be audible above the ambient, or background, noises. These ambient noises change constantly in loudness and pitch, depending upon noise-producing activities in the vicinity of the listener. Second, the warning sound must get the attention of the listener away from what he is doing. Normally, people "close out" of their minds distracting sounds that are not pertinent to what they are doing. A warning sound must penetrate this mental barrier. Tests have shown that to attract a listener's attention away from what he is doing, a warning sound must be about 9 dB(C) greater than would be sufficient to make it audible to someone who was concentrating on listening for it, and not doing anything else.

All of these factors suggest that a warning sound must be loud: loud enough to overcome attenuation with distance, to exceed the background noise, and to attract attention. Yet it cannot be <u>too</u> loud, or there is risk of injuring the hearing of some people who listen to it. This risk, which is discussed in greater detail in Sec. IV-B below, can occur when people are exposed to audible warning sounds exceeding 123 dB(C).

## III. Outdoor Warning Systems and Devices

When a civil preparedness official buys an audible outdoor warning system for his community, he will be purchasing:

1) The sound-making devices

2) The controls and equipment that operate the devices.

In this manual, we do not discuss the controls and equipment. These vary with the manufacturer and are completely described in vendors' literature. The C.P. official should be aware, however, that the costs of the system will include both kinds of components, as well as installation costs.

The sound-making devices themselves can be of three different types:

- Sirens
- Electronic (loudspeaker) devices
- Horns and whistles.

### A. Sirens

Sirens are by far the most widely used sound-making devices for outdoor warning systems. Sirens are capable of producing very intense sounds by chopping the flow of compressed gas (usually air). The fundamental frequency (pitch) of a siren sound is determined by the rate at which the flow is chopped, in cycles per second.* Sirens are powered by electric motors, gasoline engines, compressed air, or steam. Electric-motor-driven sirens are the most common for civil preparedness purposes.

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*Some sirens, known as two-tone sirens, generate two frequencies simultaneously by using two airflow chopping rates.

Some sirens are nondirectional -- that is, they continuously produce the same sound in all directions horizontally from the source. The most powerful sirens, however, use a horn that radiates a beam of sound in a single direction. The horn is then rotated several times a minute, so that the beam sweeps through the entire area around the siren. For a stationary listener, the sound from such a siren goes up and down in loudness as the horn sweeps around.

## B. Electronic Loudspeaker (or Voice/Sound) Sources

Loudspeaker sound sources have the advantage that they can broadcast voices as well as siren-like sounds. Therefore, they can be used to issue messages as well as warning sounds to the public. However, their sound-output capability is less than that available from siren sources, so that more sources may be required to cover the same area. Furthermore, sound reflections from large surfaces or simultaneous messages from several loudspeaker sources at different distances may "garble" the signal so badly that some listeners will not be able to understand voice messages.

## C. Horns and Whistles

Air horns have the advantage that the sounds they produce cannot be confused with those of emergency vehicles or fire-department sirens. When a suitable air supply is already available, the cost of a horn installation is very low. In addition, the air horn requires a minimum of maintenance and, because it weighs very little, is easily installed.

In the absence of an air supply or commercial storage cylinders, a compressor, storage tanks, and related appurtenances are necessary. These increase costs substantially, for horns require more power than many outdoor warning devices of the same decibel [dB(C)] rating.

In general, the comments on air horns apply to steam whistles as well. However, steam supplies are even more expensive than air supplies. It is generally not practical to install steam whistles unless an adequate steam supply is already available.

## D. Ratings and Specifications

The sound outputs of acoustic outdoor warning devices are given in terms of their maximum decibels [dB(C)] measured at 100 ft (30 m) from the device. The siting guidelines in this manual are based upon this figure.

The fundamental sound frequencies of almost all outdoor warning devices are in the range from 300 to 1000 Hz. (Some devices "warble" up and down in pitch within this frequency range. See Subsection E below.) Below 300 Hz, reduced human hearing sensitivity and higher background noise levels combine to restrict warning ranges. Above 1000 Hz, sounds are more rapidly attenuated in the atmosphere, so the warning range is again restricted.

The sounds from audible outdoor warning devices are generally focused into the horizontal plane surrounding the device. Sound radiated upward would be wasted, and sound radiated downward close to the device is unnecessary and may be hazardous. (See Sec. V-B.) As indicated above, some sirens may radiate a "beam" of sound in one direction horizontally, and have a mechanical means for rotating this beam around a vertical axis.

## E. Requirements for Federal Aid

Detailed requirements for an audible outdoor warning system to qualify for federal aid are spelled out in CPG 1-3, "Federal Assistance Handbook," Chap. 3, Sec. 4 Dec., 1976, as amended. In general, these requirements include the preparation of an approved *Warning Plan* and a map showing existing and proposed warning coverage.

For a warning device to qualify for federal aid, it must provide the following signals (from CPG 1-14):

- *ATTACK WARNING* - This is a *3- to 5-minute wavering (warbling in pitch) tone* on sirens, *or a series of short blasts* on horns or other devices. The ATTACK WARNING signal shall mean that an actual attack against the country has been detected and that protective action should be taken immediately. The ATTACK WARNING signal shall be repeated as often as warnings are disseminated over the National Warning System or as deemed necessary by local government authorities to obtain the required response by the population, including taking protective action related to the arrival of fallout. The meaning of the signal "protective action should be taken immediately" is appropriate for the initial attack warning and any subsequent attacks. This signal will also be used for accidental missle launch warnings.
- *ATTENTION OR ALERT WARNING* - This is a *3- to 5-minute steady signal from* sirens, horns, or other devices. This signal may be used as authorized by local government officials to alert the public to peacetime emergencies. In addition to any other meaning or requirement for action as determined by local government officials, the ATTENTION or ALERT signal

shall mean to all persons in the United States, "Turn on radio or TV. Listen for essential emergency information."

A third distinctive signal may be used for other purposes, such as a local fire signal.

# IV. Basic Facts About Sound Out of Doors

## A. Attenuation with Distance

As sound moves away from an outdoor warning device toward potential listeners, it can be greatly altered by the atmosphere. For example, everyone knows that the loudness of a sound decreases as the listener gets further from the source. Also, beyond a few hundred feet from a steady sound source, the loudness varies with time, being unnoticeable at some times and quite pronounced at others. Such effects, which are characteristic of the propagation of sound out-of-doors, are caused by the factors described below.

### *Divergence*

As sound radiates away from a source, its intensity decreases with distance because its energy is spread over a larger and larger area. From a point-source of sound, this decrease is called "spherical divergence" or "inverse square loss," because the sound intensity decreases inversely with the square of the distance from the source to the receiver (sound level decreases 6 dB for each doubling of source-receiver distance).

### *Attenuation caused by ground effects*

The ground produces a number of effects on the propagation of sound over its surface. Perhaps the simplest of these is the interferometer effect, which occurs when sound is propagated over a hard, flat surface. For any given source and receiver height, there are two sound-wave paths between the source and the receiver: one direct, and the other - somewhat longer - reflected off the ground surface. Under some conditions, the sound waves arriving at a listener along these two paths interfere with each other, and cancel out. The opposite effect can also occur: The two sound waves can add, and a "gain" (negative attenuation) is observed. When the ground is soft and absorbs some sound, this effect becomes even more complicated.

### *Barriers*

A barrier is any large solid object that breaks the line of sight between the sound source and the listener. In general, a barrier can introduce up to 20 dB of attenuation. The sound available behind the barrier comes from diffraction around the barrier, or from sound energy scattered into the region behind the barrier from other wave paths.

### *Effects of vertical temperature and wind gradients: atmospheric refraction*

The speed of sound in air increases with temperature. Furthermore, when the wind is blowing, the speed of sound is the vector sum of the sound speed in still air and the wind speed. The temperature and the wind in the atmosphere near the ground are frequently nonuniform. This atmospheric nonuniformity produces refraction (bending) of sound wave paths. Near the ground, this refraction can have an effect on the attenuation of sound propagated through the atmosphere.

During the daytime in fair weather, temperature normally decreases with height (lapse), so that sound waves from a source near the ground are bent upward. In the absence of wind, an "acoustic shadow," into which no direct sound waves can penetrate, forms around the source. Large attenuations are observed at receiving points well into the shadow zone - just as if a solid barrier had been built around the source. On clear nights, a temperature increase with height is common near the ground (inversion) and the "barrier" disappears.

Wind speed almost always increases with height near the ground. 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 a sound source, but is suppressed downwind.

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 completely surrounding a source. It is less rare, but still uncommon, for a surface inversion to be sufficiently strong to overcome an upwind shadow entirely.

### *Foliage*

Large amounts of dense foliage [100 ft (30 m) or more] can attenuate sound somewhat, although small amounts of foliage have no effect.

### *Absorption of sound in the atmosphere*

Sound is absorbed in the atmosphere in a way that depends upon the humidity. In general, this loss is most pronounced at high frequencies and is of lesser importance at the sound frequencies produced by outdoor warning devices.

### *Summary*

The combination of all the factors that cause sound to be attenuated in the atmosphere is both complicated and unpredictable. If one were to observe the sound from a warning device 1000 ft (300 m) or farther away, he would find that it varies with time as much as 20 to 30 dB, depending upon the conditions of the atmosphere and the ground. This manual provides (Sec. IV-C) a simple and conservative method for estimating warning ranges. It is important to realize, though, that this is an estimate which -- like the weather -- cannot be guaranteed.

## B. Hearing

The most important factors determining the ability of a warning sound to alert a potential listener are the barriers to sound in the listener's immediate vicinity, and the background or masking noise at his location.

### *Local barriers*

A potential listener indoors or inside a motor vehicle is much less likely to be alerted by a warning sound of a given loudness than someone out of doors. This is, of course, because of the attenuation of the sound as it comes through the walls of the structure surrounding him. In general, an outdoor warning device cannot be counted on to alert people in vehicles or buildings unless they are very close to the device.

It is interesting to note that the current activity toward improving the energy-conservation properties of buildings will have the concomitant effect of increasing their sound-attenuating properties. Thus, it is even less likely in the future that people indoors will be alerted by outdoor audible warning devices.

### *Background noise and detectability*

The most important factor that determines the detectability of a sound is the signal-to-noise ratio measured over a range of frequencies around the signal frequency. The "noise" portion of this ratio is the background noise at the listener's location. Thus, for a given level of warning signal, the background noise is critical to determining warning signal effectiveness.

Recent studies have shown that the outdoor background noise in a community is strongly correlated with local population density. This correlation presumably results from the fact that outdoor noise levels are almost always caused by motor vehicle traffic, which correlates well with population density. Thus, population density is a better metric of background noise than zoning or land-use patterns like "residential," "business," and "heavy industrial."

Recent studies have also shown that the level of sound from a warning device must be about 9 dB higher than the level detectable under laboratory conditions in order to attract the attention of otherwise preoccupied observers.

### *Deleterious Effects of Warning Sounds*

When audible warning devices are used "in earnest" to alert a population of impending disaster, it seems surprising that anyone would be concerned about any deleterious effects of the sounds themselves. Indeed, many local noise ordinances specifically exempt warning sounds from noise-level restrictions. Nevertheless, in some communities sirens are operated so frequently (such as to provide tornado warnings in midwestern towns) that complaints about their noise level have been reported. Furthermore, the warning devices must be tested from time to time, and the resulting high noise levels could be viewed as disturbing and/or damaging under these circumstances.

### *Hearing damage*

For test purposes, audible warning devices should be so located and operated that no person is likely to be subject to a sound level great enough to cause hearing damage. A suitable limit for this purpose, based upon recommendations of the Committee on Hearing, Bioacoustics and Biomechanics (CHABA) of the National Academy of Sciences, is 123 dB(C).

Loud sounds, even if not potentially damaging, can be viewed as a disturbance by some residents of a community. Operators of audible outdoor warning systems should realize this fact, and should:

- Minimize the frequency and duration of tests of outdoor warning devices. Alternatively, "growl tests" can be conducted (see Sec. VI) when the source is a siren.
- Refrain from conducting tests at night when people are relaxing and sleeping.
- Avoid locating warning devices too close to noise-sensitive activities.

### *Summary*

The detectability of an auditory warning signal is a function of the level of the signal at the potential listener's ears relative to the background noise at his location.

Because of local barriers, it is probable that a much smaller proportion of the potential listeners indoors or in vehicles can be alerted by an audible warning system, relative to the proportion that could be alerted out of doors.

No person should be exposed to the sound of an outdoor warning device if it exceeds 123 dB(C).

## C. Estimating Range of Coverage

All of the factors in the previous two subsections -- on propagation losses and on signal detection -- have been combined to obtain the warning effectiveness ranges illustrated in Fig. 1. The range, or radius, of coverage of any audible outdoor warning device can be determined from Fig. 1 on the basis of the rated output of the warning device at 100 ft. Figure 1 indicates, for example, that a warning device rated 120 dB(C) will have a range of about 3700 ft (1.1 km) in suburban and rural areas, when mounted above the rooftops. In an urban area, when the device is mounted below the rooftops, its effective range will be about 1200 ft (0.35 km).

The upper curve in Fig. 1, applicable to suburban and rural areas, is very close to 10 dB per doubling of distance for a 70-dB warning signal level. The lower curve of Fig. 1, that applicable to urban high-rise areas, takes into consideration the greater attenuation caused by shielding and the higher background noise levels existing in downtown areas.

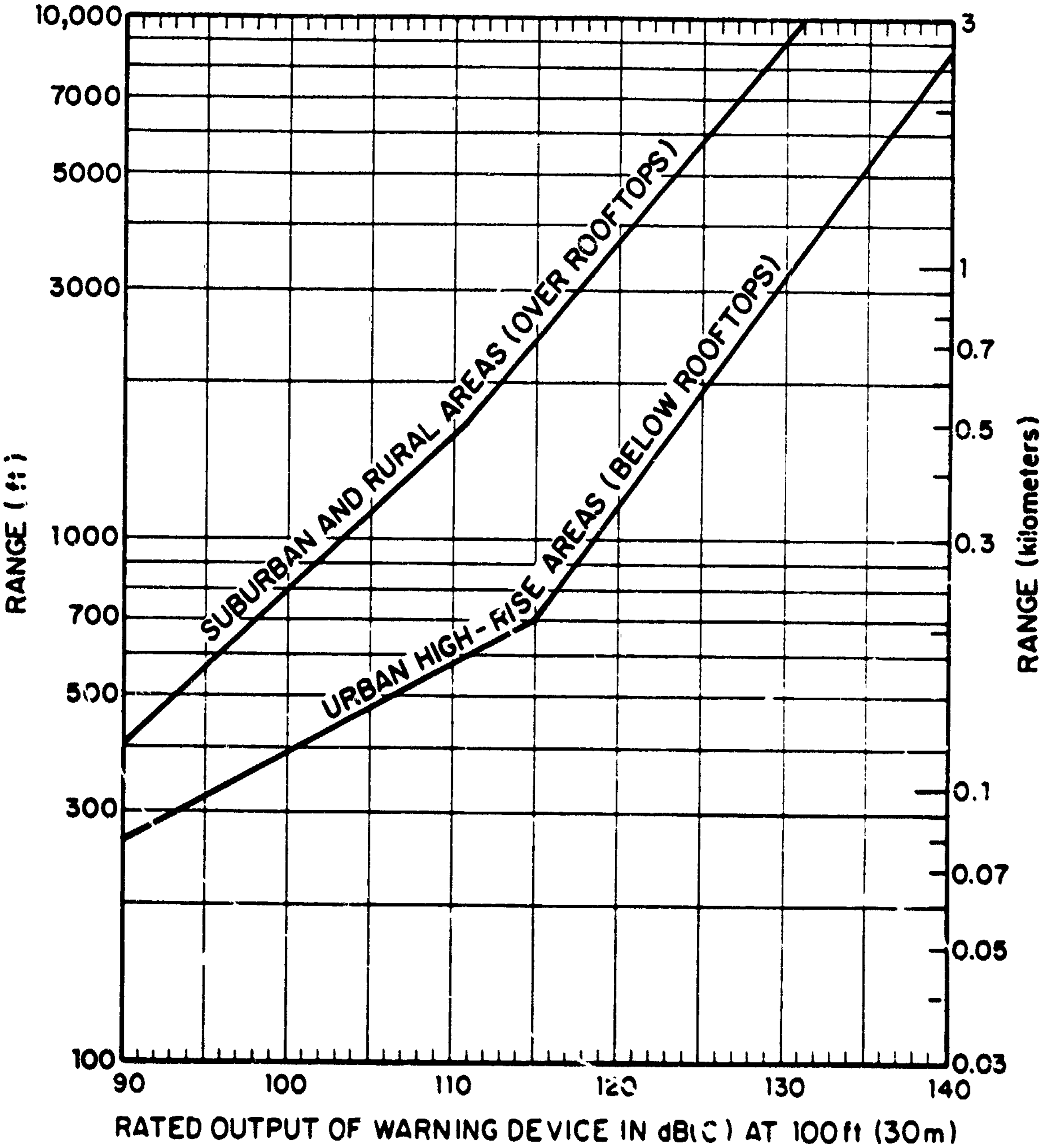

Fig. 1

Effective Ranges of Outdoor Warning Devices As a Function of Their Rated Sound Output in dB(C) at 100 ft (30 m)

NOTE: Differences less than ±2dB(C) in rated output, and differences less than ±15% in range, are not generally significant

Two important features of Fig. 1 should be emphasized. The first is the "NOTE" in the caption, which makes clear the uncertainties associated with the range prediction process. The second important point is embodied in the parenthetical remarks "over rooftops" and "below rooftops" in the labels of the curves. It is strongly recommended that warning devices be mounted above the prevailing rooftop height in areas where buildings are less than 3 to 4 stories high. In urban high-rise areas, of course, the opposite may be advisable.

## V. Planning an Outdoor Warning System

### A. Determining Warning Coverage

The basic tools for planning an outdoor warning system are a good topographic map of the community, a drafting compass, knowledge of the sound output ratings of the warning devices to be used, and Fig. 1 from this manual.

Planning itself can be broken down into the following steps:

1) The civil preparedness official should locate, on the map:

--Downtown areas that contain tall buildings;
--Hills or any other barriers that would obstruct the flow of sound;
--Residential (suburban) or rural areas with low buildings over which sound can move freely.

2) Second, the official should locate the public or business buildings that would be good sites for a warning device. (The community civil preparedness officer will, of course, have to double-check the usefulness of the site and obtain permission from the owner to install the device.)

3) Third, the official should circle, on the map, the area in which each device will be effective, using ranges read from Fig. 1.

It is a good idea to start the layout with the obvious warning device locations, such as:

--Noisy places (freeway interchanges, rail yards, etc.)

- --Locations with good line-of-sight coverage (hilltops, centers of radial street patterns)
- --Locations where permission to install the devices can be readily obtained (public buildings, parks).

Noise-sensitive locations (hospitals, schools, residential buildings) should be avoided.

Many layouts are possible for most communities, and several trials may be necessary to obtain a layout with the minumum number of devices.

The product of this planning effort should look like Fig. 2, a map covered with interlocking circles, each centered on a single warning device. (Note that the circles do not overlap to any major degree.) This layout attempts to make maximum use of warning devices rated 120 [dB(C)], so that the minimum number of different types of devices will be required.

The finished planning map can help answer a major question: What will the entire outdoor warning system cost? The number of circles indicates the number of devices needed and is a clue to the costs of installation and maintenance, as well as to the costs of control circuits for the system.

If the total cost, as estimated during planning, is too high, civil preparedness officials may want to redesign the system, perhaps decreasing the total number of devices by increasing the sound level rating of each device to be used.

## B. Siting to Avoid Hazardous Exposure

Detailed siting of each device should take into consideration the factors desirable to maximize coverage, described in Sec. V-A. Installations should also be sited to avoid exposing anyone

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March, 1979

FIGURE 2. MAP WITH CIRCLES CENTERED ON SINGLE WARNING DEVICES.

## LEGEND

| Source | |
|---|---|
| A | 125 dB(C) mounted in suburban area at fire station: Range 5900 ft (1.8 km) |
| B | 120 dB(C) mounted at major road intersection: Range 3700 ft (1.1 km) |
| C | 120 dB(C) mounted in industrial area: Range 3700 ft (1.1 km) |
| D | 120 dB(C) mounted on hilltop: Range 3700 ft (1.1 km) |
| E | 120 dB(C) mounted at turnpike interchange: Range 3700 ft (1.1 km) |
| F | 120 dB(C) mounted in park: Range 3700 ft (1.1 km) |
| G | 120 dB(C) mounted in high-rise area at city hall: Range 1200 ft (0.36 km) |
| H | 120 dB(C) mounted in high-rise area at highway interchange: Range 1200 ft (0.36 km) |
| I | 120 dB(C) mounted in high-rise area on highway bridge: Range 1200 ft (0.36 km) |

to sound levels exceeding 123 dB(C). In general, this second requirement can be achieved by mounting the device high enough above ground level so that the sound is directed mostly over the heads of people standing on the ground near the device. The minimum height needed to meet this requirement, as calculated for one type of siren with a well-designed horn, is illustrated in Fig. 3. This figure indicates, for example, that a device rated at 120 dB(C) should be mounted at least 32 ft (10 m) above the ground. Of course, a higher mounting may be desirable to place the source above the prevailing rooftop height.

Note that Fig. 3 has been established for just one type of source. It may not be applicable to other products. The public official should ask the vendor about the proper mounting height to limit the exposure of people standing on the ground to 123 dB(C) or less.

In those cases where it is impossible to mount the device high enough to achieve a safe sound level on the ground, large signs should be prominently displayed on the device, reading:

> CIVIL PREPAREDNESS WARNING ____________ (horn, siren, etc.)
>
> CAUTION!
>
> THIS ____________ (siren, horn, etc.) OPERATES AUTOMATICALLY. ITS SOUND CAN BE DANGEROUS TO YOUR HEARING. WHEN IT STARTS TO OPERATE, COVER YOUR EARS AND MOVE AT LEAST 200 FEET AWAY.

March, 1979

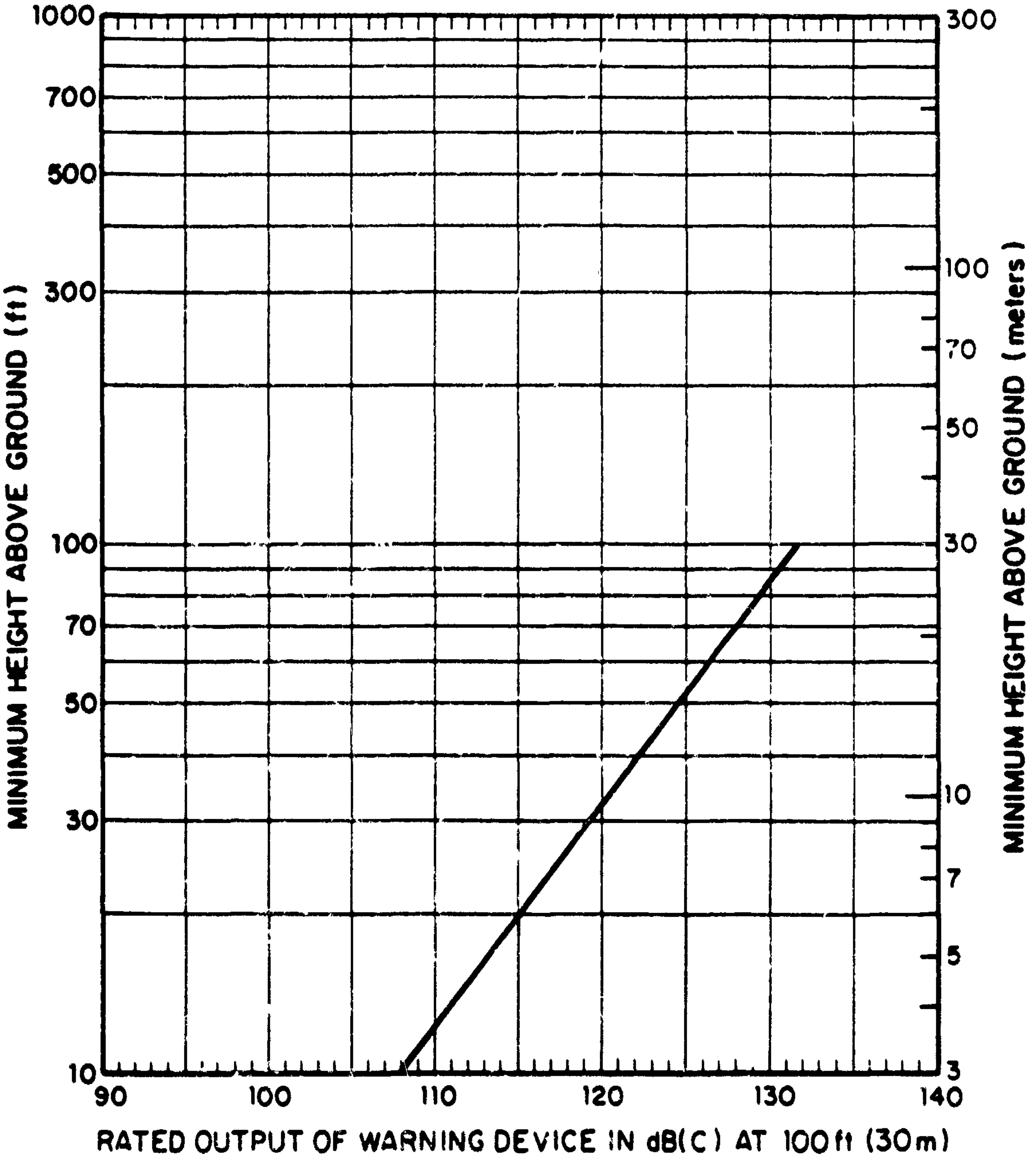

Fig. 3

Minimum Mounting Height of a Typical Warning Device to Avoid Risk of Hearing Damage to Pedestrians (for horizontal beam)

In some urban areas, it may be necessary to mount warning devices in such a way that the main sound beam is directed at adjacent buildings. When this occurs, the devices should be mounted no closer than indicated in Fig. 4. A much greater separation than indicated by Fig. 4 would be desirable for the comfort of building occupants.

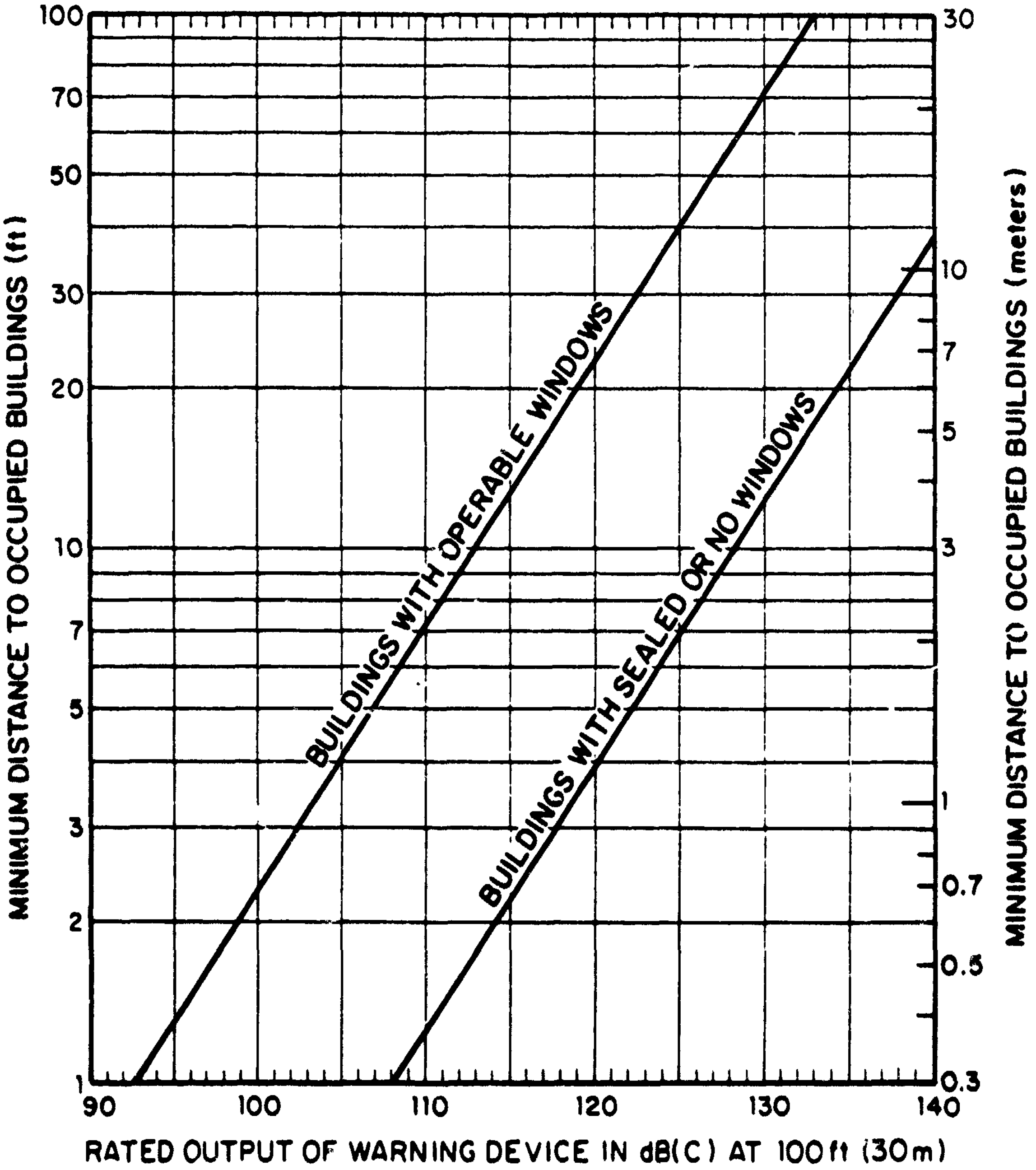

Fig. 4

Minimum Distance to Avoid Risk of Hearing Damage to Occupants of Adjacent Buildings Located in Sound Beam of Warning Device

## VI. System Testing and Use

Once an outdoor warning system is installed, civil preparedness officials must ensure that the system does indeed alert residents of the community. A system is successful only if:

- Residents of the community know how the signal sounds and why it is being sounded
- Residents can differentiate between system testing and a true alert
- Each device is operating as it should.

### *Knowledge*

Americans are almost two generations removed from the days of World War II, when the voice of the air raid siren, the information it carried, and the proper reaction to it were familiar to everyone in the community. Though the potential of enemy attack remains, the usefulness of outdoor warning systems may have dwindled. If so, civil preparedness officials can turn the situation around, primarily through a controlled program of testing and a well-planned public information campaign.

### *Testing/Alert*

Detailed information on the testing of outdoor warning systems is given in CPG 1-14. The Office of Civil Preparedness (OCP) has requested that state and local governments standardize testing of warning devices. OCP recommends that local officials

--Test the outdoor warning system approximately once a month;

--Publicize the testing day and time each month;

--Test by sounding the "Attention" or "Alert" signal (the steady sound) for no more than 1 minute;

--Follow with 1 minute of silence;

--Finish by sounding the "Attack Warning" (rising/falling signal or series of short blasts) for no more than 1 minute;

--Emphasize, in all public announcements, that testing signals are sounded for less than *1 minute only*, while in an actual emergency, all warnings would be sounded for 3 to 5 minutes and would probably be repeated.

When sirens are used, and must be tested more frequently than once a month, a "growl test" is acceptable. In a growl test, the siren is sounded for so short a time that it never produces significant sound output, yet long enough so that officials can determine that it is working.

### *Public Information Campaign*

The civil preparedness official who must create a public relations campaign has two advantages as he starts. First, the information he must communicate is neither lengthy nor hard to understand and, second, he is talking to people about their own safety. He should involve all community media, such as newspapers and radio/television stations, in his campaign; he should not overlook such useful forms of communication as posters in public buildings, newsletters sent out by community organizations, flyers enclosed in utility bills, and opportunities to address school assemblies.

The message is straightforward, and the best campaign will repeat the same announcement, in the same words, again and again.

# 4. TECHNICAL DATA FOR MATERIAL IN THE GUIDE

## 4.1 Introduction

The material in subsection A of the introduction to the Guide is drawn from Chap. V of CPF 1-14 [1] and from CPG 1-3 [2]. The availability of federal aid for the purchase of outdoor warning systems, provided they satisfy certain minimum requirements, is indicated in the third paragraph. This is intended as an indication to local officials that the information in the Guide is pertinent to qualifying for federal aid.

The "Purpose," subsection B, is paraphrased from FCDG-E-1 [3], the predecessor document to this Guide.

## 4.2 Principles of Sound

This section introduces the terminology used in the Guide and provides a brief summary of the concepts that are developed in greater detail in subsequent sections.

In the terminology subsection, the relationship between *loudness* (what people hear) and *sound level in decibels* (what one observes with an instrument) is established. Similarly, the relationship between pitch and frequency is described. The designation dB(C) is used here, and throughout the text, to avoid confusion with the dB(A) level popularly used to describe and regulate noise intrusions in communities [4]. Similarly, metric equivalents of all units are given parenthetically, for it is assumed that most readers will be more familiar with the English system of units.

The basic concept of sound attenuation with distance, described later in some detail in Sec. IV of the Guide, is introduced in subsection B. This indicates to the reader *why* he must have at least a qualitative understanding of this complex subject. Similarly, the concept of hearing, and of how hearing depends upon signal-to-noise ratio at the listener, is introduced in subsection C (and developed in further detail in Sec. IV of the Guide). The potential risk of hearing damage caused by exposure to excessive sound is also introduced.

## 4.3 Outdoor Warning Systems and Devices

The descriptions of warning devices in subsections A, B, and C follow closely the material in FG-E-1.3 [*3*], but have been updated on the basis of discussions and correspondence with vendors and DCPA personnel. Subsection D describes the important properties by which acoustic outdoor warning devices are rated. This leads directly into subsection E, which quotes the requirements of CPG 1-14 [*1*] (as ammended) on warning device performance, in order to qualify for federal aid.

## 4.4 Basic Facts About Sound Out of Doors

This section of the Guide elaborates upon the concepts of attenuation of sound with distance, and of human hearing, first introduced in subsections B and C of Sec. II of the Guide. The purpose of this elaboration is to emphasize strongly the fact that the ability of a warning device to alert people is highly variable and largely unpredictable.

During our interviews before the preparation of this Guide, we learned that some communities were asking vendors to *guarantee* the sound level produced by a device at a distance of, say, 3000 ft (900 m). Such a requirement is unrealistic, for obviously the sound level that far away will be strongly dependent on conditions (like the weather) over which the vendor has no control. Similarly, some vendors would attempt to sell their products by claiming, say, a 116 dB(C) output compared to a competitor's 115 dB(C); or a warning effectiveness range of 2300 ft (700 m) rather than 2230 ft (680 m) for competitive devices of the same rating. The local official should understand that such small differences are technically meaningless.

### 4.4.1 Propagation losses

The material in the Guide on propagation losses (attenuation with distance) has been developed from the technical literature, as follows:

*Divergence*

As sound radiates away from a source, its intensity decreases with distance because its energy is spread over a larger and larger surface area. For a point-source of sound, this decrease is called "spherical divergence" or "inverse square loss," because the sound intensity decreases with the square of the distance from the source to the receiver (that is, sound pressure level decreases 6 dB for each doubling of source-receiver distance).

If the input spectrum is specified at some small reference distance, $D_r$, then the attenuation caused by spherical divergence, $A_D$, is:

$$A_D = 20 \log_{10}\left(\frac{r}{D_r}\right) \text{ dB} \quad ,$$

where r is the source-to-receiver distance.

If the input spectrum is in terms of sound power level, PWL, in dB re $10^{-12}$ watts, then:

$$A_D = 10 \log_{10} (4\pi r^2) - 3 \text{ dB} \quad ,$$

where r is the source-receiver distance in meters, and the factor of 3 dB is an allowance for hemispherical, as opposed to spherical, radiation close to the ground. In English units:

$$A_D = 20 \log_{10} r - 2 \text{ dB} \quad .$$

*Attenuation Caused by Ground Effects*

The presence of the ground plane produces a number of interesting and interrelated effects on the propagation of sound near the ground. Perhaps the simplest of these is the interferometer effect, which occurs when sound is propagated over a hard, flat surface. For any given source and receiver height, there are two sound-wave paths between the source and the receiver: one direct, and the other – somewhat longer – reflected off the ground surface. When the difference between the lengths of these two paths is an odd number of half-wavelengths, the two waves interfere and (theoretically) cancel at the receiver. The opposite effect occurs when the path lengths differ by an even number of half-wavelengths: the two waves add and a "gain" (negative attenuation) is observed.

Obviously, the interferometer effect is frequency-dependent and would be most evident with tonal sounds. Because it is also determined by the phase relationship between the direct and reflected waves, it can occur as predicted only when the atmosphere is homogeneous and the reflection from the ground plane is specular. For normal source and receiver heights, the interferometer effect is rarely detectable beyond a few hundred feet from the source. It is normally ignored in sound propagation analyses. (For more information on the interferometer effect, see Ref. 2.5.)

When the ground is acoustically absorbent (soft), the interferometer effect changes dramatically because of the phase shift experienced by the reflected wave at the ground surface. (The shift is 180 degrees for a perfectly soft surface.) This situation has been studied by Ingard [6], by Piercy and Embleton [7], and the Chessell [8]. They have shown that, as the source-receiver distance becomes large (so that the difference between the direct and reflected paths is small), the propagation of plane acoustic waves over a soft-ground surface is not possible. Only spherical waves can propagate in this region. Because the sphericity of a wavefront decreases with distance from the source, attenuations proportional to $1/r^2$ (6 dB per doubling of distance)* are predicted. Where (in frequency and geometry) this effect occurs is greatly dependent upon the complex acoustic impedance of the ground surface.

When measurements are made of sound propagated over the ground out-of-doors, it is common to observe a peak of attenuation in the frequency range from 100 to 500 Hz. Piercy and Embleton's explanation of this peak of low-frequency attenuation can be paraphrased by pointing out that the peak should approach

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*This is in addition to, and should not be confused with, spherical divergence.

infinity as frequency goes to zero (when the path difference in wavelengths between direct and reflected waves approaches zero) because of the 180-degree phase reversal of the reflected wave from the (soft) ground. However, the peak is limited by the sphericity of the sound wave and by an increase in the ground impedance as frequency decreases. Ingard [*9*] gives a similar explanation and goes on to remind his readers that the effect is based upon coherence between the direct and reflected sound waves. It will be modified by nonspecular reflection from the ground and by atmospheric inhomogeneities.

### *Effects of Barriers*

There are well-developed analytical procedures for calculating attenuation of sound by barriers. In general, these procedures have been confirmed experimentally, provided that some allowance is made for limiting the ultimate theoretical attenuation to about 20 dB, because of sound energy scattered into the region behind the barrier via indirect wave paths.

The most widely used barrier calculation method is based upon Fresnel-Kirchhoff diffraction theory and is generally attributed to Maekawa [*10*]. This method, which has gained acceptance for use in highway noise studies [*11,12*], is the recommended procedure for environmental impact studies of proposed highways [*13*].

### *Effects of Vertical Temperature and Wind Gradients: Atmospheric Refraction*

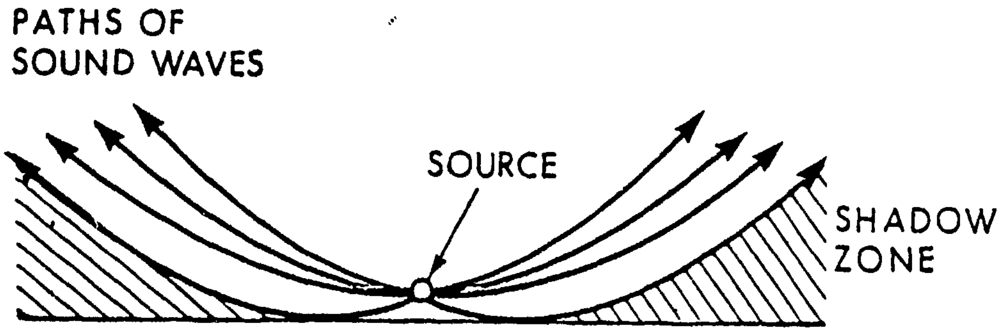
The speed of sound in air increases with the square root of the absolute temperature. Furthermore, when the atmosphere is in motion, the speed of sound is the vector sum of the sound speed in still air and the wind speed. The temperature and the wind in the atmosphere near the ground are frequently nonuniform. This atmoshperic nonuniformity produces gradients of the speed of sound, and, thus, refraction (bending) of sound wave paths. Near the ground, this refraction can have a major effect on the apparent attenuation of sound propagated through the atmosphere. See Fig. 4.1.

In analyzing this effect, one usually assumes a horizontally stratified atmosphere in which temperature and wind speed vary only with height above the ground. During the daytime in fair weather, temperature normally decreases with height (lapse), so that sound waves from a source near the ground are refracted upward. In the absence of wind, an "acoustic shadow," into which no direct sound waves can penetrate, forms around the source. Marked attenuations are observed at receiving points well into the shadow zone – just as if a solid barrier had been built around the source.

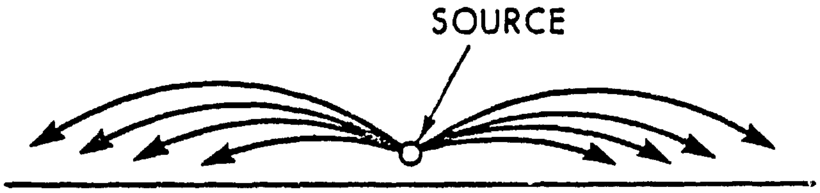
On clear nights, a temperature increase with height is common near the ground (inversion) and the "barrier" disappears.

Wind speed almost always increases with height near the ground. 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 a sound source, but is suppressed downwind.

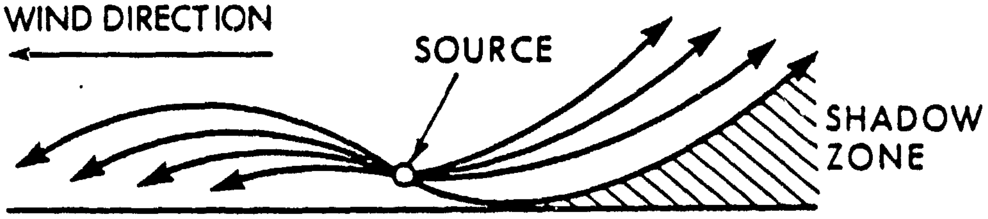
The combined effects of wind and temperature are usually such as to create acoustic shadows upwind of a source, but not downwind. Only under rare circumstances will a temperature lapse be sufficient to overpower wind effects and create a shadow surrounding a source. It is less rare, but still uncommon,



a. TEMPERATURE DECREASING WITH HEIGHT
Typical Daytime



b. TEMPERATURE INCREASING WITH HEIGHT
Typical Nighttime



c. WIND SPEED INCREASING WITH HEIGHT
ABOVE THE GROUND

FIG. 4.1. SKETCHES ILLUSTRATING THE EFFECT OF VERTICAL TEMPERATURE AND WIND GRADIENTS IN FORMING ACOUSTIC SHADOW ZONES AROUND A SOURCE NEAR THE GROUND.

for a surface inversion to be sufficiently strong to overcome an upwind shadow entirely.

Analytical procedures are available for quantitative prediction of these effects on the basis of meteorological observations at the site [*14,15*].

*Absorption of Sound by Foliage*

The study of the attenuation of sound by foliage has had a murky history. A very early study by Erying [*16*] uncovered absorptions approaching 8 dB/100 ft at 1000 Hz in "dense Panamanian jungles." This attenuation appeared to be related to visibility in the jungle. Wiener and Keast [*17*] found no such correlation. Nor did Embleton [*18*], who, in an extensive study of Canadian forests, found "edge effects" along with attenuations considerably in excess of those observed in very similar Russian forests [*19*]. The result is such a wind range of attenuation observations (neatly summarized by Kurze and Beranek [*20*]) that no useful prediction model can be postulated.

Recently, Aylor [*21,22*] has done some excellent work in this area that hints at the difficulty that may have been encountered by previous observers: inability to separate adequately the various scattering, interference, and absorption mechanisms involved in attempting to measure "attenuation due to foliage." Unfortunately, Aylor's results cover only a limited range of foliage types and require for prediction a knowledge of average leaf widths and leaf area densities.

For practical engineering purposes, the foliage-attenuation figures in Table 4.1 are often used. These apply for propagation through dense foliage, not over or under the foliage.

TABLE 4.1 ATTENUATION COEFFICIENTS FOR SOUND PROPAGATED *THROUGH* DENSE FOLIAGE [*15*]

| Octave Frequency Band, Hz | Attenuation Coefficient: dB per 1000 ft |
|---|---|
| 63 | 0 |
| 125 | 10 |
| 250 | 15 |
| 500 | 20 |
| 1000 | 20 |
| 2000 | 30 |
| 4000 | 30 |
| 8000 | 30 |

Total attenuation greater than 15 dB shall be assumed to = 15 dB.

### *Absorption of Sound in the Atmosphere*

The available information on the absorption of sound in the atmosphere was summarized by an SAE committee over a decade ago [*23*]. Although the results have been subject to some recent minor criticism [*24*], it has become common practice to use them for prediction purposes [*11,25*]. The SAE atmospheric absorption coefficients, in dB/1000 ft, are given in Fig. 4.2. The attenuation, $A_m$, is then calculated:

$$A_m = \frac{r\alpha}{1000} \quad (\text{"}\alpha\text{" from Fig. 4.2) dB} \quad .$$

### *Effects of Buildings in Urban Areas*

With the growing international interest in traffic noise, numerous studies have been made of sound propagation along urban

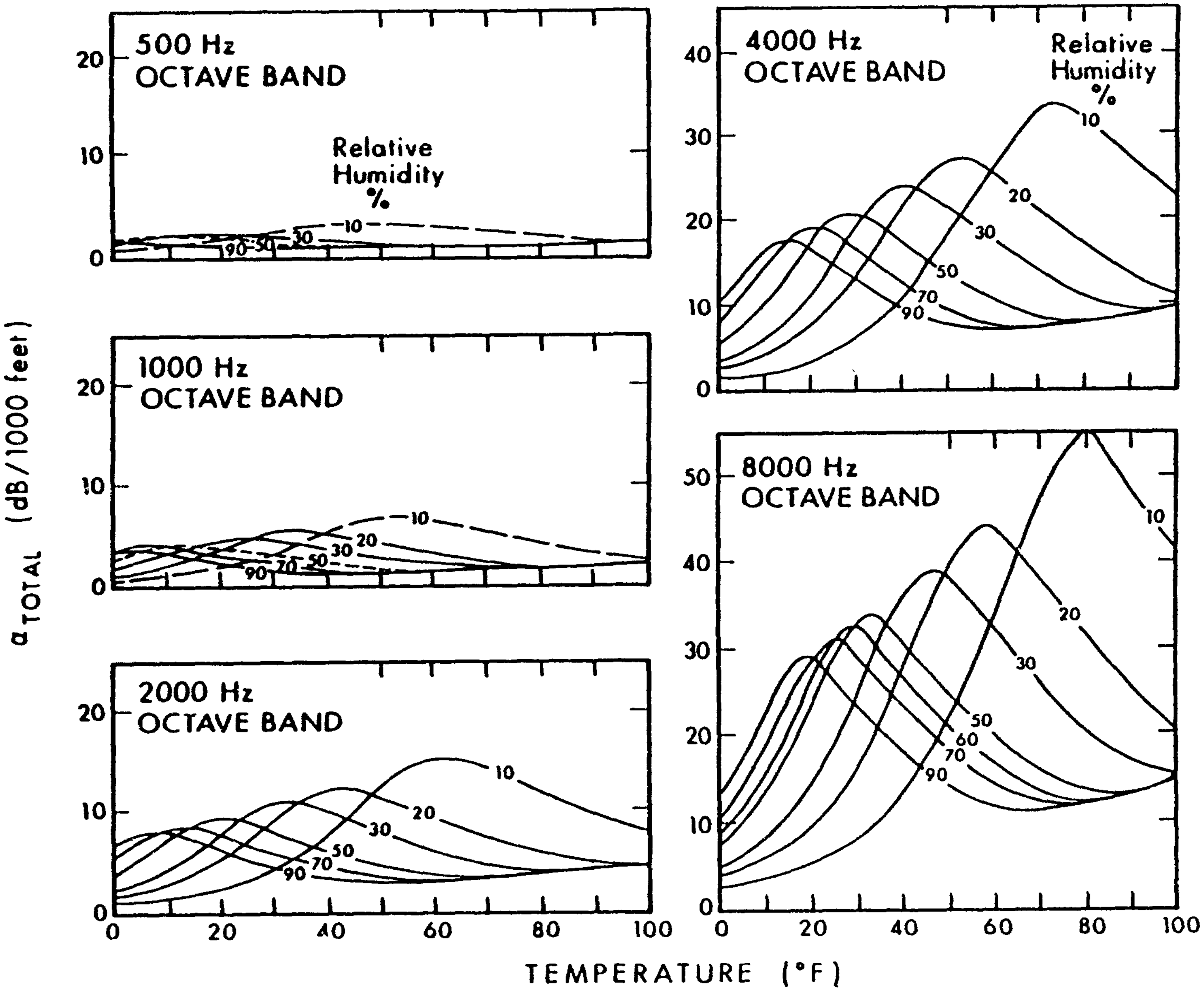


FIG. 4.2. ATMOSPHERIC ABSORPTION COEFFICIENTS FOR OCTAVE BANDS OF NOISE AT DIFFERENT TEMPERATURES AND HUMIDITIES (From SAE ARP 866, Ref. 23).

streets [*26–30*]. On the basis of all of these studies, it appears that urban propagation is relatively unaffected by atmospheric gradients, and that simple divergence plus atmospheric absorption can account for line-of-sight propagation. An additional 10-dB loss (at all frequencies) is observed for propagation around corners into side streets.

The concluding statement about the variability with time of distant sound levels from a steady source comes from many studies [*17,31,43*].

### 4.4.2 Hearing

*Local Barriers*

It is common knowledge that sound is attenuated as it passes through the envelopes of buildings or motor vehicles. Supporting data can be found, for buildings, in Refs. 32 and 33; and for motor vehicles in Ref. 34. The pertinence of current building energy conservation effects has also been described [*35*].

*Background Noise and Detectability*

The most important physical parameter for predicting acoustic detectability is the signal-to-noise ratio measured over a band of frequencies encompassing the signal energy. Much existing research concerns how the signal-to-noise ratio influences masking when the noise is steady state and the signal is a brief pulse. How masking varies as a function of signal duration, frequency, and multiple component signals is well understood and readily predicted.

For signals of finite duration observed in specified intervals of time, the detectability of the signal (or the masking effectiveness of the noise) is governed by the ratio of signal energy to the noise power density; that is, the noise power per cycle, often called the spectral level of the noise. For a single sinusiod, E, in noise, N, and a test of short duration (about 1/10 sec), the detectability index d' is approximately [36]:

$$d' \approx g(f)\, E/N \quad ,$$

where g(f) is a constant that depends on frequency d' is the detectability of the signal. A d' = 1 (sometimes called a threshold value) implies correct selection of the interval that contains a signal in a two-interval forced-choice test with about 75% accuracy. The function g(f) is about 1/10 when f = 1000 Hz, and is monotonic with frequency: g(250 Hz) = 0.15, g(2000 Hz) = 0.063, g(4000 Hz) = 0.025. Thus, the higher the signal frequency, the less noise power is needed to achieve a given level of masking.

A major difference between this body of research and the current question of predicting the detectability of a warning sound is that warning sounds are not of short duration, but are quasi-continuous, or at least of prolonged duration. This difference has been explored, and there are experimental studies indicating that the best approach is to treat the signal as incoherent. The effective detectability may then be predicted as [37]:

$$d' = \eta(W)^{\frac{1}{2}}\, S/N \quad ,$$

where d' is again the detectability index, $\eta$ is an efficiency term (a constant for any given situation), W is the 1/3-octave bandwidth centered at the signal frequency, and S/N is the signal-to-noise ratio (ratio of powers) measured in the same 1/3-octave band. For a complex signal spectrum, there are separate detectability indices for each spectral region. Thus, for a given level of warning signal, the background noise spectrum is critical to determining warning signal effectiveness.

A recent study has reported that the level of sound from emergency-vehicle sirens must be about 9 dB higher than the level detectable under laboratory conditions in order to attract the attention of otherwise preoccupied observers [*34*]. This conclusion has been used in this study, as discussed below.

Recent studies have shown that the outdoor background noise in a community is strongly correlated with local population density, as illustrated in Fig. 4.5 [*38*]. This presumably results from the fact that outdoor noise levels are almost always caused by motor vehicle traffic, which correlates well with population density. Thus, population density (readily obtainable from census tract data), is a far better metric of background noise than zoning or land-use patterns like "residential," "business," and "heavy industrial." Harlem, in New York City, is much noisier than most heavy industrial sites. Furthermore, the noise of heavy industry is increasingly being reduced by OSHA regulations and local noise ordinances.

### *Exposure to Excessive Sound Levels*

Deleterious effects on humans from exposure to excessive sound levels are well known. Hearing damage is the major consideration, and has led to federal regulations covering noise exposure of employees in industry [*39*]. Interference with speech communication and general disturbance of the community is another consideration, and this has led to federal legislation [*40*] and community noise-exposure guidelines [*41*]. However, federal law specifically delegates to the states and local communities the responsibility for regulatory exposure to sounds from fixed sources in communities, such as acoustic outdoor warning devices. Many state and local governments have no such regulations. Others have regulations that exempt warning devices: the presumption being that the audibility of the warning sound is of greater value to the public than some loss of peace and quiet.

For the purpose of establishing a limit to exposure of the public to the sounds from outdoor warning devices, we have relied upon a study by the prestigious CHABA committee, published in 1965 [*42*]. This study was done for the military services, where exposure to hazardous sounds might occur to military personnel performing their duties. Thus, the level of conservation embodied in the study is commensurate with that applicable to outdoor warning devices used for civil defense purposes.

The CHABA limits applicable to tonal sounds, such as those produced by most outdoor warning devices, are illustrated in Fig. 4.3. The limit selected for the Guide, 123 dB(C), is based upon an exposure duration of 1-1/2 min. or less, at a frequency of 1000 Hz. This is the highest fundamental frequency produced by any outdoor warning device we have identified. Note that exposures to slightly higher levels are permissible at lower frequencies. However, this fact has been ignored in the Guide for simplification, and to provide a factor of safety.

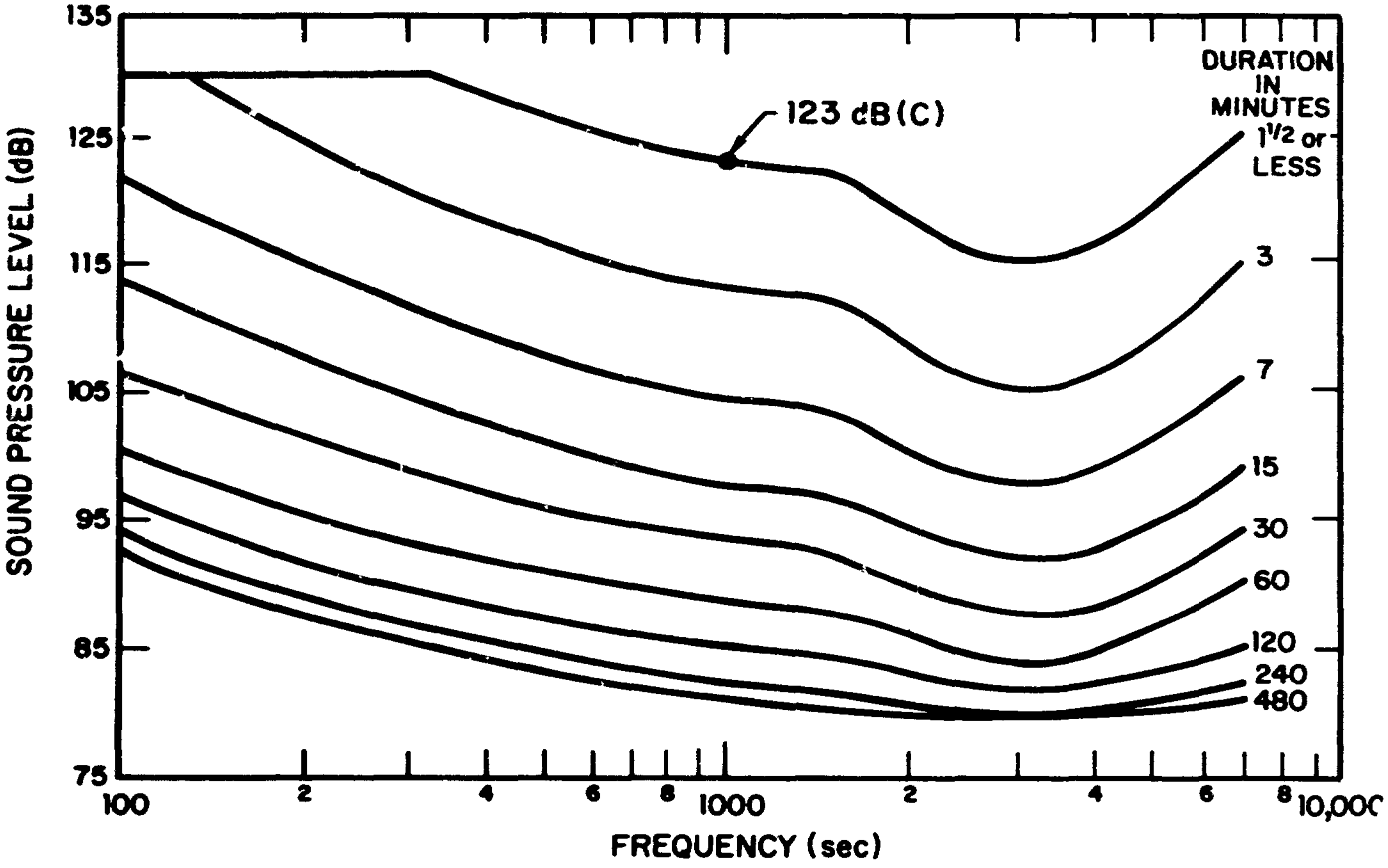


FIG. 4.3. CHABA DAMAGE RISK CONTOURS FOR ONE EXPOSURE PER DAY TO PURE TONES [42].

### 4.4.3 Estimating range of coverage

In order to develop a simple procedure for estimating the range of coverage as a function of the rated output of a warning device, it is necessary to:

- Develop an average measure of the sum of all the propagation loss factors described in Sec. 4.4.1 above
- Develop some conservative, average measure of the background noise so that a S/N ratio can be defined as described in Sec. 4.4.2
- Estimate detectability, and apply the +9 dB correction of Ref. 34 required to get the attention of otherwise preoccupied warnees.

A comprehensive report by Delany [*43*] provides an excellent discussion of the factors pertinent to outdoor sound propagation for acoustic warning devices. Even more important, however, is a summary Delany has provided of all the available experimental studies of sound propagation from warning sirens. This summary (for a 400-Hz siren producing 122 dB(C) at 100 ft (30 m)], is shown in Fig. 4.4. These data, generalized to apply to sources of all possible ratings, have been used to develop Fig. 1 of the new Guide. The differences between the suburban and urban condition in Fig. 4.4 are due to the effects of shielding and scattering by high-rise buildings in urban areas. (It is much less likely in urban settings to have a line-of-sight path from the sound source to the listener.) This difference is carried over to Fig. 1 of the Guide.

Delany places particular emphasis on the need to locate sources above the prevailing rooftop height, where practical

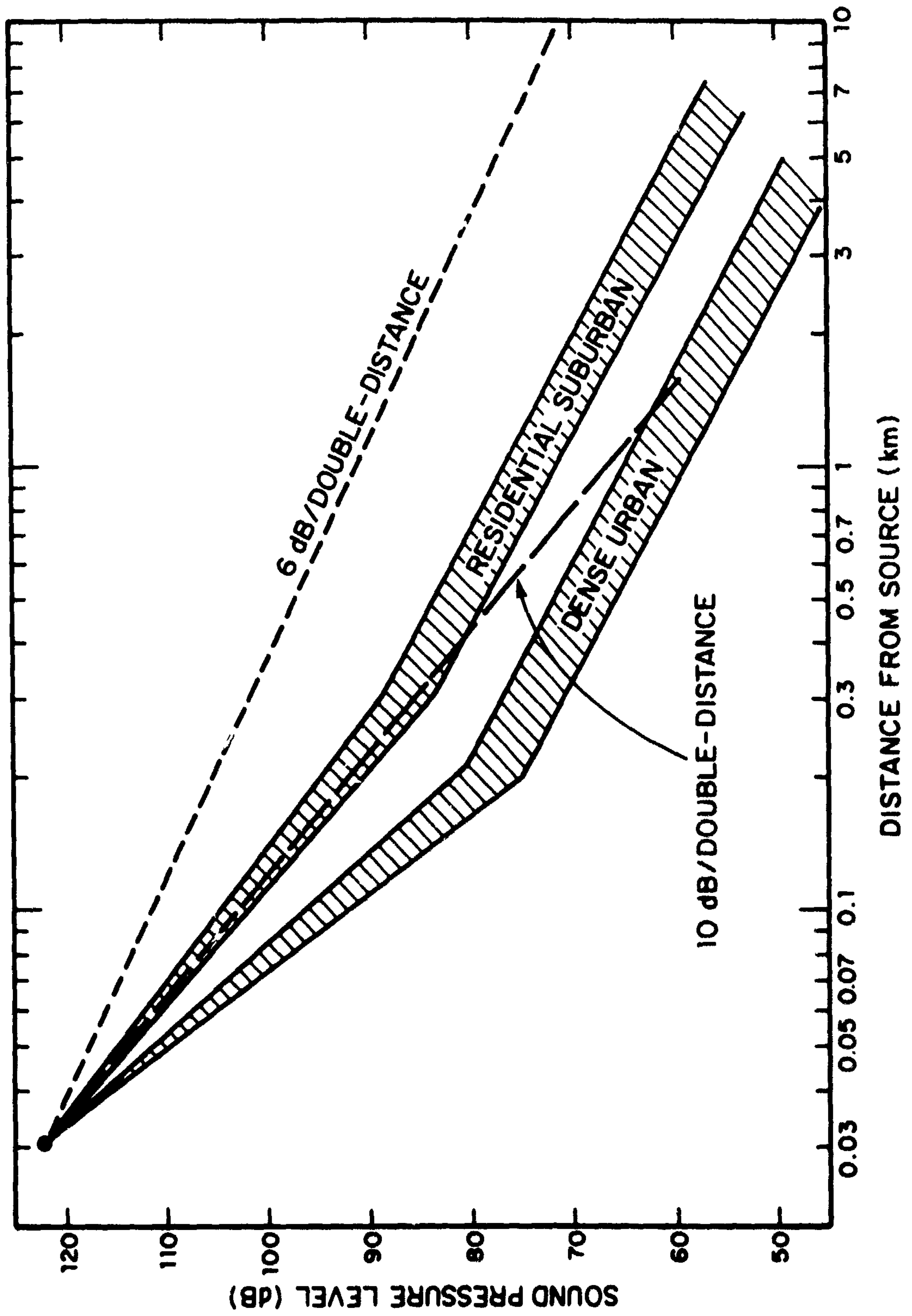


FIG. 4.4. DELANY'S SUMMARY GRAPH FOR URBAN PROPAGATION [43].

in suburban areas. This is to avoid the losses associated with two or more diffractions (barriers) as the sound propagates from source to listener. This emphasis is repeated in the Guide, for it also contributes to minimizing excessive exposures to bystanders.

Figure 1 of the Guide is based upon a background noise level of 70 dB(A) in the frequency band centered about the fundamental tone of the source. As is well known, outdoor background noise levels vary considerably with time, being determined predominantly by motor vehicle traffic. Background noise levels tend to be higher in the daytime than at night, making warning sounds harder to detect in the daytime, even though people are more likely to be out of doors during the day.

EPA has statistically sampled the background noise at over 100 residential locations throughout the United States [*38*]. A portion of these data are shown in Fig. 4.5. This figure illustrates the *A-weighted* sound level [dB(A)] exceeded 10% of the time (called the $L_{10}$) at each of the 100 locations, as a function of the population density at each location. The data are for EPA's official "daytime" period of 7:00 a.m. to 10:00 p.m. (The nighttime levels were lower.) A regression line has been fitted to the data, and points shown as open circles are from urban high-rise areas.

On the basis of Fig. 4.5, we have selected 70 dB(A) as a suitable background noise level for the purpose of deriving Fig. 1 of the Guide. A number of community background noise spectra were then examined to establish an average correction from A-weighted level to sound level as a function of frequency

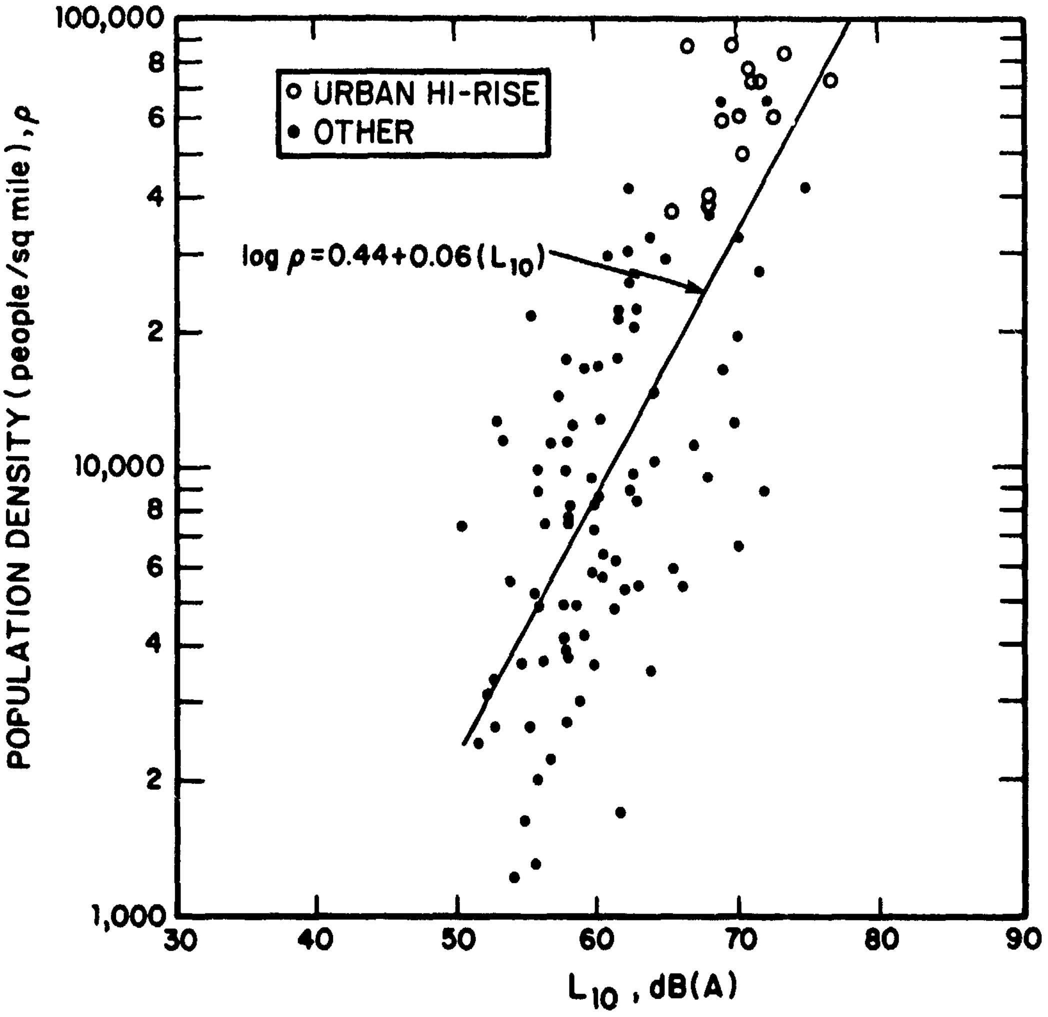


FIG. 4.5. DAYTIME $L_{10}$ LEVELS AT 100 RESIDENTIAL LOCATIONS IN THE UNITED STATES [38].

in the frequency range in which outdoor warning devices produce sounds. These average corrections and the resulting spectrum are shown in Table 4.2. The detection level (the level of a signal that will produce 50% correct judgments with a 1% false-alarm rate) in each band was then determined, and these are also listed in Table 4.2. The +9 dB correction required to get the attention of otherwise preoccupied listeners was then added, to obtain the necessary warning signal levels shown in the last column of Table 4.2 [*34*].

As indicated in the table, the level necessary to warn decreases with frequency. In the interest of simplicity, and to be conservative, we have chosen a level of 70 dB(C), corresponding to a warning signal at about 300 Hz. [It is a coincidence that the 70 dB(C) warning level is numerically equal to the 70 dB(A) background level.]

## 4.5 Planning an Outdoor Warning System

### 4.5.1 Determining warning coverage

The coverage prediction method using Fig. 1 of the Guide is applied to a typical urban situation (Bridgeport, Connecticut). On the basis of the recommendations of Delany [*43*], emphasis is placed, in the example, on locating devices at noisy places far from residences, at locations with good potential for line-of-sight coverage, and at public buildings.

### 4.5.2 Avoiding hazardous exposure

The exposure limit of 123 dB(C), from CHABA [*42*], is repeated. The importance of the vertical directivity pattern

TABLE 4.2 BACKGROUND NOISE SPECTRUM AND PREDICTION OF DETECTABLE AND "ATTENTION-GETTING" LEVELS

| 1/3-Octave Frequency Band (Hz) | Average Community Band Level vs A-Weighted Level (dB) | SPL in Band for 70 dB(A) Level (dB) | Detection Level (dB) | Attention-Getting Level (+9 dB) (dB) |
|---|---|---|---|---|
| 250 | -7 | 63 | 62 | 71 |
| 315 | -8 | 62 | 60 | 69 |
| 400 | -8 | 62 | 59 | 68 |
| 500 | -8 | 62 | 58 | 67 |
| 630 | -9 | 61 | 57 | 66 |
| 800 | -10 | 60 | 56 | 65 |
| 1000 | -10 | 60 | 55 | 64 |

of the warning device is emphasized with an example computed for the one commercial product on which such data were available. This example, Fig. 3 of the Guide, can be explained as follows: Visualize a warning device mounted on a pole some height above the ground. Sound is radiated mostly in a horizontal direction from the warning device, and its level decreases with distance. A lesser amount of sound is radiated down toward the ground. Thus, there is potentially a ring-shaped area around the warning device in which a bystander might be exposed to an excessive sound level [a level above 123 dB(C)]. The dimensions of this ring-shaped area will depend upon the sound output of the warning device, its vertical directivity pattern, and its height above the ground. For example, Fig. 4.6, computed from the available data on the one device, indicates that for a warning device rated at 115 dB(C) at 100 ft, and mounted 15 ft above the ground, hazardous noise exposures would occur to people standing more than 8 ft and less than 40 ft from the pole on which the device is mounted. Closer than 8 ft, hazardous exposures would not occur because less sound is beamed in that direction from the device. Further than 40 ft, hazardous exposures would also not occur, simply because the bystander would be too far away from the warning device.

The information contained in Fig. 3 of the Guide has been derived from the minima of the parametric curves on Fig. 4.6, and shows the *minimum* mounting height of a warning device above the ground in order to avoid hazardous sound exposures, as a function of the rated output of the warning device. The Guide figure shows, for example, that a warning device rated at 125 dB(C) at 100 ft should be mounted at least 52 ft above the ground to avoid all risks of hazardous exposure to bystanders

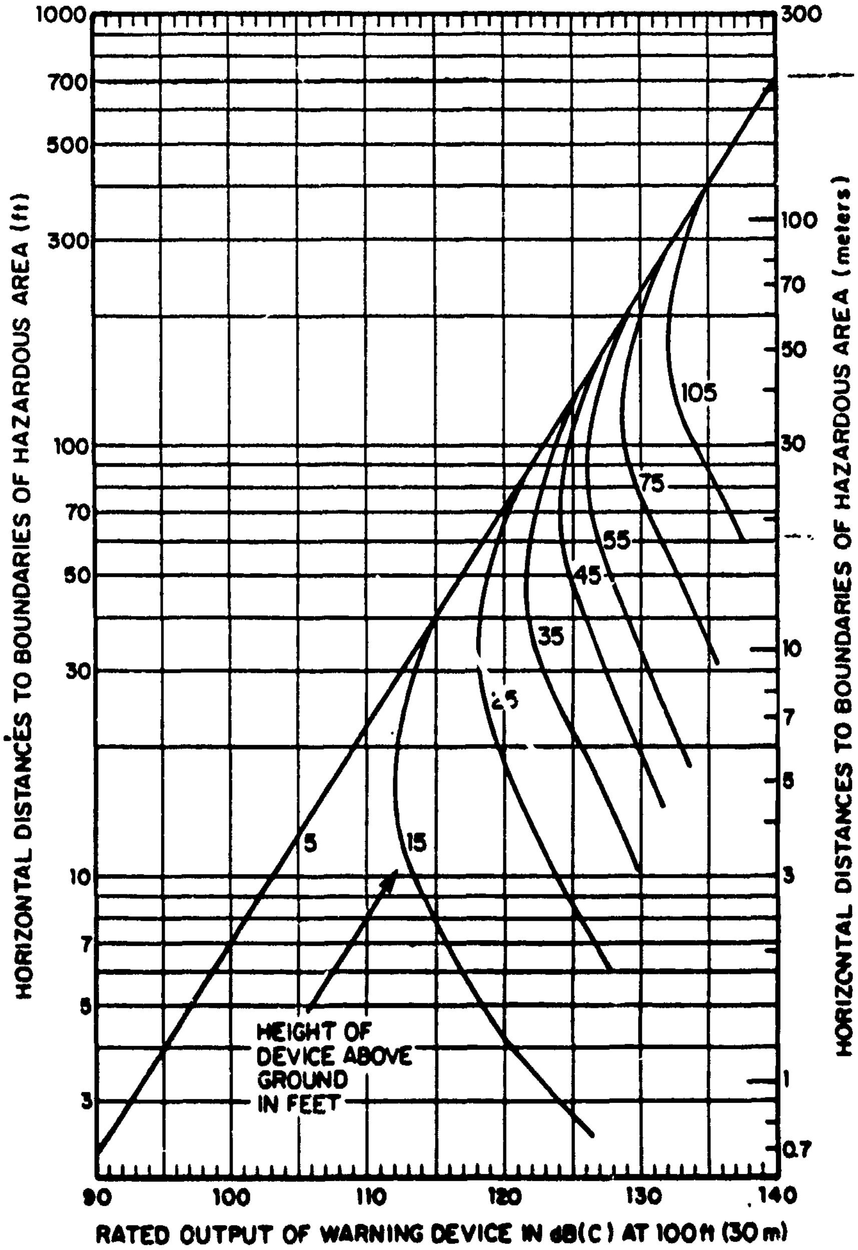


FIG. 4.6. BOUNDARIES OF RING-SHAPED AREA AROUND WARNING DEVICE WITHIN WHICH HAZARDOUS SOUND EXPOSURES TO PEDESTRIANS COULD OCCUR AS A FUNCTION OF RATED OUTPUT OF THE DEVICE AND ITS MOUNTING HEIGHT. (COMPUTED FOR ONE PARTICULAR DEVICE.)

from its sound output. If a warning device must be mounted closer to the ground than indicated by Fig. 3, it is recommended that the device carry a large sign advising bystanders to leave the immediate area when the warning device begins to operate.

It must be reemphasized that the curves on Fig. 4.6 and Fig. 3 of the Guide are based upon limited data for only one commercially available warning device. No data are available for other devices. In the Guide, the burden for avoiding exposure above 123 dB(C) is placed on the device vendor.

In those cases where a warning device must be mounted below the rooftops of surrounding buildings, such as in urban high-rise areas, consideration must be given to avoiding excessive sound exposure to occupants of nearby buildings who are located within the main sound beam of the warning device. This criterion is illustrated in Fig. 4 of the Guide. It is based upon average values of the sound-reducing properties of residential structures reported by the U.S. Environmental Protection Agency (EPA) [*41*].

## 4.6 System Testing and Use

The material in this section of the Guide is drawn from other DCPA publications, such as CPG 1-14 [*1*] and CPG 1-1 [*44*]. Note, however, that warning system tests are recommended "for no more than one minute" rather than "for at least one minute" as specified in other DCPA documents. This is to minimize community annoyance and disturbance from test sounds.

## 5. CONCLUSIONS AND RECOMMENDATIONS

The lack of data on the acoustic output spectrum of commercially available warning devices, and on their vertical directivity patterns, has been a serious limitation during this study. It is recommended that vendors be encouraged to obtain and provide such data so that more precise (and less conservative) decisions can be made about warning device siting.

Assuming the above data were available, it should be possible to prepare a computer program that would establish optimal siting of warning devices in a community, given the constraints the community wishes to place on the warning system. A computer analysis could also take into consideration the fluctuating nature of background sounds, weather patterns, human activity patterns out of doors, etc. (all of which are beyond the scope of a simplified Guide), in order to provide statistical measures of warning probability under any defined set of circumstances. It is recommended that DCPA prepare such a computer program, which could be made available to communities planning the installation or modification of an outdoor warning system.

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The guide, included as Sec. 3 of this report, covers in a simplified form the principles of sound, outdoor warning systems and devices, propagation and detection of sound out of doors, avoiding hazardous noise exposures, and warning system planning, testing, and use. Technical data in support of the Guide are given in Sec. 4 of this report, and conclusions and recommendations based upon the study are provided in Sec. 5.

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