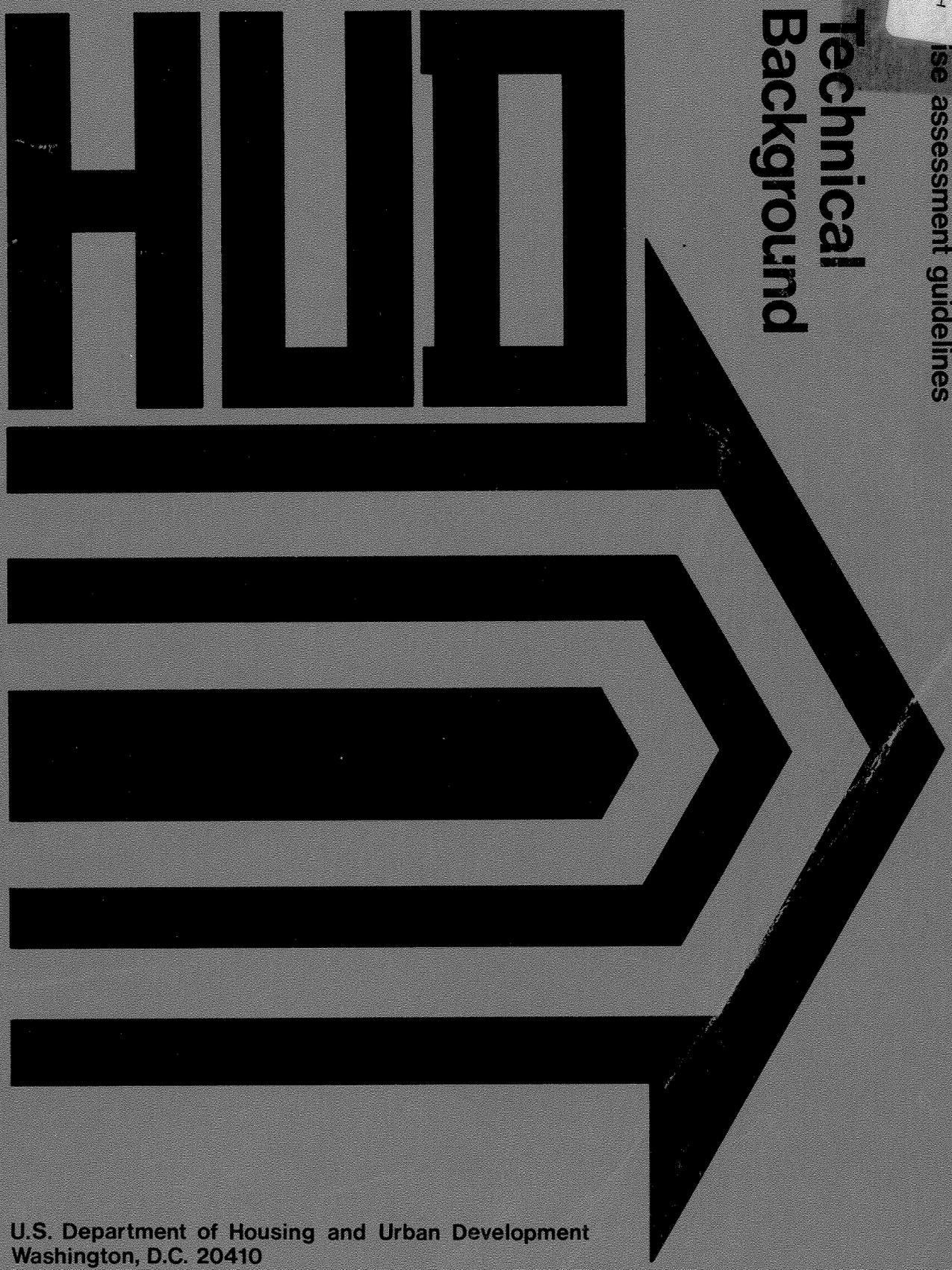


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Technical Background



U.S. Department of Housing and Urban Development
Washington, D.C. 20410

This report was originally published in September 1970 with the same title, bearing the report number 2005. At that time Chapter IV gave technical background for the evaluation procedures in "Guidelines for Noise Exposure Assessment of HUD Housing Sites," BBN Report No. 2019, also published in September 1970; numerous references were made to pages, figures and tables in the Guidelines.

When the Guidelines were re-edited to make the booklet more attractive and accessible for the reader, references in the original report No. 2005 no longer corresponded to the proper page, figure and table numbers in the revised Guidelines. Accordingly, the present report No. 2005 R represents a revision of the earlier report No. 2005, but only with respect to minor typographical errors and to Chapter IV to make it conform to the revised Guidelines. The revised pages and figures carry the number 2005 R, whereas unrevised pages carry the original number 2005. No new technical material has been added in this revision.

The contents of this report reflect the views of the contractor, who is responsible for the facts and accuracy of the data presented herein.

Report No. 2005 R

Job No. 11477

TECHNICAL BACKGROUND FOR NOISE
ABATEMENT IN HUD'S OPERATING PROGRAMS

8 November 1971

by

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and

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for

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Office of Research and Technology
Washington, D.C. 20410

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TECHNICAL BACKGROUND
FOR NOISE ABATEMENT
IN HUD'S OPERATING PROGRAMS

I. THE NEED FOR NOISE ABATEMENT

"The crescendo of noise --- whether it comes from truck or jack-hammer, siren or airplane, shatters serenity and can inflict pain. We dare not be complacent about this ever mounting volume of noise. In the years ahead, it can bring even more discomfort --- and worse --- to the lives of people." President Lyndon B. Johnson.⁷¹*

"Like those in the last century who tilled a plot of land to exhaustion and then moved on to another, we in this century have too casually and too long abused our natural environment. The time has come when we can wait no longer to repair the damage already done, and to establish new criteria to guide us in the future ..." President Richard M. Nixon.²²³

One of the most conspicuous results of current technology is that it exposes us to noise: aircraft, automobiles, trucks, railroads, construction equipment, factories --- even home appliances --- all contribute to the din that characterizes modern cities. Like air and water pollution, most noise comes of our having made particular technological choices without fully considering their impact on the people who have to live with them. Technology, to date, has typically advanced by satisfying "first order" needs with "first order" solutions --- for example, creating transportation facilities (the automobile and the highway system) to increase our mobility. It has responded to specific problems in isolation rather than anticipating the sociological effects of the solution, and has simply "built" systems, rather than designing them with an awareness of their potential overall impact on society.

* Superscript numbers refer to papers or articles listed in the bibliography at the back of this book.

This approach appeared at first to be adequate only because our natural resources of land, air and water were so great as to be practically infinite, in relation to the existing demands. But with the growth of our population and the spreading and crowding of our cities, such conventional "first order" solutions have gradually come to defeat the purposes for which they were made: we now have traffic congestion instead of mobility, and also problems of air and noise pollution as well.⁴³ Our technology is clearly not so "advanced" as we have boasted.

"Partly because noise cannot be seen and can be eliminated by turning off the source and partly because the full effects of noise on human beings are still open to question, it has not received the degree of social concern that has recently been given air and water pollution.* Yet noise has disrupted the environment just as surely as other forms of pollution and will require commensurate attention."^{81/}

There can be no doubt whatever that the noise to which our population is exposed today has become so intense as to pose a serious problem, not merely because it detracts from the amenity of an attractive living environment, but because it is now recognized as a grave threat to the public health, particularly in urban areas. 21,31,55,81,281/ (See note, page 12.)

* Possibly for the same reasons, there is only one mention of noise in the entire proceedings of a recent conference on new town planning, and that comment merely remarked that one of the advantages of siting new towns in rural areas is the avoidance of various kinds of pollution, including noise, in urban areas. This planner, instead of wishing to solve pollution problems, is prepared to turn his back on them!

Noise vs. health

Current studies of the effects of noise⁽ⁱ⁾ show clearly that people repeatedly exposed to typical city noise levels exhibit increased irritability and discomfort, severe nervous tension, loss of ability to concentrate, impaired aptitude to perform even simple tasks, and loss of sleep. Even when the sleeping person is not awakened by the noise, he suffers. Recent research shows that sleep, accompanied by dreaming, is essential to mental health. Exposure to modern-day noises disturbs the depth of slumber though it may not awaken the sleeper,⁽ⁱⁱ⁾ with the result that, although, next day, the persons may not recall being disturbed by the noise, the majority spontaneously report feeling extreme fatigue. In more noisy circumstances, of course, there is actual sleep loss, which if prolonged has been observed to lead to psychotic behavior with delusions.142,168,188,281/

During our waking hours, we all know that interruptions of conversation, TV listening, and on-going tasks by noise intrusions are a common source of annoyance,168,170/ and if the source of noise is beyond our control, these repeated interruptions may lead to feelings of frustration, irritability, anxiety and constrained rage.214,140/*

* In recent experiments by Glass and Singer, random noises caused marked irritation and frustration, as well as dramatic declines in work efficiency even after the noise was stopped. Glass suggested that powerlessness to change a situation can cause adverse effects: "If the noise is predictable and regular, or if the noise is irregular but the subject is told he can shut it off if it becomes too much for him, then frustration and inefficiency do not appear." For individuals bothered by urban traffic noise, powerlessness to change the situation may be a very important cause of their annoyance.143/

- i. See references 55,62,138,159,168,170,171,193,212,218,239.
- ii. See references 129,138,168,193,212,215,220,233.

In the long run, these repeated intrusions generate in the continually-exposed population the helpless feeling that something of great value --- the quality of the environment, the right to the quiet enjoyment of our homes, and the very value of our residential property --- has been taken away from us by "somebody else" who cannot even be identified and blamed or enjoined to stop the disturbance: we find ourselves victimized by "the system".^{103/}

One can no longer dismiss the current public concern over noise as the exaggerated complaints of neurotic cranks and hypersensitive aesthetes.* A good proportion of our urban population does, in fact, experience distressing psychological conflicts, and the addition of severe and preventable noise exposure to the other strains of daily life undoubtedly compounds the problem.⁽ⁱ⁾

"Excessive noise is literally a public health hazard."^{55/}

"... what we are really struggling with is the price of our past technological advance ... We have built our way of life and our standards of living into [the sources of pollution] and we did it rather carelessly, without thinking of the consequences ... So now we have to try to build into our economy and our technology the controlling mechanisms which will correct our past mistakes." (Senator Muskie, quoted in Ref. 81, p.550.)

The implication is that there is some "catching up" to be done; and, of course, we are beginning to catch up. In practically every industrialized country of the world conferences on noise

* As the British Justice Luxmoore put it, a man's resentment of noise ought "to be considered in fact as more than fanciful, more than one of mere delicacy or fastidiousness" and the noise complained of as "an inconvenience materially interfering with the ordinary physical comfort of human existence, not merely according to elegant or dainty modes and habits of living, but according to plain and sober and simple notions obtaining among the English people." (Vanderpont v. Mayfair Hotel Co.Ltd., 1930).

i. See References 29, 81, 147, 177, 178, 187, 192, 212, 214, 281.

have been held; 31,55,99,141,240/ a number of surveys of the existing noise environment have been made, 13,14,15,135,142/ and corresponding social surveys have been carried out to assess the extent of popular annoyance with the existing noise exposure. 80/* Quantitative measurements of urban (mostly traffic) noise have been (or are being) made in Germany, 5,28,56,142,217/ Austria, 23,24,26,27/ Belgium, 142/ India, 108/ Canada, 21,41,106,133,138/ U.S.A., (i) Spain, 107/ France, 3,31,73,83/ Norway, 142/ Netherlands, 36,142/ Italy, 194/ Poland, 269/ Australia, 97,222/ Rumania, 142,179/ Japan, 95/ the United Kingdom, (ii) Sweden, 58,78,142,194/ Switzerland, 48,118,119,230/ and the USSR. 142,226/ In addition, studies have been made on small-scale models of towns to determine how noise propagates through built-up areas; the most important of these have been in Germany 247/ France, 51,116/ Norway, 142/ and the United Kingdom. 142/ Research to determine (and predict) the psychological and physiological effects of urban noise 29,142/ has been undertaken in Austria, 23,24,26,27/ France, 31,37,82,142,148,218/ Japan, 197/ Germany, 89/ the Netherlands 142/ Canada, 138/ the United Kingdom, (iii) Sweden, 30,78,142,142/ and the U.S.A. (iv) And sleep disturbance studies are under way in Germany, 142,143,193,212/ France, 31,129,220,233/ the USSR, 142/ Canada, 138/ and the U.S.A. 215/

* An up-to-date, if not yet complete, account of the status of research and legislation and the actual administrative and legislative practices in different countries is currently in preparation (in draft form) by the Organization for Economic Co-operation and Development, Paris. 120,142/

- i. See References 19,20,22,32,33,35,39,50,53,54,60,66,68,92,98,101,102,104,105,127,128,144,145,149,227,232,242,263,273.
- ii. See References 5,17,38,40,70,86,88,93,100,114,115,130,131,136,139,150,189,278,283.
- iii. See References 17,86,93,100,122,123,124,130,213,231.
- iv. See References 14,15,32,34,47,90,101,111,236.

Equally intensive studies have been made of the magnitude and the subjective effects of aircraft noise,^{113/} principally in Germany,^{79,166/} the United Kingdom,^{18,100,125,266/} France,⁽ⁱ⁾ the Netherlands,^{163/} and the U.S.A.⁽ⁱⁱ⁾

Studies are also underway to determine the most practical ways of enforcing noise abatement procedures and legislation,⁽ⁱⁱⁱ⁾ including summaries of the present status of administrative and legislative practice in various parts of the world.^{21,63,77,120,142/}

The results of these studies are not all in complete agreement (indeed, the differences in approach among them are sufficiently great that perfect agreement might be difficult to recognize!) but all studies agree that the most extensive and pervasive sources of noise are road traffic and aircraft. And beyond this, there is sufficient consistency among the conclusions of the studies that they can serve as reliable guidelines in the choice of (present and future) procedures and criteria for the implementation of HUD's Noise Abatement Policies. Without trying to describe all of these results in detail, we summarize the most important findings, as well as the general acoustical literature dealing with noise control to provide technical background for the Noise Abatement Efforts in HUD's Operating Programs.

-
- i. See References 2,72,73,167,174,186,188.
 - ii. See References 7,8,9,13,45,46,57,67,84,91,104,160,161,172,173,183,184,185,190,201,202,203,206,207,208,210,228,229,235.
 - iii. See References 21,25,42,44,49,51,52,55,59,65,69,74,76,81,85,87,94,96,121,126,134,137,146,152,158,162,164,175,176,180,181,191,196,200,211,213,219,224,225,241,243,265,272,274,275,277,279,282,283,284.

CAUTION:

In view of the emphasis placed on the potential and demonstrated dangers of noise pollution, as described above, it may appear a bit perverse now to add a word of caution. Not that there is any doubt at all that the noise around us must be abated; but we began this chapter by considering the shortcomings of "first-order" solutions to our social problems: it would be ironical, indeed, if in attempting to correct the consequences of our first-order efforts, we should introduce new difficulties.

Man is an adaptable animal.....at least, up to a point. In the face of an increasing burden of urban noise we have all learned conscious ways of coping with the problem more or less satisfactorily. We have even, in response to who knows what social stresses, deliberately created for ourselves locally more noisy surroundings.

It is doubtful that any lasting harm would come of reducing the decibel level in rock-and-roll parlors and discotheques; but one ponders with misgivings the consequences of transistor-ectomy for the teenager (how will they study?), or ordinances that disable the beach-goer who uses his radio for establishing territorial rights; if canned music has been installed throughout the nation at considerable expense, in the presumably well-established expectancy that, ubiquitous, it will turn shoppers into foot-tapping, buying fools, then what effect will outlawing this nuisance have on the GNP?

The examples suggested above may (perhaps) be frivolous; the principle is not!* It would indeed be prudent, as we bend our

* Who, in viewing the first Model-T on an open prairie, would have taken seriously the concept of a "smog alert"?

efforts to undo the din we have made, to look into the possible consequences: at the very least to search the literature for a clue to possible "withdrawal symptoms" from a habitual, poisonous overdose of noise.

II. DESCRIBING AND MEASURING NOISE⁽ⁱ⁾; HUMAN REACTIONS

Suppose a man has heard a noise; if he wishes to describe it, he finds that he must take into consideration a number of different aspects of the noise if his account is to do justice to what he heard. First, loudness: the noise may seem loud or soft to him, or perhaps somewhere in between. In addition, it may sound shrill in pitch or rumbly, or a combination of both if it is made up of several components; its quality may be "pure" or "raucous"; also, it may be "continuous-with-steady-level," "continuous-with-fluctuating-level," or "intermittent-with-interruptions" at fixed or varying rate, regular or irregular.

All of these characterizations are needed to describe the noise; they represent aspects of how the noise sounds to him and thus are subjective attributes of the noise, perceived by his hearing sense.

Each of these subjective attributes, however, corresponds to an objective, physical characteristic of the sound wave that was heard by the man as noise. These physical characteristics of the sound would remain the same and could be measured with acoustical instrumentation, even if the man were not there to hear it.

A. The Nature of Sound

The sound itself is a rapid, small-scale fluctuation of the instantaneous air pressure above and below the local barometric

i. See References 6, 112, 154, 165, 195, 216

pressure, usually following a repetitive pattern. This disturbance may be initiated by a vibrating solid object, such as a loudspeaker diaphragm, or by turbulent airflow, such as that from a whistle or the wake of a jet engine. In every case, the sound wave radiates away from the source with a constant speed that depends only on the air temperature (and not very strongly at that!). For practical purposes, we can simply remember that sound always travels 1130 ft./sec. in air, or one mile in five seconds.

B. Sound Level

The physical measure of sound corresponding to the subjective loudness heard by the man is the sound level, measured in decibels (dB);* it depends on the strength of the pressure fluctuations around the static pressure. It is measured with a sound-level meter comprising a microphone, to convert the sound pressure fluctuations into a corresponding fluctuating electrical voltage, suitable amplifiers, and a meter on which to read the magnitude of the voltage. The whole device is calibrated so that a given voltage read on the meter always corresponds to the same sound level. The meter is marked to read the sound level directly in decibels.

*The range of sound intensity to which the human ear normally responds is enormous: it can detect intensities as weak as 1 picowatt (10^{-12} watts) and can withstand intensities over 10,000,000,000,000 picowatts. In order to deal conveniently with such a large range of numbers, we use a logarithmic measure, the decibel, that relates the sound intensity (I) in question to a standard reference intensity (I_0) representing approximately the weakest audible sound (1 picowatt), as follows:

$$\text{Sound level} = 10 \log_{10} (I/I_0) \text{ in dB}$$

(Other logarithmic scales in common use are the f-stops on

(Footnote continued)

cameras and the stellar magnitudes used to describe the brightness of celestial bodies.)

In decibel notation, therefore, the entire audible range of sound intensity, described above with such large numbers in picowatts, runs only from 0 to 130 dB.

The decibel notation is somewhat tricky: each time the intensity of a sound is doubled there is an increase of 3 dB:

<u>Sound Intensity (picowatts)</u>	<u>Sound Level (dB)</u>
1	0
2	3
4	6
8	9
16	12
32	15
64	18
128	21
etc.	

Each time the sound intensity is multiplied by ten, there is an increase of 10 dB:

1	0
10	10
100	20
1000	30
10000	40
100000	50
etc.	

Each increase of 10 dB sounds subjectively approximately twice as loud to the ear. A risk of temporary or permanent damage to hearing exists for people under prolonged exposure to noise levels above about 90 dB.

Because decibel notation is fairly complicated, particularly as to how two or more sound levels combine, we have taken great pains, in developing HUD's noise assessment procedures, to avoid the decibel concept wherever possible, proceeding from the site information directly to an assignment to one of HUD's acceptability categories.

C. Frequency

The physical measure corresponding to the subjective aspect of pitch is the frequency of the sound, that is, the rapidity of the repetitive pressure fluctuations, as expressed in the number of cycles completed per second. The recently adopted international standard unit of frequency, corresponding to the old "cycles per second (cps)," is the hertz, abbreviated Hz. A frequency of about 260 Hz corresponds to middle C on the piano keyboard; 1000 Hz is about the frequency of the high-C that sopranos sometimes strive for and miss. A healthy young ear can hear sounds with a range of frequencies from about 16 to 20,000 Hz. As people get older, however, the acuity of hearing for higher frequencies gradually diminishes, so that it is not uncommon for a 50-year-old man to be unable to hear sound with frequencies above 8000 Hz.*

D. Frequency Analysis

Most noises are made up of a mixture of components having different frequencies: the sound of a diesel tractor/trailer at high speed on the freeway combines the high-pitched singing

*At least this is the case in most industrial societies; there is some recent evidence that the gradual deterioration of our hearing is not an unavoidable consequence of the human ageing process, but is directly attributable to the community noise to which we are continually exposed, even when the level is not great enough to cause substantial annoyance. Such hearing loss does not occur either in the Mabaan tribe of Southeastern Sudan in Africa, who are never exposed to even moderately loud sounds, or among the primitive Todas who live in a quiet pastoral region of India. When the Mabaans move to Khartoum, where the noise exposure approaches that of a modern industrial community, their hearing abilities are impaired and the incidence of heart disease increases.^{159/}

of the tires and the low-pitched roar of the engine and exhaust, both of which the ear readily distinguishes. A landing jet aircraft has a clearly distinguishable whine from the compressor mixed with the "random" noise of the engine exhaust (sounds like a big waterfall). A flute, on the other hand, if played softly, makes an almost pure tone containing only a single prominent frequency. Depending on how the components of a noise are distributed in frequency, our ears make a subjective judgment of "quality". Consequently, it is important to have an objective measure of the frequency distribution.

Such a frequency analysis is obtained by means of a set of filters, tuned to different parts of the frequency range; these are electrical circuits, each of which eliminates ("filters out") all the noise components except those in a more-or-less narrow band of frequencies, so that a meter reading of the sound level in only that one band can be made. Subsequently, readings are made for all the other frequency bands. The end result is that the frequency distribution of the noise is described in terms of a set of "partial" sound-levels in contiguous frequency-bands covering the entire audible range. Usually this set of numbers is plotted on a graph to show an octave- (or third-octave-)*

*These terms describe the bandwidth of the filter according to the ratio of the upper and lower frequencies that bound the band: in an octave band, the upper bounding frequency is always exactly double the lower bounding frequency; in a 1/3-octave band, the upper frequency is always $1.26 (= \sqrt[3]{2})$ times the lower frequency. Each octave band is made up of (or contains) three equal, contiguous 1/3-octave bands.

band analysis** of the noise, depending on the bandwidth of the filters: the narrower the bandwidth, the more refined is the analysis of the sound. For a noise with components uniformly distributed over the entire frequency range, only one-third as much of the sound energy will be passed through a 1/3-octave-band filter as through an octave band-filter centered on the same frequency. As a result, a noise that has been analyzed into 1/3-octave bands would result in lower band-sound-levels than the same noise analyzed into octave bands. This is illustrated in Figure 1. The two microphones pick up the same urban noise, but Meter #2 will read, for frequencies in an octave band around f_0 , a sound level about 5 dB ($= 10 \log 3$) greater than Meter #1 because the octave band filter passes three times as much energy near f_0 as the 1/3-octave-band filter. But the 1/3-octave-band system will measure in that same octave band two other readings (for frequencies near f_1 and f_2), so that three levels are determined in the same band where the octave-band analysis determines only one; the sum of the energies in these three 1/3-octave-bands, of course, adds up to the same total energy as registered by the octave-band system. Typical results of octave-band and 1/3-octave-band analysis are shown for the same urban noise in Figure 2: the reading in each 1/3-octave-band is about 5 dB lower than in the octave band spectrum, except in the band at 500 Hz, where both the octave and 1/3-octave systems respond to a prominent pure tone: here both systems read the same level, namely, that of the pure tone itself. Thus, the presence of an isolated pure tone, mixed in with the general noise, stands out more clearly in the 1/3-octave-band analysis.

** Sometimes referred to as the "spectrum" (plural=spectra) of the noise.

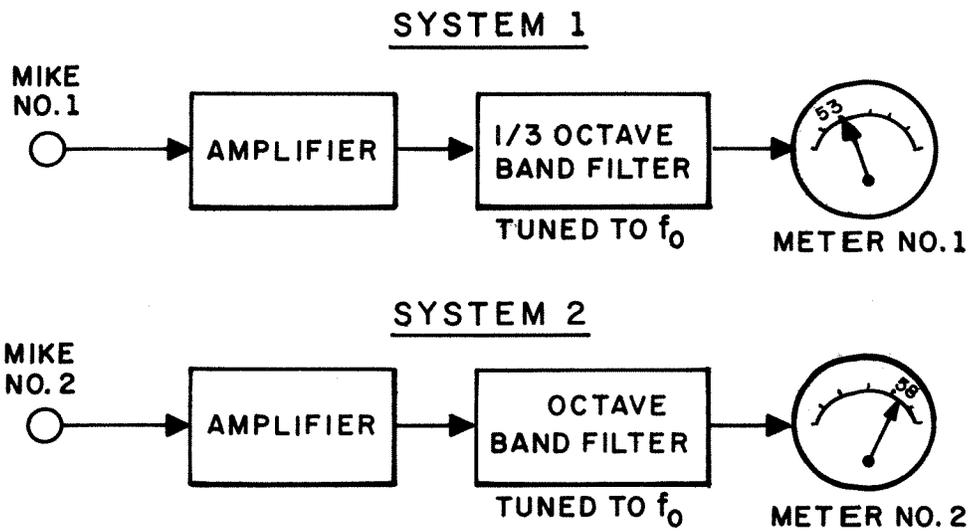
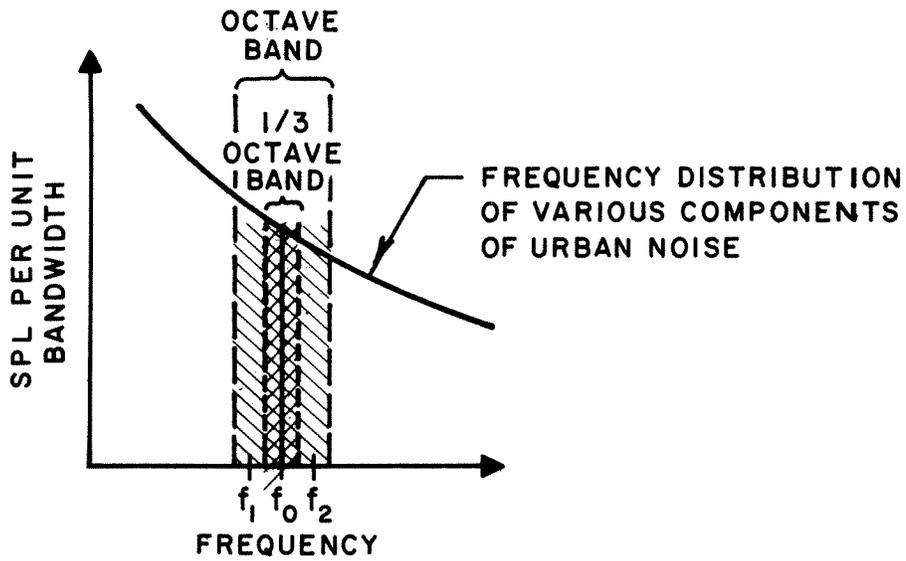


FIG. 1 COMPARISON OF URBAN NOISE MEASUREMENTS IN OCTAVE BANDS AND 1/3-OCTAVE BANDS.

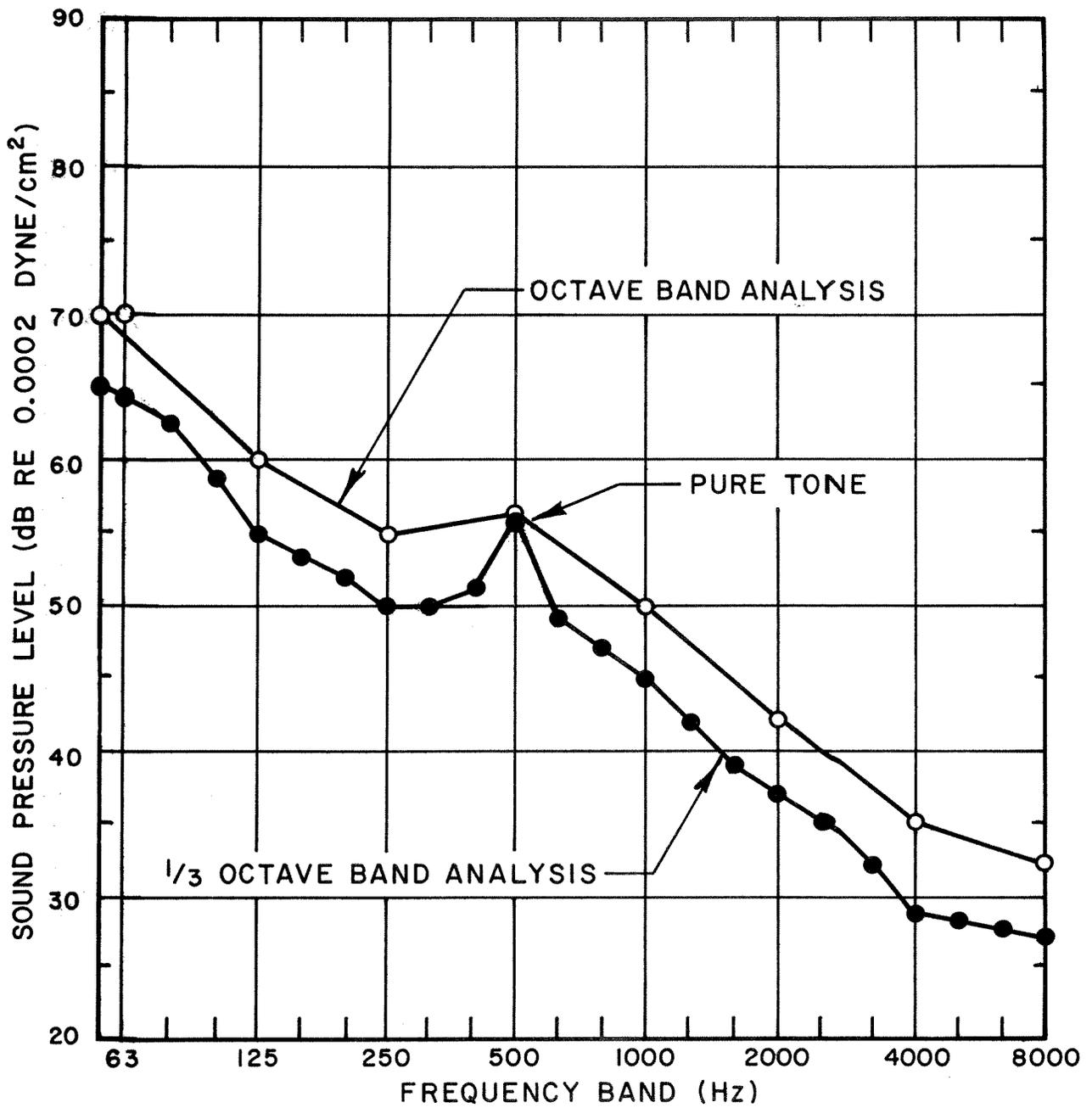


FIG. 2 COMPARISON OF THE SAME URBAN NOISE, AS MEASURED IN OCTAVE BANDS AND 1/3-OCTAVE BANDS. NOTE THAT THE PRESENCE OF A PURE TONE COMPONENT AT 500 Hz SHOWS UP MORE CLEARLY IN THE 1/3-OCTAVE BAND ANALYSIS.

Ordinarily, such strong pure tones do not appear in typical urban noises and it is usually justifiable to use the simpler octave-band analysis for dealing with community noise. In fact, an even further simplification is commonly made (see next section).

If the noise level is measured without any filters at all, the meter reading corresponds to the energy totalled over all frequencies, called the Overall Sound Pressure Level, or sometimes the C-Weighted Sound Level. This quantity, although it represents the entire energy content of the sound, does not correspond very well with how people judge noises.

E. The A-Weighted Sound Level⁽ⁱ⁾

One of the most important reasons for wanting a frequency analysis of a noise is that people not only distinguish the high-frequency from the low-frequency components in a composite noise, but they find high-frequency noises much more annoying than low-frequency noises of the same level. Therefore, to evaluate how disturbing each noise will be, we should know how much of the total sound energy is contained in each of the bands of frequency. This means keeping track of the entire set of frequency-band sound-levels for each noise: usually nine octave bands or 25 1/3-octave bands in the frequency range from 31 to 8000 Hz! If the noise level fluctuates with time, we must account for the time-varying level in every band, and this is a great chore.

Fortunately, much of this complication can be avoided by the use

i. See References 61, 109, 248

of a special weighting network in the sound-level meter; this is an electrical circuit that simulates the response of the average human ear to sounds of different frequency: each frequency of the noise then contributes to the total reading an amount approximately proportional to the subjective response associated with that frequency. Therefore, measurement of the overall noise with a sound level meter incorporating such a weighting network yields a single number called the A-weighted Sound Level, or A-Level, expressed in decibels and abbreviated "dB(A)"; the added letter A signifies that the sound level so expressed represents the weighted sum of all the components of the noise. This single-number rating has been found to correlate very well with people's subjective judgment of the annoyance of many types of noise; and thus is useful for evaluating various noise exposures in terms of the likelihood of public acceptability, without the need for dealing with complete frequency analyses of the noises. When it comes to designing noise abatement measures, however, the entire frequency analysis is usually required.

Table I shows A-Levels for typical noises in outdoor and indoor environments along with the corresponding judgments of loudness.

F. Sound Level Distribution: A Statistical Description of the Urban Noise Environment

The dominant characteristic of urban noise is that it is not steady--at any particular location the noise will usually fluctuate considerably, from quiet at one instant to loud the next. Thus, we cannot simply say that the noise level at a site is "so-many decibels". To describe the noise exposure adequately requires a statistical approach. Consequently, we should speak of the "noise exposure" of a site, meaning the whole time-varying pattern of the sound level rather than some single level,

* See Section III-A.

TABLE I

SOUND LEVEL AND LOUDNESS OF TYPICAL NOISES IN INDOOR AND OUTDOOR ENVIRONMENTS^{164/}

dB(A) Ref.: 0.0002 μ bar	SUBJECTIVE IMPRESSION	COMMUNITY* (Outdoor)	HOME OR INDUSTRY* (Indoor)	RELATIVE LOUDNESS (Human Judgment of Different Sound Levels)
130		Military Jet Aircraft Take-off With After- Burner From Aircraft Carrier @ 50 Ft. (130)	Oxygen Torch (121)	32 Times as Loud
120	Uncomfortably Loud	Turbo-Fan Aircraft @ Take-off Power @ 200 Ft. (118)	Riveting Machine (110) Rock-N-Roll Band (108- 114)	16 Times As Loud
110		Jet Flyover @ 1000 Ft. (103) Boeing 707, DC-8 @ 6080 Ft. Before Landing (106) Bell J-2A Helicopter @ 100 Ft. (100)		8 Times As Loud
100	Very Loud	Power Mower (96) Boeing 737, DC-9 @ 6080 Ft. Before Land- ing (97), Motorcycle @ 25 Ft. (90)	Newspaper Press (97)	4 Times As Loud
90		Car Wash @ 20 Ft. (89) Prop. Plane Flyover @ 1000 Ft. (88), Diesel Truck, 40 MPH @ 50 Ft. (84), Diesel Train, 45 MPH @ 100 Ft. (83)	Food Blender (88) Milling Machine (85) Garbage Disposal (80)	2 Times As Loud
80				

*Numbers in parenthesis
are A-Levels

(CONTINUED NEXT PAGE)

TABLE I (cont.)

dB(A) Ref.: 0.0002 μ bar	SUBJECTIVE IMPRESSION	COMMUNITY* (Outdoor)	HOME OR INDUSTRY* (Indoor)	RELATIVE LOUDNESS (Human Judgment of Different Sound Levels)
80	Moderately Loud	High Urban Ambient Sound (80), Passenger Car, 65 MPH @ 25 Ft. (77), Freeway @ 50 Ft. from Pavement Edge, 10 AM (76±6)	Living Room Music (76) TV-Audio, Vacuum Cleaner (70)	REFERENCE LOUDNESS 70 dB(A)
70		Air Conditioning Unit @ 100 Ft. (60)	Cash Register @ 10 Ft. (65-70), Electric type- writer @ 10 Ft. (64) Dishwasher (Rinse) @ 10 Ft. (60) Conversation (60)	1/2 As Loud
60	Quiet	Large Transformers @ 100 Ft. (50)		1/4 As Loud
50		Bird Calls (44) Lower Limit Urban Ambient Sound (40)		1/8 As Loud
40		Just Audible [dB(A) Scale Interrupted]		
10	Threshold of Hearing			
0				

18

such as the average value. The problem is how to describe this time-varying pattern adequately. The usual description is statistical. Just as the U. S. census report describes the age distribution of the American population by telling us that 90% of the population are over 5 years old, 50% are over 28 years old, and 10% are over 65 years old, etc.--so we may describe the noise exposure at a site by saying, for example, that the noise level at the site exceeds 51 dB for 10% of the time, 45 dB for 50% of the time, and 44 dB for 90% of the time. Such a description gives us an idea of the average noise level as well as how much the level fluctuates. Both the average noise level and the fluctuation are important to know, because a steady noise is more acceptable to people than a noise of the same average level that fluctuates erratically: the greater the fluctuation, the greater the annoyance.

A complete description of the noise exposure would require a statistical breakdown of the sound-level-in-percentage-of-time-exceeded for each frequency band.^{198/} For evaluating public acceptability of the noise, however, it will suffice to express the noise exposure in terms of the A-weighted Sound Level, as described above.

1. Background Noise vs Peak Levels

A typical example of urban noise fluctuation and its statistical description is shown in Figures 3 to 5. Figure 3 shows how the noise at several locations varies with time during a two-minute period, and identifies the sources of some of the conspicuous intruding sounds. Notice that in each case the noise level tends to hover about some rather low value much of the time and that individual events intrude upon this level to create peaks of

noise. In a general way, we can regard the low level as "background noise" coming from all directions and from a multitude of sources, none of them recognizable; this "background" level is exceeded (sometimes only slightly) about 90% of the time; the noise level drops below this value only 10% of the time. During another 10% of the time (included in the 90% mentioned above) the noise from individual intrusions, such as a truck passage or an airplane fly-over, causes the noise to reach considerably higher "peak" values. These are the noisy intrusions that often disturb sleep or interrupt a train of thought. The average noise level is often about equal to the 50% level, and lies about halfway between the 90% and 10% levels. The sound levels exceeded, respectively, 90%, 50% and 10% of the time are designated by the symbols L_{90} , L_{50} , and L_{10} . A reasonably reliable description of the urban noise exposure can thus be given by simply stating L_{10} and L_{90} for a given location over a specified portion of the day. In addition to the short-term fluctuations shown in Figure 3, the urban noise climate* as a whole changes during the course of a day. Figure 4 shows this change in terms of changes in the 10% and 90% levels at a certain location; (this representation, of course, averages out the details of the short-term fluctuations.) For this figure, L_{10} and L_{90} were computed on a hourly basis.

* Defined $\frac{100}{80}$ as the range of levels within which the time-varying A-level at the site spends 80% of the time; the noise climate is stated by giving both the level exceeded 90% of the time and the level exceeded 10% of the time. In Figure 4 it is represented by the range between the two curves.

Note that the choice of the 90% level to represent the "background" noise and the 10% level to represent "peaks" is rather arbitrary; the statistical analysis of the noise exposure is given by a continuous curve in which these particular levels are in no way conspicuous. Some countries (e.g., Australia) have chosen the 95% and 5% levels to define the noise climate.

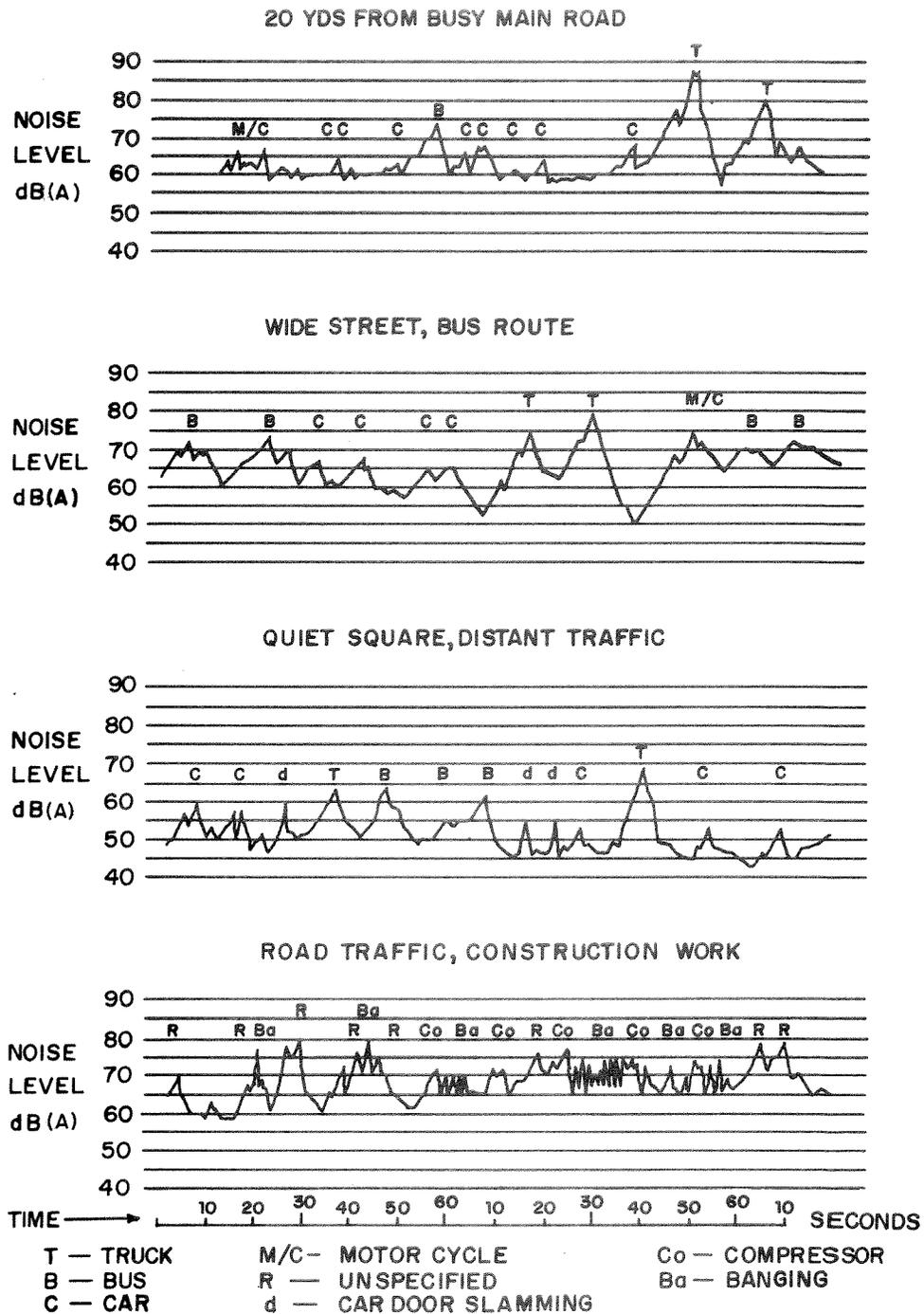


FIG. 3 PATTERN OF SHORT-TERM FLUCTUATIONS OF NOISE LEVELS AT URBAN SITES, IDENTIFYING RECOGNIZABLE SOURCES OF NOISE

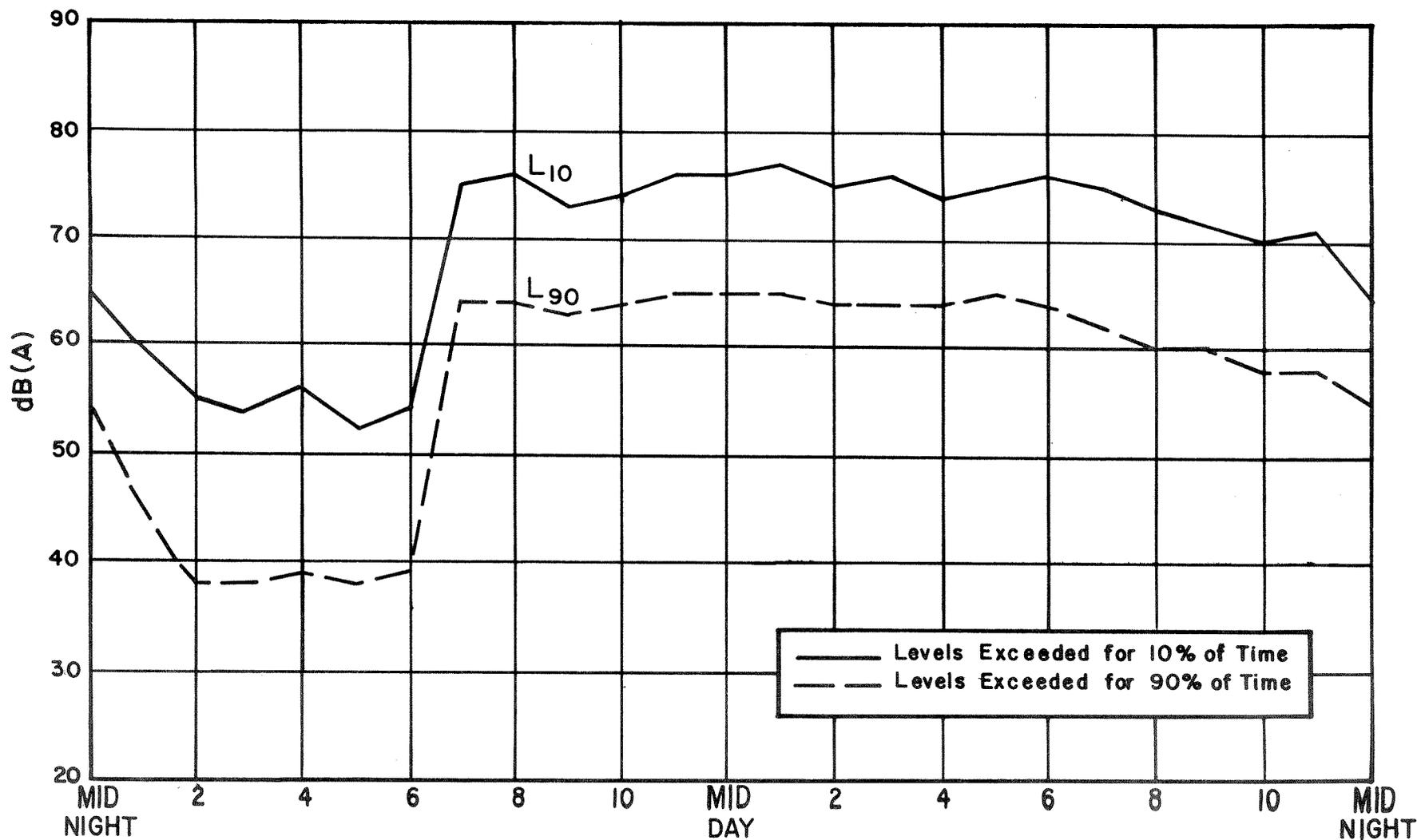


FIG. 4 PATTERN OF A-WEIGHTED SOUND LEVELS AT URBAN SITE OVER A 24-HOUR PERIOD; THE 10% AND 90% LEVELS WERE DETERMINED FOR EACH HOUR OF THE DAY

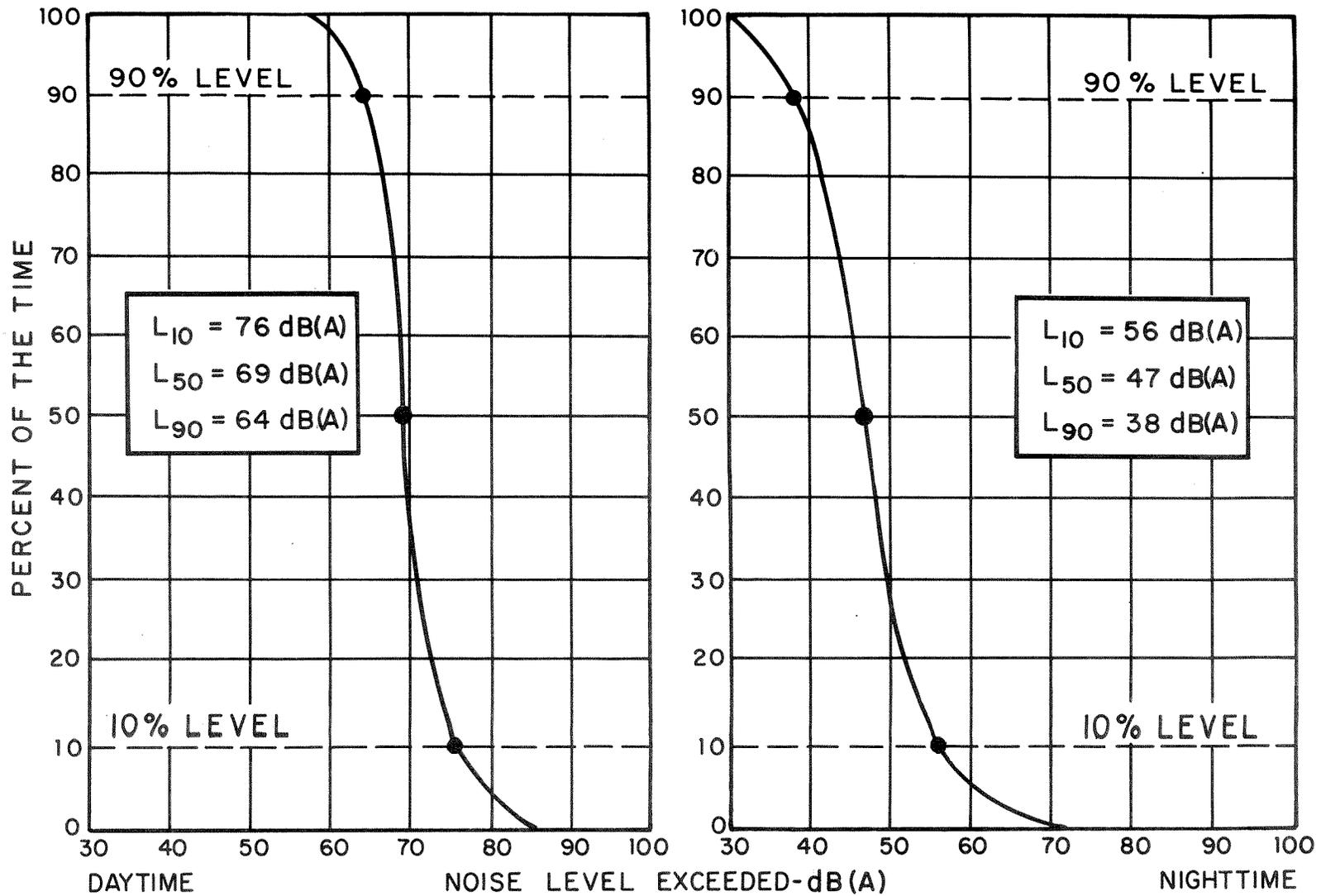


FIG. 5 STATISTICAL DISTRIBUTION OF NOISE LEVELS AT URBAN SITE, SHOWING DIFFERENCE BETWEEN DAYTIME (0700 - 2200) AND NIGHTTIME (2200 - 0700) NOISE EXPOSURE

Between 7:00 a.m. and 7:00 p.m. the noise exposure is nearly constant, both for the background noise (90% level) and the peaks (10% level); between 7:00 p.m. and 2:00 a.m. the noise gradually diminishes (by 20 to 25 dB) to levels that remain fairly constant throughout the (surprisingly short) night-time period, until 7:00 a.m. when the resumption of business activities leads to a sharp return to the day-time levels.

A description of urban noise exposure that has been found useful for displaying the time-varying nature of traffic noise is given by a statistical analysis of the noise^{165/} during the two periods when it remains reasonably stable, the day-time and the night-time (These two periods are somewhat arbitrarily chosen as 0700 to 2200, and 2200 to 0700, respectively.).

Such a description is shown in Figure 5 for the noise exposure depicted in Figure 4. During this particular day, the noise level spent half the time above and half the time below 69 dB(A); the noise level never went above 85 dB(A) nor below 58 dB(A), and spent most of the time between the 90% and 10% levels indicated; also, the noise showed relatively little fluctuation, as indicated by the very steep slope of the curve. In the night-time, both the maximum and minimum levels were substantially lower but the range of fluctuation is somewhat greater; this is because truck passages at that particular location intruded more severely into the quieter night-time background level.

These three figures might look somewhat different for the noise exposure at a different location, but they are typical and are used here to illustrate the manner in which urban noise exposure is best described.

2. Urban Noise Studies Lead to Simple Evaluation Procedures

A complete description of a site noise exposure would distinguish between week-day and week-end noise level distributions, and would also give distributions to show the difference between winter and summer. And ideally this kind of complete statistical analysis would be made to evaluate the noise exposure for all sites proposed for HUD-assisted housing! Such an evaluation is, of course, out of the question; it would require weeks of work, at different periods of the year, by experienced acoustical technicians, with an array of expensive measuring equipment.

Fortunately, enough studies and surveys of urban noise have already been made that one can predict, with reasonable accuracy for the time being, the noise exposure at a given location, using only information that can be obtained by persons without special acoustical training, and with no sound level measurements at all. A HUD Noise Evaluation Guideline booklet has been prepared that presents simple procedures to be used by acoustically untrained persons to screen a proposed site as to the acceptability of its noise exposure for dwellings.

G. Variability of Human Reaction to Noise

It should not be supposed, however, that our problems are solved once the noise exposure at a site is properly defined, for there is a considerable range of tolerance for noise among different people.

No doubt it is true, in a general way, that as the severity of the noise exposure increases, an increasing number of people will become disturbed or annoyed and may complain; in extreme

exposures there may even be legal action. But apparently about 10% of the population are so sensitive to noise that they object to any noise at all not of their own making, and thus, some complaints occur even in the quietest environments. Another sizable portion (about 25%) of the population, however, seems to be practically imperturbable: they do not complain even in very severe noise exposures.^{87/} In any given noise exposure, therefore, a variety of reactions should be expected from the people exposed, ranging from serious annoyance to no awareness of a noise problem at all. Our noise abatement efforts will evidently not affect the reactions of the ultra-sensitive or the insensitive parts of the population; only the middle 2/3 of the population will be helped by noise control.

1. Housing Occupancy vs Acceptable Environment

It is important not to draw the wrong conclusion from the observation that some people fail to react unfavorably to high-level noise. For example, it has been suggested that noise cannot be a very serious problem in large cities because all the available housing units are fully rented. We believe this is not a valid argument. Indeed, the practice of using 100% rentability to excuse sub-standard living conditions is in large part what has led to the present, undesirable degradation of our urban environment. People live in unsuitable noise environments in cities simply because, so far, there has been no quieter alternative place to live, having the advantages that an urban milieu affords.

HUD's noise abatement policy does not regard simple rentability of housing as a sufficient justification of its quality: HUD's goal is higher, and rests on the elementary responsibility

of government to preserve the public health and safety. In this light, the Federal noise control policy should resemble air pollution and radiation control and the regulation of pesticides.^{55/} It is important to keep housing units that, for any reason, are sub-standard off the market, even though some people might wish to rent them. In terms of noise exposure, this means that, beyond a certain point, it is no longer acceptable to trade off the other advantages of an urban location against the noise. Improvement of the present conditions is to be found along two approaches: reduction of noise at the source (which task lies mostly outside HUD's jurisdiction), and taking care that sites whose noise exposure is so great as to be unacceptable as a living environment are used for purposes other than housing. The consequent environmental improvement may entail an increase in cost that must simply be accepted, recognizing that, in ignoring the causes of pollution in the past, we have borrowed a bargain-price cost of living from the future and allowed our living standard to decline to an intolerable level.

Ultimately, the decision as to what improvement in our noise environment will be feasible is economic, social and political in nature: it entails a nice balance between what we need and what we can afford. It is the proper work of the government and its agencies, and requires careful attention both to the provision of the necessary costs of noise abatement and to the pacing of our noise abatement efforts, to avoid embracing, all at once, unattainable goals.

III. TECHNICAL BACKGROUND FOR HUD NOISE ABATEMENT POLICY

The present chapter summarizes the technical information on the measurement, evaluation and control of urban noise that underlies the policy and procedures in HUD's noise abatement efforts, in particular the initial specification (and possible revision) of noise criteria and standards, both present and future. Of particular relevance are the choice of the A-weighted Sound Level as a physical measure of the urban noise, the choice of the means for dealing with the fluctuating nature of urban noise, the method of evaluating aircraft noise exposure, and the criteria of acceptability for urban noise, both outdoors and indoors. These matters are dealt with in this chapter. The final chapter gives technical justification for the Site Evaluation Guideline Procedures that were developed to permit personnel without acoustical background to evaluate the acceptability of the noise exposure at a given proposed site, without the use of acoustical instrumentation.

A. Choice of the A-weighted Sound Level

Several times within the past decade, large-scale city surveys have been carried out to determine the magnitude of the urban noise problem and the subjective response of the public to the noise. 26,32,83,100,109,119 In each case, particularly in the planning stages of these surveys, questions have arisen as to whether or not it would be sufficient for the purposes of the survey to use a single-number rating to characterize the measured noise, instead of having to deal with the complete frequency-band analysis; and if so, which of the many available noise ratings affords the best prediction of people's subjective response. To answer these questions, a variety of comparisons have been made, as described in Section A-4 below.

1. Variability of Human Response to Noise

To begin with, however, it is necessary to call attention to some of the difficulties involved in predicting people's subjective response to a noise from a measurement of its physical properties. The psychophysical characteristics of a noise, that determine how people will react to it, cannot be measured directly with currently-available instrumentation. The most direct evaluation approach would be actually to present the noise in question to a sufficiently large and representatively-selected group of persons placed in exactly the same physical, psychological and social situation as the people on whom the influence of the noise is to be predicted. By observing the responses of the member of this jury, one could estimate the overall subjective effects of the noise in question. This is, needless to say, a cumbersome and time-consuming method that would hardly ever be justified.

Such a subjective evaluation by jury judgment could be replaced by objective measurements if it were possible to find some physical properties of the noise that correlate reliably with the corresponding subjective effects. A major difficulty, however, arises from the wide variety of responses that different people typically make to the same noise. Even if we were able to describe completely the physical noise stimulus received by a listener, his response to this stimulus is not at all closely predictable.^{18,32,190/} Instead, his reaction may depend on many factors, some of them completely unrelated to the stimulus itself,^{16,190,221/} such as previous noise exposure, psychological attitudes, socio-economic status, the nature of the activity into which the noise stimulus intrudes, etc. Even to the extent that his response is directly related to the noise stimulus, we cannot always say which of the possible direct effects is most important; loudness, annoyance,

interference with speech communication, or some vaguer characteristic such as auditory fatigue.*

In spite of these problems, rating scales derived from physical measurements of the noise stimulus do correlate, with useful accuracy, to certain aspects of average human response to the noise, particularly when the tests are confined to the laboratory environment. Thus, we have rating scales of loudness, perceived noise level (related to "annoyance"), articulation index (related to the ability to converse with ease), and others.

When it comes to the indirect effects of noise exposure that shape an individual's reaction to the noise outside the laboratory, there is much less quantitative evidence. Here we rely on the results of opinion surveys to get an assessment of both the direct and indirect effects as they contribute to a judgment of the overall acceptability of the noise environment.⁽ⁱ⁾ Such surveys provide our best guidance for choosing a useful rating scale as well as for selecting a criterion of acceptability of urban noise.

But even these surveys must be interpreted with care. From the point of view of establishing a physical measurement of a noise stimulus that correlates highly with the subjective response to that noise, the results of individual responses in the social surveys are invariably disappointing.^{16,221/} No physical measurement of noise has yet been developed that yields correlation with individual responses higher than about 0.45.^{132/}

* We rule out hearing damage risk on the grounds that one of the other direct effects mentioned above would intervene before the noise reached such levels that hearing damage is likely.

i. See References 14,18,20,26,27,30,32,40,66,72,82,88,93,95,100,110,114,127,135,136,145,185,202.

On the other hand, when the responses of large groups of individuals are pooled, so that the effects of the various non-acoustic contributants to response are averaged out, a much better correlation appears. In describing a jury test of the acceptability of various truck noises, in comparison with a number of physical measurements of the corresponding noise exposure, Venema^{145/} has remarked, "...these meters agree with the jury average much better than the individual jurors do. Or another way to put it is that almost any method of measurement is better than a single personal opinion."

Accordingly, in selecting the most suitable rating scale for assessing urban noise, no attempt is made to predict any individual person's response. Instead, we seek how best to describe in physical terms the nature and magnitude of the total noise exposure as it affects small areas or neighborhoods, and how to choose a suitable criterion of acceptability, that is, determining the noise stimulus that cannot be exceeded without rendering the environment unacceptable for living, for most people.

2. Single-number Rating Schemes

Quite a few single-number rating schemes have been proposed from time to time for evaluating different noises according to one aspect or another of people's subjective response to the noise.^{132,151,152/} Some of the ratings are quite simple, others are very complicated. For the purposes of this discussion we distinguish between rating "scales" and rating "procedures" as follows: a scale describes only the noise exposure itself, either in a simple way like reading the maximum A-weighted Sound Level that occurs during a transient noisy event, or in some

more complicated manner that accounts for the time-variation of the noise analyzed into bands of frequency; for example, a statistical distribution of instantaneous band levels, each regarded as a time series. In any case a scale attempts only to describe the noise stimulus itself. Examples of rating scales are:

- Overall Sound Pressure Level (OASPL)
- A-Weighted Sound Level (L_A in dB(A))
- Loudness Level (LL in phons)
- Articulation Index (AI in %)
- Speech Interference Level (SIL in dB)
- NC (Noise Criterion) Curves (no unit)
- Perceived Noise Level (PNL in PNdB)
- Noise and Number Index (NNI in un-named dB-like units)
- Traffic Noise Index (TNI in un-named dB-like units)
- Noise Pollution Level (NPL in un-named dB-like units)

A rating procedure, on the other hand, attempts to account for the context in which the noise stimulus is experienced and may introduce adjustments for various peculiar characteristics of the noise (pure tone content, duration, impulsive or intermittent nature) and of the situation into which the noise intrudes (existing background noise, type of neighborhood, time of day, week, or year, etc.). Examples of rating procedures are:

- Composite Noise Rating for Community Noise (CNR)
- Composite Noise Rating for Aircraft Noise and Land Planning (CNR)
- Noise Exposure Forecast (NEF)
- British Standard #4142 - 1967
- ISO Draft Proposal for Noise Assessment with Respect to Community Response.

These scales and ratings are briefly described in the next section, and Section A-4 gives an account of the more important studies that have been undertaken to compare these ratings among themselves.* Some of the ratings are described at somewhat greater length than others because of the possibility that they (or something very similar) will come under consideration for adoption in future HUD noise abatement procedures.

3. Description of the Available Single-number Rating Schemes

a) Overall Sound Pressure Level

The measurement 6,112,165/ simply consists of determining with a sound level meter the overall sound pressure level, corresponding to the total sound energy throughout the audible frequency range, with no frequency weighting. The unit is the decibel; the reference sound pressure is 0.0002 dyne/cm^2 . For most noise spectra, this rating is equivalent to the C-weighted Sound Level, read from a sound level meter containing an electrical network that eliminates the energy of sound components with frequencies above 8000 Hz and below 31 Hz.

Many occasions have arisen in the past to check the ability of the Overall SPL to predict people's subjective reactions to noise. In most cases, the correlation between the measure and the observed subjective response has been poor. 16,132,250/

* Reference 132 gives a detailed description of these rating schemes, as well as an account of how each was developed in the first place and what researches have been subsequently done to determine how well they fulfill their intended purposes.

b) A-Weighted Sound Level (L_A)

The apparent loudness of a sound depends not only on the strength of the pressure fluctuation but also on the frequency of the sound. We take this effect into account in measuring the overall sound by incorporating an electrical weighting network into the sound level meter that selectively discriminates against low and high frequencies in a manner that simulates the response of the average human ear. Thus each frequency of a noise contributes to the total reading an amount approximately proportional to the subjective response caused by that frequency.

Accordingly the A-Level has been found to correlate very well with people's judgments of the loudness or annoyance of a great many types of noise. 132,248/

c) Loudness Level (LL)

As originally defined, the loudness level of a sound was determined by jury test: human subjects listened alternately to the noise to be evaluated and to a standard sound (a 1000 Hz pure tone); they then adjusted the level of the standard tone until it sounded equal in loudness to the test noise. When this adjustment was made, a loudness level (in phons) was assigned to the test noise which was the same in magnitude as the Sound Pressure Level (in dB) of the equally loud 1000 Hz tone, averaged over the test subjects' responses.

Both Stevens 237,238/ and Zwicker 251,252/ have developed schemes for calculating the loudness of a complex noise, as a substitute for an auditory comparison. Indeed, so rare is it that an auditory comparison is actually made nowadays that the term loudness level

almost automatically implies a calculation procedure. Both procedures are in the process of being internationally standardized.

As the calculation procedures are complicated, and no one has seriously proposed the loudness level as a suitable measure of community noise, no detailed description is given here. A more complete account is given in Reference 132.

d) Articulation Index (AI)

The Articulation Index is a weighted signal-to-noise ratio, based on normal speech levels and measured (or estimated) background noise levels. It is, in effect, a weighted fraction representing, for a given speech channel and noise condition, the proportion of the normal speech signal that is available to a listener for conveying speech intelligibility. Two methods of computation have been standardized: the original method of French and Steinberg^{182/} based on the spectrum levels of speech and of noise in each of twenty contiguous bands of frequency that (for equal signal/noise ratios) contribute equally to intelligibility; and a similar approach^{156,204/} in which the speech and noise are evaluated in octave or third-octave bands of frequency. Naturally the octave-band procedure is less accurate for noise spectra containing narrow bands of intense energy. The articulation index has turned out to yield an accurate prediction, from purely physical measurements on a communications channel, of the intelligibility of speech transmitted over that system.^{209/}

e) (Preferred) Speech Interference Level (SIL and PSIL)

The Speech Interference Level^{154/} was devised as a simplified substitute for the Articulation Index, originally chiefly to evaluate the cabin noise in aircraft, where it has been most used. The

SIL is the arithmetic average of the sound pressure levels in the three octave bands lying between 600 and 4800 Hz. (If the level in the 300-to-600 Hz octave band exceeds the level in the 600-1200 band by 10 dB or more, this fourth band should be included in the average.) Although one can measure speech levels and combine them with the SIL to get an approximate AI, the SIL itself measures only the noise background. Reference may be made to a table^{6,154/} that indicates what voice level is required to communicate reliably over various talker-listener distances.

With the adoption in 1960 of a new set of preferred frequencies for analysis, measured octave-band data gradually became incompatible with the original definition of SIL; after trial of several proposed replacements^{199/}, the average of the levels in the octave bands centered on 500, 1000 and 2000 Hz has been recommended as the Preferred Speech Interference Level (PSIL); it appears to be gaining acceptance for the same purposes as the original SIL.

f) Noise Criterion (NC) Curves

The basis of the Noise Criterion (NC) rating^{155,157/} is a family of curves of sound pressure level vs octave band frequencies that resemble somewhat a set of equal-loudness contours, in that they are concave upward and increasingly so at lower frequencies, and are more closely spaced at low than at high frequencies. An octave band spectrum of the noise to be evaluated is overlaid on this family of curves and an NC value is assigned to the spectrum, corresponding to the highest NC curve to which the spectrum is anywhere tangent. Thus the NC rating is almost always determined by the level at a single frequency. Interpolation between NC curves is frequently required in evaluating a noise spectrum.

A similar procedure^{224/} has been under consideration in the International Organization for Standardization since 1961; although none of the draft documents describing this rating has been accepted yet as an ISO Recommendation, the method has appeared in the literature^{200/} and is frequently mentioned in the context of building noise control. The ISO curves are called either N or NR (for Noise Rating) curves, and the ISO proposals grew directly out of the Noise Criterion (NC) development.

g) Perceived Noise Level (PNL)

In jury tests where a test noise is adjusted so as to sound equivalent in some sense to a standard test sound (as described under loudness level, above), people make different judgments according to whether they are asked to equate the "loudness" of the two sounds or the "noisiness" (or "annoyance").^{208/} (The question arose in particularly acute form during the transition from propeller-driven aircraft to jet aircraft, which were judged quite differently with respect to annoyance, even when their measured levels were nearly the same.)

Accordingly, a calculated single-number rating of annoyance has been developed, along lines similar to those described above for loudness, to replace the inconvenient jury-judgment test.^{208/} This rating is called the Perceived Noise Level (PNL^{*} in PNdB); it has been modified^{205,208/} a number of times by the addition of corrections to account for the duration of the noisy event (the fly-over time) and for the presence of pure tones in the spectrum (such as those generated by the engine compressor, particularly during landing).^{203/} This rating is widely used for assessing the disturbance likely to be caused by airplanes, particularly in overhead flight.

* Or sometimes L_{PN} .

The calculation procedure originally was based on the maximum values attained in a fly-over event in each frequency band regardless of when during the event this maximum occurred and thus it led to a maximum PNL for the event. Nowadays, all the band levels are continuously recorded as they increase from the background level through the maximum during the flyover and diminish back to the background level: the PNL is calculated for each instant during the event. In both cases the calculation is done as follows, based on a table that shows for every possible noise level in each frequency band* the corresponding number of NOYS (abbreviated "N"), the unit of subjective annoyance, as determined by laboratory tests: from the table, one finds the proper value of NOYS corresponding to each of the measured levels in the various 1/3-octave bands. These 1/3-octave NOY values are all added together and the sum (ΣN) is multiplied by 0.15. To this sum is added 85% of the NOYS value of the 1/3-octave band that has the largest NOYS value. Thus, the total effective NOYS value is given by**

$$N_{\text{tot}} = 0.15 \Sigma N + 0.85 N_{\text{max}}$$

and this is converted to Perceived Noise Level (in PNdB) by means of a nomogram accompanying the dB-to-NOYS table, or by reference to the 1000 Hz NOYS-to-dB column in the Table.

The PNL rating is used in practically all current evaluations of the annoyance due to aircraft noise, and it continues to be refined by further studies.^{205/}

* Either octave-band or third-octave band; the latter is more common.

** For octave band levels the constants are 0.30 and 0.70, respectively.

It can be appreciated, however, from the description given above, that the calculation procedure is fairly complicated; in practice, therefore, particularly for calculating the variation of Perceived Noise Level during a fly-over event, a computer is essential. Thus, there has been strong motivation to find a simple, easily-measured substitute for PNL. Accordingly, a further development of the perceived noise studies has been the recommendation of a new N-weighted sound level,^{153/} to supplement the A-, B- and C-weightings on the sound level meter. This weighting function matches the shape of the (inverted) 40-NOY curve of equal annoyance, with its amplitude matched to the other weighting functions at 1000 Hz (that is, a pure tone at 1000 Hz would give the same meter reading, equal to the SPL, on all weightings).

When N-levels are compared with PNL's calculated for the same aircraft noises, however, although the correlation between N-levels and PNL is very high, the PNL is found to exceed the N-level by 7 dB on the average. Thus there is now an ISO proposal^{34/} that the reading obtained with the N-weighting be consistently increased by 7 dB to approximate the PNL in PNdB. Unfortunately, the practice has already arisen, in the last few years, of using the symbol dB(N) to designate the quantity 7 dB higher than the measured N-level; this makes "N" an ambiguous designation nowadays: some doubt always remains about how to interpret a reported reading.

To avoid this confusion, Technical Committee 29 on Electroacoustics, of the International Electrotechnical Commission (IEC/TC 29) has suggested that the letter D be used to designate the NOY-shaped weighting curve that coincides with the A, B and

C curves at 1000 Hz, so that the letter N may be used to designate a curve 7 dB higher. But the delegates to a recent meeting of IEC/TC 29 recommended unanimously that the letter N and the N-weighting be dropped altogether because of the confusion they cause, and that all direct measurements intended to approximate Perceived Noise Level be designated according to the equation

$$L_{PN} \approx L_D + 7$$

where L_{PN} is the Perceived Noise Level in dB and L_D is the D-weighted sound level.

Although this was not an official IEC or ISO recommendation, three manufacturers who had already introduced the new weighting into their sound level meters agreed immediately to change its designation from N to D.^{153/}

h) Noise and Number Index (NNI)

The base measure is the Perceived Noise Level, PNL, calculated according to the procedure given by Kryter ^{208/}in 1959, starting from a "spectrum" comprised of the highest sound pressure level attained in each octave band during an aircraft flyover regardless of when during the event this maximum occurred. This PNL is used without corrections for the presence of pure tones or for event duration.

The NNI is "A composite measure ... taking into account the average peak noise level as well as the number of aircraft heard in a specified period:

$$NNI = (\text{average peak noise level}) + 15 \log_{10} N - 80$$

where N is the number of aircraft heard in the specified period e.g. 1 day or 1 night," and the average peak noise level is:

$$\text{average peak noise level} = 10 \log_{10} \left(\frac{1}{N} \sum_{i=1}^N 10^{L_i/10} \right)$$

where L is the peak noise level (in PNdB) occurring during the passage of each aircraft and N is the number of aircraft concerned.^{100/} The constant 80 was introduced so that "zero NNI" would correspond approximately to zero public annoyance due to the aircraft noise, as determined in the social survey around London (Heathrow) Airport. Notice that the concept of background noise is implicitly included in the Noise and Number Index, whether intentionally or not, in that the quantity N, in the second term of the rating, refers to "the number of aircraft heard in the specified period."

i) Traffic Noise Index (TNI)

The base measure is the A-weighted sound level, observed outdoors as a function of time, or sampled at numerous discrete intervals, over a 24-hour period. From this record the two sound levels, L_{10} and L_{90} , are determined, respectively, the levels that, on the average over the 24-hour period, were exceeded 10% and 90% of the time. Thus, the 10% level is an average "peak" level while the 90% level is an average "background" level into which the transient noises intrude. The Traffic Noise Index^{189/}, a weighted combination of L_{10} and L_{90} , is defined as:

$$\text{TNI} = 4(L_{10} - L_{90}) + L_{90} - 30$$

The first term expresses the range of the noise climate (as defined in the Wilson Report^{100/}) and describes the "variability" of the noise, while the second term represents the background noise level; the third term, following the example of the Noise and Number Index, is introduced to yield more convenient numbers.

j) Noise Pollution Level (NPL)

The Noise Pollution Level (NPL) is based on two terms, one representing the equivalent continuous noise level and the other representing the increase of annoyance due to fluctuations of the noise level as follows: 123,231/

$$L_{NP} = L_{eq} + k\sigma$$

where L_{eq} is the "energy mean" of the noise level L_A over a specified period, σ is the standard deviation of the instantaneous level considered as a statistical time series over the same period, and k is a constant tentatively set equal to 2.56, since this value leads to the best fit with currently available studies of subjective response to noise. The first term is determined largely by the intensity of the intruding noises (because of the logarithmic averaging), unless these occur so seldom that the background noise comprises most of the total noise exposure; the second term is determined by the time-dependence (specifically, the variability in level) of the sequence of intruding noise events, rather than on the mean energy content, and is thus greatly influenced by the prevailing background noise: the lower the background noise, the greater the variability for a given sequence of intrusive events.

For most community noise situations of interest, one can use alternate expressions for the Noise Pollution Level, as follows:

$$L_{NP} = L_{eq} + (L_{10} - L_{90})$$

or $L_{NP} = L_{50} + d + d^2/60$

where $d = (L_{10} - L_{90})$ and L_{10} and L_{90} are the decile noise levels exceeded respectively 10 and 90% of the time during the observation period.

The Noise Pollution Level embodies the attractive concept of energy-equivalent exposure, and, in addition, accounts for the effect of variability of noise exposure on the resulting annoyance; it thus achieves a synthesis, in elementary algebraic terms, of experimental evidence from a number of apparently unrelated studies: the results of Griffiths and Langdon's traffic noise survey^{189/} are better fitted by the NPL than by the authors' own Traffic Noise Index; Pearsons' experiments on duration/level trade-off,^{229/} showing that the trade-off diminishes with duration, are closely predicted by the NPL; and the NPL generates a steeper rate of increase of "exposure" with number of occurrences than the 3 dB-per-doubling suggested by the simple energy summation and thus agrees with the results of a number of social surveys in the Netherlands,^{163/} Germany^{79,89,166/} and the United Kingdom;^{100/} in fact, the predicted relationship is non-linear, growing more steeply in the middle range of number of occurrences,^{73,174,186/} and in this respect accords with the results of the France airport^{2,72,167/} study. It should be noted, further, that when the NPL is used to compare situations where the statistical fluctuations are similar, the second term is essentially constant and the comparison then depends only on the mean energy level, thus possibly explaining certain studies ^{30,58,100,160,183,185/} in which the equivalent energy level alone has been found adequate to account for the subjective response.*

k) Composite Noise Rating for Community Noise^{232,236/} (1952-55)

The basic measure is Level Rank, a measure of the octave band of noise measured outdoors that contributes the loudest component to the sound.

* See second footnote, page 75.

The initial step in calculating CNR is to compare a measured graph of community noise with a family of rating curves, similar to equal loudness contours. The curves are spaced approximately 5 dB apart in the middle-frequency ranges, to yield bands, each of which is designated as a "level rank." The measured noise is assigned a level rank (identified with lower case letters from a to m) according to the highest band on the rating curves into which its spectrum protrudes. The level rank thus established is modified by taking into account ambient noise levels, percentage of time (in an eight-hour day) the noise operates, day or night operation, winter or summer operation, presence of pure-tone components, of impulse noise, and the previous noise exposure history of the community. For each of these features a "correction number" is assigned that raises or lowers the "level rank" of the noise. The initial level rank plus the algebraic sum of the several corrections yields the Composite Noise Rating (identified by capital letters).

The CNR is associated with a range of community response as follows. The public response scale consists of five points: "no reaction", "sporadic complaints", "widespread complaints", "threats of community action", and "vigorous community action". When actual case histories were plotted on a grid, using this response scale as the ordinate and the CNR ratings (from A to H) as the abscissa, the relation between rating and response is displayed as an "S"-curve.

This scheme has survived over the years, with slight modifications, and has formed the basis of a proposed rating scheme^{224/} in the International Standards Organization for predicting community response to noise of all types.

On an absolute basis, the rating scheme works only fairly well; it may predict higher or lower levels of community response than are actually observed. But the scheme works well on a relative basis: if, for example, a noise already exists in a community so that a "calibration point" is available, then changes in the operating conditions or modifications to the noise source and their corresponding effects on the community response are predicted quite well.

1) Composite Noise Rating for Aircraft Noise (1957-64)

The general approach^{184,235/} follows that of the original Composite Noise Rating Scheme (see previous section), in that it applies adjustments to the existing noise levels to account for differences in aircraft operations. The Aircraft Composite Noise Rating, originally developed to deal with problems of noise around military air bases,^{235/} has been modified^{183/} to apply also to the noise of commercial jet transport aircraft; it has had the widest circulation under this form^{184/}.

In contrast to the earlier Community Noise CNR, where the potentially-intruding noise was measured in each case, the noise levels need not be measured at all in computing Aircraft CNR. Instead, the user proceeds directly from the operating characteristics of the aircraft.

The noise from different aircraft operations are described in a series of equal-noise-exposure contours of maximum Perceived Noise Level (in PNdB), superimposed on a map of the airport neighborhood. These contours are based on generalized profiles of flight altitude vs distance from the start of take-off roll (or from the touch-down point in landing) and on a great many

measurements of the noise of various types of aircraft under different flying (and ground run-up) conditions. In order to accommodate the many kinds of aircraft currently operating, the aircraft are grouped into classes according to aircraft type (including jet transports large and small, business jet aircraft and helicopters) engine type and performance. Altogether twenty sets of contours are required. The basic noise exposure for a given location on the map is read directly from the contours, separate ratings being made for take-off, landing and ground run-up operations.

Adjustments are then applied to account for the duration of the noise as well as for daytime vs night-time operation, as follows. The duration of the noise is dealt with by applying an adjustment factor for the number of aircraft operations of each class on each runway. A second adjustment is made that weights night-time operations as though their noise levels were 10 dB higher than the actual values, to account for the greater potential for annoyance of aircraft noise at night (2200 to 0700). No explicit adjustment is made for the background noise (apart from the distinction between day and night operations), for previous exposure, for public relations or other intervening factors. (Such corrections had appeared in an early version of Aircraft CNR that applied only to military aircraft.) The various "partial CNR's" for the various run-ways and aircraft classes are finally combined into a single value for predicting community response at each location.

Based on comparison of the CNR computed as above with the overt community response found in a number of airport case histories, as shown in Figure 6, three zones of response are defined, as

indicated in Table II.

TABLE II
COMPOSITE NOISE RATING (AIRCRAFT)

<u>Takeoffs and Landings</u>	<u>Ground Runups</u>	<u>Zone</u>	<u>Description of Expected Response</u>
Less than 100	Less than 80	1	Essentially no complaints would be expected. The noise may, however, interfere occasionally with certain activities of the resident
100 to 115	80 to 95	2	Individuals may complain, perhaps vigorously. Concerted group action is possible.
Over 115	Over 95	3	Individual reactions would likely include repeated vigorous complaints. Concerted group action might be expected.

At the present time, the Aircraft CNR has not been endorsed by the civil aviation community but it has been widely used to evaluate military operations^{184/}. In addition, it has been used by many airports, communities, airport planners and engineers, and land use planners for a variety of planning purposes, and by the Federal Housing Administration in considering the guarantee of loans for new residential tract construction near airports.

m) Noise Exposure Forecast (NEF)

The NEF technique^{160/} is an extension of the 1964 Aircraft CNR technique (see previous section); it applies only to commercial and not to military aircraft. The basic measure, E (effective) PNL, is a refinement of PNL that takes account of signal duration

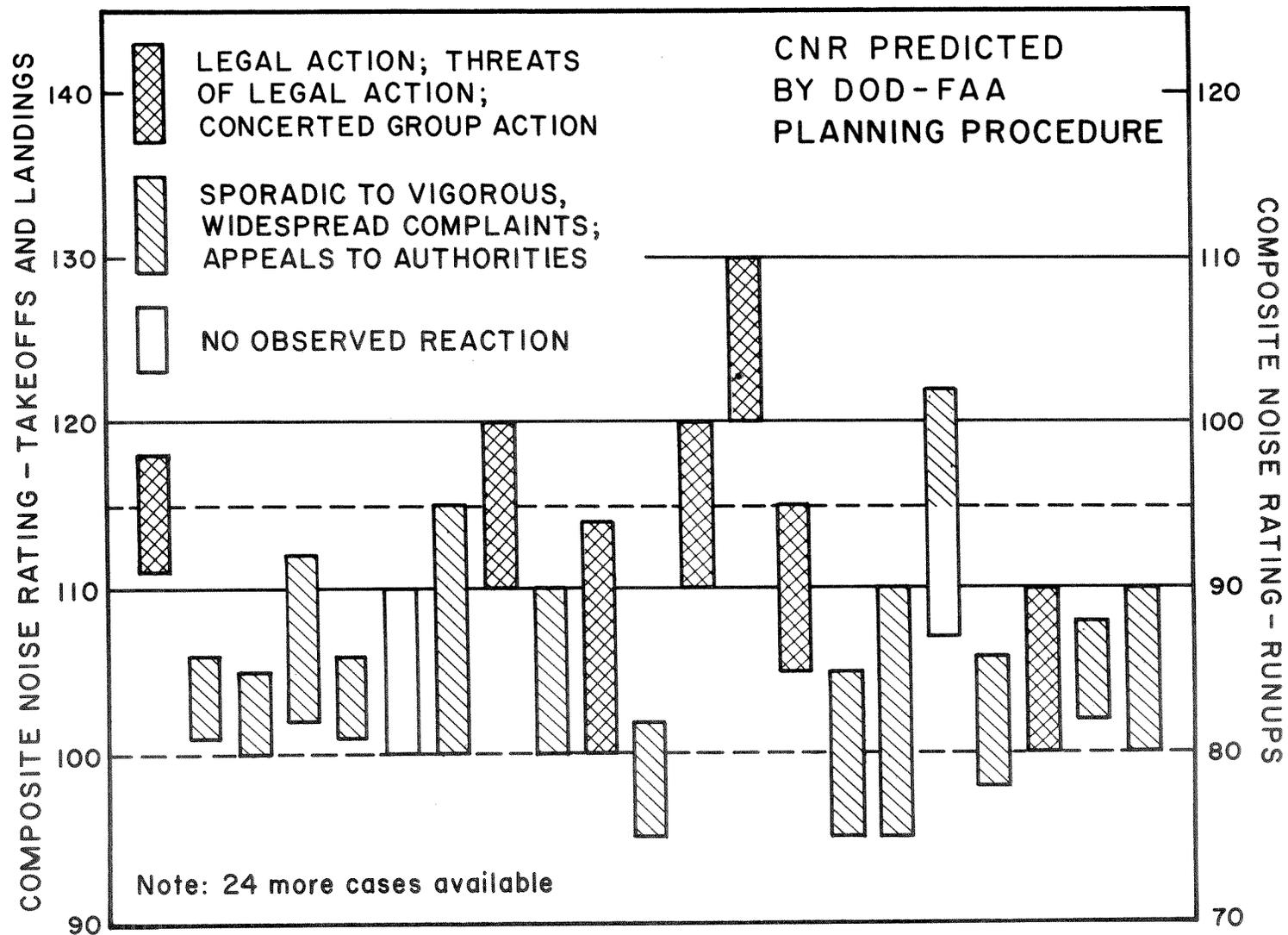


FIG. 6 CORRELATION OF CASE HISTORIES OF OVERT COMMUNITY RESPONSE WITH COMPOSITE NOISE RATINGS

and the presence of pure tones:^{203/}

$$EPNL = PNL + D + F$$

where

PNL = maximum calculated perceived noise level at any instant of time during the flyover, calculated from 1/3-octave-band noise levels.

C = $10 \log t/15$, where t is the time interval in seconds during which the noise level is within 10 dB of the maximum PNL.

F = correction for the presence of discrete frequency components; the correction is tabulated according to the third-octave band in which the tone lies and the extent to which the tone level exceeds the mean level in the adjacent bands.

The total noise exposure at a given point is viewed as composed of noise produced by different aircraft flying different flight paths. For a specific class of aircraft, i, on flight path, j, the NEF_{ij} can be expressed:

$$NEF_{(ij)} = EPNL_{(ij)} + 10 \log \left(\frac{n_D(ij)}{K_D} + \frac{n_N(ij)}{K_N} \right) - C$$

where

$n_{D_{ij}}$ and $n_{N_{ij}}$ are the numbers of operations, for day-time (0700-2200) and night-time (2200-0700) respectively

of aircraft class, i, on flight path, j.

$K_D = 20$
 $K_N = 1.2$
 $C = 75$ } The choice of these constants signifies that a single night-time flight contributes as much to the NEF as 17 day-time flights; the value of C is arbitrarily chosen so that NEF numbers typically lie in a range where they are not likely to be confused with other composite noise ratings.

The total NEF at a given ground position is determined by summation of all the individual NEF_(ij) values on an energy basis:

$$NEF = 10 \log \sum_{ij} \text{antilog} \left(\frac{NEF_{ij}}{10} \right)$$

The identification of numerical values for NEF to be used in describing the zonal separations was performed by mapping the NEF values for a series of operations against the CNR values computed for the same set of operations as indicated in Figure 7. The zone boundaries were then selected so that the NEF values would correspond approximately to the CNR values of 100 and 115.

The NEF procedures have recently been adopted by FAA, with some adjustments to incorporate information developed by the SAE committee, as ~~the~~ basis for use by FAA in evaluating land use around airports. Application of these procedures to 28 airports in the country has been completed^{161/} and a computer program for computation of NEF contours at additional airports has been developed for use by the FAA^{191/}.

n) British Standard 4142 (1967)

The rating procedure comprises three separate tasks^{219/}: the measurement of the intrusive noise, the measurement or estimation of the background noise into which the noise in question intrudes, and a comparison of the intruding noise, suitably corrected for tonal and temporal characteristics, with the background noise, suitably corrected for certain local circumstances (called the "corrected criterion").

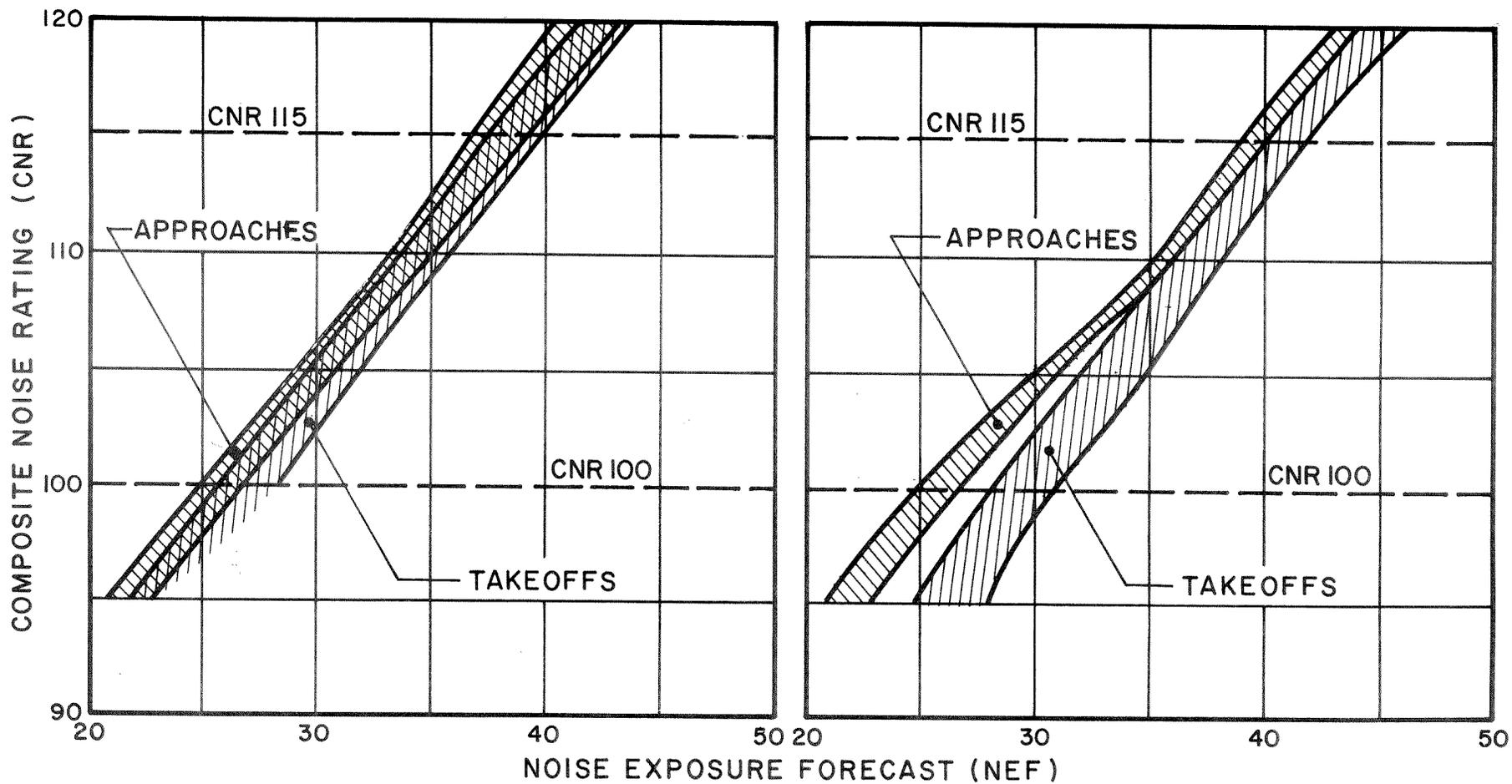


FIG.7 COMPARISON BETWEEN CNR AND NEF VALUES

The base measure for both the intruding noise and the background noise "criterion" is the A-weighted sound level, to be read outdoors, with the sound level meter dynamic characteristic set to the "slow" position, at a measurement position chosen to give results representative of the noise outside the building from which complaints have arisen or are likely. The microphone is to be at a height of about 1.2 meter (4 ft.) and at least 3.6 meter (12 ft.) from reflecting walls, if possible. Positions in front of windows are preferred since most noise enters the building via the windows.

When the intruding noise is steady, its general level L_1 , in dB(A) is measured; if it fluctuates within about a 10 dB range, the meter reading is averaged by eye. If there are periods of significantly louder or more disturbing level, in addition to the continuous noise, the higher level L_2 is also recorded, and the durations corresponding to levels L_1 and L_2 are recorded.

Corrections are applied to the measured level according to the character of the intruding noise: either if there are pure tones present or if the noise is impulsive, add 5 dB to the observed levels L_1 and L_2 ; (the standard is not explicit about what to do if the noise is both tonal and impulsive, but Robinson, who was instrumental in framing the standard, states^{123/} that the same 5 dB penalty applies to "either the first or second or both qualities".) The duration correction, generally applicable only to level L_2 , is more complicated and is different for day-time than for night-time; it is to be read from two families of curves, respectively for day and night operation, which are entered with the mean on-time duration and the total percentage on-time. The measured levels corrected according to the rules

given above are termed the corrected noise levels, L_1' and L_2' , respectively.

The background noise is to be determined at the same location during the relevant time period, but without the source of intrusive noise operating; the value to be recorded should be a "typical low value or mean minimum" and no corrections are to be applied for character or intermittency. Where measurement of the background noise is impractical, a basic background criterion of 50 dB(A) is to be assumed. Corrections are applied to this measured (or assumed) background noise criterion to account for the type of industrial installation (0 to +10 dB), for the type of neighborhood or district (-5 to +20 dB), for the time of day (-5 to +5 dB), and for the season of year (+5 dB for winter-only operation). The basic background criterion, together with the algebraic sum of the corrections, if any, described above, is called the corrected criterion.

The third part of the standard assesses the liability of the noise to generate complaints by comparing the corrected noise levels against the corrected criterion. The exact rules for this comparison are somewhat complicated, but they may be summarized as follows. Excesses of 10 dB or more can be expected to lead to complaints; a 5 dB excess is of marginal significance, but warns of the need for remedial measures to avoid a gradually increasing background noise, which in itself would eventually become a nuisance. Refinements of the rules are given for cases when the actually observed background noise is out of line with the corrected criterion derived from a basic assumed criterion of 50 dB(A).

A further procedure is given to determine, for a noise whose A-level rating predicts complaints, what frequency range is likely to be the source of annoyance. This entails comparing an octave-band analysis of the noise with a family of rating curves approximating equal-loudness contours (see Section f) above).

o) ISO Draft Proposal for Noise Assessment with Respect to Community Response

This rating procedure^{224/} is similar to that of British Standard 4142^{219/}. Differences from BS 4142 are as follows:

The sound level meter, used to measure the A-weighted sound level of the intrusive noise and the background noise, is to be set on the "fast" meter setting; instructions are given for measuring at indoor as well as outdoor locations. Instead of reading only two levels of an unsteady intruding noise (the general average level, L_1 , and a higher, more disturbing level, L_2) a full noise history is to be recorded for the measurement position, chosen to be representative of the typical exposure. For simple on-time and off-time variations of level, the intermittency correction is determined from a table; if the fluctuation is more complicated, an energy-equivalent sound level, L_{eq} , is derived from a statistical analysis of the noise history. In either case, corrections are to be applied for the presence of pure tones or for impulsive character of the noise.

The basic background criterion to be assumed when no measured data are available is more stringent than in BS 4142: a value between 35 and 45 dB(A) is suggested, depending on the country. Corrections are to be applied for day- or night-time operation

and for the district in which the noise intrudes. These corrections are all about 5 dB more restrictive than BS 4142.

The ISO document goes further than BS 4142 in rating the noise (which, incidentally, is not restricted to industrial noise). In addition to predicting that complaints are to be expected when the corrected noise level exceeds the corrected background criterion by 10 dB(A) or more, and remarking that a 5 dB(A) excess is of marginal significance, a table is presented giving more fully detailed estimates of public reaction, in categories similar to the early Composite Noise Ratings (see Section k) above).

A procedure, based on intrusion of the octave band spectrum of the noise into a family of level rank curves, is given to help determine the most likely frequency range responsible for annoyance. A further procedure is recommended for rating indoor noise in terms of the expected noise reduction of typical exterior walls, with open or closed windows.

4. Inter-rating Comparisons

The various rating schemes based on physical measurements of a noise, described in the preceding section, differ greatly in the amount of calculation effort required. Some can be read as a single value from a simple sound level meter; others must be computed, with appropriate weighting factors, from a continuous time record of the fluctuation of instantaneous levels in each of 25 third-octave bands of frequency, with subsequent complicated corrections for the presence of pure tones in the noise.

The choice of a suitable rating for the present purposes should weigh the trouble involved in determining the rating against the probable precision in predicting community reaction, as indicated in the inter-rating comparison studies described in this section.

Three different comparison approaches have been used: 1) comparing one noise rating against another, for a variety of different real or artificial noise spectra, (with no appeal to people's judgment) to see how well the ratings correlate with one another, or, more specifically, to see how well the more complicated ratings can be predicted from the simpler ones; 2) investigating which of the ratings assigns the most nearly uniform values to a series of noise events that are independently judged by people to be subjectively equivalent in some respect; or 3) determining which rating most consistently puts each noise in the same qualitative category to which subjective judgments have assigned it.

Some of these inter-rating comparison studies are reviewed here; Ref. 132 describes these studies in greater detail.

a) Comparison of the Noise Ratings Among Themselves

i. Parkin 109/

In 1960, in preparation for a large-scale survey of noise in London, calculations were made of loudness level, according to the then-current procedures of both Stevens²³⁷/ and Zwicker²⁵²/, and of perceived noise level²⁰⁸/, and these ratings were compared against the calculated values of sound level with A, B, and N-weightings, for a group of 185 noises: 71 spectra representing road traffic, 49 measurements of rail traffic, 41 noises from air traffic, and 24 industrial noises. The Stevens phons, the Zwicker

phons and the PNdB were plotted in turn against the three sound levels for all the noises. Straight lines of the form:

$$y(\text{phons or PNdB}) = m \cdot (A, B \text{ or } N\text{-weighted dB}) + c$$

were "best-fitted" to the points, and the range and standard deviation of the points about the lines were calculated, as shown in Table III.

The N- or the A-weighting agreed with the Zwicker phons most accurately (standard deviation = ± 1.7), B-weighting gave the Stevens phons best (s.d. = ± 1.2). These standard deviations are not much greater than those observed between calculated and subjective loudnesses in other studies.

ii. Robinson et al^{125/}

The A-weighted sound level was used to report the main results of the first Farnborough experiment^{125/} on judging the noise from aircraft in flight. As a matter of interest the A-levels were compared against calculated perceived noise levels for a representative group of flyover octave-band spectra from the Farnborough tests, as well as for 230 other examples privately communicated by N. Fleming. The differences, PNdB - dB(A), are shown in Table IV.

Robinson concluded that "the round number 13 expresses the difference with sufficient accuracy for present purposes." A similar procedure, carried out for noise observed indoors, led to a mean difference of 14.4 dB.

TABLE III
(Parkin)^{109/}

y	x	m	c	Standard deviation	Range
Stevens phons	dBA	1.05	10.1	±2.0 phons	+8.5 phons -4.5
Zwicker phons	dBA	0.99	20.5	±1.7 phons	+5.5 phons -4.5
PNdB	dBA	1.04	13.0	±2.4 PNdB	+6 PNdB -6
Stevens phons	dB	1.09	2.8	±1.4 phons	+5.5 phons -3.5
Zwicker phons	dB	1.01	14.3	±1.9 phons	+4 phons -7
PNdB	dB	1.06	7.0	±2.9 PNdB	+9 phons -6.5
Stevens phons	dB	1.01	4.8	±1.7 phons	+3.5 phons -5.5
Zwicker phons	dB	0.94	15.8	±1.7 phons	+3 phons -7
PNdB	dB	1.02	6.7	±1.2 PNdB	+2 PNdB -5

TABLE IV
 (Robinson, et al)^{125/}

	(PNdB - dBA)			
	Farnborough		Fleming's data	
	Mean	Range	Mean	Range
Jet Aircraft	12.3	10.7 to 14.4	11.9	8.8 to 15.6
Jets (approach)	12.1	10.1 to 14.0	15.3	10.4 to 19.5
Propeller aircraft	14.3	13.0 to 15.9	14.2	11.2 to 16.7
Propellers (approach)	16.0	15.4 to 16.7	14.7	13.1 to 17.3
Helicopters (piston)	13.6	11.8 to 15.5	--	-----

iii) Botsford^{16/}

An extensive comparison of noise ratings against one another has recently been made by Botsford, who used a sample of 953 noise spectra comprised of 580 factory noises, 212 neighborhood noises, and 161 noises measured at the positions of operators of large earth-moving vehicles. A wide variety of noise spectrum shapes was included. (Information on the spectrum shape is provided by the difference between the un-weighted and the A-weighted sound levels: the greater the difference, the more low-frequency energy in the noise; this difference ranged from zero to 23 dB in the noise spectra used in the study.)

The method of comparison was to: 1) "calculate a particular noise index for each noise of the sample, using the octave-band sound pressure levels; 2) sort the noises into groups by values of "unweighted level minus A-weighted level" abbreviated "C-A" ; 3) plot the index of each noise versus the A-weighted sound level, using C-A as a parameter; 4) draw a curve through each set of points; 5) determine the standard deviation of the scatter of the points about these curves; 6) calculate the correlation coefficient between indices predicted by the curves using sound levels and those determined from octave band sound pressure levels." No subjective judgments were involved. The results of greatest interest to the present study are summarized in Table V.

TABLE V
 (Botsford)^{16/}

Quantity estimated from A-weighted sound levels	Reference (this report)	Value Estimate from A-level vs. calculated value	
		Correlation coefficient	Standard deviation(s.d.)
300-2400 Hz average	199	.994	2.4 dB
Speech interference level	199	.983	2.9 dB
Annoyance level rank	232	.989	.30 rank(≈1.5 dB)
NR number (150)	224	.989	1.5
NC number	155	.995	1.0
Perceived noise level	258	.993	1.0 dB
Loudness*			
Stevens VI	238	.995	1.1 phon
Zwicker diffuse	280	.995	1.0 phon

* Zwicker's loudness levels averaged 5.34 phons higher than Stevens' levels, with s.d. = 1.47, which is highly significant.

Concerning the precision of the relations shown in this table, Botsford remarks: "In all the plots of noise indices against sound levels, the points cluster well and define curves precisely Considering the variety of noise spectra considered and the complexity of the noise weighting methods dealt with, better correlation with the readings of the simple sound level meter could hardly be expected. In many cases, the relations depended so slightly on the C-weighted sound level that it could be dispensed with and the A-weighted sound level alone used."

He comments on the relation of noise ratings to human responses as follows: "The correlation of any noise rating number with the human responses elicited in any group is inherently poor because of the wide variation of individual responses to the same stimulus. Better correlations can be obtained only by taking into account the social and psychological parameters responsible for these variations. Better correlations cannot be obtained by refining the noise measurement and evaluation procedure The coefficient between any noise rating number and human response is represented by r_1 which is typically 0.85 or less. The coefficient of correlation found between sound levels and the noise rating number, designated r_2 , is typically 0.99 or better. The coefficient of correlation relating sound levels directly to human response is r_3 which is equal to the product of the other two. Because r_2 is nearly unity, r_3 is essentially equal to r_1 . Thus, sound levels correlate with human responses as well as any of the noise ratings. So refinement of noise rating methods beyond sound levels is a futile

exercise as far as improvement of ability to appraise human response of groups is concerned."

b) Comparison of Noise Ratings for Noises Subjectively Evaluated as Equivalent

One form of investigation, to see which of the noise ratings assigns the most nearly equal values to noises subjectively judged to be equivalent, can be carried out in terms of speech interference.

i) Kryter and Williams^{210/}

"Word-intelligibility tests at various intensity levels were administered to a crew of trained listeners in the presence of recorded noise from jet and propeller-driven aircraft. The noise was that which would be present outdoors and in a house as the result of engine run-up operations and if aircraft were flying overhead shortly after takeoff and prior to landing. According to visual inspection of the data [per cent words correct vs ratings] methods of measuring or evaluating aircraft noise predict the results of the speech tests in the following order of merit, from best to worst: 1) articulation index (AI), 2) perceived noise level in PNdB, 3) speech-interference level (SIL), 4) noise criteria (NC), 5) over-all sound-pressure level (SPL A scale), and 6) over-all SPL C scale. The differences among PNdB, SIL, NC, and dB(A), in this regard, are probably not significant according to these tests."

Another way of comparing noise ratings with subjective judgments is to see whether or not they assign the same value to noises subjectively judged to be intrinsically "equally annoying" (or "noisy"), without specific reference to speech intelligibility. A number of such tests have been made. The most comprehensive of these for aircraft noise has recently been reported by Young and Peterson.

ii) Young and Peterson^{250/}

The authors describe their work as follows: "Results of judgment tests on the noisiness of aircraft sounds published during the past decade [and cited in ^{203/}] were analyzed collectively to find the relative precision with which the judgments are explained by calculated perceived noise level, calculated loudness level, and Sound Levels A, B, C, and D (formerly N). For consistency, all levels were recalculated, in accordance with current rules, from published noise spectra. Application of standard statistical procedures to the available data indicates that differences among [the perceived noise level, the loudness level, A-level and D-level], in their correlation with judged noisiness, are not statistically significant. The authors conclude from the re-evaluation of this collection of data: "... the standard deviations for L_A , LL, PNL, and L_D could indeed come from populations of the same variance. Only the B and C levels are clearly inferior as predictors of noisiness."

Young and Peterson call attention to other studies with similar results: "A similar analysis by Klimuhin and Ossipov* for the group of five equally noisy 'outdoor spectra' of aircraft as originally published^{208/} led to standard deviations of 1.6, 2.0, 2.6, 2.6 and 5.8 dB respectively, for L_A , PNL, LL, L_D , and L_C . Only the standard deviation for L_C level was significantly greater than the others. Those authors concluded that Sound Level A 'corresponds to the subjective reaction of listeners and there is no hindrance preventing using this simple and convenient system for measurement and evaluation of aircraft noise'."

"When Pearsons**obtained judgments by 20 subjects of equal noisiness of shaped bands of noise (sometimes with tones added) for a group of 33 sounds, he arrived at standard deviations of 4.2, 4.4, 4.7, 5.0, and 6.8 dB, respectively for L_A , L_D , PNL, LL, and L_C . With corrections of two kinds to PNL for spectral discontinuities, the standard deviations were reduced respectively to 4.2 and 3.6 dB. When Wells**used the same test sounds with 30 subjects he arrived at standard deviations of 3.8, 4.8, 6.6, and 8.0 dB, respectively, for LL, PNL, L_A and L_C . Only the standard deviation of the C level was significantly greater than most of the others.

"Since Sound Level A predicted the judged noisiness of the aircraft sounds as precisely as did calculated loudness level or perceived noise level, this readily measured

* Vith Int. Congr. Acoust., Tokyo (1968), Paper F-1-7.

**Op. Cit., Paper

sound level may well be applied to the rating of aircraft noise along with other noises in the community."

c) Comparison of Noise Ratings with Subjective Assignments of the Noises into Qualitative Categories

i) Young

A re-evaluation by Young^{249/} of the office data used by Beranek^{155/} in developing the NC curves showed that the rank-order correlation coefficients between the subjective noise ratings made by executive office personnel and various physical measures of the office noise are as given in Table VI.

TABLE VI (Young^{249/})

<u>Rating</u>	<u>Rank-order Correlation Coefficient</u>
A-Level	0.96
B-Level	0.96
NC-Level	0.95
NCA-Level	0.95
ISO N-Level	0.96
SIL	0.86
LL	0.96
PNL	0.96
N-Level	0.95

Young concludes, "Since subjective ratings of office noise appear to be correlated with the A-sound level as well or better than with other commonly known noise ratings, and since the A-sound level can be measured readily with widely available meters, it is recommended as a replacement for the NC level in single-number specifications for office noise."

Young^{250/} and Peterson also point out:

"In recent rating experiments with 100 sounds of passing trucks, Hillquist^{66/} found: LL (equivalent-tone), LL (Stevens), PNL, L_A , L_D , L_B , and L_C , with respective standard errors of estimate of 1.4, 1.6, 1.7, 1.9, 2.0, 2.2, and 2.8 dB. Again, there was no significant difference among the loudness levels, PNL, L_A , and L_D ."

5. Simple vs. Complicated Ratings

In view of the uncertainties of predicting subjective reactions to noise, mentioned in Section A-1 above, and the high degree of correlation among all the schemes for rating noise based on physical measurements, it appears that the measurement and computation effort entailed in the more complicated rating procedures is not justified; though the advantages of the complicated procedures can sometimes be demonstrated in carefully controlled laboratory tests, they are not significantly better than the simpler ratings in dealing with real-life situations. We have already encountered Botsford's strong views based on his analysis of factory noises, neighborhood noises and construction industry noises: "...refinement of noise rating methods beyond sound levels is a futile exercise as far as improvement of ability to appraise human response of groups is concerned."^{16/}

Connor^{173/} is equally firm with respect to aircraft noise: "The best known measures of aircraft noise exposure, CNR, NNI, and NEF are more highly correlated among themselves than is any one of them with annoyance, and they are about equally effective in conjunction with social variables in the prediction of annoyance. It follows that the elaborate procedures which have been devised for calculating the effective perceived noise level of aircraft

flyovers offer no advantages over relatively simple measures in dealing with community reaction..."*

* * * * *

Beranek^{87/} has summarized the comparisons of these rating methods against the subjective reactions of humans, as follows:

"The conclusion to be drawn from these various studies appears to be that, if a spectrum is (1) continuous in time, (2) continuous in frequency, (3) contains no sharp peaks or dips, and (4) extends over a wide frequency range, the dBA is as satisfactory a single-number method for rating noise as is the PNdB or loudness level in phons calculated by either the Zwicker or the Stevens method. In those instances, however, where a spectrum is quite non-uniform (some bands are much louder than others) or where it contains pure tones, or where the noise is intermittent, the dBA may not be a satisfactory measure of the subjective evaluation. Indeed, the other methods may not be entirely satisfactory either."

* Nevertheless, for the time being HUD will, in deference to current FAA usage, evaluate aircraft noise exposure in terms of Noise Exposure Forecasts or Composite Noise Ratings, both of which are based on Perceived Noise Level rather than A-Level measurements.

6. The A-weighted Sound Level as the Measure of Urban Noise Exposure at a Site

Our requirements for a suitable measure of urban noise exposure at a site differ from those of a local planning board, whose goal may be to establish local noise ordinances, or from those of an acoustical consultant, who may need to design noise control measures for some specific noise source*. We are not trying to determine that one type of automobile or aircraft is more or less acceptable than another, nor to certify that an individual noise source meets a specified criterion. We are concerned only to establish whether the noise environment at a particular site lies within a range of concern, and where it lies in that range. For this purpose we must be able to specify the total noise exposure of a given locale at a particular time, arising from the combination of all sources of noise; for this task we must select a tool that is neither more nor less complex than is needed for the job.

No doubt, the overt reactions of different individuals or even of different local communities to a given total noise exposure may be somewhat different. But it is not necessary to be able to predict accurately the response of particular communities in order to assess magnitude of the urban noise exposure at a site. We must not, of course, expect that it will be possible to arrange things so as to eliminate complaints of noise annoyance altogether; we saw earlier that a certain portion of the population expresses annoyance even in very quiet locales.

What we can do is to select the simplest rating that correlates well with average human response to noise, point out how this response grows with increasing noise exposure and thus provide a

background for choosing a criterion of acceptable noise exposure for a dwelling site. This criterion choice, itself, however, is not for the scientist to make, for it involves social and political considerations. But armed with the technical, scientific background which it is the purpose of this report to provide, governmental agencies, such as HUD, can arrive at a firmly based decision as to what magnitude of urban noise exposure constitutes, for most of the population, an acceptable living environment.

The studies reported here serve to establish the utility of the A-Level in predicting subjective response. In all but the most particular kinds of research, this measure correlates practically as well with human response as any other of the established ratings. It has the further merit of simplicity, to such a extent that it will lend itself well to monitoring urban noise levels. Moreover, the A-Level has already been widely chosen for use in other surveys,⁽ⁱ⁾ so that it will be a simple matter to compare the measurement results of previous work with HUD's urban noise data. Finally, in assessing the total noise exposure from a number of different noise sources, it is an advantage that the measure chosen has had previous application in a wide variety of noise studies. The A-level is, therefore, recommended for use as the base measure for HUD's noise abatement efforts.

(i) See references 18, 26, 27, 32, 78, 83, 93, 95, 101, 107, 108, 110, 114, 119, 125, 127, 179, 186, 189, 226

B. Coping with the Fluctuations of Urban Noise

As stated above, the noise level in a community is not steady: it fluctuates from moment to moment, depending on the character of the dominant sources of noise. On the one hand, the conglomerate of distant noise sources of all kinds creates a more or less steady background noise in which usually no particular noise source is identifiable; this background noise may change slowly during the day, depending on average traffic density throughout the city. At city locations far away from traffic arteries and aircraft flight paths, it is this background noise that is mostly heard, particularly at night.

On the other hand, since such locations are increasingly rare, in most places one hears a succession of identifiable noisy events of short duration intruding upon the background noise. Such transient events are often associated with transport or construction, and are particularly noticeable near airports, main streets, arterial roads, bus routes, railroad or rapid transit lines, or near building construction sites.

The significance of these fluctuations is that people find a fluctuating noise level much harder to live with than a steady, neutral background noise that they can get used to. Thus, in order to assess the severity of urban noise exposure at any given site, it is important to include in the evaluation some indication of how much and how often the noise level changes.

The problem is to find a meaningful way to measure and describe the noise fluctuation, in enough detail to permit useful estimates of people's subjective reactions, without requiring complicated

and expensive measuring equipment.* Some of the possibilities available in the present state-of-the-art are described below.

1. Measuring the Noise As It Varies With Time

A brief description of urban noise fluctuation was given in Chapter II; Figure 3, for example, showed the short-term noise level variations over a two-minute period at various urban locations. The data for that figure were obtained by making tape recordings at each of the locations, using a calibrated sound level meter and tape-recorder, both battery-operated; the recordings were subsequently replayed in the laboratory, using an A-weighting network, and the resulting signal was continuously drawn out on a slowly-moving strip of paper, to provide a record of how the A-level in each case varied with time. (The equipment for making this paper-strip record is called a graphic level recorder)**.

* This is quite apart from the sometimes necessary complication, described earlier, of performing a frequency analysis of the noise: we have already decided that the adoption of A-weighted Sound Levels will let us avoid that difficulty, while still getting useful indications of public acceptability.

** Alternately, the graphic level recorder and sound level meter (with A-weighting network) could be carried to each location, thus eliminating the need for calibrated tape-recording and playback; but this equipment is bulky and requires a source of 110-volt electrical power; for on-site analysis all the required equipment is customarily mounted in a station wagon or van, with its own source of electrical power.

In principle, a similar record of the time-varying noise level fluctuations could be obtained by a two-man team, equipped with only a sound level meter: one man would make a series of A-Level meter readings at equally spaced time intervals (perhaps every ten seconds) and the other would keep a running written record which later is hand-plotted on a graph to yield an approximation to the curves of Figure 3. The closer together the level readings are spaced in time, the less likelihood there is of missing a particular peak of noise; but, of course, also the greater the amount of trouble in recording and plotting the data.

Whether the noise record is automatically drawn by a graphic level recorder or is hand-plotted, the result of the measurement is a brief time record of the noise exposure. For a more complete record, the period of observation could be extended as desired. To get an idea of how this noise exposure changes at different times of the day, the procedure would have to be repeated as often as required to get the desired amount of information. Measurement procedures similar to this have been reported in the literature.^{127,128/} In locations with practically no intruding transient events, where the noise consists entirely of the steady background noise from distant sources, the noise exposure may be adequately described by noting the average value of several meter readings^{216/} and repeating this procedure several times during the day to distinguish between peak-traffic-periods and the intervening quiet intervals.

2. Interpretation of Time Record of Noise Level

In any case, the interpretation of such time records is far from simple: it is not at all clear, from a visual inspection of the four records of Figure 3, which one is likely to lead to the greatest public annoyance. In the top record, for example, the background noise hovers around 60 dB(A) most of the time with quite a number of small (5 to 6 dB) intrusions by cars and a few extremely loud truck passages, up to 87 dB(A); one cannot say, offhand, whether this location is more or less acceptable than that of the third record, where the background level is only 45 to 50 dB(A) but frequent bus and truck intrusions occur that increase the level by 15 to 20 dB(A). Although we may be aware that public annoyance increases both as the average noise level increases or as the levels become more variable, we cannot conveniently make a site evaluation from these paper-strip records, even if we knew the exact trade-off between mean noise level and variability.

3. Statistical Analysis: Histograms vs Cumulative Distribution

Therefore, in order to deal in a consistent manner with urban noise fluctuations, particularly due to road traffic, it has become standard, for the purposes of evaluating the noise exposure with respect to public annoyance to make a statistical analysis of the time record of the noise.⁽ⁱ⁾ This may be done manually, by marking off on the paper-strip record of A-Level vs time a series of narrow decibel-ranges (say, 2 to 5 dB wide) and counting what percent of the time the noise level spends in each of those ranges. The analysis may be made automatically by means

i. See references 3,4,23,24,26,27,28,39,42,48,54,73,78,83,86,88,95,106,107,110,114,115,119,123,127,128,130,189,195,198,213,217,226,227,231.

of a statistical distribution analyzer used in conjunction with a graphic level recorder^{165/}.

The results may be plotted as a "histogram" to show the statistical distribution of the noise level readings over the observation period. For example, the recorded noise level might spend 1% of the time between 70 and 75 dB(A), 36% of the time between 75 and 80 dB(A), 39% of the time between 80 and 85 dB(A), 10% of the time between 85 and 90 dB(A), 2% of the time between 90 and 95 dB(A), and 1% of the time between 95 and 100 dB(A), as shown in Figure 8-A. Such a histogram is not very practical to use in evaluating urban noise exposure, and the standard deviation, a common measure of the statistical fluctuation, cannot be determined directly from the figure. A more frequently used statistical presentation is found by adding together the data from the histogram to determine the "cumulative distribution," that is, the percent of the time that the noise level exceeds each of a series of A-Levels; this, too, can be done either by hand calculation or automatically by the statistical analyzer. In the example above, the level exceeded 65 dB(A) for 100% of the time, 70 dB(A) for 99%, 75 dB(A) for 88%, 80 dB(A) for 52%, 85 dB(A) for 13%, 90 dB(A) for 3%, 95 dB(A) for 1% of the time, and never exceeded 100 dB(A) at all (at least during the observation period), as shown in Figure 8-B. In this case the median (approximately the average) level is 80 dB(A), and the standard deviation, σ , is about 5 dB (half the difference between L_{16} and L_{84}).

This is the form of presentation used in Figure 5 of Chapter II and is typical nowadays of statistical data presentation for urban noise. (The peculiar scale for the "percent-of-time-exceeded" in Fig. 5 is chosen for standard statistical representation in

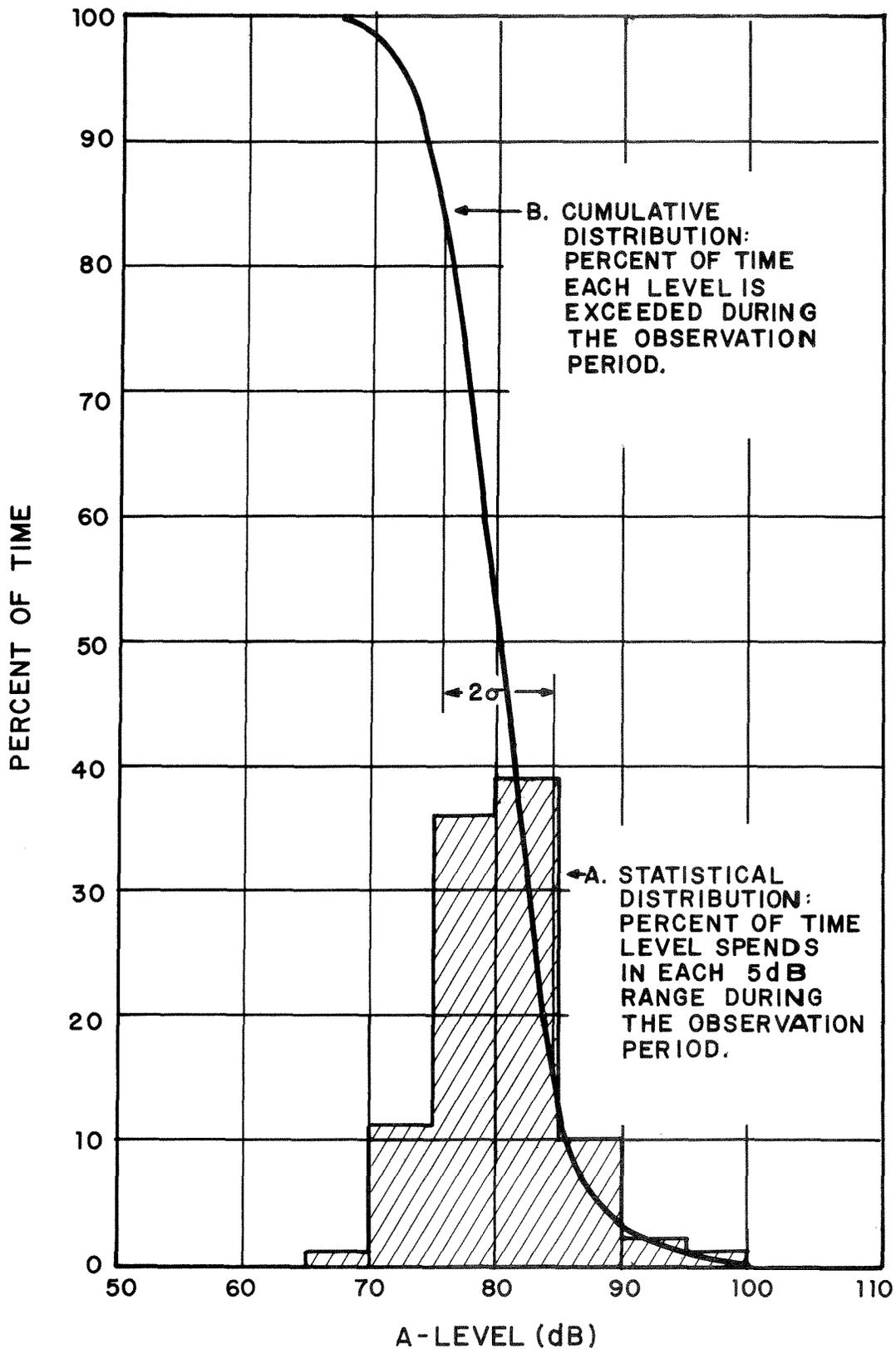


FIG. 8 HISTOGRAM SHOWING STATISTICAL DISTRIBUTION (A) AND CURVE SHOWING CUMULATIVE DISTRIBUTION OF NOISE LEVELS AT A SITE.

order that a commonly occurring type of distribution known as "Gaussian".... of which the noise of dense road traffic is a good example will plot as a straight line on the graph: indeed, the straightness of a curve plotted on such standard statistical graph paper is a measure of how nearly Gaussian the distribution in question is, a matter of some importance in statistical calculations more sophisticated than we will deal with here.)

Such a statistical plot of the noise gives a good idea of the intensity of the noise exposure in terms of the A-Level exceeded half of the time: the so-called 50% Level, designated by L_{50} , halfway between top and bottom of the graph. And it also indicates how much the noise level fluctuates, by the slope of the curve: if the curve is almost vertical, this means that the noise hardly ever varies from the 50% Level and thus is practically constant; night-time background noise levels in country areas often have curves of this shape. On the other hand, if the curve slopes considerably away from the vertical, it indicates a substantial difference between the background level and the level of intruding peak noises; this might be the case for a location very near a street with infrequent truck passages, or for an otherwise calm suburban site near an airport.

For practical purposes, we usually identify three important levels in the cumulative statistical distribution, as shown in Figure 5: these are the levels exceeded, respectively, 90%, 50% and 10% of the time, designated L_{90} , L_{50} and L_{10} . Of these, L_{90} represents a good estimate of the background noise level, L_{50} the median or average level, and L_{10} the peak level. The difference $(L_{10} - L_{90})$ has been defined as the "Noise Climate" of a location $\frac{100}{10}$; it indicates the range within which the noise levels spend most that is, 80% of the time.

In many cases it is of interest to carry out the statistical analyses described above for various periods during the day. This was done on an hourly basis throughout one day to develop the data presented earlier in Figure 4; this representation shows how both the background noise level and the peak levels (L_{90} and L_{10}) stabilize for the daytime and the night-time periods.

It should be clear by this time why it is not sufficient to characterize an urban noise exposure by any single (i.e., the average or median) noise level alone, for this would wrongly imply that a quiet period compensates for a noisy one^{136/}; many different kinds of site exposure, with widely varying Noise Climates and correspondingly different public reactions, can be represented by one and the same average noise level.*

4. Single-number Rating to Include Both Average Noise Level and Fluctuation

Mention was made above of a possible trade-off between the average noise level and the noise fluctuation for determining how people will react to various noise exposures. We would like to have a formula to express how much the mean level of a noise exposure must be reduced, in order to achieve the same public acceptability, if, instead of being steady, the noise level fluctuates a certain number of decibels. A few studies have been made to determine how the mean noise level and the fluctuation of noise exposure combine to cause public annoyance; the best known of these studies are those from which the Traffic Noise Index (TNI)^{189/} and the Noise Pollution Level (NPL)^{231/} were

* In the same sense, it may not be safe to wade across all streams having an average depth of only two feet!

developed. Both ratings require a knowledge of statistical parameters, such as the 90%, 50% and 10% levels of a cumulative distribution.* Other studies^{26,163,166/} have attempted to account for the related matters of the duration of intruding transient events^{89,203,229/}, or of the number of such events^{2,79,100,174,183,230/}. Such studies are being pursued by comparison of the objectively measured noise exposure, expressed by ratings calculated from various combinations of the statistical terms, with the observed subjective response in a variety of situations. These studies will eventually show not only how public annoyance varies with exposure to different kinds of noise but also will develop criteria of acceptability, namely, the degree of noise exposure which should not be exceeded if we wish to provide a healthful living environment for people.

5. Statistical Analysis Both Desirable and Unavoidable

In the meanwhile, based on the best information available at the present time, HUD has, in its policy circular on Noise Abatement, adopted certain interim criteria of acceptability for dwelling sites, and has expressed them in terms of a **series** of A-levels not to be exceeded for brief periods out of a day, or portion thereof. In order to determine whether or not a given proposed site for a HUD program complies with these criteria, it is necessary to have a complete statistical analysis of the kind described above, in terms of a cumulative distribution of the noise levels at the site, or something very similar to it.

* Interesting comparisons between the TNI and NPL are given on pages 91-93 below.

* Increasing the duration of an event may increase the average noise level without increasing the fluctuation; increasing the number of events increases both the average level and the fluctuation.

It is expected that new data coming from the continuing studies of public response to noise will eventually permit HUD's criteria to be formulated in more concise form, preferably in terms of a rating procedure that accounts for both the level and the fluctuation of the noise in a single number.

However, until the acoustical community finally settles on the best formula for combining the parameters of a statistical analysis of urban noise to describe the exposure, it is clearly desirable to have urban noise data measured and recorded in such form as to be adaptable to the best rating available at any particular time. *

Moreover, there are strong arguments in favor of fostering both national and international uniformity with respect to the "tools" used in noise abatement, for this readily allows us to take advantage of all research, wherever it is done, that is aimed at improving community noise evaluation techniques, particularly the current attempts to bring the results for different types of noise source into agreement. **

For these reasons it is in HUD's best interest to adopt the standard statistical cumulative distribution format for describing noise exposure at a site, despite the fact that, at present, the only commercially available measurement equipment that permits this kind of analysis is both expensive and complicated

* Even though the standard test procedures of France and England do not at present require full statistical analysis for evaluating community noise, the surveys carried out in the last decade have in fact made full use of the statistical approach.

** See second footnote, page 75.

to operate.* A companion report (#2024) on measurement procedures addresses itself to how this problem can best be overcome for HUD's noise abatement operations.

C. Noise Exposure Forecast (NEF) and Composite Noise Rating (CNR) for Airport Neighborhoods Compared With Alternate Ratings

In the course of the past two decades, the procedures for evaluating urban noise in general and aircraft noise in particular have pursued somewhat different paths. Consequently, it does not yet appear feasible to deal with all kinds of noise under the same criteria.** Accordingly, while site noise from all other sources is judged according to one set of rules in HUD's Noise Abatement Standards, the noise from airports is treated in terms of one or the other of two rating schemes developed specifically to apply to aircraft.

* Because of this complication both the British^{219/} standard and the current U.S.^{216/} draft standard for assessment of community noise tend to avoid statistical analysis; the U.S. draft makes no attempt to account for fluctuations at all and the British standard tries to cope with the problem by reporting both a background noise and a second, intrusive, level, with very complicated corrections (different for daytime and night-time) for duration of the intrusive level, not a very satisfactory procedure. The ISO community noise measurement standard^{224/}, however, requires a full noise history with statistical analysis if appropriate. The Swiss standard^{42/} takes a middle position and attempts to account for fluctuation in terms of a background level and the levels of frequent (i.e., 7 to 60 per hour) and infrequent (1 to 6 per hour) peaks. This determination requires a graphic level recorder, is unspecific as to what constitutes a "peak", and does not really come to grips with the problem.

** There is reason for hope, however. Preliminary results from^{253/} a current study of public response to a combination of road traffic and aircraft noise appear to validate the Noise Pollution Level concept^{231,268/} with a correlation of 0.96 between L_{PN} and the median dissatisfaction scores.

*Reviewing still
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The Noise Exposure Forecast (NEF) is the more recent rating; the FAA is currently adopting it for land use planning around commercial jet transport airports. It cannot be applied to military aircraft yet, though there is no reason in principle why the necessary data could not be developed. The other rating is the immediate predecessor of the NEF, namely, the Aircraft Composite Noise Rating. It has, until recently, been used by FAA for evaluating all airport neighborhoods and continues to be used by the U.S. Armed Forces to evaluate the noise from military air bases. Both of these ratings were described in Section III-A above.

Just as the ratings developed in different countries to evaluate traffic (and other urban) noises show certain differences in approach, as well as in the prediction of public acceptability, there are variations in the ratings for aircraft noise in different countries. These have been well summarized by Galloway,^{183/} who has compared the aircraft noise rating schemes of the USA,^{160,183/} the United Kingdom,^{100/} France,^{174/} the Netherlands,^{163/} and Germany.* The U.S. ratings (the Aircraft CNR and the NEF) have been described above, as has the Noise and Number Index (NNI) of the United Kingdom. The Isopsophic Index of France, designated *N*, differs from the U. S. Aircraft CNR only by a constant** for

* Robinson^{123/} has carried out a similar comparison that includes also the results of road traffic surveys and other studies.

** It is identical with the most recent formulation^{2/} of another French rating, the Classification Index, designated R.^{2,174,183/} Earlier forms of R used, instead of the value of 30 for the final constant, a value of 34 (for example, Refs. 72, 73, 167 and 168); Robinson^{123/} reports a form for R that includes a term, $5 \log \xi$, where ξ is an annual runway usage factor, and uses a constant value -46. Present usage conforms to the formula used in the text, above.

operations during daylight hours (0600-2200):

$$\begin{aligned} N &= \overline{L_{PN}} + 10 \log N - 30 \\ &= \text{CNR} - 18 \end{aligned}$$

The treatment of night operations in the Isopsophic Index is considerably more complicated than in other procedures. Nighttime is considered in two intervals, 2000 to 0200, and 0200 to 0600 hours. Operations in the first period are treated as three times more significant than in the second; but the "10 log" summation is replaced by $6 \log_{10} (3n_1 + n_2) - 1$, where n_1 and n_2 are the numbers of operations in the two nighttime periods. This expression is ignored if $3n_1 + n_2 < 64$, and a straight "10 log" summation is then used, as for daylight operations.

The Dutch and German ratings (respectively, the Total Noise Load, designated B, and the Mean Annoyance Level, designated \bar{Q}) have formats similar to those of the other four ratings, but they allow for slightly different rates of growth of annoyance with duration and number of fly-over events; in addition, the Dutch rating is calculated from basic measurements in A-Level, whereas the others start from measurements of Perceived Noise Level in PNdB. Since, for aircraft noise, there is a very close correspondence between the A-Level and PNdB, ($L_A = \text{PNdB} - 13$) there remains a close family resemblance among all these aircraft noise ratings; and there is a corresponding similarity in the ways they rate a given series of aircraft operations.

A particularly interesting comparison can be made between the CNR and the NNI, by using the noise and operations data (from the London Survey) that were used to develop the NNI, and calculating instead the CNR. When this is done and the results are fitted to the mean annoyance scores from the Social Survey, as in Figure 9, it can be seen that the CNR rating fits the subjective

judgements of the noise as well as the NNI. Moreover, it can be argued from this that the "energy addition" principle embodied in the term "10 log N" of the CNR accounts for the London annoyance data as well as the less plausible "15 log N" term of the NNI.

1. Direct Inter-Comparison of NEF, CNR, NNI, \bar{Q} , B, \bar{Q}

A method of comparing all five of the indices and the community response zones they define, is to select a single type of aircraft with its corresponding noise level, vary the number of operations, and examine the effect on the indices. The values for these indices, based on different numbers of daytime operations at an average maximum noise level of 110 PNdB (or 110 EPNdB for NEF) and an effective duration of 15 seconds, are plotted in Fig. 10. The equations used to derive this figure are summarized below:

$$\text{CNR} = 10 \log_{10} 10^{\frac{L_{pn}}{10}} + 10 \log_{10} N - 12$$

$$\text{NEF} = 10 \log_{10} 10^{\frac{L_{epn}}{10}} + 10 \log_{10} N - 88$$

$$N = 10 \log_{10} 10^{\frac{L_{pn}}{10}} + 10 \log_{10} N - 30$$

$$\bar{Q} = 13.3 \log_{10} 10^{\frac{L_{pn}}{13.3}} + 13.3 \log_{10} N - 47$$

$$\text{NNI} = 10 \log_{10} 10^{\frac{L_{pn}}{10}} + 15 \log N - 80$$

$$B = 20 \log 10^{\frac{L_{pn}-13}{15}} + 20 \log N - 65$$

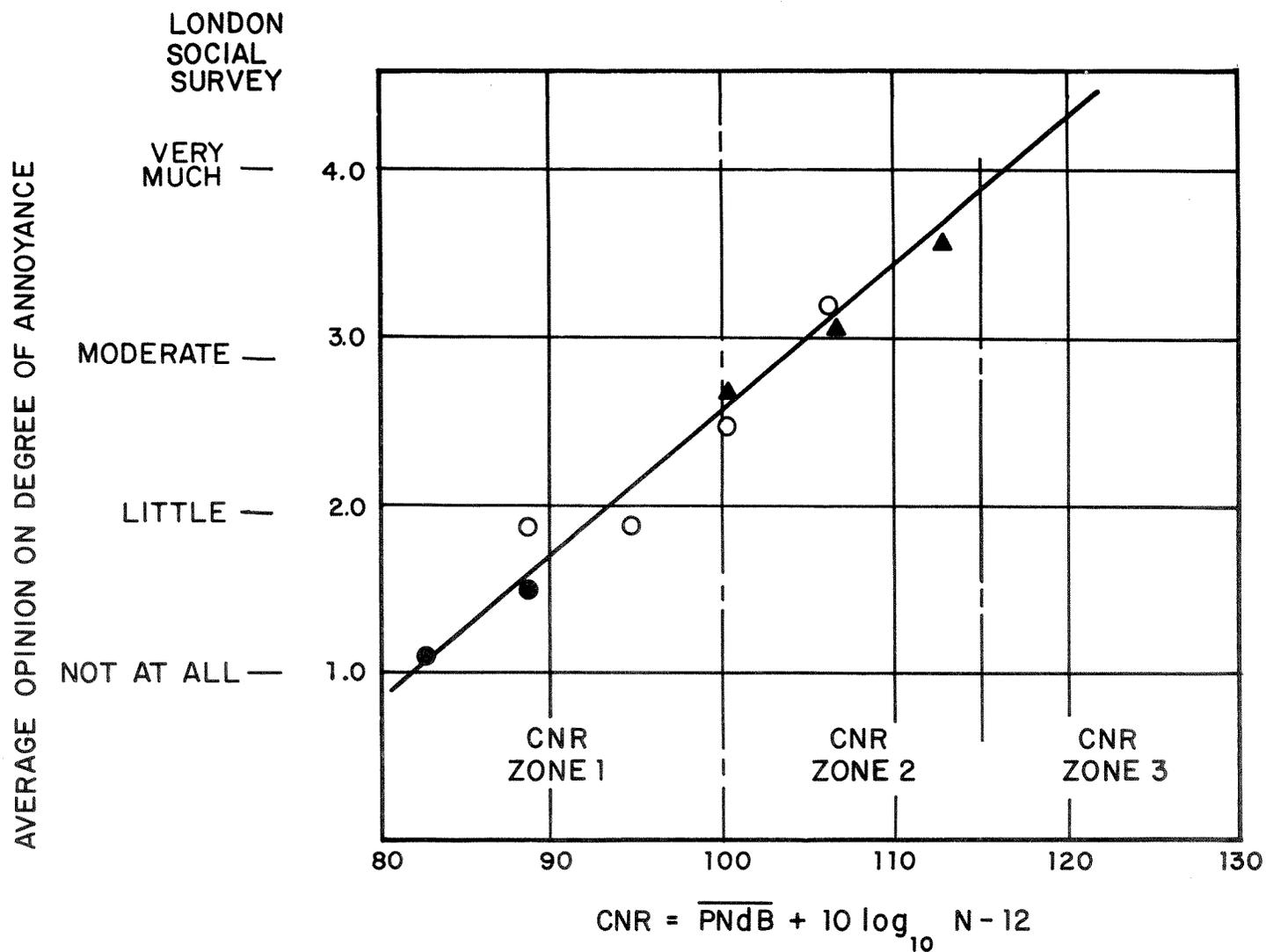


FIG. 9 CALCULATED CNR VS. LONDON SOCIAL SURVEY ANNOYANCE SCALE

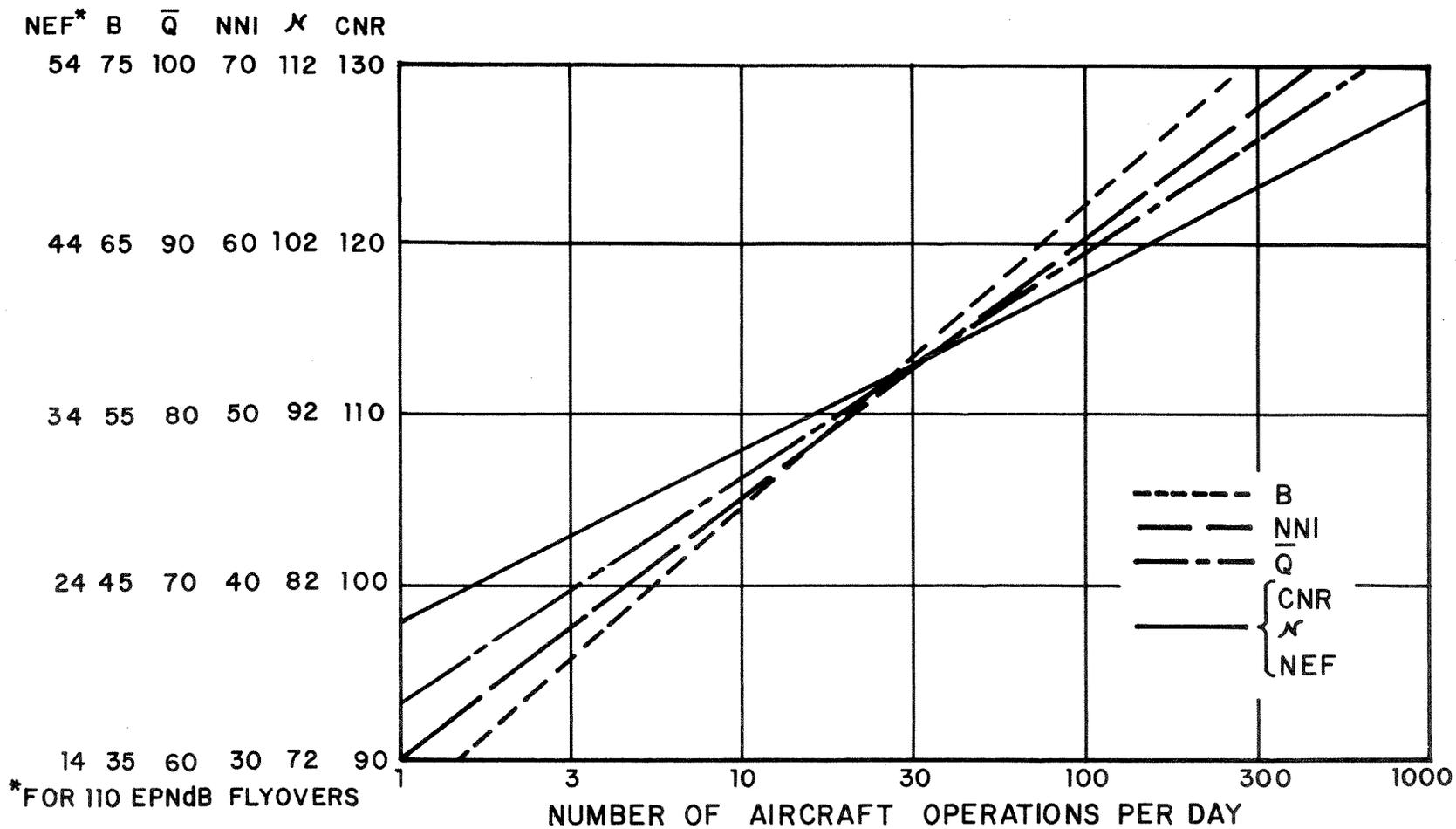


FIG. 10 COMPARISON OF VARIOUS AIRCRAFT NOISE EXPOSURE INDICES FOR A FLYOVER NOISE LEVEL OF 110 PNdB AND VARIABLE NUMBER OF OPERATIONS.

If one were to hold the number of operations constant, and instead vary the noise levels (and the flyover signal durations) in accord with the way flyover signals characteristically change with distance from an aircraft, the correlations among indices would be somewhat different from those expressed above. (An example of this was given earlier in Fig. 7, which reflected the fact that as distance from an aircraft is varied, the relationship between EPNL and PNL values changes, because the EPNL, which explicitly includes a duration factor, decreases with distance at a slower rate than the PNL.)

There is a special advantage in the use of a rating for aircraft noise that embodies the coefficient 10 for the term accounting for the number of operations, rather than 13.3 (Germany), 15 (United Kingdom) or 20 (Netherlands). Since in the case of general noise nuisance, not specifically due to aircraft, the concepts of duration and repetition for individual events blur and the noises merge into a semi-continuous pattern, it is obviously desirable to have a rating system that is compatible both with patterns of identifiable events and with an undifferentiated continuum. In its simplest form, this is the principle of "energy addition", expressed as $10 \log N$, as in the CNR, the NEF, V and R ; such a form at least keeps the door open for a common rating for aircraft and all other urban noise sources.

From these considerations one can conclude that the NEF or the Aircraft CNR will do as good a job of accounting for the observed subjective response, in the surveys so far carried out, as any other available rating for aircraft noise. The NEF is to be used for evaluating the neighborhoods of airports operating commercial jet transport airplanes and the Aircraft CNR is to be used for areas near military air bases.

What about
mix?

D. Criteria of Acceptability

Once a method of measuring and concisely expressing the urban noise exposure is agreed upon, we are well on the way to setting a criterion of acceptability for the noise environment. Before such a criterion can be chosen, however, it is necessary to consider in a quantitative way the effects noise may have on people. These effects may be grouped into three categories: 1) subjective effects, described by such words as annoyance, nuisance, dissatisfaction, disturbance, etc., that concern the intrinsic "unwanted" character of the intrusive noise; 2) behavioral effects, involving interference with an on-going activity, such as speech, learning, TV-watching, sleep, or the performance of any general task; and 3) physiological effects, both temporary (such as startle reactions and temporary threshold shift) or enduring (such as permanent hearing damage or the cumulative physiological effect of prolonged sleep loss). Obviously, the latter effects will have something to say about the maximum permissible noise levels to which people should be exposed without special protection, even for short periods; the Walsh-Healey legislation deals with such conditions in industry, but they usually involve noise levels much higher than would ever be considered for defining an acceptable living environment for people. The first two categories of effects, than, are our most reliable resource for establishing criteria of acceptability.

1. Subjective Effects of Noise

We have already mentioned the variability of people's response to noise; this variability creates great difficulties in evaluating the effects of noise; and this is nowhere more evident than in the results of social surveys, some of which appear to

have yielded conflicting conclusions. A Swedish survey,^{123,142,143/} conducted in 1966 and 1967, showed close correlation between subjective disturbance and the average energy level of the noise exposure. On the other hand, in a recent (1967-68) London traffic noise survey^{110,189/}, the subjective dissatisfaction depended not so much on the absolute level of the noise but on how much the intrusive individual peaks of noise exceeded the background level. In other surveys only a weak correspondence was noted between mean noise level and annoyance^{32/} (1966-67), and in some cases (at least for road traffic) no correlation at all^{88/} was found (1961-62). (This latter result, though it caused some initial consternation, is now thought, in the light of subsequent investigations, to be explained by the particular sampling methods used^{189/} and perhaps a limited range of noise exposure^{88/}.)

The concensus of most researchers nowadays is that, although a number of personal idiosyncrasies may intervene to make the prediction of an individual's reaction to a given noise virtually impossible, several noise ratings have been developed that predict with reasonable accuracy the median response of a group of people exposed to the noise. We shall come back to the survey results after considering the other two categories of effects of noise.

2. Behavioral Effects on Specific Activities

a) Speech Communication

One of the most obvious effects of urban noise is interference with communication. A noise level that is not intense enough to cause hearing damage may still disrupt speech communication or interfere with the enjoyment of music or television. Also,

interference with the ability to hear warning shouts or commands increases the probability of accidents.

According to Beranek^{154/}, if television and radio are to be understood comfortably, the indoor noise level should not exceed 40 or 45 dB(A). Since the facade of a house with open windows reduces the noise by about 5 dB(A)^{26/}, the outside levels for satisfactory television and radio listening inside should be no more than 45 to 50 dB(A), with the windows open. The maximum outside levels for satisfactory listening may be increased by approximately 10 dB(A) if the windows are of conventional single-pane construction and are kept closed.

b) Interference With Sleep^{267/}

Social surveys show that conscious interference with sleep is frequently cited as a major reason for annoyance with neighborhood noise^{26,31,32,100,129,138,270/}. But sleep interference can exist even without a person's being consciously awakened.*

In Thiessen's experiments^{138/}, sleeping subjects were exposed to a recording of the noise from a passing truck, played at a selected peak level several times each night. It was found that there is a 5% probability of awakening the subject at the 40 dB(A) level and a 30% probability at 70 dB(A). If, however, one includes significant changes in the electroencephalogram records of the sleeping subjects, there is a 10% probability of a shift in sleep level (including awakening) at the 40 dB(A) level and a 60% probability at 70 dB(A).^{21/} Some subjects awaken more than half the time at a peak noise level of 50 dB(A); other practically never awaken, even at 75 dB(A). (Cited in Ref. 54, p. 109).

* The Province of Baden-Württemberg^{44/} recognizes that noises in the 30-65 dB(A) range may rouse a sleeper to a shallower level of sleep and that frequent noises of such level may make deep sleep impossible.

In 1957, Steinecke [cited in Ref. 142] analyzed the effect of noise on sleep for 350 people of different ages, sexes, and occupations. The initial noise level was 30 dB(A) for a spectrum ranging from 50 to 5000 Hz; the noise was continued for 3 minutes at each level, and raised successively by 5 dB steps until the sleeper awoke, when the noise-emitting apparatus automatically cut out. His results showed that 52% of the subjects were awake when a level of 45 dB(A) was reached; that sensitivity to noise varied widely with the individual, some subjects waking at 35 dB(A) others not until 70 dB(A); that people under 30 and elderly people are more readily awakened by noise than middle-aged people; and that manual workers are more susceptible to noise awakening than intellectual workers. The study concluded that the noise level in a bedroom should not exceed 35 dB(A).

Research^{142,212/} in the U.S.S.R led to these results: when continuous noise is at a level of 50 dB(A), falling asleep is a lengthy process (one and a half hours) and the intervals of deep sleep are fairly short (one hour), followed upon waking, by a sense of fatigue accompanied by palpitations. At 40 dB(A), it took 30 to 40 minutes to get to sleep and there were longer periods of deep sleep, with no special feeling of tiredness upon waking. The level of 35 dB(A) can be considered as the threshold for optimum sleeping conditions, since at this level it takes only 20 minutes to fall asleep and the period of deep sleep lasts from two to two and a half hours.

The Center of Applied Physiology of the Faculty of Medicine at the University of Strasbourg has conducted laboratory studies of sleep disturbance by traffic noise.^{129,220,233/} Observations were made of the electroencephalograms, the electrocardiograms,

the muscular electrical potentials, the eye movements and the body movements of nine young college-age men under three sets of noise stimuli: a control condition with no traffic (median level = 48 dB(A)); continuous noise of heavy traffic (median = 70 dB(A)); and continuous noise of light traffic (median = 61 dB(A)). The latter condition caused the greatest sleep disturbance, approximately doubling both the time required to get to sleep (11.9 to 29.1 min.) and the time before the onset of deep sleep (32.6 to 52.0 min.) despite the fact that the median level of this noise exposure is 9 dB less than for the heavy traffic stimulus. The heavy-traffic stimulus, by contrast, was hardly distinguishable from the no-traffic control condition. It appears that the explanation is to be found in the very different characteristics of the peak-to-background noise levels in the two cases. The results suggest that an increase in the number of noise peaks increases the time to fall asleep, even if the average noise level is lowered. This may explain why the Russian subjects needed $1\frac{1}{2}$ hours to get to sleep in 50 dB(A) noise (of unspecified spectrum and time pattern) while the French students needed only 12 minutes in 70 dB(A) heavy truck noise.

Lukas and his associates at the Stanford Research Institute^{215/} are studying the effects of simulated jet aircraft flyover noise and sonic booms on human sleep. In one study the subjects were college-age males; in a second study, still being analyzed, both males and females were used as subjects and the age span was from 7 to 72 years. The tentative conclusions are that older people are much more susceptible to sleep disturbance by such noises than the younger people; the older people were awakened by about 70% of the booms (0.63 to 1.25 psf) and by about 55% of the jet aircraft flyovers (103 to 107 PNdB)*; in a typical house people

*90 to 94 dB(A)

under about 50 years of age are more likely to be awakened respectively, 25% vs 3% ... by jet noise (100 to 113 PNdB * measured outdoors) than by sonic booms (0.7 to 2.5 psf, measured outdoors); at least as far as the college students were concerned, they were able to adapt only to sonic booms of low intensity (about 0.7 psf) and even then only in sleep stage 2 (one of the plateaus preceding and following deep sleep and REM (Rapid Eye Movement or dreaming sleep)).

Jansen's studies^{193/} indicate that noise of modest intensity (55 to 70 dB white noise) influences the deepest stage of sleep of subjects exposed to stimuli having durations between 300 msec. and 90 min. As for quantifying these findings, however, although seven persons were studied for more than 120 nights, the study was unable to establish the sound level for white noise that consistently led to sleep interference.

3. Physiological Effects^{257,262/}

a) Immediate Effects

Several immediate physiological effects appear from exposure to noise levels comparable to those of urban traffic. Lang and Jansen^{193,212/} conclude from a survey of various researches that noise results in increasing sympatico-tonic reactions in the human body. Dilation of pupils is a common noise reaction and can be shown to be linked to sound intensity, rather than being simply the initial effects of fear or pain; this is due to the somatic influence of noise, apart from its psychic effects. Mery^{218/} has also summarized psychological and physiological effects of noise, with similar conclusions.

*87 to 100 dB(A).

Temporary threshold shift (TTS) in acuity of hearing varies considerably with the individual and the length and intensity of exposure to noise. Exposure need not be severe -- a 12-hour drive in an automobile or 45 minutes with a power lawnmower can produce a detectable loss in acuity for many people.^{271/} It is not yet clear that the normal (although high) urban noise levels could produce TTS; however, only a little is actually known of the possible effects of such noise levels.

An unexpected noise elicits startle or fright reactions. Physiological changes, such as a decrease in peristaltic contractions and a flow of saliva and gastric juices or a rise in intracranial pressure, have been recorded following sharp loud reports or unexpected noises.^{171,193/} When the noises cease, these internal physiological changes subside. However, as Broadbent suggests^{62/}, such widespread physiological responses may be expected to interfere with other activities at the time the sound occurs. Also, too frequent an occurrence of such changes might be detrimental to health.

b) Cumulative Effects*

i. Hastening of presbycusis

One possible important -- but as yet unproven -- effect of traffic noise concerns the hastening of age-induced hearing loss (presbycusis). The quality of the noise environment, as perceived by the individual, is degraded. However, since such hearing losses progress slowly, this effect of urban noise is probably the least apparent, even to the affected person. He continually adjusts to the way things sound --- and thus rarely notices the change. Recall in this connection the studies --- mentioned earlier in Chapter II, page 12 --- of the Mabaan tribe in

* See note, page 127.

Southeast Sudan and the Todas in India, who in the absence of noise exposure at levels comparable to those in our industrialized cities show hardly any evidence of presbycusis and have much lower incidence of heart disease.

ii) Sustained Sleep Interference

People are especially annoyed by noise if it interrupts or prevents their sleep. For most people, lack of sleep, even for a single night, usually causes some grouchiness and may lead to the need for a midday nap. But since urban noise is becoming practically continuous, the city dweller finds that it is taking him longer to get to sleep, that his sleep is disturbed or interrupted nearly every night, and that he still feels tired when he awakes in the morning. It is likely that, without his knowing it, he is changing his sleep habits: he probably has fewer and shorter periods of deep sleep and fewer dreams.^{142/}

It is well established that sleep, a complete withdrawal from the stimuli of the world around us, is essential for physical and emotional health. It is probable that the cumulative physiological effect of a lack of adequate deep sleep is damaging to most people.^{178/}

To summarize the findings on the behavioral effects of noise, the average outdoor noise levels should not exceed 45 to 50 dBA for comfortable radio and TV listening with windows open (or 55 to 60 dBA with windows closed). To avoid sleep interference (not limited just to conscious awakening), the peak outdoor levels should not exceed 40 to 45 dBA, corresponding approximately to mean indoor levels of 35 to 40 dBA with windows open; with

ordinary windows closed, the outdoor levels may be permitted to increase to 50 or 55 dB(A). In addition, the peak-background noise structure is important, the more peaky pattern being the most likely to cause disturbance.

The studies of physiological effects of noise bear on the establishment of an acceptable living environment only by setting an absolute upper limit on tolerable noise exposure, of the order of 80 to 85 dB(A), measured outdoors.

4. Social Surveys Related to Noise Other Than from Aircraft

We now return to the results of several social surveys, made in connection with urban noise measurement programs, to see how the results discussed above, mainly from laboratory studies, are borne out in real life. And since these surveys were almost invariably undertaken to help establish criteria of acceptability for noise exposure of one kind or another, it will be further useful to compare the various criterion recommendations that grew out of the surveys. These results comprise the distillation of an enormous amount of measurement and research dealing with urban noise and its effects over the past two decades.

The earliest serious effort^{135/} to measure community noise was apparently begun in 1924 in New York City^{98/}; a review of this and other noise surveys during the next 25 years* is given by Hardy.^{60/}

* Despite well-circulated reports of steadily-increasing city noise levels, in New York City, at least in the period between 1952 and 1959, the levels actually decreased by 5 to 11^{135/} dB. The new HUD noise survey, currently in the planning stage for New York City, should be particularly interesting according to whether it confirms or denies the widely held view that New Yorkers have lost considerable ground in the battle against noise since 1959!

More recently, city noise surveys have been made in Dusseldorf^{217/}, Dortmund^{28/}, Tokyo^{95/}, Philadelphia^{20/}, Seattle^{127/}, Ottawa^{106/}, Manchester^{40/}, New York^{92,104/}, Madrid^{107/}, Calcutta^{108/}, Jassy (Rumania)^{179/}, Los Angeles^{144/}, Boston^{149/}, Brussels^{142/}, Oslo^{142/}, The Hague^{142/}, Delft^{142/} and Rotterdam^{142/}. These studies, however, attempted only to measure the existing noise in the respective cities, without assessing public reaction to it.*

Of greater immediate interest are the noise measurement surveys that were accompanied by efforts to determine how people react to their noise exposure.

a) England

Of these, the **earliest**, the best publicized and most influential was described in the Wilson Report^{100/}, dealing with noise from all sources in the vicinity of London. The researches reported by the Wilson Committee were very productive; they characterized London's noise more completely than had ever been attempted before, and led to the development of the Noise and Number Index^{100/} (NNI) for evaluating aircraft noise, to a British Standard^{219/} for rating industrial noise affecting mixed residential and industrial areas, and to an implied urban noise rating scheme. Without actually defining a rating index, the Report recommends that certain indoor noise levels^{**} in dB(A) should not be exceeded for more than 10% of the time^{123/}, (thus lending weight to the 10% A-Level as a useful measure of public acceptance of noise), as follows:

* We will ignore for the moment the programs concerned only to measure existing noise without correlating it with subjective response. These studies will be referred to later, when we consider the implications of acceptability criteria for present-day large cities.

** Living rooms and bedrooms.

TABLE VII

WILSON REPORT RECOMMENDATIONS FOR
MAXIMUM INDOOR NOISE LEVELS

SITUATION	LEVEL, L ₁₀	
	Day	Night
Country areas	40 dB(A)	30 dB(A)
Suburban areas away from main traffic routes	45 dB(A)	35 dB(A)
Busy urban areas	50 dB(A)	35 dB(A)

The Report also recommends levels that should not be exceeded outside the window of an occupied room nearest a temporary construction site: 70dB(A) for rural, suburban, urban areas away from main road traffic and industry; and 75 dB(A) for urban areas, near main roads and heavy industrial areas.

These recommendations were based largely on the noise measurement survey that defined London's noise exposure in 1961 in terms of a group of typical Noise Climate categories, as shown in Figure 11 (the Noise Climate is the range between the 10% and 90% A-Levels).

The Wilson recommendations for indoor noise, as given in Table VII above, have been criticized ^{86,130}(a) as being excessively severe, since many existing dwellings fail to meet the criteria by as much as 20dB; also the interior noise levels from domestic sources are likely to exceed the criterion levels; and it would require enormous set-backs from arterial roads to meet the requirements; (b) because they are expressed in terms (the 10% A-Level) that are not readily predictable; and (c) that the 10% A-Level has not been shown to be correlated with public acceptability. Moreover, since in many urban communities the 10% noise level outdoors remains nearly constant throughout the entire 24-hour day, this effectively sets the same indoor noise criterion for

both daytime and night-time. And finally, as it is difficult to know how the occupants will actually use their windows, a control criterion for urban noise defined in terms of the indoor noise levels is of doubtful significance.

The Wilson limits do seem strict, at first sight: an indoor A-Level of 35 dB not to be exceeded more than 10% of the time at night (i.e., these are the near-peak levels*) implies outdoor peak levels of about 40 dB(A) with windows open, or about 50 dB(A) with windows closed. In a sample of 350 (out of the total of 540) measurement locations in the London survey, only 1/3 would meet these requirements with the windows closed, and none at all would pass with windows open! However, this only points up the reason for the Wilson study, namely, the fact that cities have become so noisy.

In connection with noise problems in town planning, Purkis^{115/} remarks of the Noise Climate categories found in London by the Wilson study (Figure 11) that Noise Climates in the loudest two categories (A and B) would be intolerable to people living in most present-day building types; but it would be unreasonable to expect noise levels as low as the quietest two categories (F and G) in a densely packed urban area. As remarked above, even this last climate would not meet the Wilson indoor noise recommendation for rooms with open windows. Since these Noise Climates represent extremes separated by more than 20 dB, Purkis' proposes a middle course, to limit peak levels to, for example, $L_{10} = 65$ dB(A) by day and 55 dB(A) by night.

Langdon and Scholes^{86/} adopt a different approach to control of traffic noise, based on the Traffic Noise Index, developed in

* Median (L_{50}) and background (L_{90}) levels would be approximately 3 to 6, and 6 to 12 dB lower, respectively.

the course of a more recent traffic noise survey. They suggest that a noise level of 74 TNI represents a reasonable standard of amenity in today's urban conditions since, according to the noise measurements and social survey conducted by the (British) Building Research Station^{189/} in 1966 and 1967, at that exposure there would be only one chance in forty that more than half the population would be dissatisfied by the traffic noise environment.

Assuming a typical value, for the ($L_{10} - L_{90}$) term in the TNI formula, of 12 dB, an exposure of 74 TNI is roughly equivalent to $L_{90}=56$ dB(A), $L_{50}=62$ dB(A) and $L_{10}=68$ dB(A)*, levels slightly higher than recommended by Purkis, above, for either night or day. On the other hand, in the limit of a completely steady, unvarying noise exposure ($L_{10}=L_{50}=L_{90}$), the 74 TNI criterion permits a continuous noise exposure of 104 dB(A)! This would clearly be so intolerable as to suggest that the TNI has validity only within quite restricted limits.

Accepting Robinson's suggestion^{123/} that a reasonable criterion of acceptable noise exposure^{**} is expressed by a Noise Pollution Level of 72, then...again taking a typical value of ($L_{10}-L_{90}$) as 12 dB...we find corresponding values for the decile A-Levels as follows: $L_{90}=51.5$ dB(A), $L_{50}=57.5$ dB(A) and $L_{10}=63.5$ dB(A), values that are not too far out of line with the other recommendations above. Even for the unlikely "un-varying" case, the continuous noise exposure would be only 72 dB(A); this represents a noise exposure that is consistent with the present standards of HUD's noise abatement policy, that actually exists in a number of cities (see below), and that could be handled without extreme

* Since the TNI is reckoned on a traffic count over an entire 24-hour day, it is not clear how to break this down into day-time and night-time criteria.

**Less than 35% of the population annoyed.

LEGEND:

Noise Climate
Category

Location

- A Arterial Roads with many heavy vehicles and buses (curbside)
- B (i) Major roads with heavy traffic and buses
(ii) Side roads within 15-20 yds. of roads in group A or B(i) above
- C (i) Main Residential roads
(ii) Side roads within 20-50 yds. of heavy traffic routes
(iii) Courtyards of apartment houses screened from direct view of heavy traffic
- D Residential roads with local traffic only
- E (i) Minor roads
(ii) Gardens of houses with traffic routes more than 100 yds. distant
- F Parks, courtyards, gardens in residential areas well away from traffic routes
- G Places of few local noises and only very distant traffic noise

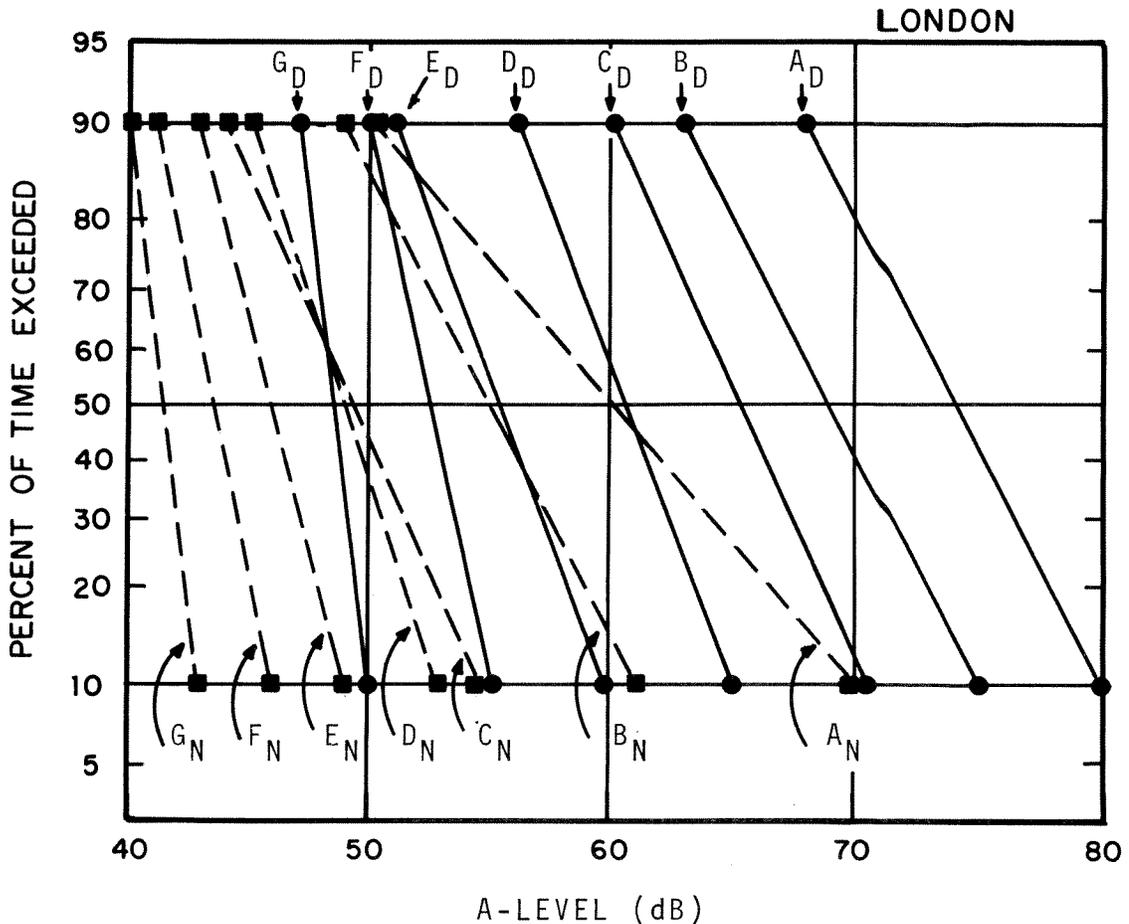


FIG. 11 URBAN NOISE CLIMATES BY CATEGORY; LONDON, 1961; (DAYTIME (D) AND NIGHT-TIME (N)) REF. 100, CHAPT. IV, TABLE III, p. 23.

sound isolation measures in the building.

All these values would, of course, be somewhat differently related to one another if we were to assume different typical values for $(L_{10} - L_{90})$; Table VIII shows how the actual levels would change, as differences in traffic mix change the value of $(L_{10} - L_{90})$, all the while meeting the TNI and NPL criteria mentioned above. For typical values of $(L_{10} - L_{90})$,....that is, 8-14 dB....the NPL criterion holds the noise levels to more tolerable values than the TNI.

Another comparison of the TNI and the NPL is given in Figure 12, where results calculated from the traffic noise data of Lamure and Auzou^{82/} are plotted to show how these two ratings change with increasing traffic volume flow. It is somewhat disturbing (and even rather implausible) to find the TNI falling off significantly as the traffic density increases up to 5000 vehicles per hour, at which point the average A-Levels have risen to 80 dB with L_{10} peaks of 85 dB! The implications of the NPL rating seem more reasonable, namely, that the decreasing variability of the noise of heavier traffic just about makes up for the slightly increased absolute noise levels.*

b) Sweden

In a Swedish survey^{256/} in 1966-67, when the 24-hour average A-Level outside the windows of dwellings exceeded 55 dB(A), more than 20% of the people reported a high degree of annoyance. Since, however, the noise levels at the windows were not actually measured there, but were calculated from measurements made quite near the roadway, it may be that the actual level to which the residents were exposed were somewhat higher, including various outdoor noises other than road traffic. It is also notable

* In response to a similar question, however, Scholes has reasserted his trust in the implications of the TNI^{276/}.

Table VIII
Effect on Noise Climate as the Noise Variability Changes,
Always, However, Satisfying the TNI and NPL Criteria

$d = (L_{10} - L_{90})$	TNI = 74			NPL = 72		
	L_{10}	L_{50}	L_{90}	L_{10}	L_{50}	L_{90}
16	56	48	40	59.5	51.5	43.5
14	62	55	48	61.5	54.5	47.5
12	68	62	56	63.5	57.5	51.5
10	74	69	64	65.3	60.3	55.3
8	80	76	72	67	63	59
6	86	83	80	68.4	65.4	62.4
4	92	90	88	69.7	67.7	65.7
2	98	97	96	71	70	69
0	104	104	104	72	72	72
$TNI = 4d + L_{90} - 30 = 74;$ $L_{90} = 104 - 4d;$ $L_{50} = L_{90} + d/2;$ $L_{10} = L_{90} + d;$			$NPL = L_{50} + d + d^2/57 = 72;$ $L_{50} = 72 - (d + d^2/57);$ $L_{90} = L_{50} - d/2;$ $L_{10} = L_{50} + d/2;$			

94

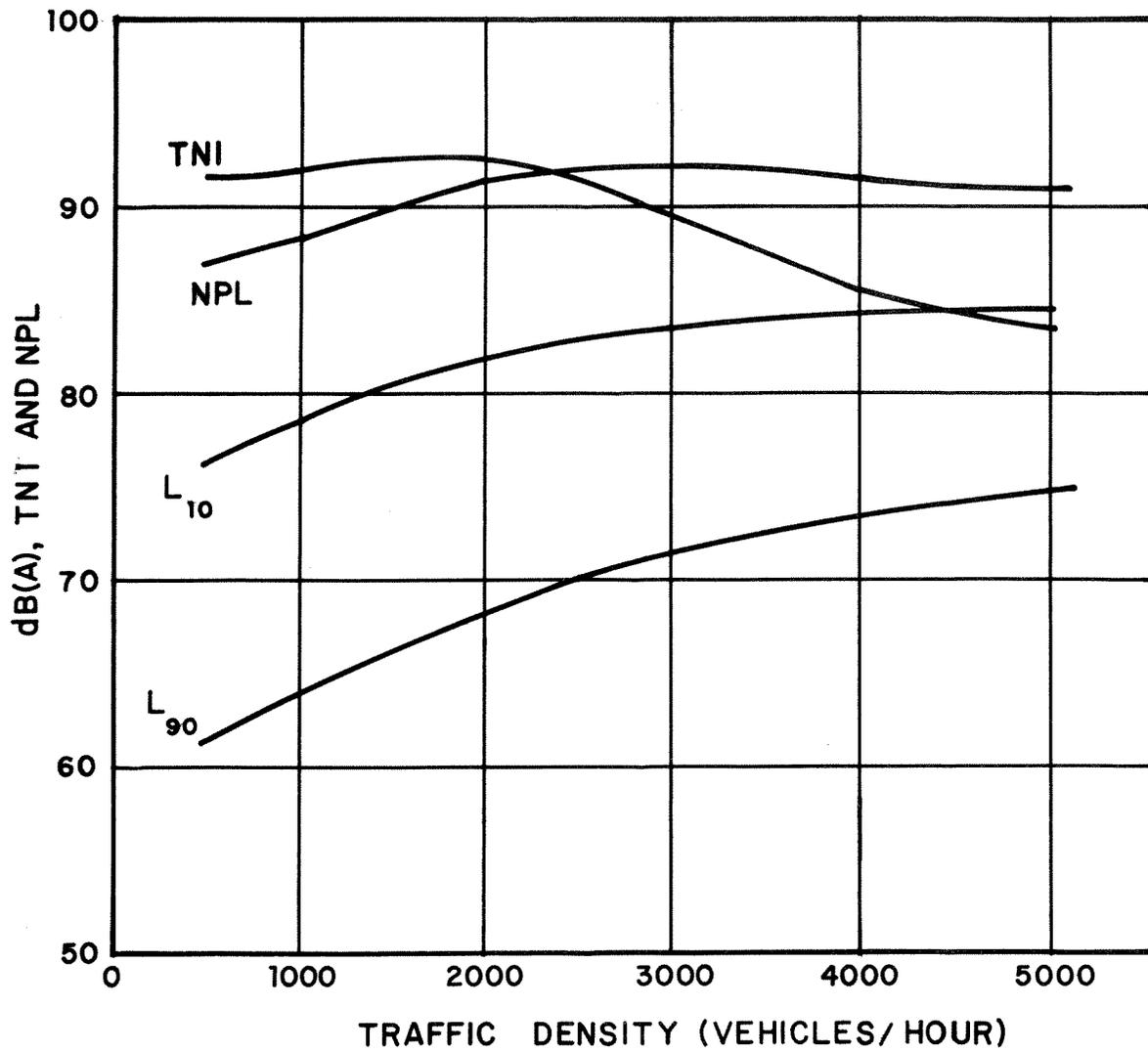


FIG. 12 COMPARISON OF TNI AND NPL AS A FUNCTION OF TRAFFIC VOLUME FLOW, CALCULATED FROM THE DATA OF REF. 83 FIGURE 17.

that this survey is one of the few that achieved good correlation between measured noise data and people's subjective response without having to take into account the variability of the noise: Robinson^{123/} suggests, however, that this may be because there was very little difference in the noise variability at the various sites evaluated.

c) Austria

The work of Bruckmayer and Lang^{23-27/} was carried out in Vienna between 1964 and 1968, on the disturbance due to noise in dwellings, offices and in schoolrooms. For the purpose of characterizing the noise exposure, they adapted the German^{79/} rating, \bar{Q} , developed for evaluating aircraft noise. (see Section III-C above). In their studies, the rating took the form

$$\bar{Q} = 13.3 \log \frac{1}{100} \sum 10^{Q_i/13.3} \times f_i$$

where Q_i is the A-Level defining each class in the statistical distribution of observed noise levels (as in the histogram of Figure 8 above), and f_i is the probability of finding the noise level in the i th class.

Measurements were made of the traffic noise as heard 1.5m inside the room with open window, and these data were compared with the results of interviews with the residents or users of the various spaces tested.

Since the \bar{Q} rating explicitly includes the fluctuation of the noise exposure (like the Noise Pollution Level and the Traffic Noise Index) one can make a direct comparison among these ratings, and with the decile values for A-Level, only for a particular time pattern of noise. Lang^{259/} has observed, however, that

during the daytime hours (0600 to 1800) their data show the following approximation to hold:

$$\bar{Q} = L_m + 2 \pm 1 \text{ dB(A)}$$

while during the evening and night-time the approximation is:

$$\bar{Q} = L_m + 6 \pm 3 \text{ dB(A)}$$

where L_m is the average value of the level distribution, often nearly equal to L_{50} .

With these approximate equivalences, we can evaluate the social results of the Viennese surveys (which dealt with road traffic, railroad noise and aircraft noise) for residences, as shown in Table IX.* (Approximate values for L_{50} are shown in the table (different for night and daytime) according to the formulas given just above.) For example, with windows open in the daytime, for exposures of $\bar{Q} = 35-40$, 100% of the people questioned were not at all or only slightly annoyed, whereas at exposures of $\bar{Q} = 45-50$, 55% were either annoyed or extremely annoyed: for the same exposures at night, 46% were annoyed or highly annoyed at the 35-40 dB(A) exposure, compared with 82% for the 45-50 dB(A) exposure. Note, also, that an exposure of $\bar{Q} = 35-40$ dB(A) seriously annoys no one during the day with windows open; the same exposure observed indoors with windows closed makes 49% of the people either annoyed or extremely annoyed. In this survey, as in others, we find some people annoyed in the quietest of noise

* Griffiths and Langdon^{89/} calculated values of \bar{Q} for their London Traffic noise survey data and concluded that \bar{Q} evaluates the corresponding social survey data marginally less well than their TNI.

exposures, while a few are apparently unperturbed even in the highest noise levels.

Similar results were obtained for measurements in offices, as well as for schoolrooms, with the slight difference that in the schoolrooms the transition from no annoyance to severe annoyance occurred at slightly higher noise levels but much more abruptly than in offices and dwellings.

These results, indicating that for people to sleep undisturbed at night with open windows, the \bar{Q} should not exceed about 35 dB(A) corresponding to $L_{50} = 29$ dB(A) are consistent with the recommendations of the Wilson report that L_{10} should be about 35 dB(A) in urban areas.

Bruckmayer^{25/} has also adapted the same collection of survey data to derive curves of recommended noise exposure for use in urban zoning; the noise levels measured inside rooms with open window were converted to recommended maximum acceptable outdoor levels by the addition of 5 dB, a value that represents rounding off of the actually-measured difference of 7 dB between indoors and outdoors with one open window. These zoning curves are shown in Figures 13 and 14; the types of area for which they are recommended are shown in Table X.

So far, however, these recommendations have not been officially adopted in Austria; instead there are proposed limits for urban noise as follows: For quiet residential or rural districts, 25 phons (approximately equivalent to dB(A)) by day and 15 phons by night; in busy urban areas, 35 phons by day, 25 by night; and in industrial areas, 40 phons by day and 30 by night. Since

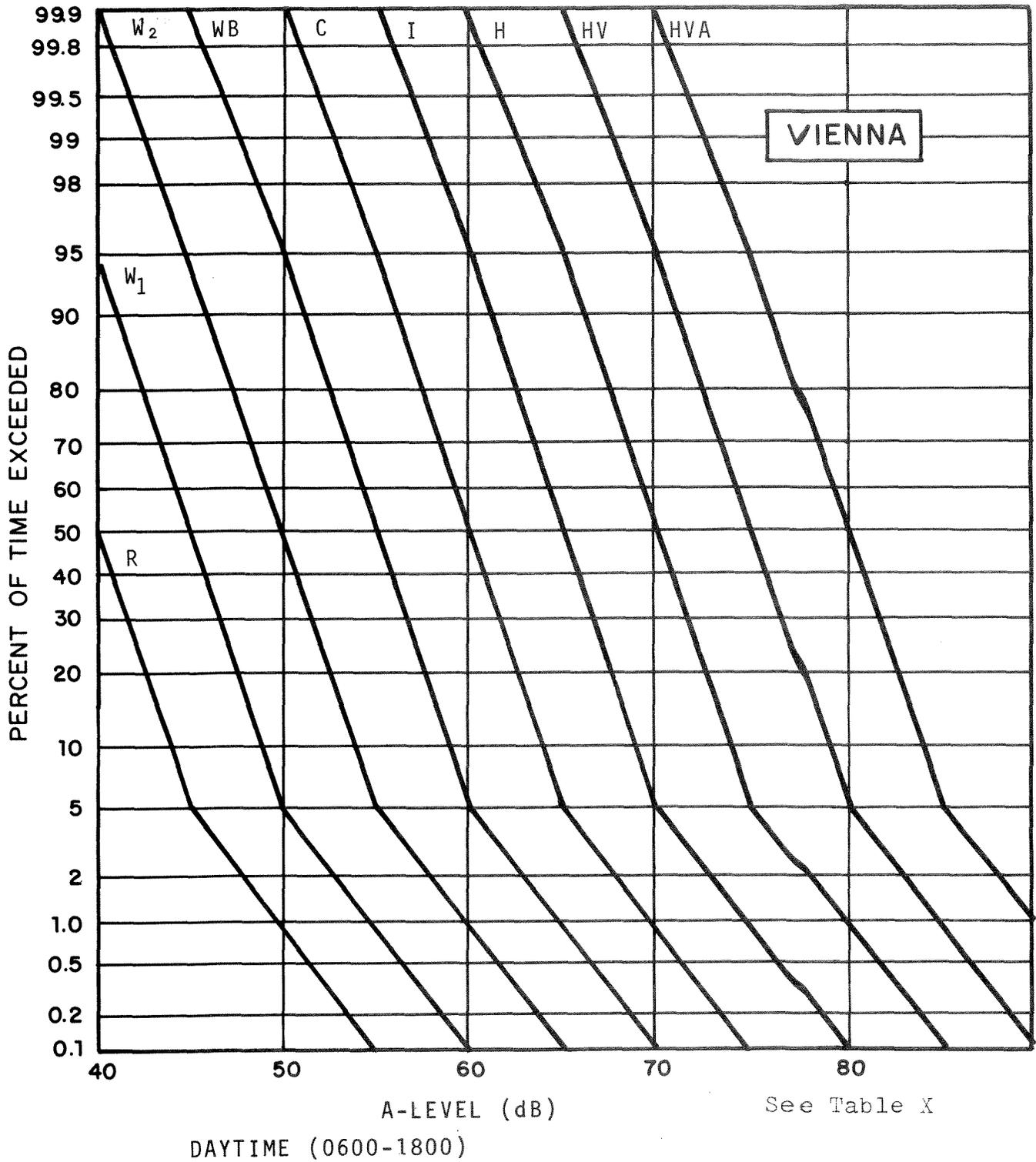


FIG.13 RECOMMENDED DAYTIME CRITERIA:
VIENNA, 1965. (REF. 25)

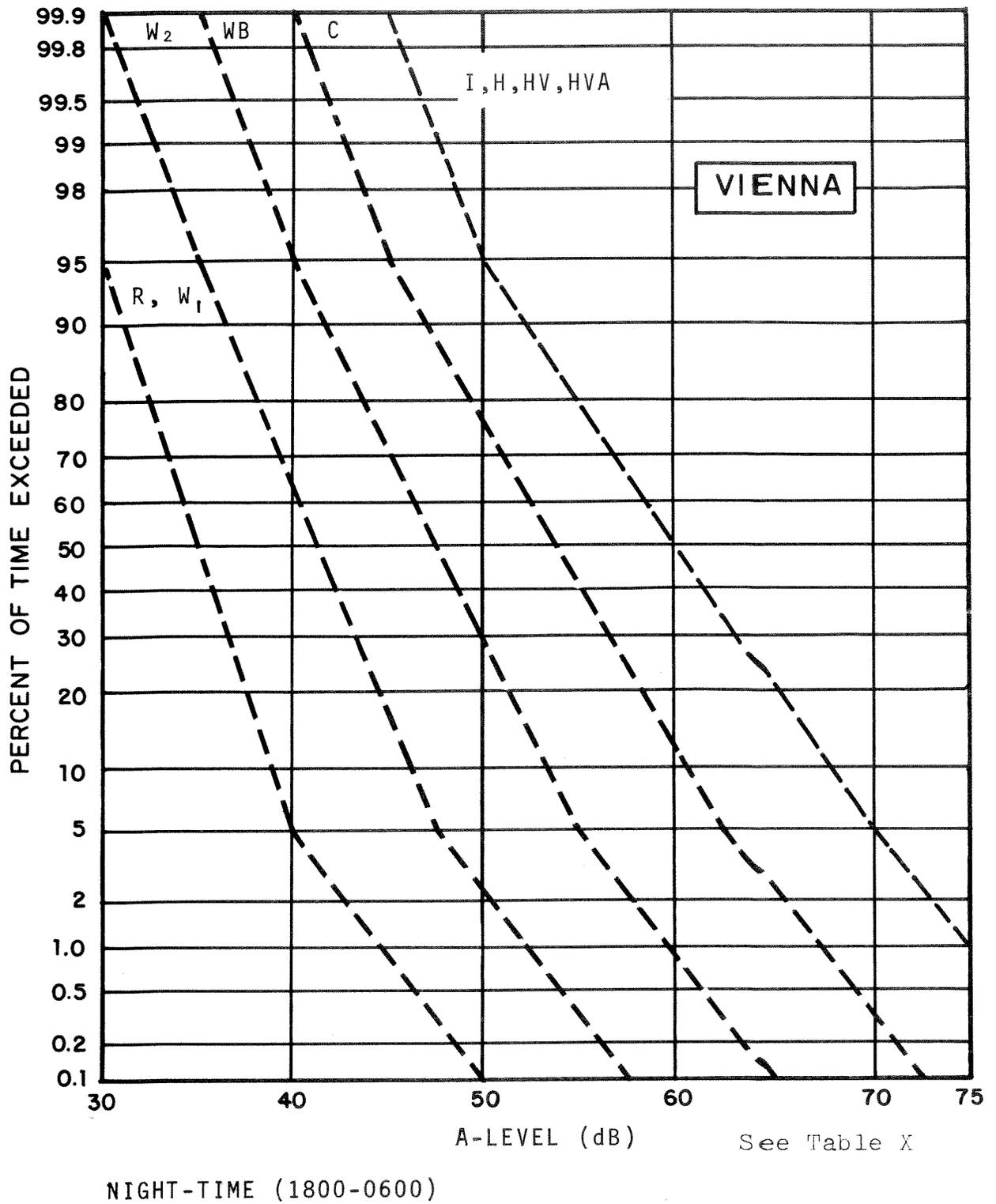


FIG.14 RECOMMENDED NIGHT-TIME CRITERIA:
VIENNA, 1965. (REF. 25)

Table X

Kinds of Areas for which the Limit Curves of Figs 13 & 14 are Recommended

Limit Curve	Suitable for:	Characteristic Utilization of Area and the Traffic Conditions
R	Rest	Hospitals, traffic restricted
W ₁	Quiet dwellings	Residences, light traffic
W ₂	Moderately quiet dwellings	Residences, moderate traffic
WB	Dwellings and offices	Residences mixed in with offices and shops, considerable traffic
C	City	Office and shop area in center of city, considerable commercial traffic
I	Industry	Industrial area, considerable heavy truck traffic
H	Main streets	Street/highway, considerable local traffic
HV	Major highways	Street/highway, considerable through-traffic
HVA	Major expressways	Street/highway, faster and heavier through-traffic

these are recommended background levels, presumably about L_{90} , we would expect the 10% levels to be 10 to 14 dB higher.

d) France

At the request of the Paris District authorities and the Ministry of Equipment, the Scientific and Technical Center for the Building Industry (CSTB) carried out a survey^{3,73,82,83/} in 1965 among people living alongside the southern expressway and the ring expressway in Paris; 420 families were interviewed and the 50% A-Levels were measured outside their dwellings. The dwellings ranged from 10 to 150 meters distant from the expressways and the measured noise levels ranged from 53 to 81 dB(A). From their survey results, the CSTB concluded that a critical (>25% annoyed) level is attained when the noise exposure reaches $L_{50} = 60-65$ dB(A) just outside the buildings.^{82/} Another, much more extensive, survey has just been completed in France (the results were supposed to be available at the end of July 1970); measurements were made at 100 points throughout Paris, representing a wide variety of streets and roads, twenty people being interviewed at each location.

e) The Netherlands

In 1955 in the Netherlands, the Institute of Public Health Engineering of the T. N. O.* conducted a survey concerning the annoyance due to noise in 1400 apartments in Rotterdam and the Hague (summarized in Ref. 142, p. 31). The chief goal of the surveys was to evaluate isolation between spaces inside the buildings, but enough data were taken on noises from outdoors to conclude that 61% of the tenants heard and 25% were annoyed by traffic noise. Measured noise data corresponding to these

* Toegepast Natuurwetenschappelijk Onderzoek, the Dutch Institute for Applied Scientific Research at Delft.

judgements are not available.

f) Intranational Differences

In citing data from studies made in various countries to determine the noise exposure that people will find acceptable, it is tacitly assumed that people in different countries are basically similar, and that the acceptability criteria determined for one country may be applied with reasonable confidence in another. Indeed, if no surveys have been carried out in ones own country, there is little choice in the matter: one accepts what guidance is available.

A single study has been conducted, so far, to investigate directly national differences in tolerance for urban noise. Comparative surveys of annoyance reactions to traffic noise were conducted both in Stockholm and Ferrara in 1967¹⁹⁴/. Many precautions were taken to insure that the questionnaires (drawn up by expert linguists) and the noise measurement procedures would be comparable in the two cases. In both cities measurements were made inside apartment dwellings, (mostly at the first floor level) both with windows open and closed, with nearly identical traffic conditions and densities (about 8000 vehicles/24 hours) roadwidths and building layouts. The sample populations to be interviewed were similarly selected from the sociological standpoint (200 people in Stockholm, 166 in Ferrara), using identical criteria of sex, age, family situation and social and occupational groups.

The mean A-Levels were found to be higher in Ferrara than in Stockholm, but the attenuation provided by the windows was higher in Stockholm:

TABLE XI. MEAN A-LEVELS MEASURED IN STOCKHOLM AND FERRARA, 1967

<u>City</u>	<u>Windows Closed</u>	<u>Windows Open</u>	<u>Open vs Closed Difference</u>
Stockholm	44.7	59.9	15.2
Ferrara	52.7	65.3	12.6
Difference	8.0	5.4	2.6

However, in spite of their milder noise exposure, a higher percentage of Stockholm interviewees were annoyed with the noise than in Ferrara:

TABLE XII. PUBLIC RESPONSE TO NOISE IN STOCKHOLM AND FERRARA, 1967

	<u>Stockholm</u>	<u>Ferrara</u>
Respondents spontaneously mentioning traffic noise	92%	63%
Respondents disturbed by traffic noise	61%	49%

On the other hand, the Italians seem to have "shorter steps" on their scale of tolerance than the Swedes: the transition from no annoyance to much annoyance occurs abruptly in Italy.*

These observations warn us that if we must rely on data from other countries to help us formulate interim criteria for noise abatement, we should proceed with caution and, as much as possible, trust only those results that are in reasonable agreement from one country to another. The most desirable

* Robinson^{23/} remarks, "From the detached vantage point of an Anglo-Saxon (he) would have guessed these results correctly without the aid of an experiment." Grandjean^{188/} has called attention to a similar, though not as marked disparity in the results of the British and French studies of public response to aircraft noise: the British are somewhat more critical of noise than the French (See Section III-D-8-h, below).

procedure, no doubt, is to use criteria developed in ones own country.

g) United States

Unfortunately, no wide surveys combining urban traffic noise measurement and evaluative questionnaires have been conducted in the U. S; the situation is somewhat better with respect to aircraft noise.

Lacking wide-scale noise/social surveys in the U. S., we have had to rely on an accumulation of "case histories" to evaluate probable public response to noise exposure.^{87,232,236/} The earliest attempt to organize such information was the 1953 report^{232/} in which staff members of Bolt Beranek and Newman organized their community noise experience over the previous five years to develop the Composite Noise Rating, CNR, (described above in Section III-A-3-k and in more detail in Ref. 87, pp. 51-68); a very similar scheme has been adopted in Europe and proposed as an international standard^{224/} for the assessment of community noise.

Since the CNR rating procedure explicitly includes considerations of the character of the neighborhood where the new noise intrudes, as well as the existing background noise from other sources, it is not possible to make a strict comparison between the CNR and the measures of noise exposure discussed above. Nevertheless, if we make "neutral" choices for those factors for which corrections are to be made to the basic CNR noise exposure (e.g., continuous operation, no pure tones, non-impulsive, familiar type of sound in neighborhood), then we can say that, for summertime night-time conditions, one would expect no more than a few spontaneous complaints about the new noise if the A-Level were

around 49 dB; and this is a rather permissive criterion, compared to the European evaluations of urban traffic noise.* However, it should be recalled that by the time spontaneous complaints have started to arise, the public annoyance is probably already severe.

An evaluation more pertinent to our present purpose can be derived from the background noise level that is assumed in the CNR to be "normal," that is, for which no correction is required; this background is equivalent to an A-Level of 40 dB, more nearly in line with the other results. (Similar conclusions may be derived from the proposed ISO rating procedure²²⁴).

A recent recommendation⁵⁴ to the U. S. Highway Research Board for a design goal pertaining to the introduction of new highway noise into a community is based partly on case histories and partly on theory; the permissible noise exposure is expressed by the formula:

$$L_{A50} \leq Y_0 + 1.28 \sqrt{\sigma_x^2 + \sigma_y^2}$$

where L_{A50} is the 50% A-Level of the new intruding noise; Y_0 is the 50% A-Level of the existing ambient noise; and σ_x and σ_y are, respectively, the standard deviations for the statistical distributions of the new traffic noise and the existing ambient noise; $\sigma = (L_{10} - L_{90})/2.56$.

Converting this formula to the terms in which we have been dealing,

* Recall Thiessen's results (see p.82): truck passages at about this level wakened some of his subjects 50% of the time; more than half of Steinecke's subjects wakened by the time the A-Level reached 45 dB.

that is, $d = (L_{10} - L_{90})$, this criterion becomes:

$$L_{50_{\text{traffic}}} \leq L_{50_{\text{ambient}}} + \frac{1}{2} \sqrt{d_{\text{tr.}}^2 + d_{\text{amb}}^2} ;$$

The greater the variability of either the old or new noise the more the new noise is permitted to intrude.

When the quantity $(L_{10} - L_{90})$ is about the same for both the new and the existing noise exposures, we have

$$L_{50_{\text{traffic}}} \leq L_{50_{\text{ambient}}} + 0.7 (L_{10} - L_{90})$$

If $(L_{10} - L_{90}) = 10$ dB, the average A-Level of the new noise is permitted to exceed the old average level by 7 dB; or, if $(L_{10} - L_{90}) = 13$ dB, which is not at all unusual, the new average noise level may exceed the old average level by 9 dB.

In any case, according to this recommended criterion, the new noise would be audible above the old background noise for 90% of the time; and the new peak levels of traffic noise would be more than 10 dB higher than the old background level for almost half the time!

This recommended criterion is thus exceedingly permissive and will do little to halt the encroachment of highway noise upon the urban environment. Fortunately, the table in that same report that interprets the design goal formula for specific

kinds of buildings (and that most designers will refer to, in preference to the formula) appears to be a good deal more reasonable in its recommendations (all A-Levels):

TABLE XIII. RECOMMENDATIONS TO U.S. HIGHWAY RESEARCH BOARD FOR MAXIMUM NOISE LEVELS^{54/}

		L ₅₀		L ₁₀	
		Day	Night	Day	Night
Residences	Inside	45	40	51	46
	Outside	50	45	56	51
Hospitals Convalescent Homes	Inside	40	35	46	41
	Outside	50	45	56	51
Hotels, Motels	Inside	50	45	56	51

One brief U. S. survey may be mentioned in this connection: in 1968, the Bureau of Public Roads, Washington, interviewed patients in hospital rooms and correlated their responses with measurements made of the noise levels in the rooms. (The results are cited in Ref. 142, p. 28). It was found that patients are not much disturbed by A-Levels below 52 dB, but considerably annoyed at indoor levels above 60 dB(A).

5. Existing Legislation and Recommendations

Another useful approach to the problem of setting criteria of acceptability for noise exposure is to look at what other countries, states or agencies have recommended as noise limits. Some of this information has already been introduced in the preceding section in connection with the conclusions drawn from noise/social surveys, particularly in Austria and England. Other material is presented here.

a) West Germany

Noise levels in front of building should not exceed the following values $\frac{21,44}{}$ / (thus, these presumably represent approximately L_{10}):

<u>Zone</u> *	<u>Day</u>	<u>Night</u>
Purely residential	50 dB(A)	35 dB(A)
Mixed residential	60 dB(A)	45 dB(A)

(Cited in Ref. 142, p. 63; it is not clear whether this regulation applies throughout West Germany or only in the state of Baden-Württemberg).

b) Sweden

The Swedish national government lays down, for use in building by-laws, maximum tolerable noise levels in various normally furnished rooms, as follows:

<u>Type of Room</u> *	<u>In particularly noisy district</u>	<u>In particularly quiet district</u>
Living room	40 dB(A)	30 dB(A)
Hospital room	25 dB(A)	25 dB(A)
Workroom on business or office premises	45 dB(A)	35 dB(A)
Schoolroom	40 dB(A)	30 dB(A)
Hotel (or guest) room	40 dB(A)	30 dB(A)

The noise measurements are to be made in the center of the room with windows and doors closed. (Cited in Ref. 142, p. 67).

* There are others not relevant to HUD's operating programs.

c) Scandinavia

In 1967, the Nordiske Komite för Byggningsbestemmelser, abbreviated NKB (the Nordic Committee for Building Regulations, which affects Sweden, Norway and Denmark) presented a report "Stoj og Byplan" ("Noise and City Planning"), containing guidelines for evaluating and controlling traffic noise. Though these recommended standards are not mandatory, they are widely accepted in Scandinavia for urban planning, highway construction and building design.

The Committee has recommended as the maximum permissible noise exposure from road traffic an A-Level L_{50} of 59 dB (the average over a 24 hour period) measured immediately in front of the dwelling. This corresponds to an indoor L_{50} level of 35 dB(A), since double-glazed windows (customary throughout Scandinavia for reasons of thermal insulation) offer a sound attenuation of about 24 dB. The Committee indicates that even lower levels from road traffic would be desirable, to permit acceptably low indoor noise levels with the windows open; but the committee also admits that this would entail such large set-backs from the road as to be economically unfeasible. As it is, there are recommendations, more or less respected, requiring distances between a motorway and the nearest dwelling ranging from 30 to 100 meters.

d) Switzerland

The recently adopted Recommendations for Noise Abatement in Dwellings^{42/} specifies maximum permissible indoor noise levels, both from in-house equipment, such as ventilating systems and from outside intrusive noise. Mechanical equipment noise is limited basically as follows though, limits are also placed on noise from individual fixtures, such as toilets, washing

machines, pumps, etc.:

Bedrooms	30-40 dB(A)
Studies	50-70 dB(A)

The higher values in the ranges given above pertain to noisy city areas, the lower values to quiet suburban sites. The sound levels are to be measured with closed windows in locations in the rooms ordinarily occupied by people.

Limits on noise coming from outside the dwelling are as follows, measured at an open window (A-Levels):

<u>Zone</u>	<u>Background Noise</u>		<u>Frequent Peaks</u>		<u>Highest Peaks</u>	
	<u>Night</u>	<u>Day</u>	<u>Night</u>	<u>Day</u>	<u>Night</u>	<u>Day</u>
Hospitals and Convalescent homes	35	45	45	50	55	55
Suburban residential	45	55	55	65	65	70
Mixed residential	45	60	55	70	65	75
Business	50	60	60	70	65	75
Industry	55	65	60	75	70	80
Through traffic and Expressway areas	60	70	70	80	80	90

The levels in the table above are described as maximum tolerable limits; desirable levels are 10 dB lower, except that there is no reason to insist on levels below 30 dB(A). The "Background Noise" in the table is understood to be the 50% level, the time average over an unspecified, but presumably rather long, period. The "frequent peaks" are the levels that occur 7 to 60 times per hour; the "infrequent" or "highest" peaks are those that occur only 1 to 6 times per hour. Night-time is from 2200 to 0630.

Temporary construction noise from building sites is permitted to exceed the values given in the table above as follows:

By 5 dB for 20% of the time
" 10 " " 5 " " "
" 15 " " 1 " " "

If the levels in the table are exceeded, the authorities must, if requested, take all legal and practical measures to reduce the noise.

e) U.S.S.R.

Very little detailed information is forthcoming from Russia, but Ref. 142 states, "In domestic buildings the admissible limit for intruding noise is 30 dB by day and 25 dB by night in the 100-cycle band. There are also limits (not given) [sic!] for other octave bands. Levels are reduced by 5 dB for intermittent or thumping noise. The octave levels for the limit of penetrating noise correspond roughly to 35 dB(A) by day and 30 dB(A) by night."

f) Japan

Again, information on noise limits is incomplete. Ref. 142 reports the following specified maximum A-Levels (presumably average) for the City of Tokyo, with no explanation of why no limits are set for night-time noise:

<u>Zone</u>	<u>0800-1900</u>	<u>0600-0800 & 1900-2300</u>
(1) Exclusively residential and school district	50 dB(A)	45 dB(A)
(2) Residential green belt	55	50
(3) Commercial, semi-industrial and industrial districts	60	55
(4) Same as (3) but within 10 meters of road more than 11 meters wide	65	60
(5) Designated area in center of city and within 10 meters of road more than 18 meters wide	70	65

Though it is not stated, these are presumably outdoor noise levels.

g) United States

Although there are as yet no federal restrictions on outdoor noise levels, many communities have regulations. Most nuisance laws, worded qualitatively and directed at specific noise sources; they have turned out in practice to be unenforceable for the most part 55,76,77,81,175,181/ (a remarkable exception is the City of Memphis, which though it has no quantitative noise limits, has, by dint of an enthusiastic and persistent civic effort, won a reputation as the quietest city in the United States).

The City of Coral Gables, a quiet suburb of Miami, has reacted to the enormous increase in the number of home air-conditioners in use there, by enacting an ordinance restricting the noise from this source 10/ to a value of about 36 dB(A) at an indoor point of

complaint, or 5 dB higher if the complainant requests that a measurement be made out of doors. The Air-Conditioning and Refrigeration Institute regards this limit as too restrictive, and suggests 60 dB(A) as an attainable alternative. (Such a level has, indeed, been set by Etobicoke township, a suburb of Toronto). However, if everyone owned an air-conditioner just meeting this alternate criterion, it would constitute a real degradation of the environment, since the whole neighborhood would then be exposed to 60 dB(A) continuously.^{21/}

Other cities have zoning laws according to which noise from fixed installations (meaning mostly industry) is limited to certain levels measured at the boundary of the property or of the zone; in all cases, noise from transportation is exempt from the restrictions, as being impractical to control. Some of the quantitative anti-noise ordinances are given below (pp. 113-122). (Ref. 63 quotes the ordinances at much greater length).

A number of these zoning noise limits are plotted as curves of sound pressure level vs. frequency in Figure 15; the NC-30 and NC-50 criterion curves are also shown for comparison. The A-Level equivalent of most of the noise limits are indicated, and are plotted in Figure 16 for ready intercomparison.

It is clear from a consideration of the data cited above (pp. 88-112 and Figs. 11-16), that HUD's current criteria* for acceptable traffic noise exposure at a housing site are exceptionally lenient, both in terms of percentage of population shown to be extremely annoyed when outdoor mean levels rise to 60-65 dB(A), and in comparison with the criteria recommended in other countries. The current Policy Circular standards may keep the present dwelling noise exposures from getting much more severe, but they cannot be expected to achieve really acceptable living environments. It will be seen (pp. 136-140) that the same is true for the aircraft noise criteria.

* As stated in the Noise Abatement Policy Circular, 1390.2, 16 July 1971; see also Figure 28.

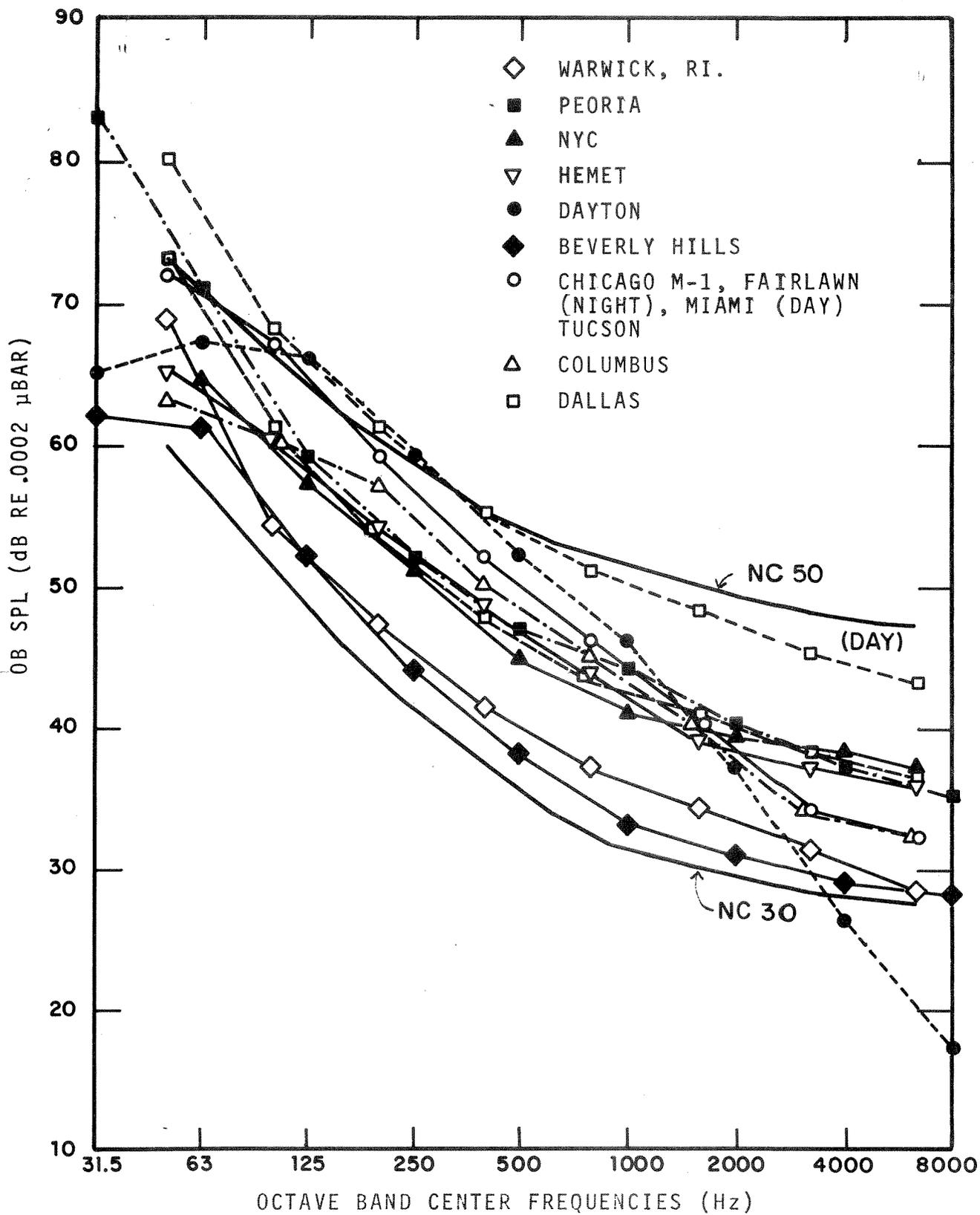
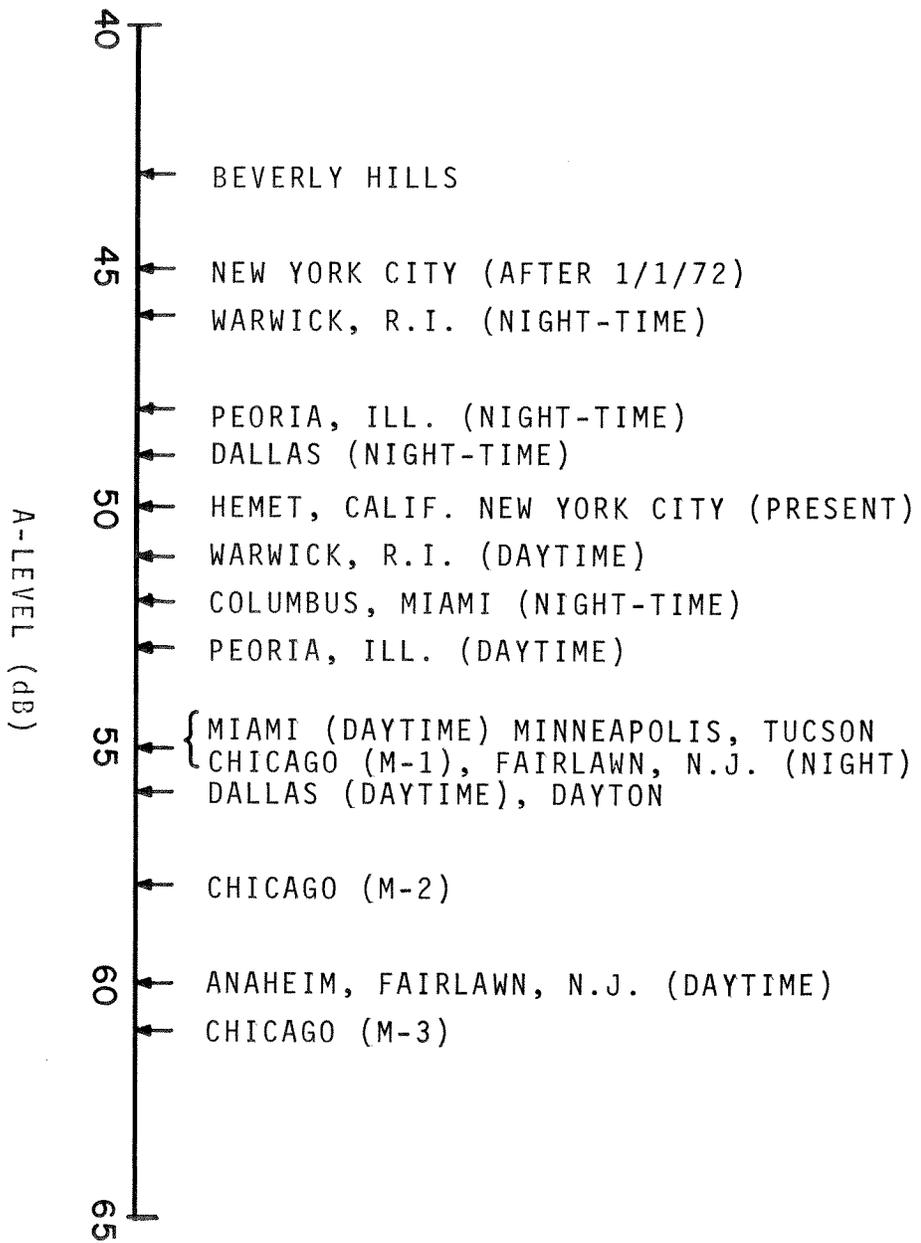


FIG. 15 QUANTITATIVE CITY ANTI-NOISE ORDINANCE LIMITS [TRAFFIC NOISE SPECIFICALLY EXEMPTED FROM THESE LIMITATIONS]

FIG. 16
 CITY ANTI-NOISE ORDINANCES:
 MAXIMUM A-WEIGHTED NOISE LEVELS (EXCEPT
 TRAFFIC) AT RESIDENTIAL BOUNDARY



- i) Anaheim, Calif. (Public Health & Safety): <60 dBA at property line
 (6/18/68)
 (traffic noise excepted)
 (construction noise excepted from 0600 to 2200)

- Traffic | ii) Anchorage, Alaska (City Ordinance: Health & Sanitation)
 (6/28/66) <88 dBA* at 50±2ft. from ϕ of traffic lane and speed <25 mph (no arrest until 90 dBA is reached);

- iii) Beverly Hills, Calif. (Municipal Code): SP Level in any octave band from machinery may not exceed either the ambient or the following levels by more than 3 dB at the property line:

<u>Freq. (Hz)</u>	<u>Octave Band SPL (dB re .0002 μbar)</u>
31	59
63	58
125	49
250	41
500	35
1000	30
2000	28
4000	26
8000	25
16000	24
0A	60

(N.B.: this value is incompatible with OB levels given)

Calculated: 40 dBA or 62 dB OASPL
 or NC 35

iv) Chicago, Ill.(Zoning Ordinance): Manufacturing Noise at the boundary line (or 125 ft beyond) shall not exceed*:

Freq. Band (Hz)	ZONE M-1		ZONE M-2		ZONE M-3	
	Residential Boundary	Business Boundary	Res. Bndry.	Bus. Bndry.	Res. Bndry.	Bus. Bndry.
0/75	72	79	72	79	75	80
75/150	67	74	67	74	70	75
150/300	59	66	61	68	65	70
300/600	52	59	56	62	59	64
600/1200	46	53	50	56	53	58
1200/2400	40	47	45	51	48	53
2400/4800	34	41	41	47	44	49
4800/---	32	39	38	44	41	46
A-Level	55	62	58	64	61	66

v) Columbus, Ohio (Zoning Code): Manufacturing noise (in M-1 and M-zones) at the boundary line shall not exceed*:

Freq. (Hz)	Residential	Business
0/150	65	75
150/300	57	67
300/600	50	60
600/1200	45	55
1200/2400	40	50
2400/4800	34	43
4800/---	32	40
A-Level	52	62

Traffic vi) Cincinnati, Ohio 95 dB(A) at 20 ft to right of motor vehicle* (12/13/58)

* No explicit reference level given.

- vii) Dallas, Texas (Zoning Ordinance) Manufacturing Noise-
Daytime levels at boundary lines shall not exceed:

Freq. Band (Hz)	ZONE			
	1-1,1-2,PD	1-3	Residential	Retail or Commercial
37/75	86	90	80	84
75/150	76	80	68	73
150/300	70	74	61	67
300/600	65	69	55	62
600/1200	63	65	51	58
1200/2400	58	62	48	55
2400/4800	55	60	45	52
4800/9600	53	58	43	50
A-Level	65	70	56	63

Corrections for night-time (-7 dB), pure-tone or impulsive (-7dB) and intermittent (+10 dB for 1:12 duty cycle)

- viii) Dayton, Ohio (Zoning Ordinance) Manufacturing Noise
(traffic and construction (0700-2100) noise exempted)
shall not exceed*:

Freq. Band (Hz)	ZONE			
	B-3 General Business B-4 Central Business I-1 Light Industrial at boundary of zoning district	At bndry. of lot	I-2 Gen'l Industrial (at bndry. of zoning district)	I-3 Heavy Industrial (at bndry. of zoning district)
31	65	76	76	90
63	67	74	74	81
125	66	68	68	71
250	59	63	63	66
500	52	57	57	61
1000	46	52	52	56
2000	37	45	45	52
4000	26	38	38	50
8000	17	32	32	47
A-Level	56	60	60	64

* No explicit reference level given.

- ix) Fairlawn, N.J. (Borough Ordinance): Noise reaching a "point of annoyance" from an establishment, business, residence, or other facility shall not exceed:
(9/25/62)

<u>Freq. (Hz)</u>	<u>Octave Band SPL*</u>
0/75	72
75/150	67
150/300	59
300/600	52
600/1200	46
1200/2400	40
2400/4800	34
4800/9600	32
A-Level	55

Corrections: for daytime only (0700-2300) = +5 dB
for pure tone character = -5 dB

- x) Hemet, Calif. (City Code): Electrical and mechanical noise produced in M & C-M zones projected onto residential property shall not exceed:
(12/12/66)

<u>Freq. (Hz)</u>	<u>SPL</u>
0/75	65
75/150	60
151/600	55
601/2400	45
2400/----	40

(Approximate levels in standard octave bands are given on next page.)

* No explicit reference level given.

<u>Freq.(Hz)</u>	<u>Octave Band SPL</u>
0/75	65
75/150	60
150/300	54
300/600	49
1200/2400	44
2400/4800	39
4800/9600	50

For daytime (0700-2200) noise, corrections for duration:
 Noise on not more than 20% of any one hour = +5 dB
 " " " " " 5% " " " " = +10 dB
 " " " " " 1% " " " " = +15 dB

(NB: ref. level for dB given as 0.002 μ bar instead of 0.0002)

xi) Inglewood, Calif. (City Ordinance) Machinery levels at residential zones shall not exceed:

<u>Freq.</u>	<u>Daytime (0700-2200)</u>	<u>Night-time (2200-0700)</u>
63	73	63
125	68	58
250	63	53
500	58	48
1000	53	43
2000	48	38
4000	43	33
8000	38	28
A-Level	60	50

Corrections

Pure tone content	-5 dB
Impulsive character	-5 dB
Duration for non-continuous sounds (daytime only)	
1 min/hr	+5 dB
10 sec/10 min	+10 dB
2 sec/10 min	+15 dB

xii) Los Angeles (City Ordinance): Automatic car wash noise shall not be audible over the traffic ambient on adjacent property except that such noise need never be reduced below 65 dB (presumably OASPL) in a "A" or "R" zone, or 70 dB in a "C" or "M" zone. No reference pressure given for dB.

xiii) Miami, Fla. (Building Code): All noise in C-4 (general commercial), C-5 (commercial), I-1 (light industrial) and I-2 (general industrial) districts limited to maximum permissible levels* as follows:

<u>Freq. (Hz)</u>	<u>Residential Boundary (0800-1800)**</u>	<u>Industrial or Commercial Boundary</u>
0/75	72	79
75/150	67	74
150/300	59	66
300/600	52	59
600/1200	46	53
1200/2400	40	47
2400/4800	34	41
Over 4800	32	39
A-Level	55	62

xiv) Minneapolis, Minn. (Zoning Code): For M-1 districts, the maximum permissible levels on the boundary of any operation or plant are same as those of Miami, above.

(No night-time correction)

xv) New York City (City Ordinance): In Manufacturing Districts, (12/15/61) the SPL shall not exceed, at any point on or beyond any lot line, maximum permitted levels as follows (noise of motor vehicles or other transportation facilities excepted):

* No reference for dB given

** Between 1800 and 0600, levels are decreased 3 dB.

Freq. Band (Hz)	Zone M-1		Zone M-2		Zone M-3	
	Residential Boundary	Business Boundary	Res. Bndy.	Bus. Bndy.	Res. Bndy.	Bus. Bndy.
20-75	73	79	73	79	74	80
75-150	68	74	69	75	69	75
150-300	60	66	62	68	64	70
300-600	53	59	56	62	58	64
600-1200	47	53	50	56	52	58
1200-2400	41	47	45	51	47	53
2400-4800	35	41	41	47	43	49
Above 4800	33	39	38	44	40	46
A-Level	56	62	58	64	60	66

xvi) New York City (Building Code): Exterior mechanical equipment levels, 100 feet away inside adjacent dwelling, shall not exceed:
(1968)

Frequency (Hz)	Present	After 1 Jan. 1972
63	64	61
125	57	53
250	51	46
500	45	40
1000	41	36
2000	39	34
4000	38	33
8000	37	32
A-Level	50	45

xvii) Orlando, Florida: Perceived Noise Level on boundary line shall not exceed:

Max. PNL Limits:

District	Perceived Noise Level (PNdB)	Approximately Equivalent A-Level (dB(A))
C-3	70	58
I-1	70	58
I-2	70	58
I-3	70	58
I-4	80	68
I-5	80	68

Regulations do not apply to aircraft in flight or in normal landing, take-off, or taxiing, but do apply to testing of aircraft not involved in normal landing take-off or taxiing.

Corrections

Daytime only	+5 PNdB
Impulsive character	-5 PNdB
Pure tone character	-5 PNdB
Duration for non-continuous noise*:	
Less than 20% of any one hour period:	+5 PNdB
" " 5% " " " " " "	+10 PNdB
" " 1% " " " " " "	+15 PNdB

xviii) Peoria, Ill. (Supplementary Regulations): Noise of any activity or operation (except those not under the control of the industrial use, such as traffic noise) shall not exceed**:

<u>Freq. (Hz)</u>	<u>Adjacent to lot line</u>	<u>At commercial district boundary</u>	<u>At residential district boundary***</u>
31	88	88	83
63	79	79	71
125	69	69	59
250	62	62	52
500	58	58	47
1000	54	54	44
2000	51	51	40
4000	49	49	37
8000	47	47	35
A-Level	62.5	62.5	53

*** Between 1900 and 0700, limits are decreased 5 dB.

* Only one of these corrections may be applied at a single site.

** No explicit reference for dB

xix) Peoria, Ill. (Municipal Code): Traffic Noise - Sound level A* vs distance from right rear wheel of vehicle in motion as it passes the sound level meter:
(1/21/58)

	<u>Distance</u>	<u>Maximum A-Level</u>	
TRAFFIC	50 feet	85	
	45 feet	86	
	40 feet	87	6 dB
	35 feet	88	per double -
	30 feet	89.5	distance
	25 feet	91	
	20 feet	93	
	15 feet	95.5	

xx) San Francisco (Building Code): Auto parking devices (elevator?) shall not make noise at the property line of the structure, in excess of 5 dB (presumably OA) above the ambient (defined as the power average of several readings taken at 15 sec. intervals over a 5 minute period without the device operating).
(9/11/61)

xxi) Tucson, Ariz. (City Code): Noise by street vendors and advertising unlawful: a) if >70 dBC** at 50 ft. from push-cart, vehicle or bicycle; b) if vehicle is not in motion; c) if between hours of 1300 and 1500 or between 2100 and 1000.

* No explicit reference for dB

** No reference level given

xxii) Tucson, Ariz. (Planning & Zoning Ordinances): Manufacturing noise (excludes traffic noise) shall not exceed following levels at boundary line:

<u>Freq. (Hz)</u>	<u>Residential or Business district or any property zoned other than I-2</u>	
0/75	72	
75/150	67	
150/300	59	
300/600	52	Taken from Chicago
600/1200	46	Code
1200/2400	40	
2400/4800	34	Ref. for dB given as
Over 4800	32	0.002 μ bar instead of
A-Level	55	0.0002 μ bar

xxiii) Warwick, R.I.: Continuous manufacturing noise shall not exceed following levels between 2200 and 0700, measured on the nearest Heavy Industrial District boundary line or for Light Industrial Districts, measured on any property line.

(10/16/58)

<u>Freq. (Hz)</u>			
20/75	69	Corrections for non-smooth or non-continuous noise:	
75/150	54		
150/300	47	Daytime operation only +5dB	
300/600	41	Apply { Operates <20% of any one hour +5dB	
600/1200	37		only one { " <5% " " " " +10dB
1200/2400	34		of these { " <1% " " " " +15dB
2400/4800	31		Impulsive (hammering) character -5dB
4800/10000	28	Pure tone -5dB	
A-Level	46		

xxiv) Washington, D. C. - like Chicago Code

Figure 17 shows a regulation^{21/} included in the present Canadian bylaw (but not necessarily always enforced); it applies to noise levels at the property line or at a distance of 150 feet, whichever is nearer to the noise source. Corrections are required for

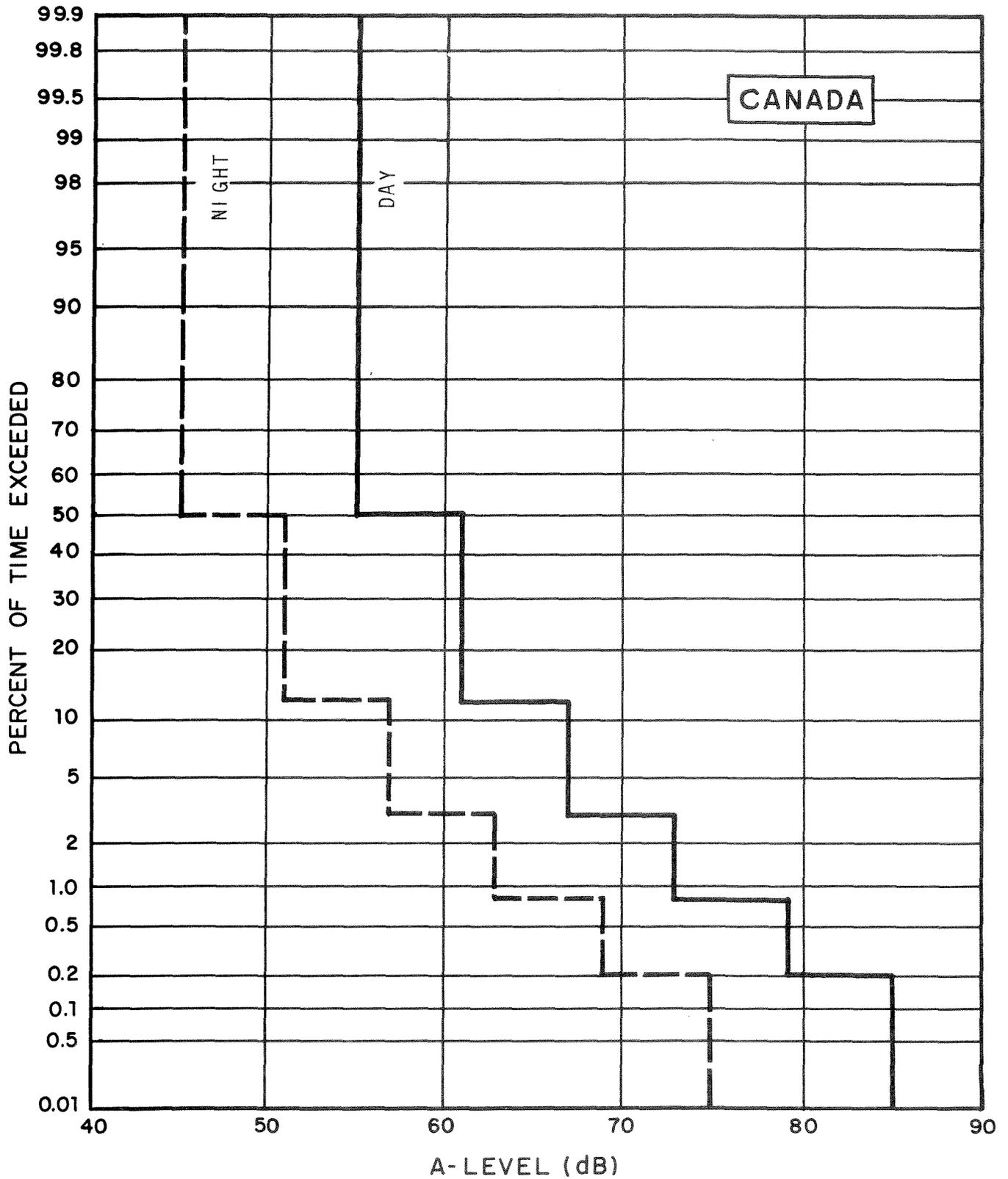


FIG. 17 RECOMMENDED CRITERIA FOR LIMITING NOISE FROM INDUSTRIAL OR COMMERCIAL OPERATIONS; MEASUREMENTS TO BE MADE AT THE PROPERTY LINE OR AT A DISTANCE OF 150 FT., WHICHEVER IS NEAREST TO THE SOURCE. REF. 21, § 10.2 (a) AND TABLE II

unusual character of the noise.

Only six quantitative traffic noise regulations exist in the United States, ^{260, 261/} and five of these are aimed at limiting the maximum noisemaking capability of individual vehicles, regardless of how they are operated in practice. The Commonwealth of Connecticut monitors actual road-side noise level and arrests particular offending drivers.

QUANTITATIVE TRAFFIC NOISE REGULATIONS

- | i) | Cincinnati | < 95 dB(A) at 20 ft. | | | | | | | | | | | | | |
|------|-----------------------------|--|--|------------|----------|---|----------------|------------|--|------------|---|----------------|------------|--|------------|
| ii) | Peoria, Ill. | < 93 dB(A) at 20 ft.
(other values specified at other distances, based on 6 dB/double distance; e.g., < 85 dB(A) at 50ft.) | | | | | | | | | | | | | |
| iii) | Anchorage, Alaska | < 88 dB(A) at 50 ft. from centerline of traffic lane, speed < 25 mph. | | | | | | | | | | | | | |
| iv) | New York State
July 1965 | < 88 dB(A) at roadside toll stations, 50 ft. from centerline of traffic lane, speed < 35 mph. | | | | | | | | | | | | | |
| v) | California State | <table border="1" style="border-collapse: collapse; margin-left: auto; margin-right: auto;"> <thead> <tr> <th style="border: none;"></th> <th style="border: none; text-align: center;">< 35 mph</th> <th style="border: none; text-align: center;">> 35 mph</th> </tr> </thead> <tbody> <tr> <td style="border: none; padding-right: 5px;">{</td> <td style="border: none; padding-right: 5px;">passenger cars</td> <td style="border: none; padding-right: 5px;">< 82 dB(A)</td> <td style="border: none; padding-right: 5px;"> </td> <td style="border: none; padding-right: 5px;">< 86 dB(A)</td> </tr> <tr> <td style="border: none; padding-right: 5px;">{</td> <td style="border: none; padding-right: 5px;">trucks & buses</td> <td style="border: none; padding-right: 5px;">< 88 dB(A)</td> <td style="border: none; padding-right: 5px;"> </td> <td style="border: none; padding-right: 5px;">< 92 dB(A)</td> </tr> </tbody> </table> <p style="margin-left: 40px;">— at 50 ft from centerline of traffic lane.</p> | | < 35 mph | > 35 mph | { | passenger cars | < 82 dB(A) | | < 86 dB(A) | { | trucks & buses | < 88 dB(A) | | < 92 dB(A) |
| | < 35 mph | > 35 mph | | | | | | | | | | | | | |
| { | passenger cars | < 82 dB(A) | | < 86 dB(A) | | | | | | | | | | | |
| { | trucks & buses | < 88 dB(A) | | < 92 dB(A) | | | | | | | | | | | |
| vi) | Connecticut | < 85 dB(A) at 25 ft. from road; action taken only when 88 dB(A) is reached. | | | | | | | | | | | | | |

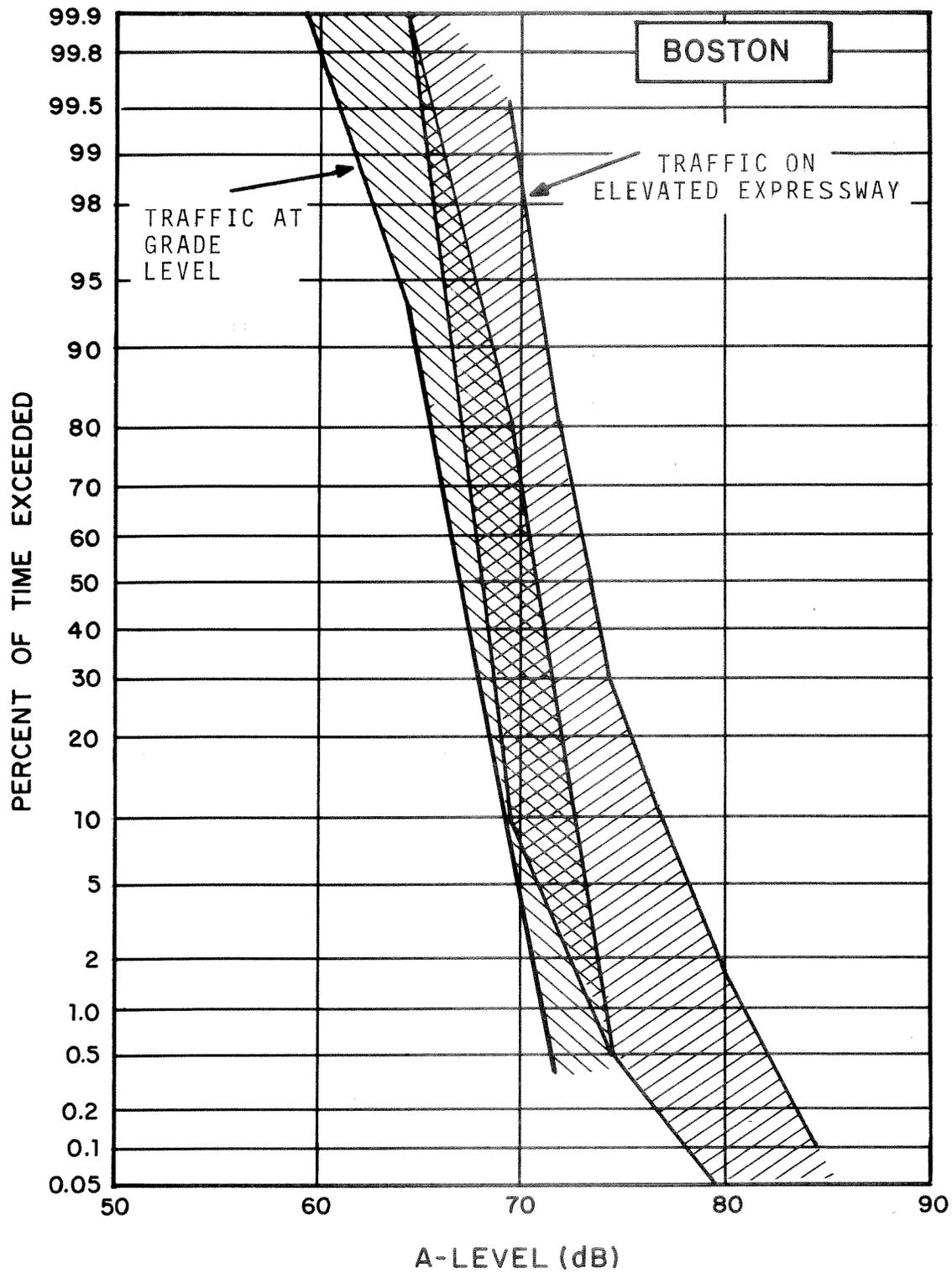
6. Existing Noise Exposures

A final matter of interest in the setting of criteria for acceptability of urban noise exposure is the question of what noise exposures actually exist at the present time in various cities of the world. The relevance of this is that it will help to form an estimate of how great a change (that is, how much cost) would be involved in enforcing a given criterion. Since, as noted above, the only meaningful presentation of city noise data is in statistical terms, only those cities for which such data exist are represented here. Figures 18 to 26 show the noise exposures, measured within the past decade, in Boston, Dusseldorf, New Orleans, Ottawa, Seattle, Tokyo and Vienna (the latter includes, for comparison, typical noise exposure due to indoor noise sources unrelated to road traffic). Figure 27 summarizes existing noise exposures by day and night in different city areas.

7. Preferred Format for HUD's Noise Abatement Criteria

In order to compare the urban noise exposures presented in the figures of the preceding section with the standards set out for non-aircraft noise in the current draft of HUD's policy circular on noise abatement, HUD's standards have been plotted in Figure 28 on the same probability graph paper as the curves of city noise. The comparison is readily made by overlaying any of the noise curves over the HUD criterion graph.

A preferred format for HUD's urban noise abatement standards is shown in Figure 29. The reasons for preferring a statistical representation have been given earlier (Section III.B.5); further considerations are that the statistical format eliminates complicated verbiage and a decided appearance of arbitrariness.



BOSTON: ALL POSITIONS NEAR J.F. KENNEDY (SOUTHEAST) EXPRESSWAY,
 1:00 P.M. TO 5:00 P.M. DAILY TRAFFIC COUNT = 76000 VEHICLES

FIG.18 ROAD TRAFFIC NOISE - MAJOR ARTERY
 REF. 39, Figs, 11 & 12.

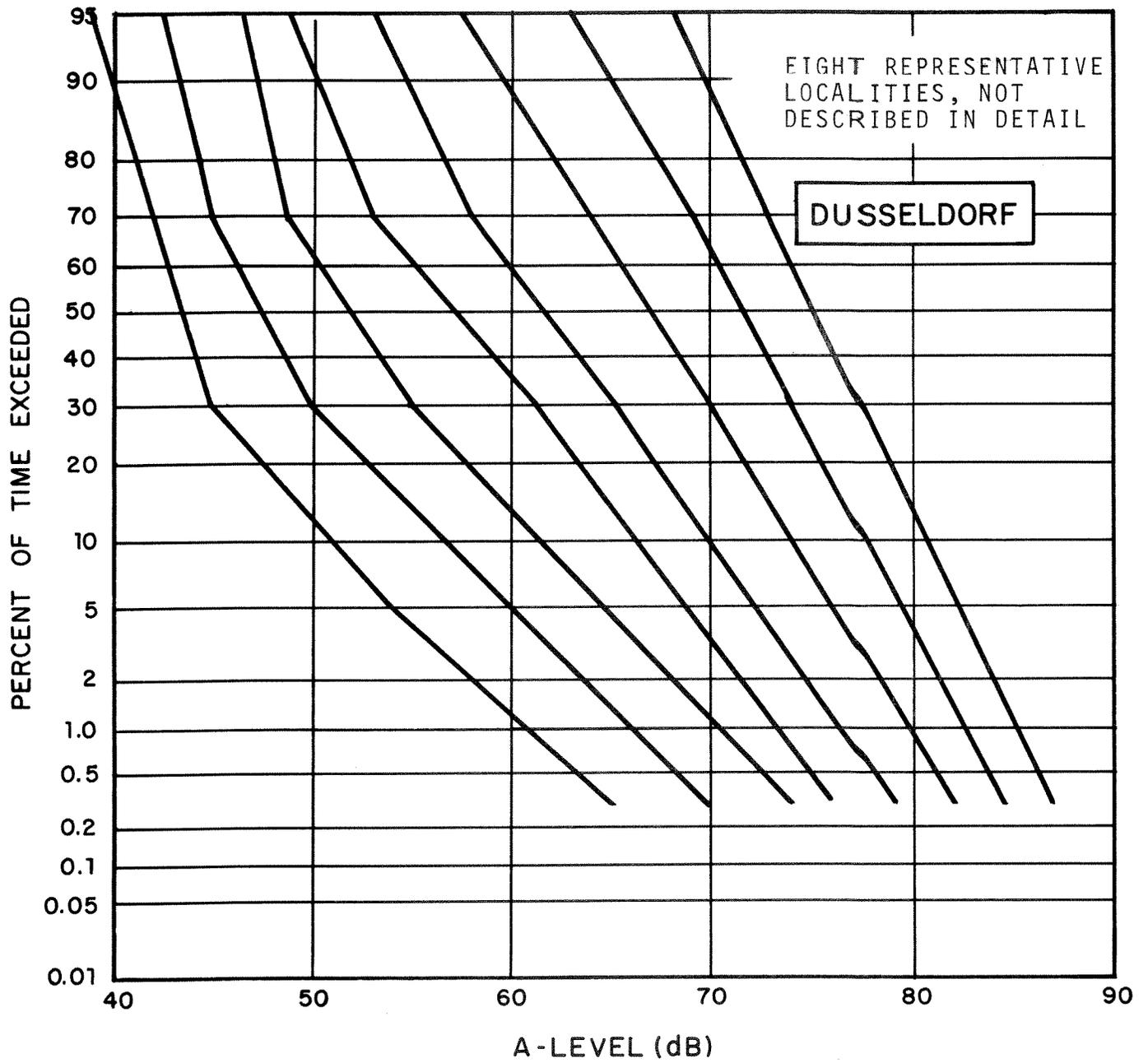


FIG.19 URBAN NOISE LEVELS: DUSSELDORF, WEST GERMANY, (DAYTIME ONLY). REF. 28.

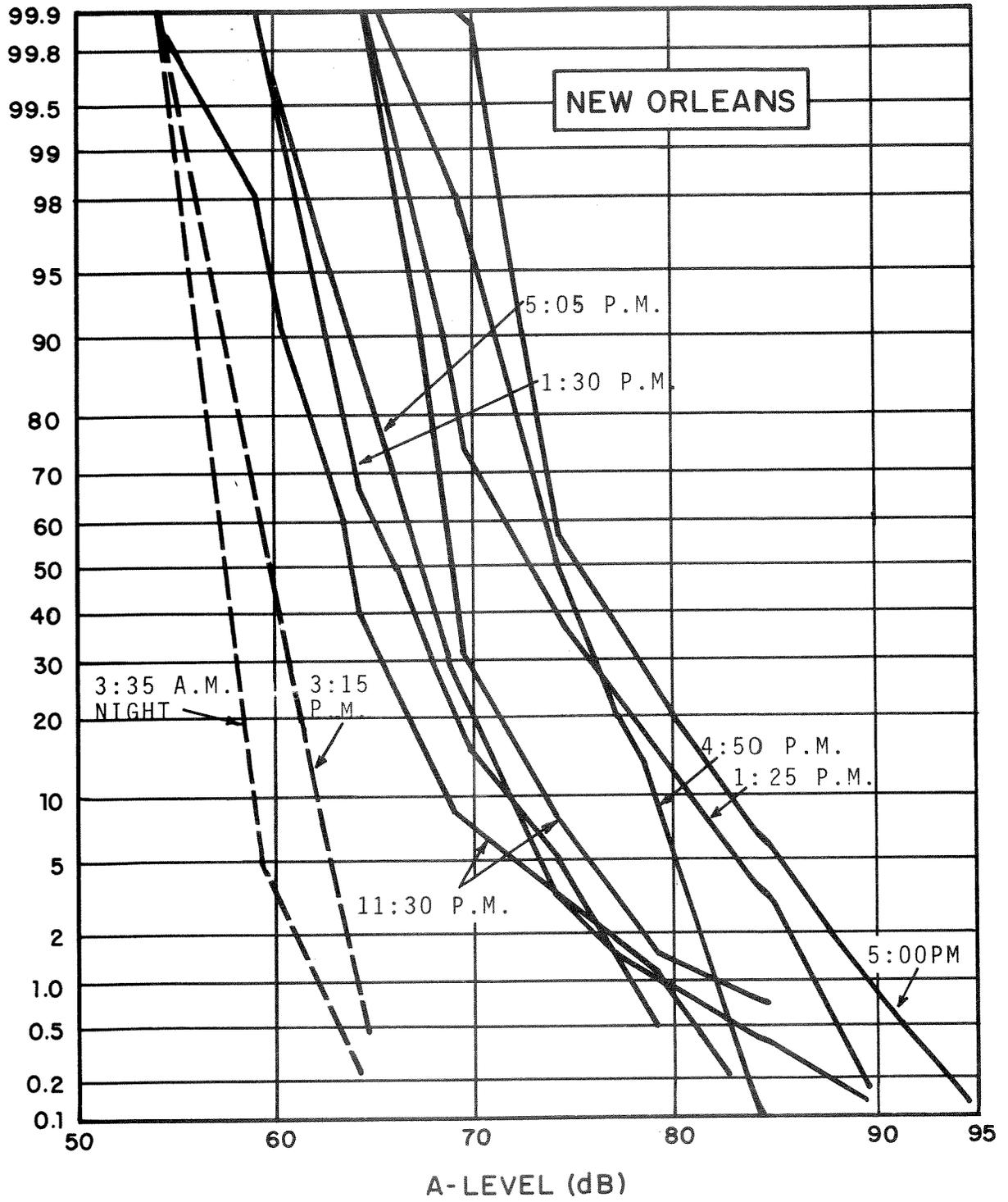
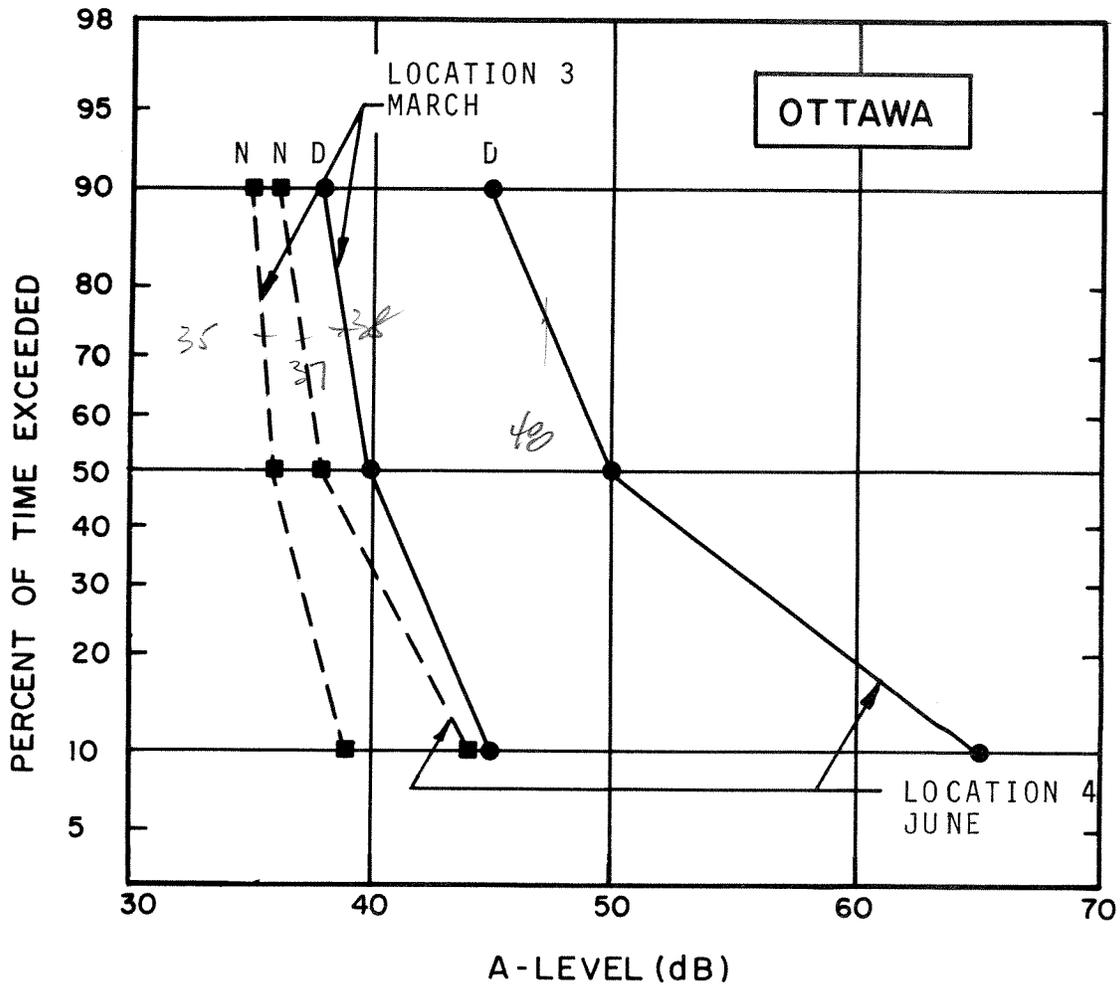


FIG.20 URBAN NOISE LEVELS: JACKSON SQUARE, NEW ORLEANS, REF. 39, FIGS. 2, 3 & 7.

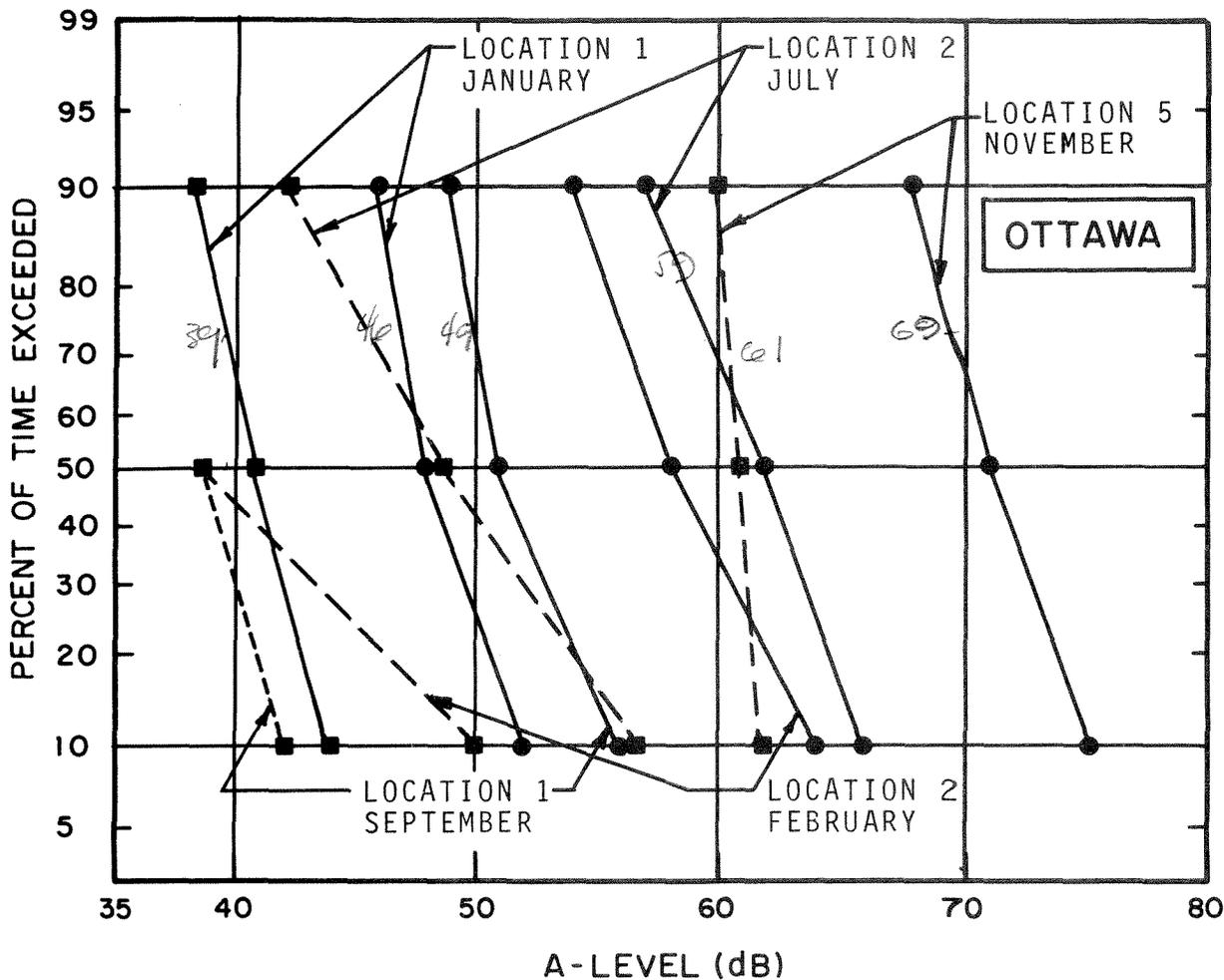
loc	d	n	L _{dn}
3	38	35	42
4	48	37	48



- LOCATION 3 PRIVATE HOME, NEW RESIDENTIAL AREA NEAR OUTER BOUNDARY OF CITY; 1/2 MILE FROM NEAREST COMMERCIAL STREET W/HEAVY TRAFFIC
- LOCATION 4 PRIVATE HOME, PREDOMINANTLY RESIDENTIAL AREA; 0.2 MILE FROM STREET WITH MODERATE TRAFFIC, BUT IS ON A BUS ROUTE: NOTE HIGH L₁₀

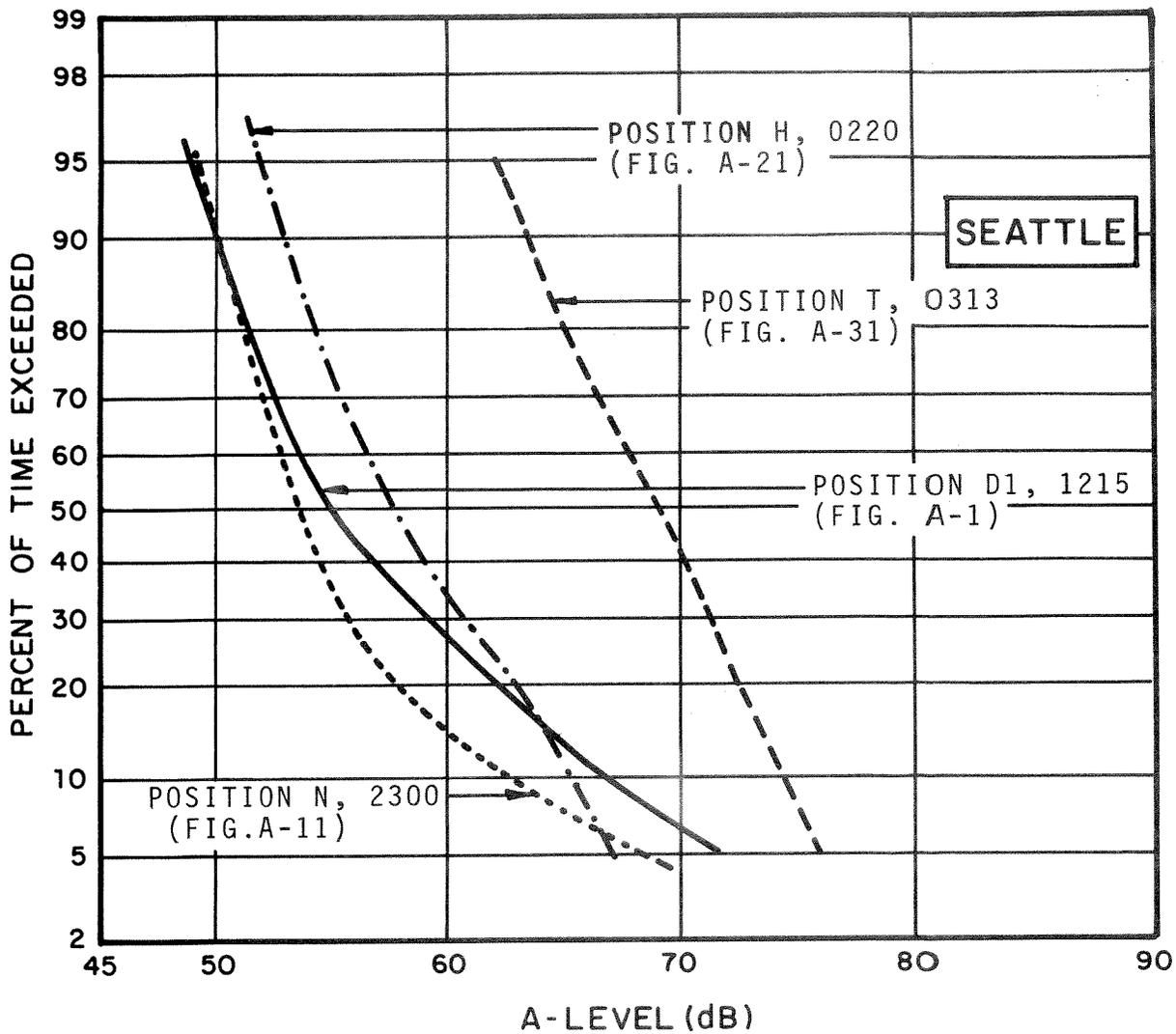
FIG. 21 URBAN NOISE LEVELS: OTTAWA, 1968; (DAYTIME & NIGHT-TIME). REF. 106.

Loc.	day	nt	Ldn
1	49	39	= 49
2	59	46	= 57
3	69	61	= 70



- LOCATION 1 PRIVATE HOME, PREDOMINANTLY RESIDENTIAL AREA 400 FEET FROM TWO INTERSECTING STREETS W/MOD. TRAFFIC; NEAREST COMMERCIAL STREET W/HEAVY TRAFFIC IS 0.4 MILE AWAY
- LOCATION 2 PRIVATE HOME ON MULTILANE STREET, PREDOMINANTLY COMMERCIAL WITH HEAVY TRAFFIC; ALSO 1000 FEET FROM EXPRESSWAY
- LOCATION 5 DOWNTOWN HOTEL, AIR-CONDITIONING MACHINERY ALL AROUND

FIG.22 URBAN NOISE LEVELS: OTTAWA, 1968; (DAYTIME & NIGHT-TIME). REF. 106.



- POSITION D1 RESIDENTIAL, ON RIDGE LINE OF HILL, 200 FEET FROM MILITARY RD; BOEING FIELD PLANT II AND HIGHWAY (5) VISIBLE
- POSITION H RESIDENTIAL, NEXT TO SCHOOL; OVERLOOKS BOEING FIELD, PLANT II AND HIGHWAY (5)
- POSITION N RESIDENTIAL NEXT TO CHURCH; SHIELDED FROM NEARBY ARTERY BUT OVERLOOKS DISTANT HIGHWAY (5) AND BOEING FIELD
- POSITION T RESIDENTIAL, SOUTH BOEING FIELD AND HIGHWAY (5) VISIBLE (NO APPARENT REASON WHY LEVELS SO HIGH)

FIG.23 URBAN NOISE LEVELS: SEATTLE, 1968; (DAYTIME & NIGHT-TIME) REF. 127, APPENDIX A.

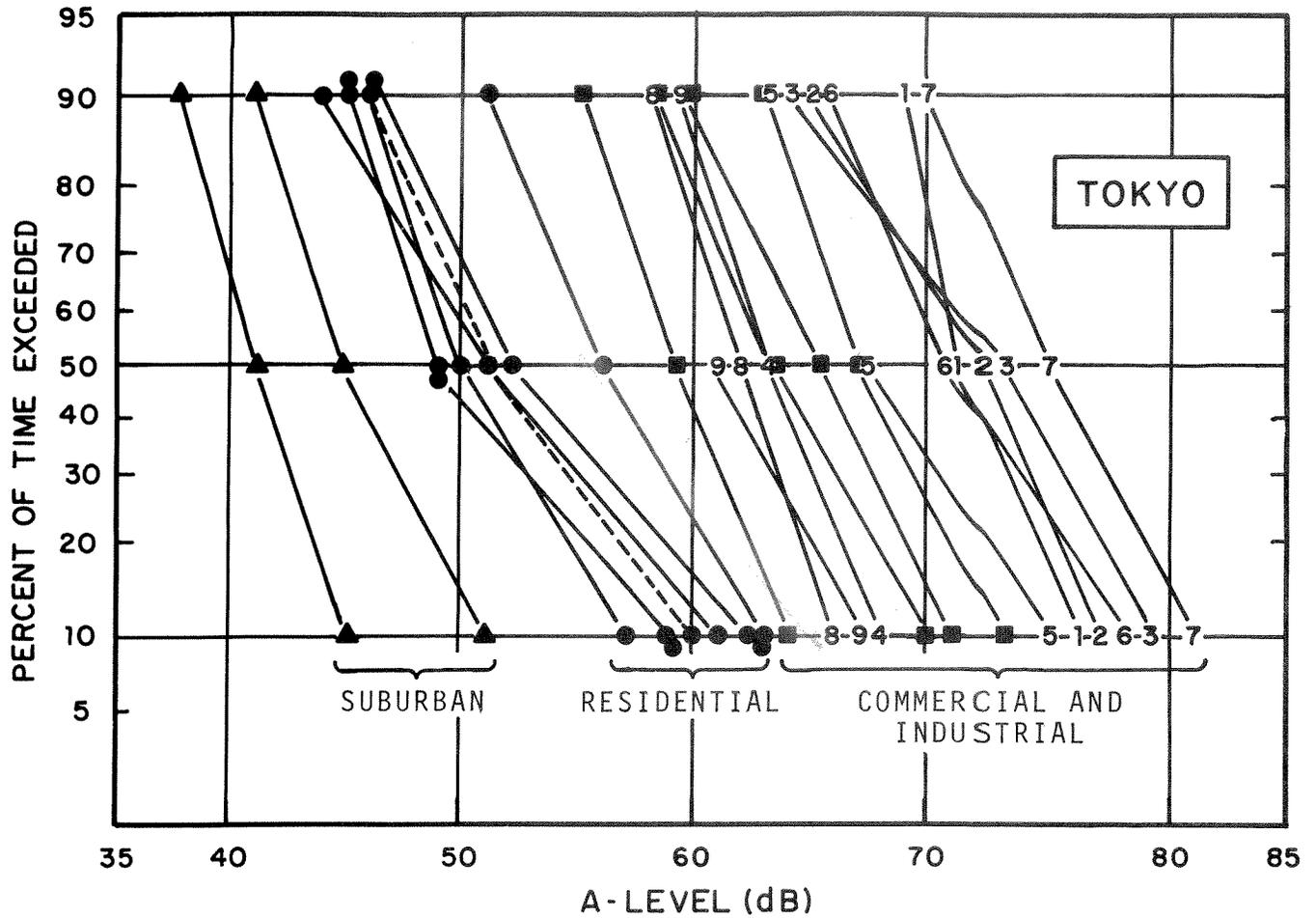


FIG. 24 URBAN NOISE LEVELS: TOKYO, 1966; (DAYTIME ONLY)

REF. 95; NUMBERED POINTS FROM TABLE 2, P. 149, FOR "COMMERCIAL ZONE - BUSY TOWN" (0950-1215)
 OTHER POINTS FROM TABLE 3, P. 157, VARIOUS TIMES DURING DAYTIME.

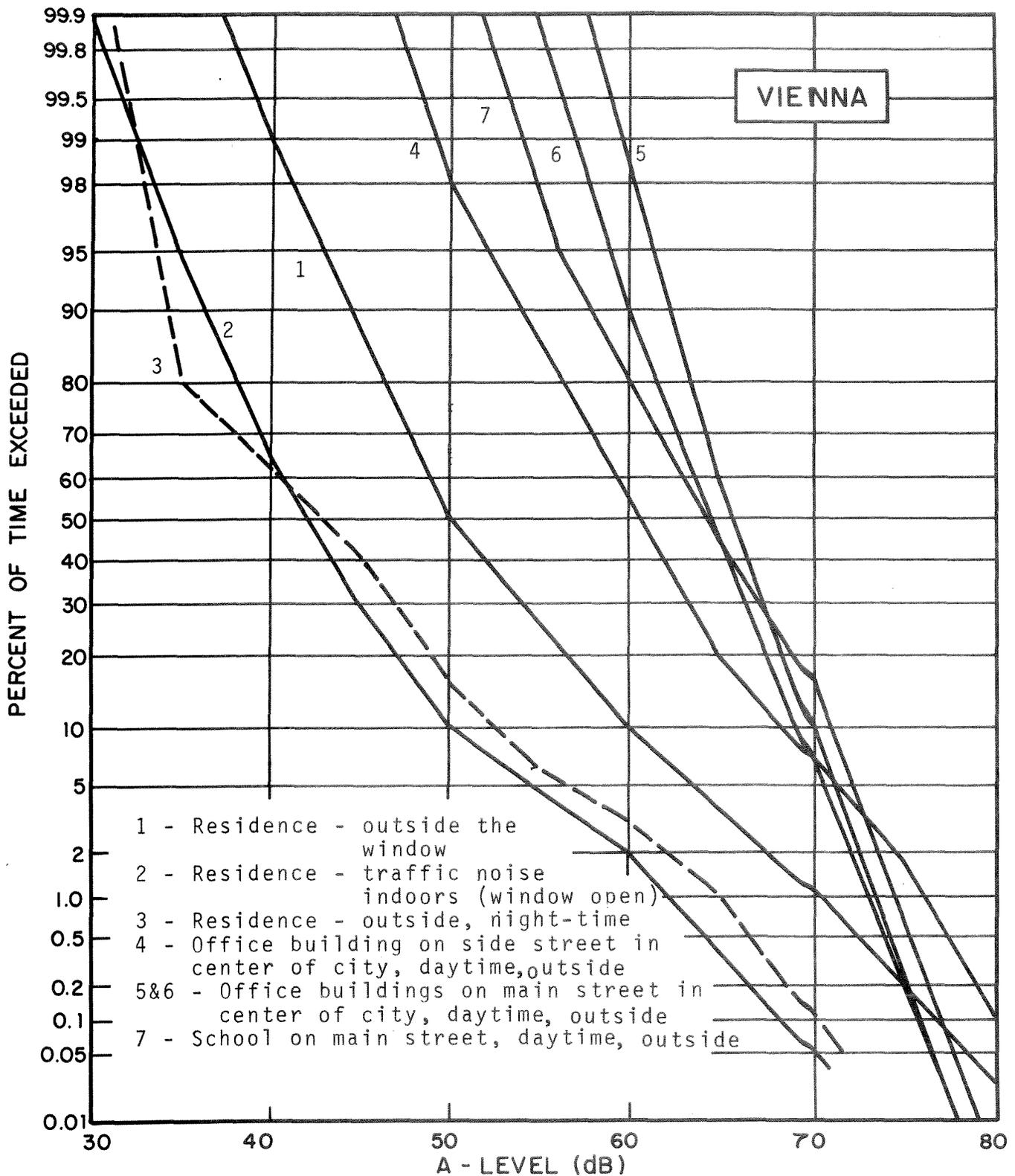


FIG. 25 URBAN NOISE LEVELS = VIENNA, 1964; REF. 26, FIG. 12. IN THE RESIDENTIAL ZONE, THE NIGHT-TIME OUTDOOR LEVELS ARE VERY SIMILAR TO THE DAYTIME INDOOR LEVELS WITH THE WINDOW OPEN.

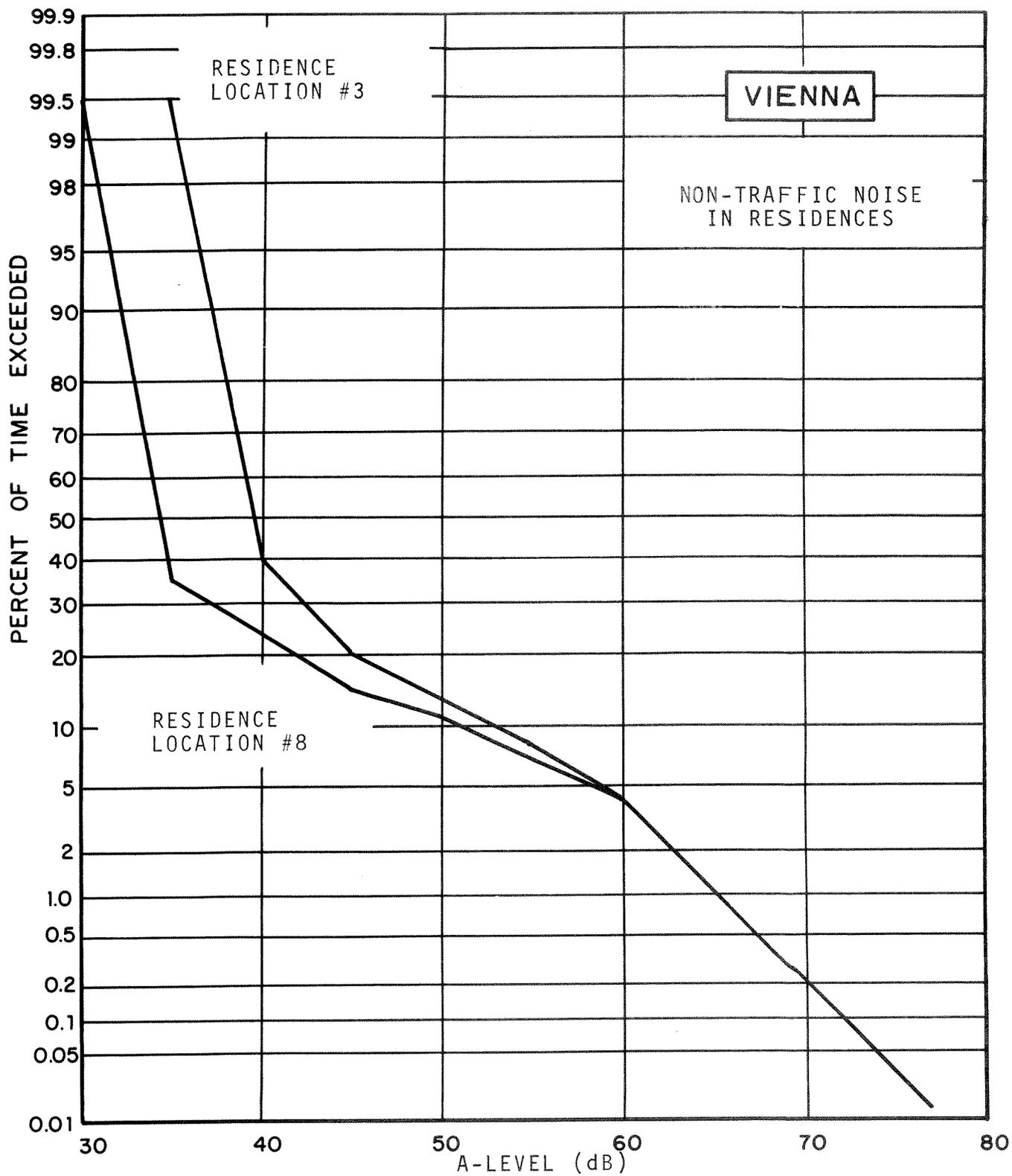


FIG. 26 INDOOR DAYTIME NOISE LEVELS FROM SOURCES OTHER THAN TRAFFIC; WINDOWS CLOSED, VIENNA, 1964. REF. 26, FIG. 12.

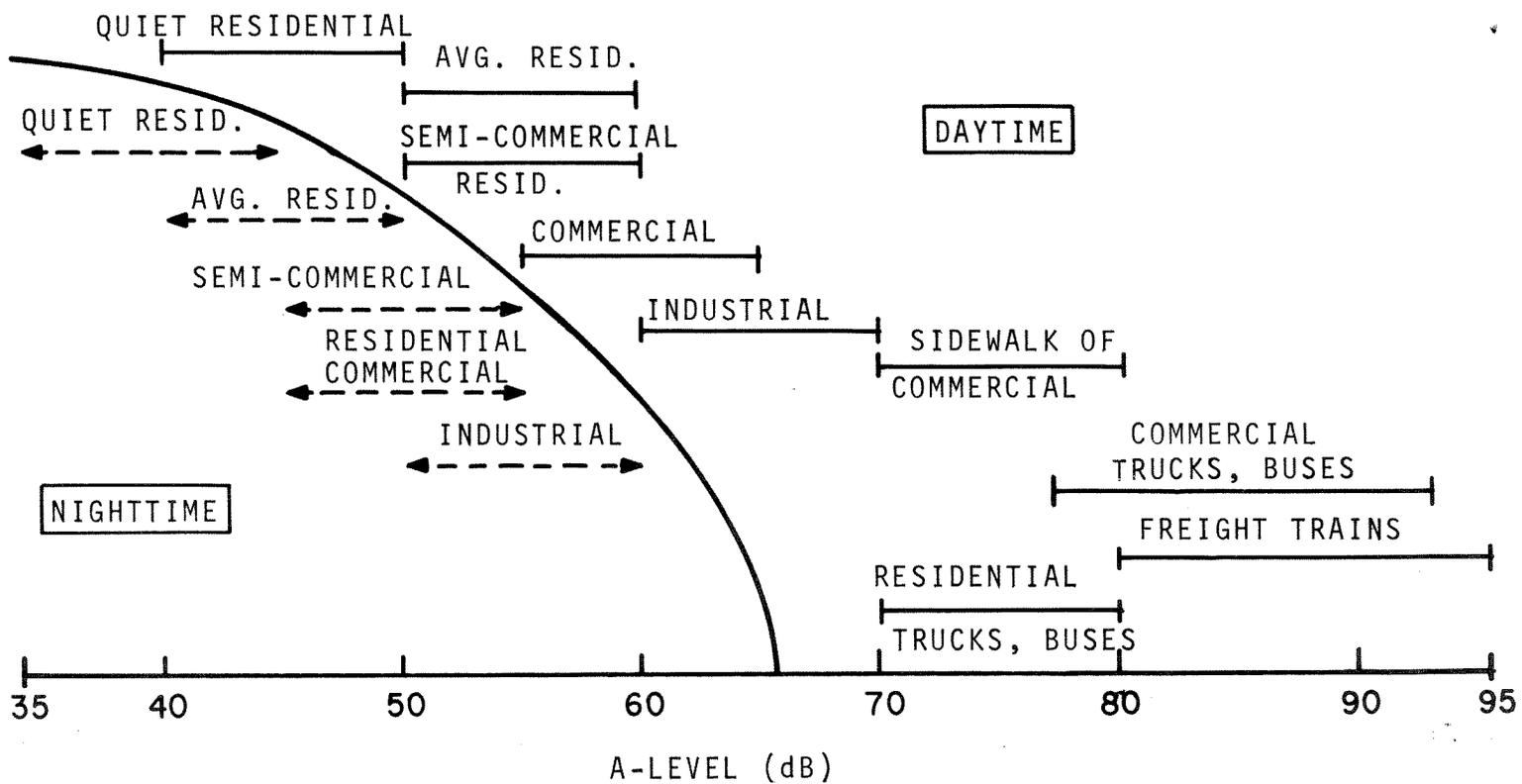


FIG.27 SUMMARY OF EXISTING NOISE EXPOSURES BY DAY AND BY NIGHT IN DIFFERENT U.S. CITY AREAS

*NOT FOR RIPAAT
ECC TBS
12/20/73*

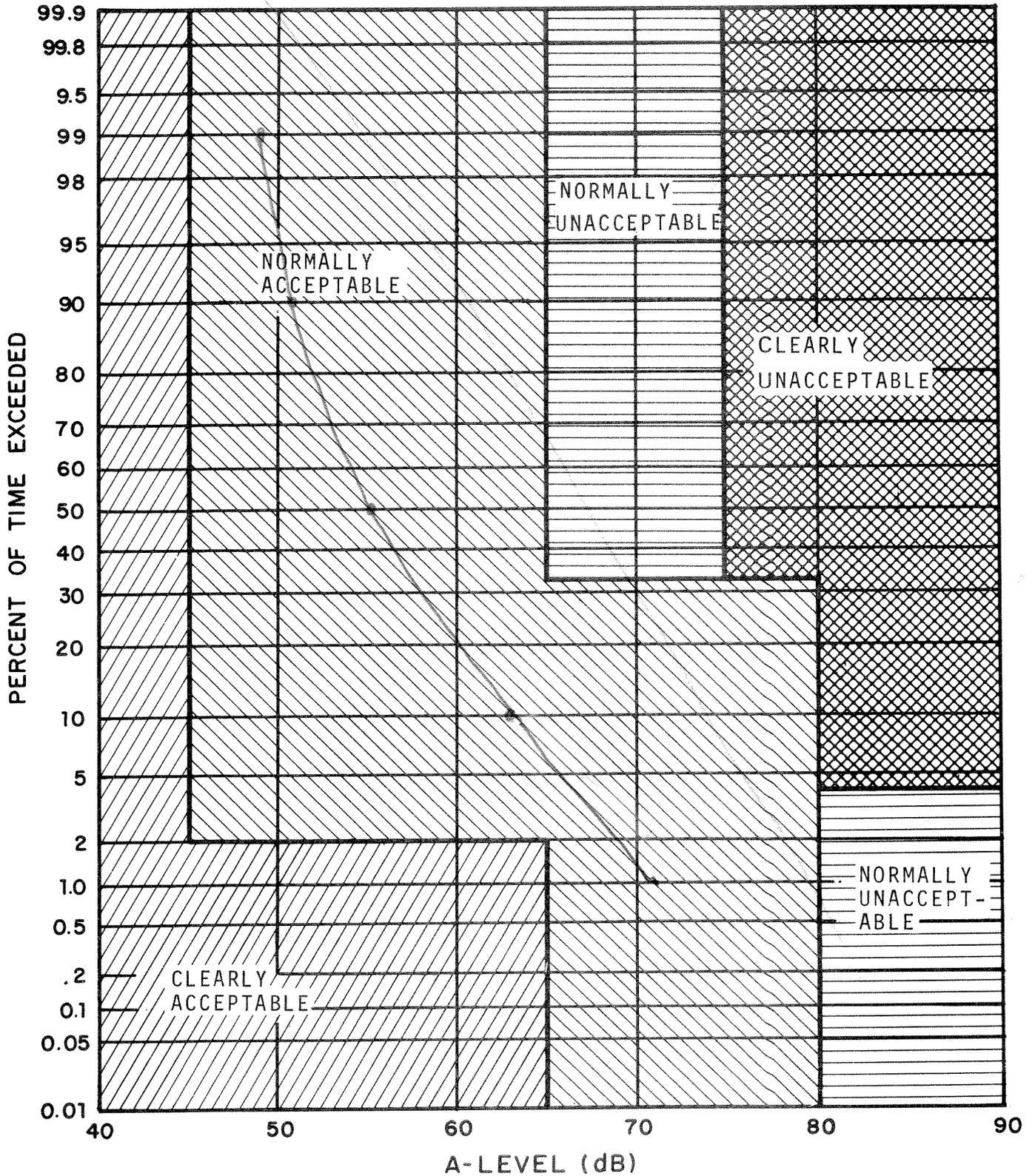


FIG. 28 CURRENT HUD CRITERIA FOR NON-AIRCRAFT NOISE

(For explanation of dots, see text on page 146.)

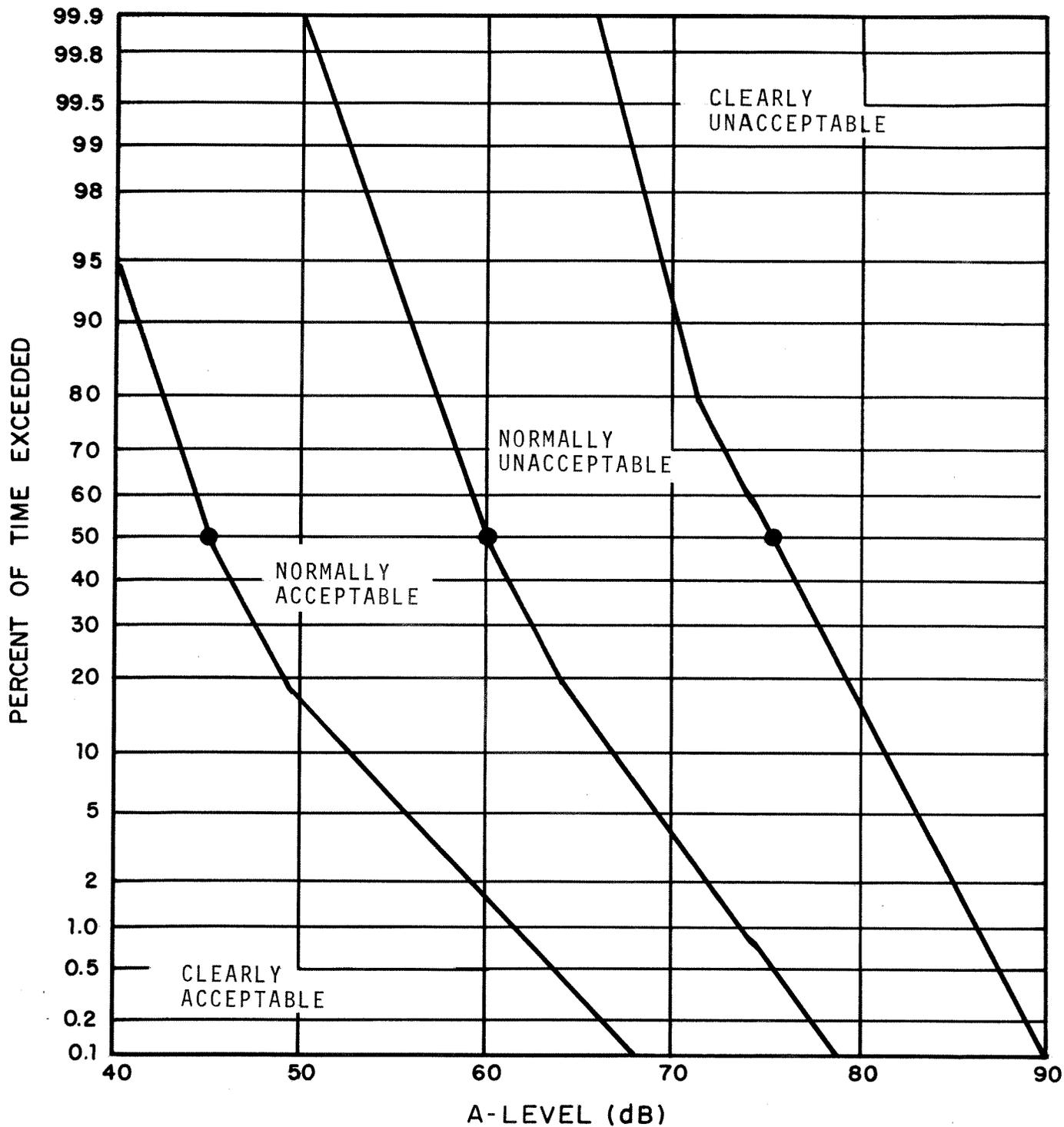


FIG. 29 PROPOSED ALTERNATIVE FORMAT FOR HUD'S CRITERION FOR NON-AIRCRAFT NOISE

8. Criteria of Acceptability for Aircraft Noise

As with the noise from non-aircraft sources discussed above, comparison have been made between the physical measurements of aircraft noise, as expressed in a number of different ratings (See Section III.C, p. 75) and the corresponding public response elicited by the noise exposure. Surveys in England, 18,100,125/ France, 2,72,174/ The Netherlands, 163/ and Germany 166/ have resulted in single-number ratings, as described above on pages 75-79, where these ratings were compared with the Aircraft Composite Noise Rating (CNR) and the Noise Exposure Forecast (NEF) of the United States. It was shown that all these ratings evaluate a given series of aircraft operations (that is, a given aircraft noise exposure) in a similar way. It is of further interest now to intercompare the criteria developed from these studies for the purpose of defining an acceptable noise environment.

A. England: Among the earliest of these studies* were the Farnborough experiments, 125,18/ carried out at the request of the Wilson Committee in 1961 and 1964, and the Social Survey in the vicinity of London (Heathrow) Airport. 100/ The main features of the first Farnborough experiment were that groups of people (both indoors and outdoors) were exposed to the noise of various aircraft operations over the course of a three-day air show at Farnborough, and were asked to make subjective judgments of the noises; propeller and jet aircraft were included, as well as helicopters. The average subjective ratings of the noises were compared with their measured A-Levels. The various aircraft were judged to be "quiet" when the sound levels at the ear did not exceed 66 dB(A), but were judged

* Borsky's pioneering work in 1956^{14/} dealt only with the neighborhoods of military airbases; his study formed the basis for the development of the aircraft Composite Noise Rating.

"too objectionable" when the level reached 105 dB(A) out of doors; indoors, however, the aircraft noise was judged more harshly, for the same degree of intrusiveness was reached when the levels were 18 dB lower.

The tentative explanation of this last result was that the subjects "projected" themselves to the outside situation. It may be, however, that the following remark, made in the context of the second Farnborough experiment, is more relevant: "Thus for relatively low level noise it is accepted that the excess over the background level determines the annoyance, whilst for high levels it is the absolute level which matters." The break-over may have occurred, for the Farnborough results, within that 18 dB range.

Around the same time a social survey in the vicinity of Heathrow permitted a comparison of the responses of the populace (about 2000 interviewed) to questions about what elements of their environment were disturbing to them, with the results of measurements of the noise exposure. A fair correlation was found between the subjective responses and the Noise and Number Index (NNI) discussed above. The following conclusions summarize people's reaction to aircraft noise in comparison with other aspects of the environment that bothered them:

- The number of people who most dislike aircraft noise exceeds those who dislike all other causes of dissatisfaction (spontaneously mentioned) when NNI reaches 53.
- Those who would change aircraft noise outnumber those who would change all other aspects (spontaneously mentioned) of the environment when the NNI reaches 48.

— Subjective rating of aircraft noise becomes worse than that of any other individual item at an NNI of 50-54.

— At 55 NNI aircraft noise is the dominant reason given by people who like the area in which they now live less than they used to, as well as by people who felt like moving away from the area.

At various values of NNI, the percentage of people disturbed by aircraft for various reasons is as follows: 100/

	NNI	<u>30</u>	<u>35</u>	<u>45</u>	<u>50</u>	<u>55</u>
Startles		43	48	58	59	61
Keeps from going to sleep		23	27	38	47	57
Wakes up		41	47	60	65	70
Disturbs rest or relaxation		26	30	38	44	50
Interferes with TV sound		43	51	72	75	79
Causes TV picture to flicker		59	64	74	75	76
House vibrates		43	51	72	74	76
Interferes with conversation		36	45	68	73	78

It is clear that annoyance begins to grow very rapidly around 35 NNI, even in the daytime. From these figures it can be seen that the public annoyance is not at all trivial at these levels of noise exposure. Even NNI 30 cannot be described as "acceptable" noise exposure, when 23 to 59% of the people are disturbed for various reasons. One may even question whether such exposure could be regarded as "tolerable". In spite of these indications of serious disturbance, the Wilson Committee, on the basis of these and the Farnborough results, concluded that exposure to aircraft noise reaches an "unreasonable level" in the range 50-60 NNI for the daytime and 30-45 NNI for nighttime, but formally defines 50-60 NNI as the "maximum acceptable level" (Ref. 100, page 75, emphasis added).^{*} In practice, 45 NNI, where aircraft noise emerges above all other causes of dissatisfaction, is taken as the break-point between acceptable and unacceptable exposure for which no special precautions or noise

^{*} A recent study^{281/} covering two years of admissions to a London psychiatric hospital showed a significant higher rate of admissions from neighborhoods where aircraft noise exposure exceeds 55 NNI (or 100 PNdB) than from quieter areas.

abatement effort is required!

B. France

In France,^{2/} the noise measurement and social studies indicated that people's annoyance increases sharply as the exposure increases beyond a Classification Index R 88-93.* In all neighborhoods where the exposure reached R 88-93, the percentage of people who were extremely annoyed exceeded the percentage of people who were not at all annoyed, while the reverse was true at lower levels of exposure. Between R 82-87 and R 88-93, the proportion of those who were very much disturbed in their work doubled (up to 20%), and doubled again at locations where the exposure was up to R 94. The increase of annoyance with R becomes roughly geometric for exposures above R 88, but not until this value is reached. Above R 88-93 more than half the people designate aircraft noise as more disturbing than all other noise sources; and noise emerges above all other sources of dissatisfaction in the environment when R exceeds 88. The proportion of people who are interrupted in conversation by aircraft noise increases from 30 to 60% between R 82-87 and R 88-93.

At various values of the Classification Index R, the percentage of people sometimes or often disturbed by aircraft noise for various reasons is as follows:

* In its most recent formulation, the Classification Index, R, is identical to an alternate French rating for aircraft noise, *N*, the Isopsophic Index; for comparison, R88-93 is approximately equivalent to *NI* 46-51 (for 110 PNdB flyovers).

	R: <u>Under 81</u>	<u>82-87</u>	<u>88-93</u>	<u>Over 94</u>
Startles	21	22	28	34
Keeps from going to sleep	8	13	20	28
Wakes up	15	28	37	53
Generally extremely disturbed	16	23	48	73
Interferes with radio/TV	38	50	74	83
House vibrates	44	51	68	77
Interferes with conversation	19	30	59	80

Even in the mildest of these exposure zones, 8 to 44% of the people are disturbed, in one activity or another.

From these and other more detailed conclusions, it appears that annoyance accelerates rapidly as the exposure exceeds R 88, and this value was accordingly taken as the upper limit for an acceptable environment; at this exposure 20 to 74% of the people are seriously disturbed in various activities. If the exposure exceeds R 88, special sound isolation should be provided, as shown in the following table:

TABLE XIV. RECOMMENDATION FOR ADDITIONAL SOUND ISOLATION TREATMENT IN DWELLINGS EXPOSED TO AIRCRAFT NOISE WITH FRENCH CLASSIFICATION INDEX EXCEEDING R 88

<u>R</u>	<u>Type of Windows</u>
< 88	Ordinary windows
88-93	Windows with 0.2" panes and careful gasketing or sealing
94-98	Double windows with 0.11 to 0.22" panes, separated by 4 inches, and well sealed.
98-103	Same but with interpane spacing of 6 inches.

The value R 88 is equivalent to a mean peak level of 103 PNdB for 30 aircraft operations heard in a 24 hour period, or to 98 PNdB for 100 operations in 24 hours, when the measurements are made outside the dwelling; the corresponding indoor levels are about 80 PNdB (67 dB(A)) if the windows are closed and about 90 PNdB (77 dB(A)) if the windows are open.^{2/}

Alexandre^{2/} points out that 80 PNdB is about the level that Metz^{220/} and Schieber^{129,233/} found acceptable in their studies of sleep disturbance (82 PNdB), except that the R 88 value corresponds to an entire 24-hour period, whereas Metz considered only the nighttime.

As a result of their studies, the French have established various zones for different land uses, on the basis of noise exposure, as follows:

	TABLE XV. FRENCH LAND-USE CRITERIA	
AREA A	(R) > 96	(CNR > 114)

All buildings are prohibited except those relating to airport activities, unless soundproofing is provided so that living conditions are at least as good as they would be if the buildings were located in Area C.

AREA B	89 < (R) < 96	(107 < CNR < 114)
--------	---------------	-------------------

Development of existing communities is restricted to areas within the smallest possible perimeters. Construction for residential purposes will be authorized subject to adequate soundproofing. Density limitations (number of inhabitants to the hectare) will also be established for this type of residential area.

Erection of public buildings (i.e. schools, hospitals, etc.) and residential buildings should be avoided. Should the erection of such public buildings be considered essential, soundproofing should conform to a certain given value and each case should be studied individually.

AREA C 84 < (R) < 89 (102 < CNR < 107)

New residential developments should be avoided. Density limitations (number of inhabitants to the hectare) will be established for all residential buildings and it will be recommended that such residential buildings, as well as public buildings, be provided with adequate soundproofing, each case being studied individually.

AREA D (R) < 84 (CNR < 102)

No building restrictions.

Areas B and C are seen to be comparable in noise exposure to the CNR region between 100 and 115, or the NEF region between 30 and 40.^{183/}

c) The Netherlands

In the Dutch studies, the results of a similar social survey were related to the noise exposure expressed in terms of the Total Noise Load, B, (see Section III.C), the results led to these conclusions: the correlation between average noise exposure expressed in values of annoyance scores is very high (coefficient of 0.95); the correlation coefficient between the annoyance series and NNI was 0.94. The B-rating was preferred to the NNI because it used A-Levels for the basic noise measure, rather than the more complicated Perceived Noise Level. They found (as did the French study) that it was not necessary to use Perceived Noise Level as a physical measure of the noise, since the A-Level gave equally good correlation with the subjective results. When the Total Noise Load reaches B 45, 28% of the people are sometimes or even frequently annoyed by interruptions of conversation, 66% are sometimes frightened by aircraft noise, and 13% are sometimes or often awakened by aircraft. Comparing their data with the British NNI, the Dutch conclude that the maximum tolerable level of annoyance is reached when the exposure attains B 45, or about 42 NNI.

d) Sweden

A Swedish survey on a somewhat smaller scale (300 interviewees) concluded (like Borsky's early U.S. studies¹⁴*) that when the A-Level for a single overflight reaches 90 dB(A), 50% of the people are annoyed and 25% are extremely annoyed.

* To compare the Borsky results with the Swedish data requires a 20 dB correction for a number of aircraft operations ¹⁰ to 20 times greater in the American than the Swedish study.²¹

e) Germany

The Mean Annoyance Index, \bar{Q} , in Germany was used to compare the measured noise exposure with subjective response, and the results of this comparison led to the definition of four zones around an airport that define suitable land use,^{183/} as follows:

Zone I	$\bar{Q} > 82$. No residential building, uninhabitable.
Zone II	$77 < \bar{Q} < 82$ Residential building only in urgent cases (e.g., for airport personnel). Strong sound suppression measures are required.
Zone III	$72 < \bar{Q} < 77$ Not recommended for residences. Sound suppression measures are indicated if dwellings must be built here.
Zone IV	$\bar{Q} < 72$ No restrictions, but no new hospitals, rest homes, homes for the aged, schools, churches, or scientific institutions may be built in the vicinity of the boundary to Zone III.

f) Correspondences between the Ratings and the Criteria of Tolerable Exposure

Alexandre^{2/} and Grandjean^{188/} give correspondences between the NNI, R (or *N*) and CNR, for various mean peak values of Perceived Noise Level during flyover and various numbers of aircraft operations, as shown in Table XVI. Depending on which of the proposed national criteria of exposure one selects, the correspondences among these ratings will vary somewhat, as indicated in Table XVII. This table was constructed by interpolation in Table XVI, using Galloway's approximate relation between CNR and NEF ($NEF \doteq CNR - 76$) and the criterion values of NNI 45, R 88, CNR 100 and NEF 30.

Table XVI.

Correspondences between the English (NNI), French (R=N)
and American (CNR) Indices

N	80 PNdB			90 PNdB			100 PNdB			110 PNdB			120 PNdB		
	NNI	R	CNR	NNI	R	CNR	NNI	R	CNR	NNI	R	CNR	NNI	R	CNR
1	0	50	68	10	60	78	20	70	88	30	80	98	40	90	108
10	15	60	78	25	70	88	35	80	98	45	90	108	55	100	118
50	26	67	85	36	77	95	46	87	105	56	97	115	66	107	125
100	30	70	88	40	80	98	50	90	108	60	100	118	70	110	128
200	35	73	91	45	83	101	55	93	111	65	103	121	75	113	131
500	41	77	95	51	87	105	61	97	115	71	107	125	81	117	135
1000	45	80	98												
2000	50	83	101												
5000	56	87	105												
	45= 80= 98			45= 83= 101			45= 86= 104			45= 90= 108			45= 95= 113		
	NEF = 22			NEF = 25			NEF = 28			NEF = 32			NEF = 37		

Criterion Chosen	80 PNdB					90 PNdB				
	N	NNI	R	CNR	NEF	N	NNI	R	CNR	NEF
NNI = 45	1000	45	80	98	22	200	45	83	101	25
R = 88, NEF 30	6000	57	88	106	30	500	52	88	106	30
CNR = 100	2000	49	82	100	24	175	43	82	100	24
Criterion Chosen	100 PNdB					110 PNdB				
	N	NNI	R	CNR	NEF	N	NNI	R	CNR	NEF
NNI = 45	50	45	86	104	28	10	45	90	108	32
R = 88, NEF 30	65	47	88	106	30	5	42	88	106	30
CNR = 100	20	38	82	100	24	2	33	82	100	24
Criterion Chosen	120 PNdB									
	N	NNI	R	CNR	NEF					
NNI = 45	3	45	95	113	37					
R = 88, NEF 30	1	42	88	106	30					
CNR = 100	1	37	82	100	24					

TABLE XVII.

CORRESPONDENCE BETWEEN NNI, R(OR *M*), CNR AND NEF FOR VARIOUS CHOICES OF CRITERION

g) Comparison of Land-Use Zoning Criteria

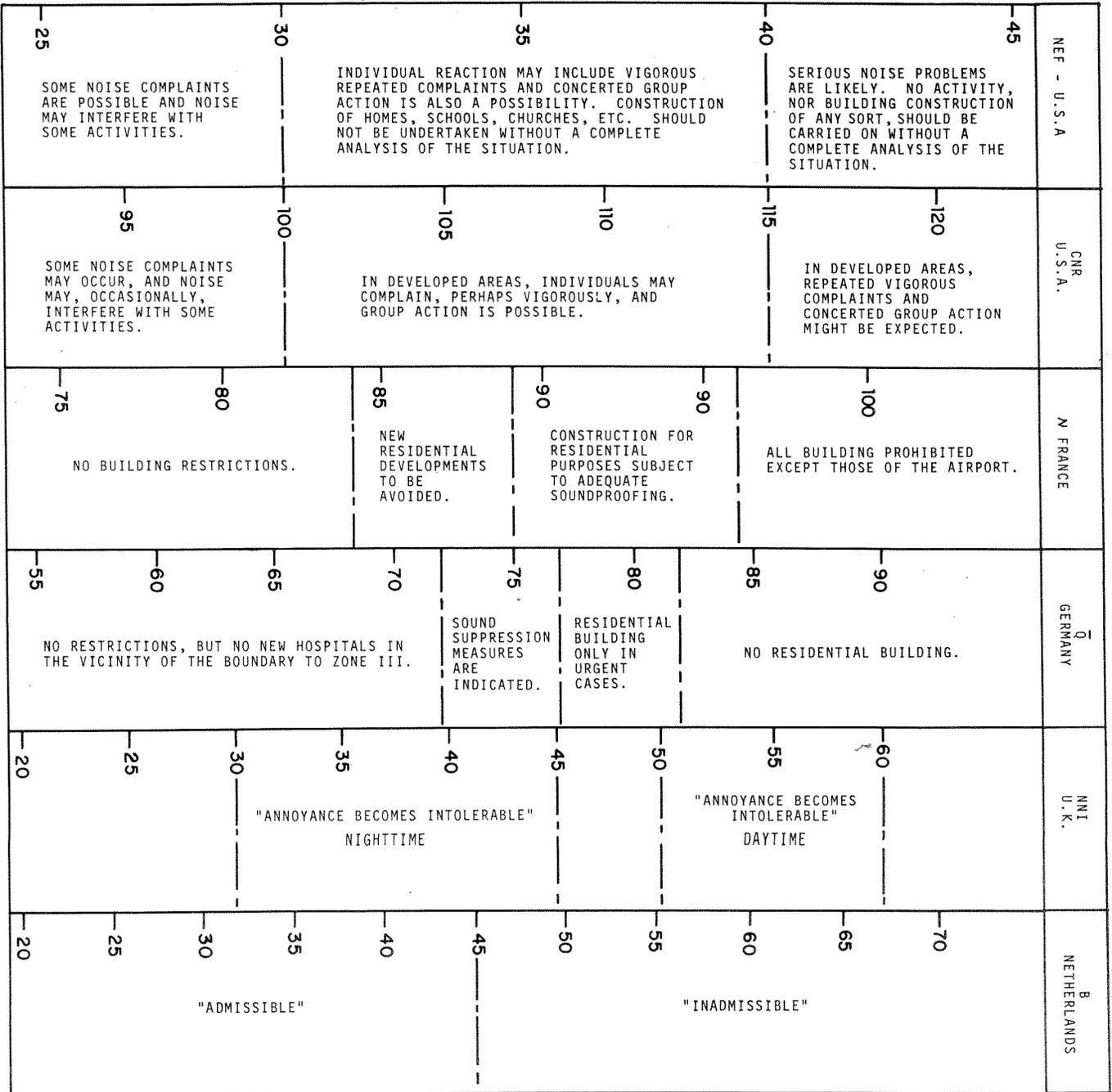
Galloway^{183/} has derived a table of equivalences that allows the zonal boundaries for different land use restrictions for the various indices to be intercompared. These results are shown in Fig. 30.

The comparisons shown in Fig. 30 with the exception of the Dutch limits, identify an upper boundary of acceptable noise exposure for residential use between NEF 38 and 42. At lower levels of noise exposure, where no restrictions on land use are indicated, the equivalent NEF values range from 30 to 33. The diversity of conditions, study methods, and noise exposure computational techniques of these studies all provide conclusions which support each other quite closely. The identification of the three NEF zones ("less than 30", "30 to 40", and "greater than 40") along with their descriptors, seems to be consistent with these other studies (but see below, page 138).

h) Summary of Current Aircraft Noise Abatement Criteria

Alexandre has shown^{2/} that the combined data on overall annoyance from the social surveys in France, England and the Low Countries all are well correlated with, for example, the NNI, (correlation coefficient = 0.916). This suggests that we are perhaps on firmer ground in basing an aircraft noise criterion on results from various countries than in the case of traffic noise, where at least one study has shown significant differences in public response to approximately the noise exposure. Even in the case of aircraft noise, however, there is evidence of national differences in public response to the exposure. Grandjean^{188/} has compared in detail the British and the French studies of response to aircraft noise; he concludes that at a noise exposure

FIG. 30
COMPARISON OF LAND-USE ZONAL BOUNDARIES IN
VARIOUS RATING SYSTEMS FOR AIRCRAFT



between 30 and 40 NNI about 25% of the people in England are annoyed on all counts (disturbance in itself, wishing to change the noise conditions, effects on sleep, reactions of fear, difficulty in conversing, etc.) In France, however, if one bases a judgement on spontaneous mention of disturbance and on difficulty in conversing, about 25% of the people are annoyed when the exposure ranges between 35 and 45 NNI, about 5 dB higher than in England; but judged in terms of difficulty with sleep and reactions of fear, the French do not appear to be significantly annoyed until the exposure reaches 47 to 53 NNI. Like the study comparing the Swedish and the Italian responses to road traffic noise, there is a suggestion here that people are less tolerant of noise intrusion the farther away from the equator they live!

Summarizing the results of the ratings that account for both the level and the number of operations:

The English studies recommend a maximum acceptable level of NNI 45 for night-time; the French studies recommend R 88 (i.e., 45-50 NNI) as a maximum acceptable value, reckoned over a 24-hour period; the Dutch and Germans conclude that $B = 45$ and $\bar{Q} = 72$, respectively, corresponding to about NNI 40-42 for a 24-hour period, is tolerable. Galloway^{183/} equates this exposure (assuming mean peak flyover levels of 110 PNdB) to about NEF 30 (see Fig. 10), the criterion of acceptable exposure in the U.S.; Alexandre and Grandjean^{188/} equate this exposure to a range of NEF from 25 to 37, or of CNR from 98-113, depending on the mean peak flyover level ranging from 80 to 120 PNdB. (See Table XVI).

It should be emphasized that criteria in the NEF 30 range must be regarded as provisional. In each of the national studies in which these limits were developed, these levels of noise showed up as "maximum tolerable" and were regarded as turning points above which annoyance increased very rapidly; but sizable portions of the population were seriously disturbed at much lower levels. These turning points, however, were seized by the authorities and treated as acceptable levels, such that special precautions and noise abatement measures are required only for more severe exposure. The situation is even more extreme in the U.S., since the criteria are based on overt action in terms of complaints or legal action. It is well known^{14,15,34,100/} that serious public annoyance is prevalent long before official complaints are lodged. It is therefore obvious that these criteria are not adequate for aircraft noise abatement in the long run, since they are deliberately permissive. While they may be useful for the immediate purposes of halting the degradation of the noise environment, they are hardly suitable as goals for substantially improving it.

i. Long Term Goal for Aircraft Noise Abatement Criteria

It is necessary to insist on this point because of the currently entrenched view that if a desirable goal is very difficult or expensive to realize in the present state of the art, this fact alone is sufficient excuse for abandoning all attempts to attain the objective.^{2,188/}

What, then is a reasonable goal for long-term aircraft noise abatement criteria? One can surely say that the aircraft noise intensity reaches an intolerable level when it affects the psychological and physical well-being of men, this influence being demonstrated when a considerable portion of the population

- spontaneously declares that aircraft noise is an annoying factor in their homes;
- spontaneously declares that aircraft noise is annoying enough to make them want to move to a quieter location;
- declares, in response to a direct question, that the noise interrupts their sleep, makes them afraid, and interrupts conversation, etc.

The question is, "What constitutes a 'considerable portion of the population'?" As we noted above, we know from social surveys that even in very quiet zones (0 to 20 or 30 NNI) about 10% of the people interviewed complain of the aircraft noise; these same people complain also about other aspects of their environment in general and may be habitual complainers. We recall, too, that about 25 to 30% of the people never complain even in extremely noisy environments.

If we choose to overlook the complainers, we might declare the onset of significant annoyance when, say, 20 to 25% of all the people spontaneously mention their annoyance with the noise. And, taking into consideration the possible effect of suggestion under direct questioning, one might regard the annoyance as serious when 30 to 40% of the people complain in response to direct questions. These percentages, then will define the "considerable portion of the population" described above. With these criteria of public acceptability of the aircraft noise exposure, the British studies indicate corresponding NNI values of 30 to 40, rather than 45, 50 or 60. The French studies would permit about 5 dB higher exposure. That is, we should aim in the long run at a goal of about NNI 35, which is equivalent (for 110 PNdB flyovers) to CNR 95, or NEF 20. (Equivalences corresponding to other peak flyover levels may be found in Table XVI).

Finally, considering the intensity of the noise alone, that is disregarding the number of intrusions, it appears that an outdoor limit of 100-103 PNdB is an upper tolerable limit, on which the French and British studies are in complete agreement. In the U.S., also, Kryter^{206,207/} estimates that individual or group complaints may be expected for levels above 100 PNdB. Similarly, U.S. and Swedish studies showed that above 100 PNdB more than half the population are annoyed. With such a level outdoors, the indoor level with closed windows will be approximately 80 PNdB, which is near that proposed by Metz as the maximum acceptable level from the point of view of sleep interference. Thus, it appears to be well agreed that 100 PNdB represents a threshold that should not be exceeded for outdoor noise levels for a single aircraft operation, no matter what the NEF value for total aircraft noise exposure. As shown in Table XVI, levels of 100 to 120 PNdB occur even for NEF 30 to 40.

Again it should be emphasized that this is a maximum tolerable limit, not the desirable goal, since it imposes the necessity to keep the windows closed to avoid significant disturbance to large numbers of people.*

And again it should be emphasized that setting the balance between criteria for an acceptable noise environment and the cost, (as well as a reasonable schedule) for attaining it is the proper concern of government; such planning involves complex social, political and economic decisions that can be only partially guided by technology.

* An interesting development bearing on this question has been reported recently: after 15 months of limiting night-time jet aircraft flights at Kloten Airport (Zürich) to about 12 operations, the Zürich Cantonal Parliament has now banned such flights altogether, because of the noise. (Flight International, 9 July 1970, p. 44).

IV. SITE EVALUATION GUIDELINE PROCEDURES

Pursuant to the enforcement of HUD's policy on noise abatement, procedures have been devised to evaluate the noise exposure (existing or projected) at building sites for which assistance is requested under any of HUD's operating programs. Among these procedures are techniques developed to permit personnel without much (or any!) acoustical background to evaluate the acceptability of a site, without the use of either acoustical terminology or instrumentation. These procedures are described in detail in HUD's "Noise Assessment Guidelines"²⁹¹/*.

In the Guidelines, simple graphs and tables are provided to help assign a proposed site to one of HUD's four acceptability categories (see Table XVIII) by establishing the relation of the site to an airport, to a railroad, to an above-ground rapid transit line, or to busy streets or roadways. These graphical aids permit a noise evaluation of the site without direct reference to acoustical data or to sound measuring equipment. Indeed, in developing HUD Guidelines, great pains were taken to avoid the "decibel" concept altogether: one proceeds directly from the site information to an assignment of the site to one of HUD's acceptability categories.

The great advantage of avoiding the use of decibels, for personnel without acoustical training, is gained at the cost of a slight disadvantage: for sites that are exposed to noise from

* Ref. 291 is a re-edited version of Ref. 287, to make it compact, attractive and accessible for use by acoustically untrained people.

TABLE XVIII

HUD's Acceptability Categories for
Proposed Housing Sites

Clearly Acceptable:

the noise exposure is such that both the indoor and outdoor environments are pleasant.

Normally Acceptable:

the noise exposure is great enough to be of some concern but common building constructions will make the indoor environment acceptable, even for sleeping quarters, and the outdoor environment will be reasonably pleasant for recreation and play.

Normally Unacceptable:

the noise exposure is significantly more severe so that unusual and costly building constructions are necessary to ensure some tranquility indoors, and barriers must be erected between the site and prominent noise sources to make the outdoor environment tolerable.

Clearly Unacceptable:

the noise exposure at the site is so severe that the construction costs to make the indoor environment acceptable would be prohibitive and the outdoor environment would still be intolerable.

two or more critical and nearly equal sources, there is no really satisfactory way to assess the combined exposure in terms of HUD's acceptability categories. The Guideline procedures give (rather arbitrary) directions as to how to deal with such situations; in case of doubt, a noise measurement or an approximate assessment at the site may be required to resolve the question (see below).

A site evaluation must be carried out for each type of noise source to which the site is exposed: in order to evaluate a single site, therefore, a number of evaluation procedures* are followed; of these, the evaluation that assigns the site to the least acceptable category determines the ultimate disposition of the site.

The Guideline procedures are equally useful for assessing present noise exposure and also future conditions. Certain cases may also justify a visit to the site to get an estimate of the existing noise exposure though still without requiring the use of acoustical instrumentation. (The Walk-Away Test, see below).

HUD's Guideline predictive evaluations are, needless to say, approximate, for it will never be possible to ~~account~~ for all the peculiarities of the proposed site that may affect the noise exposure. But HUD's goal is not to measure the noise level at the site with great precision, but to screen out unacceptably noisy housing sites; the predictive guideline procedures will go a long way toward reducing the number of housing units in the U.S. with excessive noise exposure.

* For aircraft, for autos, for trucks, for railroads, etc.

In the event that the Guideline procedures should, for some reason, fail to categorize the site satisfactorily as to noise exposure, the existing noise levels must be actually measured in quantitative terms (decibels); and the data must be presented in such a form that the results can be compared with the interim standards set forth in HUD's policy circular on noise abatement^{292/}. Such a measurement requires the use of acoustical measuring equipment of a fair degree of complexity^{290/}, and would be undertaken by technically-trained persons.

It is the purpose of this chapter to give the technical background underlying the predictive procedures of the Guidelines, that is, to justify the Guidelines approach by reference to the extensive literature that documents the present state of the art in measurement, evaluation, and abatement of urban noise. The background material that accounts for the selection of the rating methods used in expressing HUD's noise abatement standards and for the particular interim criterion values adopted by HUD in the noise abatement policy circular is given in Chapter III above. Other material directly relating to HUD's current noise abatement efforts will be found in Refs. 288, 289, 290, and 293.

In the Guidelines, the various important sources of urban noise are dealt with separately; the same scheme is followed here, and in the same order as in the Guidelines, to facilitate cross-reference, when desired, between an evaluation procedure and its technical background.

First, however, we describe the method we have used to relate the requirements of HUD's interim noise standards to the information on noise and noise abatement existing in the literature.

A. Interpretation of HUD's Interim Policy Standards for Developing "Guidelines"

It will be recalled, from the discussion in Section III-D-7 (p. 124), that the interim standards for non-aircraft noise set out in HUD's Policy Circular on Noise Abatement are not presented in standard statistical format; neither are they written in such a way as to prescribe average or typical noise levels that would be judged acceptable. (The exact wording of HUD's interim standards is given in Appendix A of this chapter.)

On the other hand, practically all the available studies of existing noise exposure, and the recommended criteria of acceptability in various countries of the world are framed in statistical format or in terms of median (L_{50}) noise levels (see Chapter III).

In order to apply the noise abatement information in the literature to the assessment of noise exposure at a site in terms of HUD's acceptability criteria, therefore, it is necessary to interpret HUD's criteria in a manner compatible with the available published data. We have suggested in Figure 29 a preferred format for HUD's interim acceptability criteria that closely approximates the actual decibel numbers in HUD's interim policy standards, as currently stated, and is also consistent with the consensus of criteria recommended in other countries, while conforming to the statistical format. Considering the variability of human reaction to noise (see p. 22 and pp. 26-28), this statistical format is in practice equivalent to, and may be used interchangeably with, the current HUD interim standards. We hope it will be possible eventually to adopt this statistical format in the policy circular.

The state of the art has not yet advanced to the point where, for the purposes of developing Guideline procedures, we can predict with confidence the entire statistical curve of noise exposure at a site. Instead, we have taken as the basis for the predictive procedures in the Guidelines the median (L_{50}) levels bounding the areas that define the statistical equivalent of HUD's site acceptability criteria, shown as heavy dots in Figure 29. (There is no way of determining acceptable median levels corresponding to the interim standards as stated in the Policy Circular, see Fig. 28.) Note that the boundary median levels derived by the procedure described above are separated by 15 dB(A).

A further technical point supports the choice of 15 dB intervals between the boundaries separating the four acceptability categories as shown in Figure 29: it concerns the increments in noise isolation that practical building construction measures can achieve: it is not possible, as one might wish, to match a certain excess of noise exposure at a site with a corresponding building construction improvement that precisely compensates the excess noise and brings the site just into conformity with a given noise acceptability goal. Instead, practical noise improvements come in fixed increments of about 15 dB: these increments may be attained either by closing the windows of a building with ordinary construction, by adding well-sealed double-windows to an ordinary building construction (and providing the necessary supplementary ventilation), or by providing an effective

barrier between the site and the source of noise.⁽ⁱ⁾ Combinations of these measures give increments in multiples of about 15 dB. Thus, when it becomes necessary to provide special noise isolation measures to make a site acceptable as a living environment, any 15 dB improvement will change the noise assessment by one whole category and the desired result will be achieved, no matter where in the unacceptable range the site initially lay.

The next five sections give the technical acoustical background underlying each of the procedures that are given in non-acoustical terms in the Guidelines.

(i) See refs. 2, 7, 8, 26, 27, 36, 45, 51, 52, 57, 74, 85, 87, 91, 94, 96, 100, 101, 110, 116, 121, 126, 142, 146, 149, 150, 152a, 162, 211, 219, 224, 247, 272, 274, 275, 284, 285.

B. Aircraft Noise

The evaluation of housing sites with respect to civil aircraft noise exposure is based on the Noise Exposure Forecast (NEF) contours recently adopted by the U. S. Department of Transportation.* These contours take into account the total annual number of aircraft operations of various types of airplane using a given airport, the proportion of daytime to nighttime flights, the percentage use of the various available runways, and the noise generated by each type of aircraft, weighted according to frequency in such a way as to approximate people's subjective reaction to that noise.

*Current FHA instructions for underwriting on home mortgages (Section 14 of the FHA Manual, paragraphs 71453 through 71453.9) provide that the FHA should seek guidance from the FAA Airport District Offices with respect to CNR contours for civil air bases and from the commander of the military base for CNR contours to be used in the valuation analysis of residential properties in the vicinity of a military airport.

The Composite Noise Rating (CNR) has been used by the FAA for some years for land use planning in the vicinity of both civil and military airports. The FAA is currently changing over to the Noise Exposure Forecast (NEF) for land use planning around civil airports. Current NEF procedures do not permit evaluation of the noise of military aircraft but plans are being made to develop the necessary noise and aircraft performance data that would allow the NEF to be extended to military air bases; these same plans include provision in the NEF procedures to evaluate the noise of ground run-ups (this type of operation is already covered by the CNR). Ground run-ups are not usually a major problem around civil airports, though they often cause complaints around military air bases. For these reasons, until the revised NEF procedures are ready, only the Composite Noise Rating is appropriate for rating military bases, but NEF procedures are to be used for civil airports.

The NEF contours are used as follows:

To evaluate the noise exposure around a particular civil airport, a number of these NEF contours of equal noise exposure are superimposed upon a map of the region to suggest compatibility of land use; that is, appropriate land use patterns that will minimize unacceptable noise exposure for various types of buildings.

The two NEF contours of greatest significance to HUD's Guideline noise assessment are NEF-30 and NEF-40, the lower number (not related in any direct way with decibels) indicating a less severe exposure. For all sites lying "well outside" the NEF-30 contour,* there should be no adverse effects of aircraft noise on residences at all, and thus this area would correspond to HUD's "Clearly Acceptable" category. Sites lying "just outside" the NEF-30 contour** correspond to the Normally Acceptable category; normal building construction will protect the interior environment though the outdoor environment may be somewhat deteriorated. On the other hand, for all sites lying inside the NEF-40 contour, the acoustical treatment required to make the indoor environment habitable would be so expensive as to be unreasonable, and the outdoor environment would not be acceptable at all. This area falls into HUD's "Clearly Unacceptable" category. The area lying between the NEF-40 and NEF-30 contours corresponds to HUD's "Normally Unacceptable" category; for sites in this area an analysis of building noise reduction requirements should be made

*In practice, "well outside" is arbitrarily taken to mean outside the NEF-30 contour by a distance at least as great as the distance between the NEF-40 and NEF-30 contours along a radius connecting the proposed site to the center of the runway area of the airport.

**That is, outside the NEF-30 contour but at a distance less than the separation between the NEF-40 and NEF-30 contours along the radius to the center of the runway area.

and the needed noise control features must be included in the building design. If the CNR, rather than the NEF, Contours are available for the airport in question, the assignment to HUD's acceptability categories is made as follows:

<u>If the Site Lies:</u>	<u>Category:</u>
"Well outside" the CNR 100 Contour	Clearly Acceptable
"Just outside" the CNR 100 Contour	Normally Acceptable
Between the CNR 100 and the CNR 115 Contours	Normally Unacceptable
Inside the CNR 115 Contour	Clearly Unacceptable

The most reliable procedure for evaluating a proposed housing site with respect to aircraft noise is to rely on the local office of the Federal Aviation Administration to supply calculated Composite Noise Rating (CNR) or Noise Exposure Forecast (NEF) contours for all the civil airports in the region in question. For military airbases, the base commander will sometimes have calculated CNR contours.

Nope

For cases where the FAA is unable to supply computer-calculated contours of Composite Noise Rating (CNR) or Noise Exposure Forecast (NEF) for the nearby airports, HUD's Guidelines present a predictive procedure for evaluating the exposure of a site to aircraft noise. This procedure consists of drawing approximate contours corresponding to NEF-30 and NEF-40 on a map of the neighborhood of the airport in question, based on information about the number of jet operations at that airport by day and by night. (No approximate procedure can be given for constructing CNR contours).

The aircraft noise evaluation guideline procedure was developed from an analysis of the computer-calculated NEF contours for thirty U. S. airports 9,282/, ranging widely in size in various parts of the country, for numbers of jet aircraft operations projected into the year 1975. A comparison of the NEF contours of these airports shows that U. S. airports can be broken down into four "number-and-type-of-operation" classifications in each of which the "size" of the NEF contours are very similar. Thus, if one knows the number of daytime and nighttime operations of jet aircraft into and out of an airport, and the major flight paths that they follow, one can construct approximate contours corresponding to NEF-30 and NEF-40, and consequently can screen sites in the neighborhood of that airport according to their HUD acceptability category.

For convenience in categorizing the airports, an Effective Number of Operations is defined, based on the formula for calculating the Noise Exposure Forecast.^{183/} The term in the NEF formula that accounts for the number of flights is

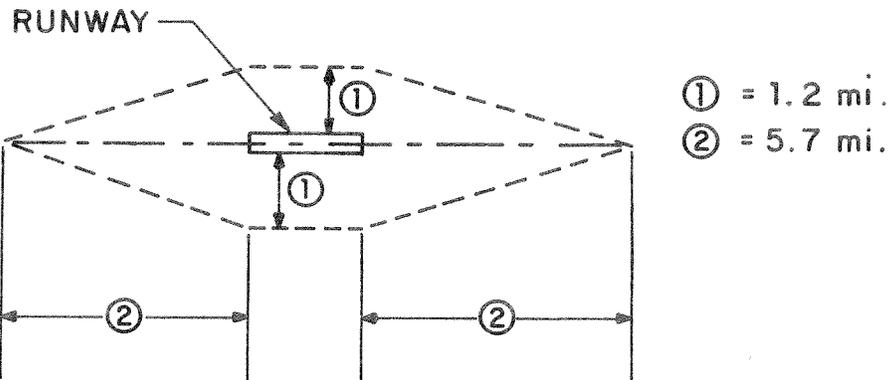
$$10 \log (N_d/20 + N_n/1.2)$$

where N_d and N_n are, respectively, the numbers of jet operations during the daytime (0700 to 2200 hours) and nighttime (2200 to 0700 hours) periods. The constants (20 and 1.2) were chosen to satisfy the following two requirements: 1) for a constant number of flights per hour, the NEF for "all nighttime" operations will be ten units higher than for "all daytime" operations (this is roughly equivalent to treating the noise of a nighttime flight as though it were 10 dB louder than its actual value); and 2) the formula is normalized (that is, this operations term should be zero) for an airport operations load of 20 daytime flights, with no nighttime flights.

The Effective Number of Operations (ENO) for HUD's Guidelines procedure is just the argument of the NEF operations term, above, multiplied by twenty in order to simplify the constants in the expression:

$$ENO = N_d + 20/1.2 N_n = N_d + 17 N_n$$

This ENO parameter was calculated for each of the airports for which computer-generated NEF contours have been developed. In addition, the sizes of the computer-generated NEF-30 and NEF-40 contours for each of the airports were measured (from the contours plotted on maps of the neighboring region), in terms of the distance along the ground under the flight path (from either end of the runway) to the contours, and the distance to the contours along the ground to either side of the runways. Thus, the "size" of each actual NEF contour is given by a pair of numbers (such as "5.7/1.2 mi."), meaning that the contours for the major runways at the airport have a "lozenge shape" with those dimensions, as illustrated in the accompanying sketch:



Construction of Approximate NEF Contours
Using the Distances ① and ②, as in Table XX

TABLE XIX. DEVELOPMENT OF AIRCRAFT NOISE EXPOSURE ASSESSMENT PROCEDURE

CITY	JET AIRCRAFT OPERATIONS			NEF CONTOUR SIZE		
	Day	Night	SST	Airport Traffic Parameter, ENO	NEF 30	NEF 40
Concord, Calif.	6	0	0	6	0.1/0.04 mi.	None
Van Nuys, Calif.	22	0	0	22	0.37/0.13 mi.	None
Ithaca, N. Y.	5	0	0	5	0.66/0.1 mi.	None
Atlanta (Fulton)	13	0	0	13	0.57/0.1 mi.	None
Columbia, Mo.	3	1/2	0	11	1.0/0.2 mi.	700/100 ft.
Wisconsin Rapids	1	0	0	1	0.5/0.05 mi.	None
Colorado Springs	80	5	0	165	1.5/0.38 mi.	3500/1000 ft.
Huntsville, Ala.	98	0	0	98	2.65/0.38 mi.	3500/1000 ft.
Nashville, Tenn.	164	27	0	623	3.2/0.57 mi.	7000/1000 ft.
Little Rock, Ark.	108	7	0	227	2.65/0.47 mi.	5000/1000 ft.
Erie, Pa.	40	4	0	108	3.0/0.4 mi.	5000/500 ft.
Raleigh-Durham	130	19	0	453	3.5/0.5 mi.	6000/1500 ft.
Melbourne, Fla.	87	20	0	427	3.0/0.66 mi.	9000/2000 ft.
Tulsa, Okla.	199	16	0	488	4.5/0.85 mi.	12000/2000 ft.
San Diego	267	46	0	1049	6.0/1.5 mi.	12000/3000 ft.
Kansas City	302	86	0	1762	5.7/1.2 mi.	13000/2000 ft.
Hartford	115	32	0	659	5.7/0.66 mi.	14000/2000 ft.
El Paso	130	36	0	742	4.5/0.75 mi.	9000/1200 ft.
Milwaukee	210	38	0	856	5.1/0.55 mi.	14000/1100 ft.
Dallas/Ft. Worth	704	131	0	2931	6.8/1.3 mi.	22000/2000 ft.
Washington (Nat)	614	64	0	1702	9.3/1.0 mi.	15000/2000 ft.
Wash. (Dulles)	332	82	10	1722+SST	10.0/2.1 mi.	25000/3000 ft.
Tampa	366	120	0	2400	5.5/1.3 mi.	17000/2000 ft.
Boston	680	136	17	2990+SST	11.0/1.9 mi.	20000/3000 ft.
Portland, Ore.	360	64	0	1450	9.5/1.0 mi.	20000/2000 ft.
Detroit	544	114	0	2484	10.0/0.75 mi.	24000/2000 ft.
Los Angeles	1089	185	19	4234+SST	9.5/1.0 mi.	30000/2000 ft.
Chicago	1637	315	0	6992	8.0/0.75 mi.	22000/2000 ft.
Seattle/Tacoma	280	88	8	1776+SST	10.0/1.7 mi.	24000/4000 ft.
New York (Kennedy)		171	36	3927+SST	- /0.75 mi.	26000/2000 ft.
	1020					

153

Table XIX summarizes the data on the number of operations and the contour sizes for the thirty airports studied. The airports group themselves into four categories in terms of the approximate contour sizes, and these size categories can be identified by corresponding values of the effective operations parameter ENO, as shown in Table XX.

TABLE XX. DISTANCES FOR APPROXIMATE NEF CONTOURS

Effective Number of Operations ENO	Distances to NEF- 30 Contour		Distances to NEF- 40 Contour	
	①	②	①	②
0 - 50	1000 ft	1 mile	0**	0**
51 - 500	1/2 mile	3 miles	1000 ft	1 mile
501 - 1300	1-1/2 miles	6 miles	2000 ft	2-1/2 miles
More than 1300 or any supersonic jet operations*	2 miles	10 miles	3000 ft	4 miles

X This is the information given in Table II of the Guidelines; the distances tend to be on the high side, and thus give a conservative evaluation of the noise exposure.

*The number of supersonic transport operations, day or night, does not enter explicitly into the determination of the Effective Number of Operations; however, the existence of any SST operations at all automatically assigns the airport into the largest category.

**For small airports, there is usually no NEF-40 contour at all; that is, there is no area outside the airport boundary that would, according to the HUD Policy Circular, fall into the Clearly Unacceptable category; remember, however, that all sites lying inside the NEF-30 contour are judged Normally Unacceptable and must be handled accordingly, with proper administrative approval and careful attention to providing additional sound isolation in the construction.

Approximate NEF contours (NEF-30 and -40) should be constructed, using these data, for all the major runways of the airport. The outlines of all the NEF-30 contours for the individual runways are connected to form a single NEF-30 contour for the airport as a whole; and similarly for the NEF-40 contour. Then any proposed housing site in the airport neighborhood is assessed as to its aircraft noise exposure according to the rules on page 149, above.

An attempt was made to refine the NEF approximation for airports where there are, say, two runways carrying nearly equal traffic and oriented at about 90° to one another (or three runways at about 60°). It turned out that the resulting changes in contour size are not very great and the improvement in noise assessment was not worth the added complication in the procedure, which already entails a fairly large amount of graphical construction.

C. Automotive Traffic: Streets, Highways and Expressways

The U. S. population has increased by a factor of only one-third since 1950; but the number of automobile registrations has increased by a factor of 2.25; trucks have become 2.3 times and motorcycles 6 times more numerous in this twenty-year period. Although important efforts are currently underway to help alleviate the noise exposure due to automotive traffic...for example, ordinances to control the maximum noise-making capability of individual vehicles, ordinances to limit the noise actually produced in operation on streets and roads, and the design of streets and highways (in terms of routing, depression of roadway, and roadside barriers) to minimize the amount of noise reaching the majority of the population...none of these efforts lies directly within HUD's jurisdiction. The most HUD can do for the time being is to make the best possible use of the sites available

for housing; that is, HUD is taking care that, given the existing noise exposure at various places in the community, sites with noise exposure too severe to be acceptable as a living environment should be used for purposes other than housing.

1. Guidelines Assessment Procedure for Noise from Expressways and Highways

Acceptability guideline curves for sites exposed to the noise of road traffic are presented in Figures 2 and 3 of the Guidelines for automobiles and trucks, respectively. (Those figures are reproduced here as Figures 31 and 32.) The noise exposure expected at many such sites can be predicted with reasonable accuracy in terms of the mean traffic speed, the traffic volume, and the distance from the nearest edge of the roadway. Surveys of traffic noise show that the noise also depends in a complicated way on the percentage mix of trucks and automobiles in the traffic volume. To avoid this complication here, we deal with automobile and truck traffic as separate and independent populations; one noise evaluation should be made for the volume flow of automobiles and a separate evaluation for the volume flow of trucks (buses count as trucks). The Acceptability Guidelines curves for autos and trucks (Figures 31 and 32) apply to flat arterial roadways at ground level where the mean automobile travel speed is about 60 miles per hour, and the mean truck speed is 30 miles per hour, with a wide range of volume flow for both automobiles and trucks. The basic noise evaluation determines whether or not a problem will exist for sites near such roads. The curves are used as follows, for a basic evaluation; subsequent corrections are applied to account for possible road gradient, stop-and-go traffic, differences in actual road speed, and the presence of barriers.

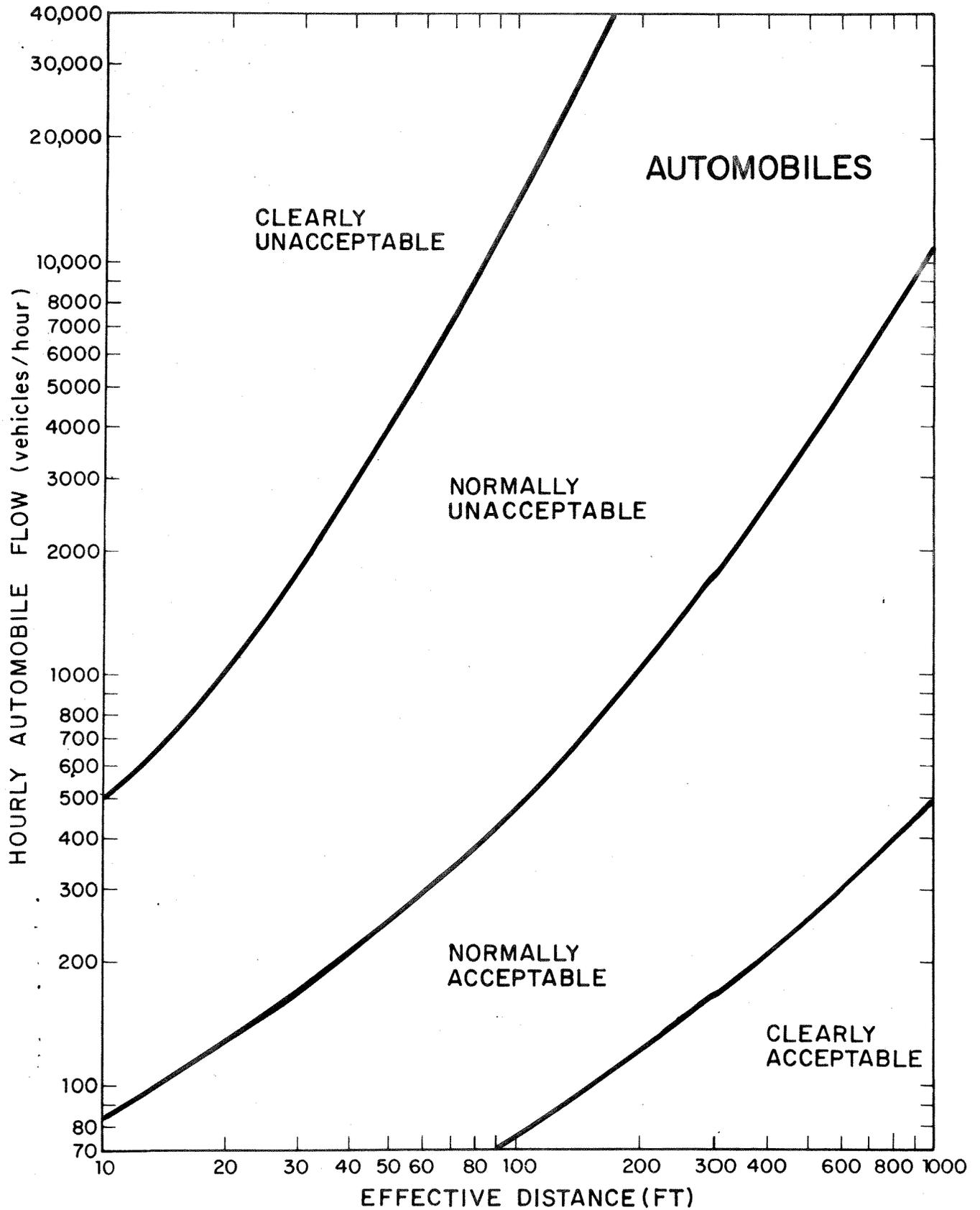


FIG. 31 SCREENING CRITERIA FOR SITES NEAR MAJOR ROADWAYS
AUTOMOBILE TRAFFIC

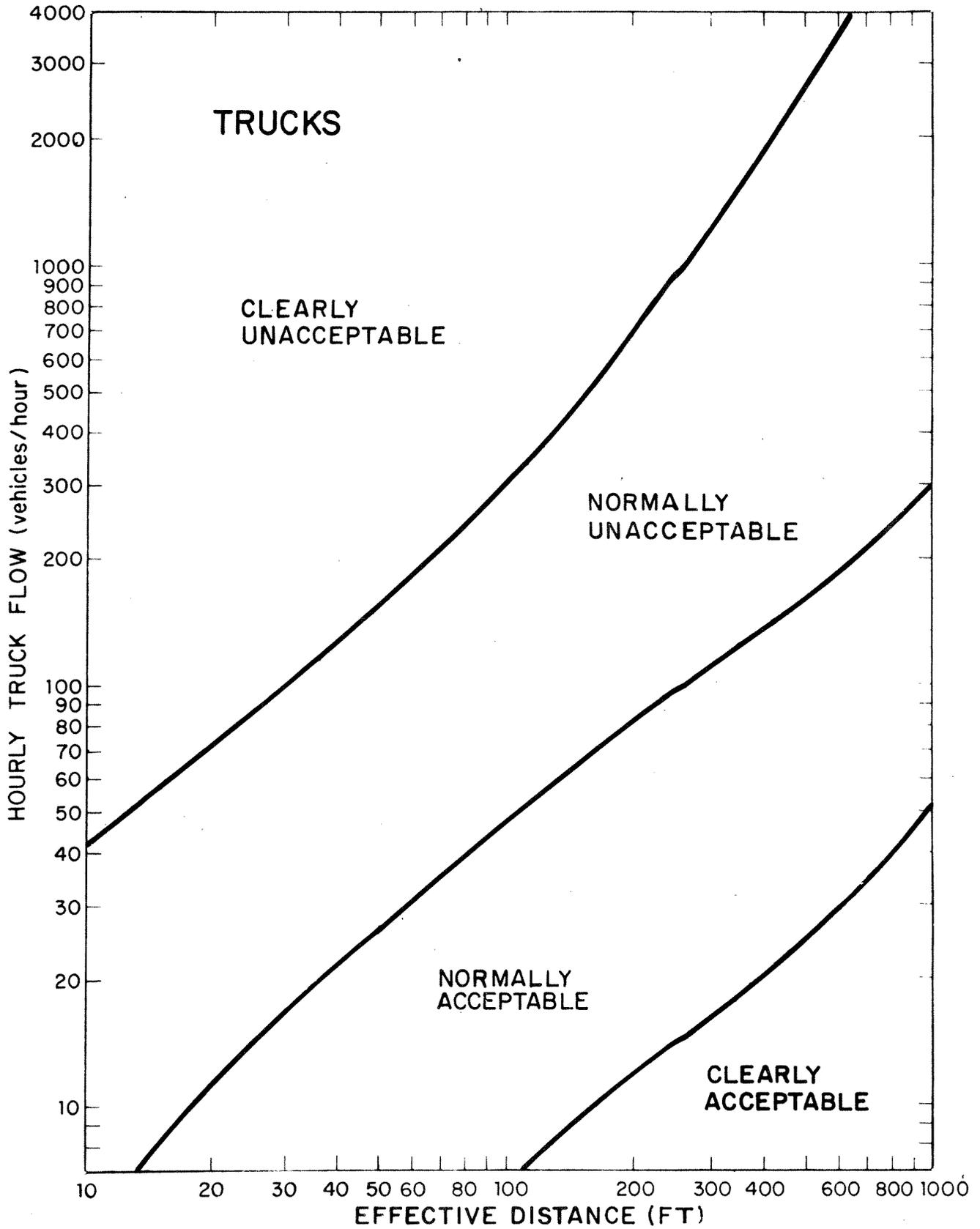


FIG. 32 SCREENING CRITERIA FOR SITES NEAR MAJOR ROADWAYS
TRUCK (AND BUS) TRAFFIC

With the typical peak hourly automobile and truck traffic flows and the distance to the road, enter Figures 31 and 32 respectively; the point determined by the distance to the roadway and the peak traffic flow in each case indicates in which of HUD's acceptability categories that site location lies.

2. Basic Automobile and Truck Noise Data

The data on which the assessment of sites with respect to roadway noise is based are summarized in Ref. 54*, Figs. 3 and 4 (re-produced here as Figures 33 and 34) for automobiles and trucks, respectively, operating at various speeds on level roadway with clear line-of-sight to the observer's position, with no intervening barriers, no elevated roadway, no depressed roadway, and no nearby traffic signals. These data are based on a combination of two approaches: 1) summarizing the bulk of measured acoustical data on road traffic noise by means of mathematical expressions that best describe the observed noise levels in terms of the various traffic flow parameters, e.g., speed, vehicle flow rate, observation distance, etc.; and 2) from measurements of the acoustic power generated by individual vehicles of various types, developing traffic noise models that predict noise levels resulting from the superposition of a number of vehicles with different mixes of vehicle type, speed, spacing along the road, etc., by means of computer calculation. The results of a number of recent traffic noise studies 22,32,70,86,87,93,100,101,105,110,136,138,142,149,189/ are accounted for in these summary figures, and in the accompanying tables of corrections for various road and traffic parameters.

*This report has been republished by the Highway Research Board (Ref. 286); in the following text, references are given for both published versions. Copies of Ref. 286 are available from the Highway Research Board, National Academy of Sciences, 2101 Constitution Avenue, Washington, D.C., 20418 (\$4.60).

HUD's roadway noise guideline curves in Figures 31 and 32 were constructed from the basic Highway Research Board^{286/} data as follows. Refer first to the curves for a mean automobile road speed of 60 mph and an observation distance of 100 ft. in Figure 33. In Figure 31, for automobiles, the boundary line between the Clearly Acceptable and the Normally Acceptable regions represents a locus of constant median auto noise level (L_{50}) equal to 45 dB(A); it is found by reading from Figure 33 the median levels at 100 ft. corresponding to various flow densities (at 60 mph), and then calculating the distance from the roadway at which an observer would have to locate himself to find a median level of 45 dB(A).

For this purpose, a mean value, for the attenuation of median noise level with distance, of 4.5 dB per doubling of distance was assumed: this value lies midway between the theoretical values for a point source of sound, such as an isolated noisy vehicle (6 dB/double distance) and for a continuous line of closely-spaced vehicles (3 dB/double distance). The 4.5 dB value corresponds most nearly to the bulk of the noise measurements, both for automobiles and for trucks, at the distances most likely to be of concern in HUD's noise evaluation procedures.

The result of the calculation described above is a set of pairs of numbers relating automobile traffic volume and "distance-to-45 dB(A)"; these numbers are plotted on Figure 31 to define the boundary between Clearly and Normally Acceptable.

A similar procedure was followed to define the other two boundaries on Figure 31 as well as the three boundaries on Figure 32 dealing with truck noise; note that the basic truck noise curves assume an average truck speed of 30 mph, instead of 60 mph, as for

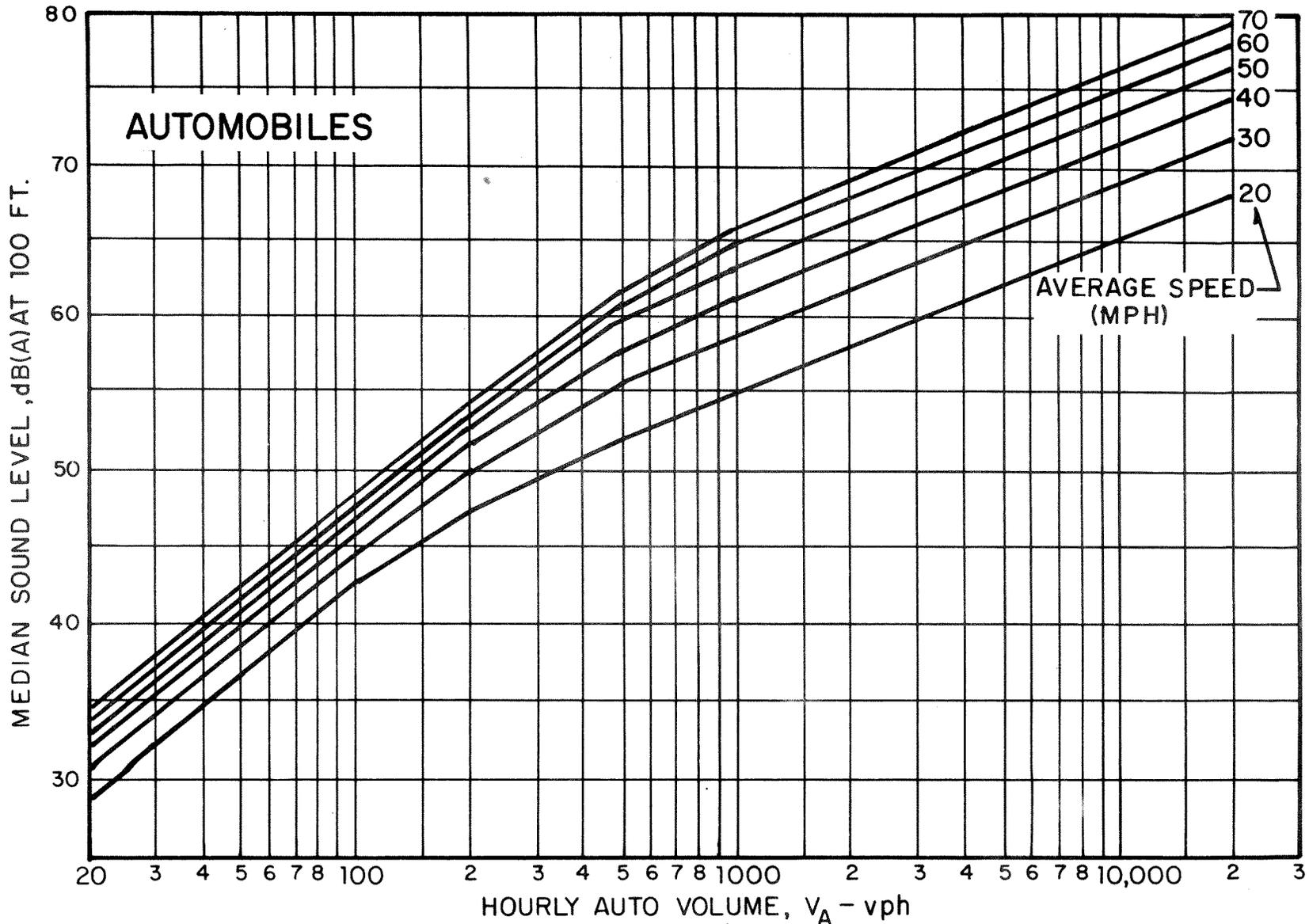


FIG. 33 PLOT OF L_{50} FOR AUTOMOBILES AS FUNCTION OF VOLUME FLOW AND AVERAGE SPEED

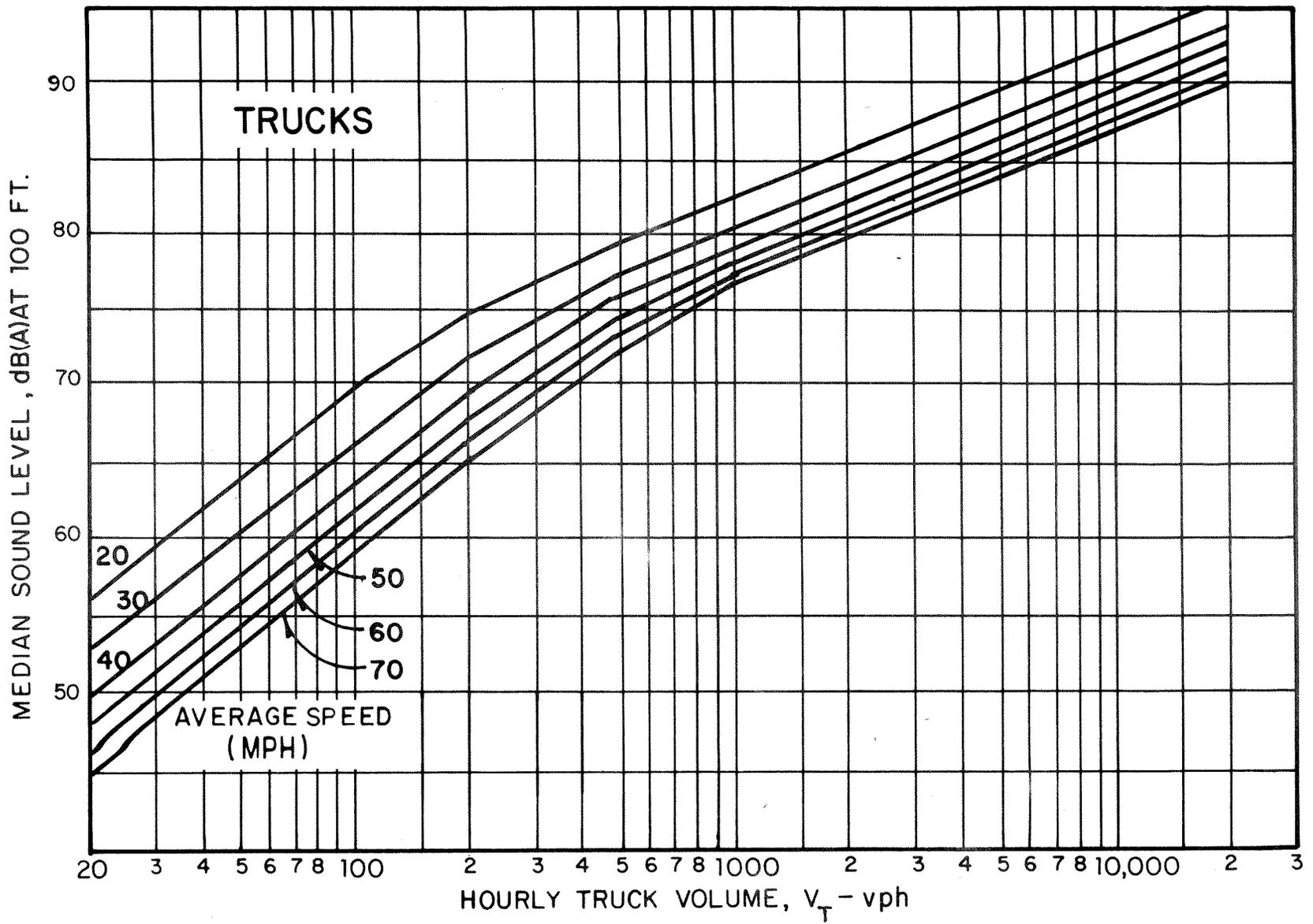


FIG. 34 PLOT OF L_{50} FOR TRUCKS AS FUNCTION OF VOLUME FLOW AND AVERAGE SPEED

automobiles. The basic evaluation of Figures 31 and 32 thus correspond to a "probable noisiest traffic speed". (See C. 3. c. below).

3. Adjustments to Basic Evaluation to Take Account of Various Significant Factors

The curves of Figures 31 and 32 assume a clear line-of-sight between the proposed site and the roadway, with no roadway barriers or cuttings (depressed roadway), no stop-and-go traffic, a mean automobile traffic speed of 60 miles/hour or a mean truck speed of 30 miles/hour, no road gradient, and a total traffic volume that flows largely in the lane nearest the site (since the distance to the road edge was used without accounting for road width). Any of these factors, ignored in the basic evaluation, could affect the noise levels reaching the site in one way or another; and if several factors act together, say, to increase the noise level, their combined effect may be sufficient to shift the noise exposure of the site to a less acceptable category.

The various adjustments recommended in the Guidelines are, therefore, intended to permit a more critical evaluation of the roadway noise exposure than the basic evaluation of Figures 31 and 32.

a. Road Width

On a multilane roadway the traffic (in both directions) is spread out more or less uniformly over the entire road, rather than being concentrated in the near lane of the roadway, as implied in using the distance from the site to the edge of the road in Figures 31 and 32. To handle this situation, Ref. 54 (p.42) and Ref. 286 (equation 26, p. 11) define an effective distance D_e from the site to the road as:

$$D_e = \sqrt{D_n \cdot D_f}$$

where D_n and D_f are respectively the distances in feet to the centerlines of the nearest and the farthest lane of traffic. The computation of D_e is simplified by the nomogram of Figure 35 (this figure is the same as Figure 1 of the Guidelines). For example, if the distance to the centerline of the near lane is 300 feet and to the centerline of the far lane is 366 feet, these two values are connected by a straight line and the effective distance, D_e , is found from the center scale of the nomogram to be 330 feet.

The effective distance D_e is then used to enter Figures 31 and 32 in this refinement of the basic evaluation procedure, instead of the simple distance from the site to the road edge.

b. Road Gradient (Slope)

The noise of trucks, but not of automobiles, increases on up-hill grades; therefore, when we use the traffic flow volume, the up-grade volume flow of trucks near a site must be distinguished from the down-grade flow. Automobiles moving in both directions may be lumped together.

The volume flow for trucks is adjusted for a road gradient in the up-hill direction according to the recommendation of Ref. 54 (Table 1, p. 53, or Ref. 286, Table 1, p.14), which is given in decibels as follows:

Percentage Gradient:*	<2	3-4	5-6	>7
Adjustment in dB:	0	+2	+3	+5
*Feet of rise per 100 foot length of road.				

In order to avoid dealing with decibels in the Guidelines, these adjustments were converted to adjustments in truck volume flow by reference to the basic truck data of Figure 34. Utilizing the portion of the 60 mph curve for flow volume exceeding about 500

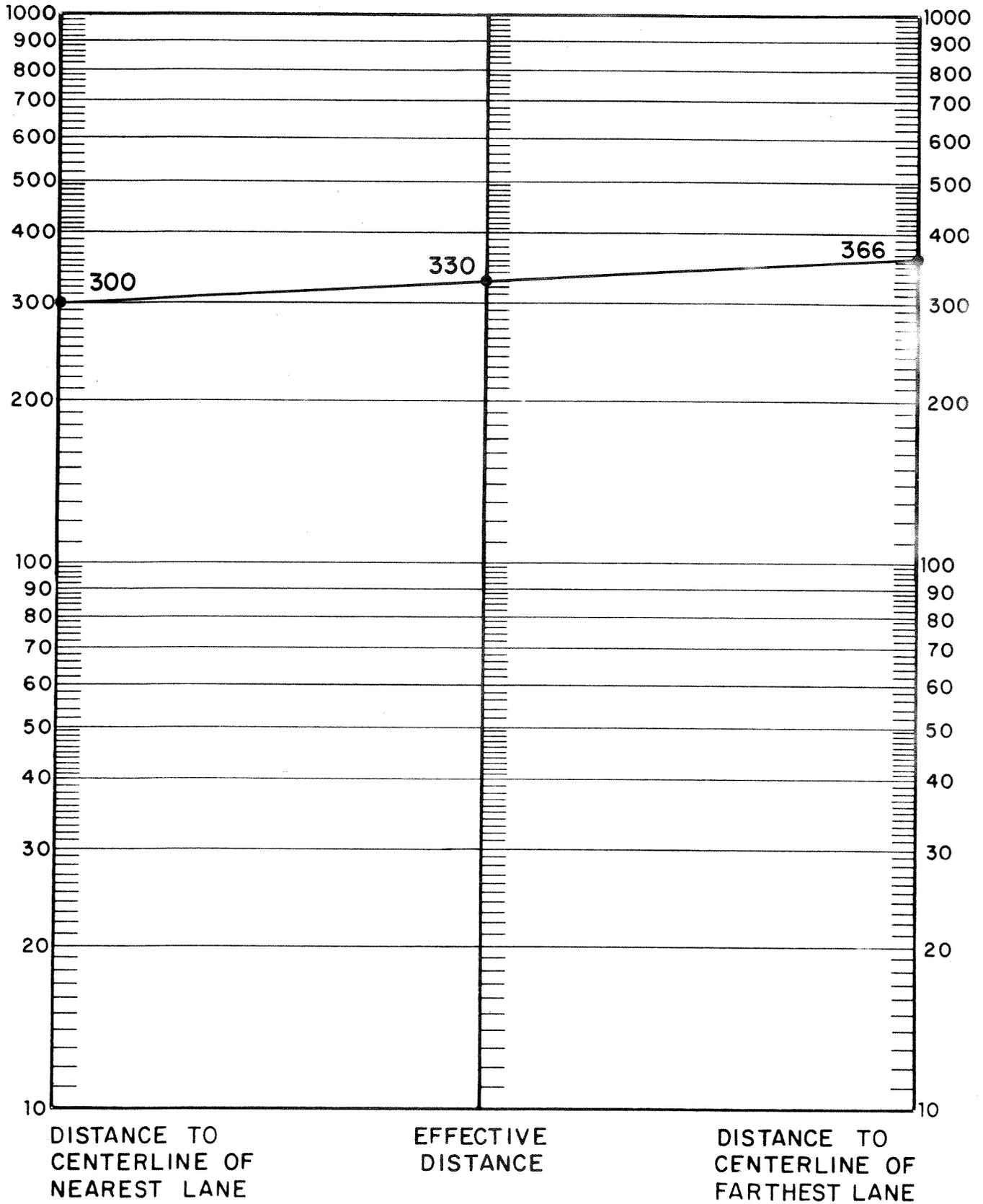


FIG. 35 NOMOGRAM FOR CALCULATING EFFECTIVE DISTANCE FROM ROADWAY

vehicles/hour, the increase in truck volume flow was found that causes the same increase in noise level as the various adjustments in dB for road gradient, as shown above; the results are as follows, corresponding to the table of Road Gradient adjustments given on page 10 in the Guidelines:

Percentage Gradient:	3-4%	5-6%	>6%
Multiplier of truck volume flow:	1.4	1.7	2.5

The adjusted uphill truck volume flow is then added to the actual (unadjusted) downhill truck flow to get the total hourly effective truck volume flow, for use in Figure 32.

c. Mean Traffic Speed

The noise at a certain distance from a given flow of traffic usually changes as the mean vehicle speed changes.*

*Paradoxically, it does not always increase for faster speeds. This is because automobiles and trucks are operated quite differently in freely-flowing road traffic, and also because of differences in the dominant sources of noise for automobiles and trucks.

For an automobile, both the engine exhaust and the tires are dominant sources of noise; both of these sources get noisier with increasing road speed and engine rpm. For a truck, the engine exhaust is usually more prominent than the tire noise; moreover, the operator drives so as to maintain nearly constant engine rpm, for maximum efficiency; thus, the noise of a truck remains fairly constant with changes in speed, over the range of speeds encountered in freely-flowing traffic. The only way to increase the noise from freely-flowing truck traffic (no autos) is to increase the number of trucks that occupy the stretch of road near the observer: for a given number of trucks per hour (i.e., fixed volume flow), this can be done only by decreasing the average speed of the trucks. Alternately, for a given average truck speed, the noise would be increased by crowding more trucks onto the road, increasing the hourly volume flow. (Continued on next page)

The following procedure was followed to determine the adjustments to the traffic volume flow to account for differences in mean traffic speed: notice, for example, in Figure 33, in the region of automobile volume flows exceeding about 500 vehicles/hour, that in moving down from 60 mph to 30 mph for the same volume flow (say, 15,000 vehicle/hr.) the noise level drops by the same amount as dropping from 15,000 to 3500 vehicle/hour along the 60 mph curve; therefore, the effect of the slower automobile speed can be accounted for in the noise evaluation by entering the Guideline curve (Figure 31, drawn for 60 mph) with a traffic flow equal to 25% (or 0.25 times) of the actual automobile traffic flow.

Therefore, if the mean automobile speed is actually 30 mph instead of 60 mph, one would multiply the actual hourly automobile volume flow by 0.25, and use the resulting effective volume flow, along with the effective distance, D_e , in entering Figure 31 for the automobile noise evaluation. Corrections to the volume flow for other mean automobile speeds are derived in a similar way, and are shown in the following table:

(Footnote continued from previous page.)

For automobile traffic (no trucks), on the other hand, the noise level increases with either an increase in average speed or an increase in volume flow; in fact, an increase in average speed usually increases the volume flow, too, since the between-automobile spacing does not ordinarily increase in proportion to speed. These differences in behavior explain the opposing adjustments for trucks and automobiles on page 163.

<u>Automobile Mean Traffic Speed</u>	<u>Adjustment Factor</u>
20 (mph)	0.12
25	0.18
30	0.25
35	0.32
40	0.40
45	0.55
50	0.70
55	0.85
60	1.00
65	1.20
70	1.40

This table is given on page 9 of the Guidelines for evaluating automobile noise.

A similar procedure is used to construct a table of adjustment factors to account for mean truck speeds different from the 30 mph assumed for Figure 32. The resulting values are given below, in a table that also appears on page 11 of the Guidelines for evaluating truck noise.

<u>Truck Mean Traffic Speed</u>	<u>Adjustment Factor</u>
20 (mph)	1.60
25	1.20
30	1.00
35	0.88
40	0.75
45	0.69
50	0.63
55	0.57
60	0.50
65	0.46
70	0.43

d) Stop-and-Go Traffic

The adjustment for stop-and-go traffic proposed in Refs. 54 and 286 was not used in the HUD Guidelines, since it was based on a traffic mix containing 2% trucks; at this mix of auto and truck

traffic there was only a negligible difference between stop-and-go traffic and freely-flowing traffic at 50 mph, for the same traffic volume. Instead, the Guidelines require an adjustment appropriate to traffic flows corresponding to 100% automobile and 100% truck traffic, for the necessary separate evaluations of the automobile and truck populations.

Suitable corrections for stop-and-go traffic are suggested, separately for autos and trucks, in the recent measurements of traffic noise on Connecticut highways.^{254/} Measurements made on the Merritt Parkway, a limited access road with no commercial traffic, supply the data for purely automobile traffic on dry, flat roads at 60 mph speed limit vs. the noise at a toll booth: the mean and median values are in each case nearly the same, and the A-levels for freely flowing traffic exceed the stop-and-go levels by 8 dB at mid-day, 9 dB at the rush hour and 10 dB at night.

Measurements made on secondary roads, with about 1% slowly-moving commercial traffic, indicated that the noise of freely-flowing traffic exceeds that at a stop-light by only about 1dB at any time of day; evidently it takes only a few commercial vehicles to change significantly the relationship between the freely-flowing and the stop-and-go noise levels! (This result, incidentally, tends to confirm the findings of Ref. 54 for a mix of 2% trucks).

This feature is further emphasized by the measurements made on the Connecticut Turnpike, which carries a heavy traffic load of commercial vehicles, particularly at night, when the dominant noise exposure is almost exclusively due to heavy trucks. Under these conditions, the noise of the freely-flowing traffic was 11

dB less than at the toll booths, where the trucks accelerate up through the gears.

Again, to avoid dealing with decibels, these stop-and-go corrections were converted to adjustments to the traffic volume flow for use in the HUD Guidelines: referring to the (60 mph) automobile curve of Figure 31, the noise near a traffic signal is assessed by multiplying the actual automobile volume flow by 0.1; referring to the (30 mph) truck curves of Figure 32, the truck noise near a traffic signal is assessed by multiplying the actual truck volume flow (adjusted if necessary for road gradient) by 5 (not 10, because the 30 mph truck noise is already greater than the 60 mph noise to which the stop-and-go data in the Connecticut tests were compared). These adjustments agree with values extrapolated to zero speed from the mean speed adjustment tables, above.

e. Shielding and Barriers

Where a site is shielded from line-of-sight to the traffic*, the noise levels will be attenuated, depending on a number of factors: the higher the frequency of the noise, the closer the barrier to either the source of noise or the listener, the higher the barrier and the wider the barrier, the greater the noise protection it affords. Even small gaps in a barrier tend to nullify the full effect of the acoustic shield; and the scattering of sound by atmospheric turbulence as well as the "spilling" of noise around the barrier limit the maximum shielding that can be expected from even the best barrier. Nevertheless the presence (or provision) of an effective barrier is one of the most useful means

*Or other source of noise at ground level; barriers are of no use for protection against noise from airborne aircraft.

of making a housing site acceptable that otherwise would be highly undesirable. It both protects the outdoor (garden, balcony, patio) environment and also reduces the required amount of noise control construction in the exterior walls of the buildings.

The barrier may be formed either by (1) the road profile: elevation (effective only for sites very near the roadway) or depression (effective at greater distances); (2) solid stone or concrete walls or earth-berms along the right-of-way; (3) a continuous row of buildings, such as shops, offices, parking facilities, warehouses or single-aspect multifamily dwellings facing away from the traffic, etc. Occasionally, the terrain itself will shield the site from the noisy source.

Note that two barriers are not necessarily better than one. As one moves away from a noisy motorway in a built-up neighborhood, once line-of-sight to the traffic is lost, the noise level tends to remain fairly constant at all locations as the sound is reflected back and forth from the various buildings.

The attenuation of a barrier may be taken into account in the site evaluation by an adjustment to the effective distance between the proposed site and the roadway (or other source of noise). Figure 36 shows in a schematic way how an actual barrier separating a noise source and an observer can be replaced by an equivalent "knife-edge". In the case of an elevated roadway, the position of the knife-edge corresponds to the outer edge of the shoulder; for a depressed configuration the knife-edge corresponds to the intersection of the cut-slope with the level terrain; for a barrier building or wall, the position of the knife-edge corresponds to the side of the structure nearest the source or the

observer, whichever is nearest to the barrier.* The distance between the observer (site) and the noise source (the roadway) is the effective distance D_e determined in Section IV C. 3. a. above.

The important dimension to calculate is the difference, δ , between the path length that the noise must travel with the barrier in place and the straight-line path length that the sound would travel without the barrier; in Figure 36, this would be

$$= x + y - z \text{ (feet)}$$

where

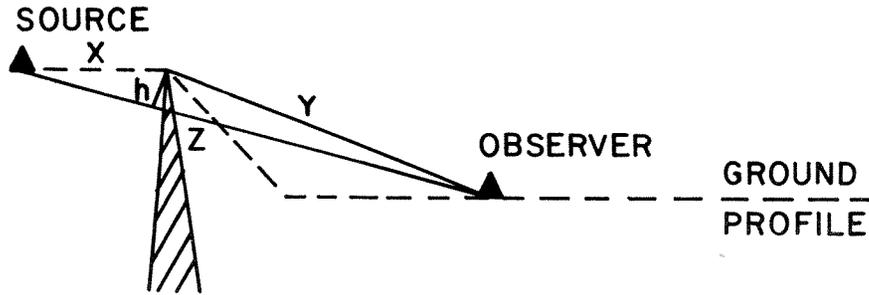
- x is the distance from the source position, assumed near the road surface, to the top of the knife-edge;
- y is the distance from the observer position (that is, the site location in question; this may be at any level in the proposed building) to the top of the knife-edge;
- z is the straight-line distance from the source position through the barrier to the observer position (if both source and observer are at approximately ground level, z is the same as the effective distance D_e).
- h is the effective height of the barrier measured along a perpendicular to the direct source/observer line, z, as shown in Figure 6; the quantity, h, does not enter directly into the calculation of the barrier attenuation, but it is clear that as the barrier height, h, increases, the parameter δ must also increase; δ also increases with decreasing distance between the barrier and either the source or observer.

The adjustment for barrier attenuation is adapted from recent work of Maekawa,^{284/} Rathe^{264/} and Scholes^{285/}. Maekawa's and Scholes' experimental curves (A and B on Figure 37) show the attenuation

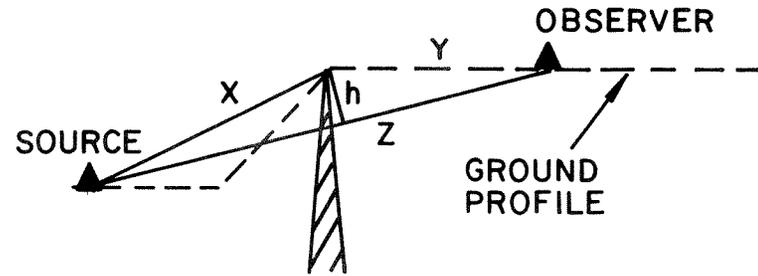
*If the highest part of the building is in the middle of the building, place the knife-edge there.

due to a barrier (in the absence of wind) as a function of the parameter, δ . For HUD's site evaluation, these curves were arbitrarily derated, as shown in Curve C, to account for the extended source, for possible flanking by reflections, and for atmospheric gradients that often limit barrier performance. 54,285/ This barrier attenuation, A, in decibels, is converted (by means of the 4.5 dB/double distance relationship discussed above) to an adjustment factor, $M = 2^{(A/4.5)}$ that multiplies the effective distance between site and roadway; the adjustment factor, M, is represented in Figure 37 on the right-hand vertical scale.

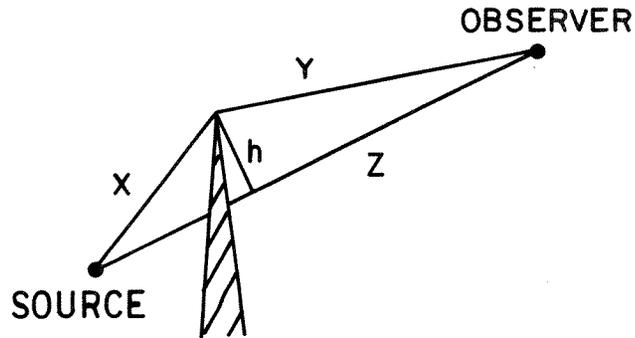
For simplicity of application in the Guidelines assessment procedure, this calculation is reduced to a nomogram (Figure 4) into which each of the important barrier parameters are introduced one at a time to arrive at an adjustment for effective distance. The effective distance adjusted for the presence of the barrier is then used with the adjusted traffic volume in the basic Figures 31 and 32.



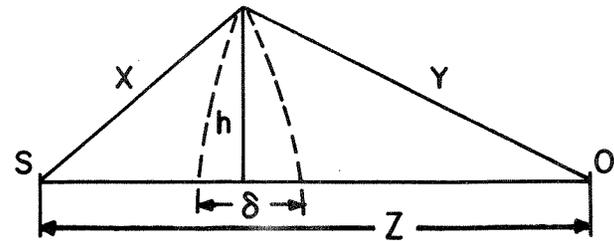
A. SCHEMATIC OF ELEVATED HIGHWAY



B. SCHEMATIC OF DEPRESSED HIGHWAY



C. GENERALIZED GEOMETRY OF ACOUSTIC BARRIER



D. GRAPHICAL DETERMINATION OF $\delta = x + y - z$

FIG. 36 ACOUSTIC SHIELDING BY BARRIERS

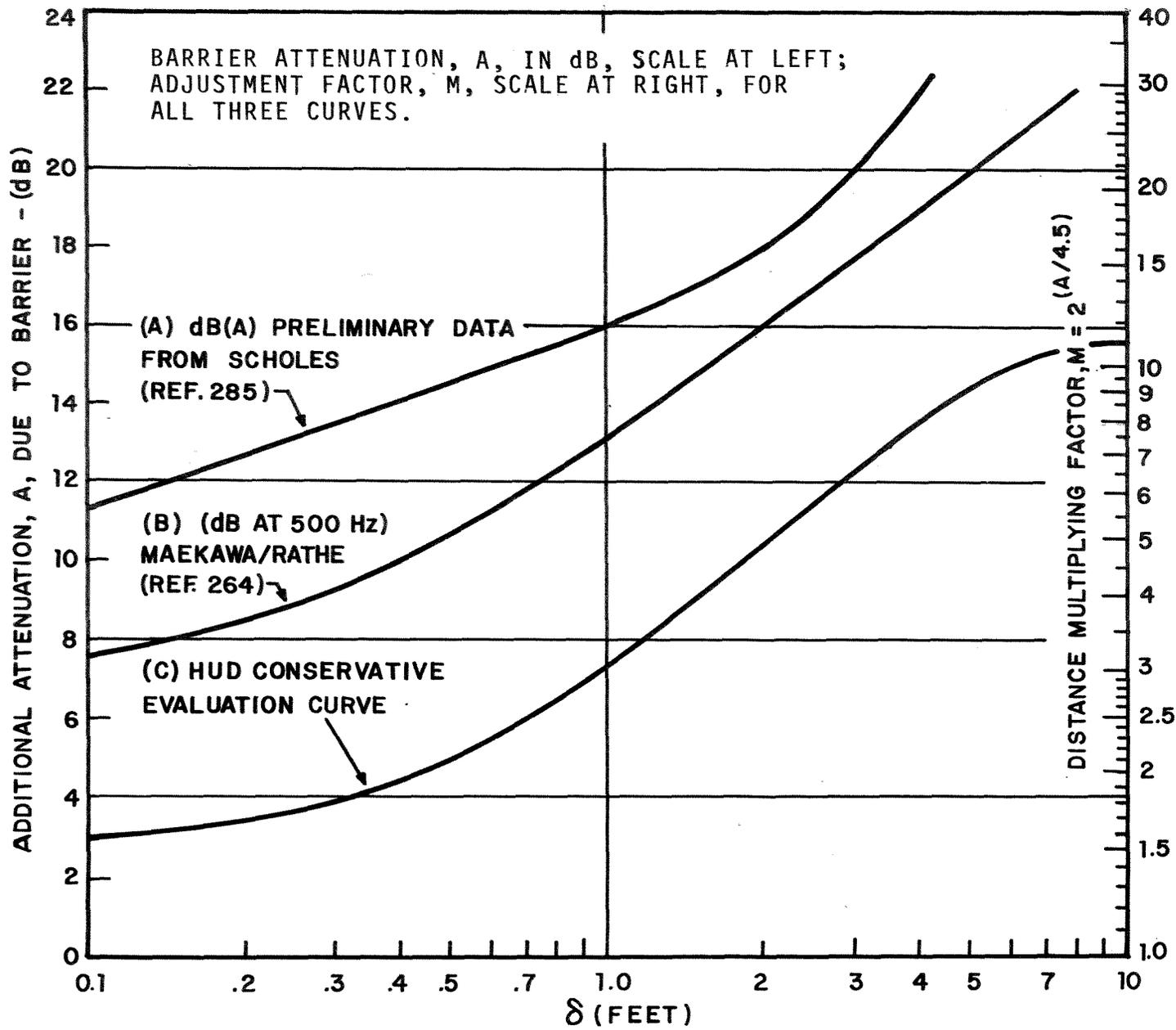


FIG. 37 DEVELOPMENT OF ADJUSTMENT FACTOR, M, THAT MULTIPLIES THE ACTUAL DISTANCE BETWEEN SOURCE AND OBSERVER, TO ACCOUNT FOR ACOUSTICAL SHIELDING OF A BARRIER.

D. Railroad and Above-ground Rapid Transit Trains

Information on the noise of American trains is not abundant in the literature; in particular, very little effort has been devoted to exploring the influence of traffic density, train loading, number of cars, etc. on the train noise. This is in large part because the noise of trains depends so strongly on the condition of maintenance of the track and rolling stock. A long, heavily-loaded train made up of well-maintained equipment rolling on smooth, welded track may be considerably quieter than a single traction car with many "flats" on the wheels operating on jointed rails. As a consequence, it has proved impractical, in the present state of the art, to account for factors other than distance to the right-of-way in estimating the basic train noise.

This prediction is, therefore, somewhat rough. Figure 38 shows data points representing the maximum A-Level observed during train passages for the available measurements of train (both railroad and rapid transit) noise. 1,5,41/ A considerable scatter is evident in the noise levels observed at any given distance. No trustworthy information at all is available as to the statistics of the noise exposure due to trains, but the straight-line curve represents roughly the median of all the measured peak A-level data. Embleton and Thiessen 41/ have adapted the anti-noise ordinance of a certain (un-named) township to apply to train noise, and reach the conclusion that, for an urban residential community exposed to a certain amount of noise other than that from the trains, and for a train traffic density amounting to about ten passages during an eight-hour nighttime period, a peak noise (during train passage) level of about 60 dB(A) is the maximum

acceptable exposure^{*}. As explained above (in Section IV - A) we have interpreted the statistical median A-Level of 60 dB(A) as the criterion boundary between Normally Acceptable and Normally Unacceptable categories for site assessment, corresponding to HUD's interim acceptability standards. The other two criterion boundaries lie, respectively, 15 dB above and 15 dB below this value (75 and 45 dB(A)). Regarding the median (L₅₀) level of a statistical noise exposure as more or less equivalent to the median curve in the scatter of peak A-level observations for train passages, we can interpret these criterion boundaries as the maximum acceptable train noise levels, and can hence find from Figure 38 the required distance from the railroad right-of-way for these levels not to be exceeded. We thus arrive at the following guidelines for acceptable train noise exposure at a site that has clear line-of-sight to the trains:

<u>Distance from right-of-way (feet)</u>	<u>HUD Acceptability Category</u>
Greater than 3000 ft.	Clearly Acceptable
601 to 3000 ft.	Normally Acceptable
101 to 600 ft.	Normally Unacceptable
Less than 100 ft.	Clearly Unacceptable

These are the data given in Table III of HUD's Guidelines, page 15.

Adjustments are also provided in the Guidelines evaluation to account for the shielding provided by a complete and effective barrier; this correction, amounting to a flat 15 dB attenuation, reduces the effective distance from the site to the railroad track

* They actually gave maximum acceptable octave band levels..... approximately those defining the NCA (Alternative Noise Criterion) -50 curve of Beranek⁶/ ...; this is equivalent to 60 dB(A).

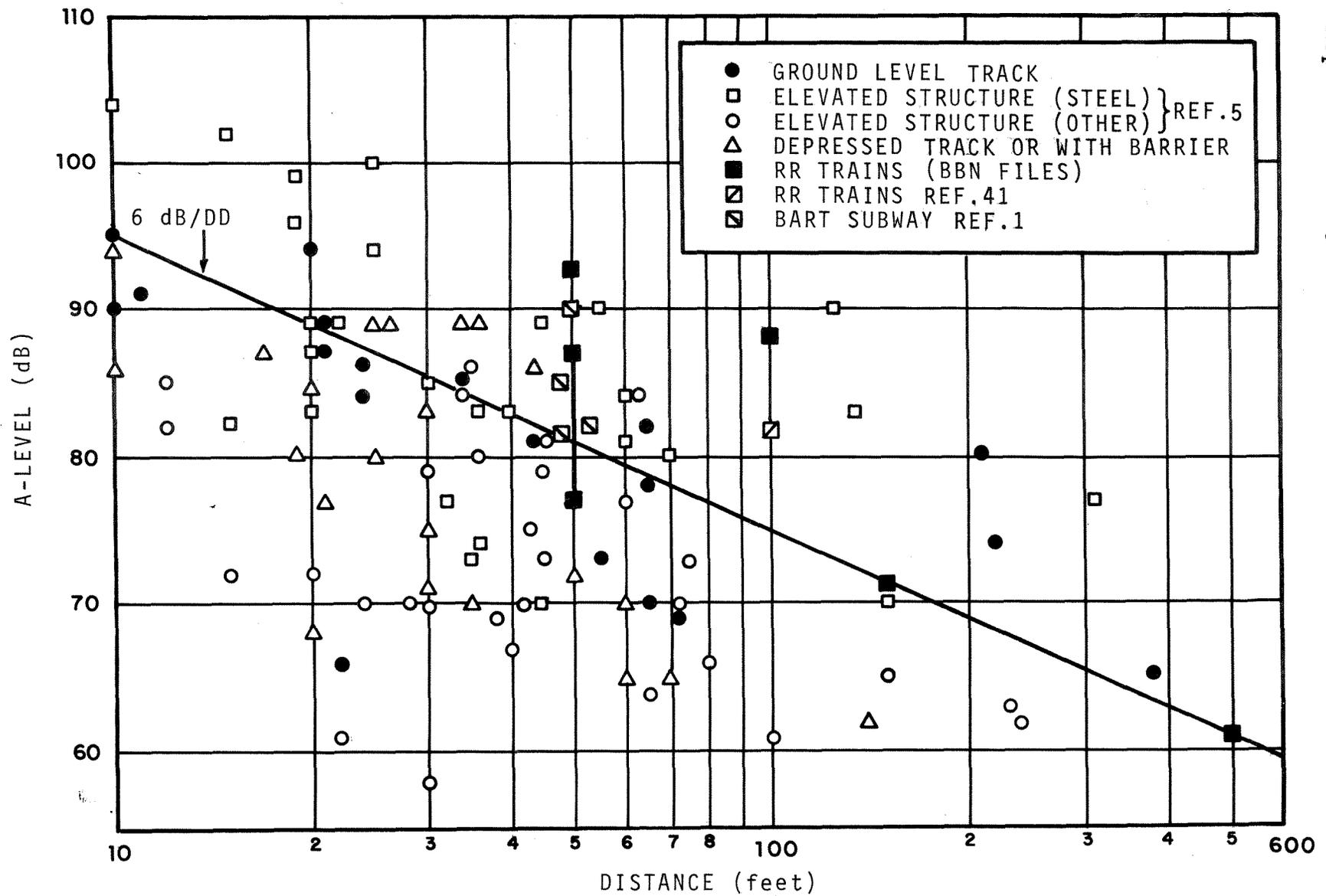


FIG.38 TRAIN AND SUBWAY NOISE OUTDOORS: PEAK A-LEVEL DURING TRAIN PASSAGE VS. DISTANCE FROM TRACK

by a factor of about six: that is, given an effective acoustical barrier between the site and the trains (by placing the track in a cutting, for example), the same noise exposure would be found at distances only one-sixth as great. This accounts for the distances given in the middle column of Table III of the Guidelines (except that the shortest distance cannot be reduced by so great an amount, for the distance/level relationship becomes somewhat more uncertain at short distances and the question of ground vibration, overlooked in the previous estimates, also suggests that the distance to the track should not be reduced much below 100 ft).

In the Guidelines site evaluation procedure an adjustment is made to account for smaller numbers of trains passing during a night-time period. These adjustments were adapted directly from Embleton and Thiessen ^{41/} (their Table II), the only changes being: 1) their adjustments in decibels have been converted, for use in HUD's Guidelines, to a correction applied to the distance from the site to the track; and 2) for consistency in defining the night-time period throughout the Guidelines, we have applied the Embleton and Thiessen criteria, defined for the number of trains passing in an eight-hour night-time, without change to the Guidelines' nine-hour night-time period: given the scatter in the measured data and the approximate nature of the train noise criteria, applying a correction to account for this one-hour difference in the night-time period would imply a much higher degree of accuracy than can be claimed for the prediction procedures.

E. The "Walk-Away Test"

In the final portion of HUD's Guidelines, a procedure is given for estimating the typical noise level existing at a site, without,

however, requiring the use of acoustical instrumentation. The procedure is based on two observations: 1) that the total acoustical power output does not vary greatly, for normal conversational effort, from one male speaker to another; 156,182/ thus, if one avoids speakers with conspicuously loud or soft voices, an adult male speaker is not too bad an approximation to a "calibrated acoustical source;" and 2) that word intelligibility drops very sharply as the speech signal becomes just masked by noise 182,209/; therefore, the distance at which a normal male speaker can just not be understood is a fairly good measure of the noise existing at that location.

The test procedure consists of having one (male) person read in a conversational tone a passage of text unfamiliar to the listener, who then moves progressively farther away from the speaker to the point where he can just barely hear a word or two in a ten-second period of listening. The distance at which this occurs is measured and becomes an implicit measurement of the noise at the location. The test is repeated a number of times, and the averaged results are used to assign the site to one of the HUD acceptability categories. (The roles of the speaker and the listener are interchanged to aid in the averaging.) Of course, the speaker must take care to maintain normal conversational level rather than trying to maintain communication with the listener.

Webster^{244, 245/} gives a table (reproduced in HUD's Policy Circular) showing the distance at which face-to-face communication is possible for different amounts of background noise, expressed in dB(A). The judgement as to when "communication is possible", however, is rather vague; one can understand the gist of a sentence

even if some or most of the words are missed. This judgement, then, is much less well defined than the decision that understanding is just impossible, for the latter transition occurs abruptly as the noise level increases or the speech level is lowered, as by moving away from the speaker.

It is well established^{156,182,255/} that the range of signal-to-noise ratios, corresponding to the articulation index range from zero (no words understood) to unity (understanding all words), is about 30 dB. It is also agreed^{123, 54, 255/} that an articulation index of about 60% is adequate for normal understanding of speech; and this value is assumed to correspond to the graph given by Webster, as described above. Thus, if we want to know the A-Level for the background noise that just prevents understanding of speech (corresponding to an articulation index of about 5%), then Webster's noise levels must be increased by an amount equal to the percentage change (decrement) required in articulation index ($0.60 - 0.05 = 0.55$) multiplied by the signal-to-noise ratio range corresponding to the full range of articulation index, that is 30 dB: $0.55 \times 30 = 17$ dB(A). Consequently, if Webster's curve shows that communication is possible at 16 ft. in a noise background of 51 dB(A), than communications is just impossible at the same distance in a background noise of $51 + 17 = 68$ dB(A). Following this line of thought for different distances, one can construct a curve showing, for various background noise levels in dB(A), the distance at which only a word or two of normal conversational level speech will be understood; such a curve is shown in Figure 39. It can also be used, according to the test procedure described above, to make an estimate of the existing noise level at a site.

Such estimates have been made for a number of different sites and noise sources. The "walk-away" test was performed for each location to determine the critical distance for "just not understanding"; the existing noise background was also measured, to see how well the walk-away test procedure estimated the actual A-Level at the time of the test. These points are entered on Figure 39; if the theory and the procedure were perfect, all the points would lie on the theoretical line derived from the argument given above. Instead, there is some scatter in the data, and the experimentally determined curve falls off more sharply than the theory predicts. Some of the scatter in the data may be due to "non-standard" voice effort on the part of the speakers in the test, but it is more likely due to the fluctuating character of the noise background, itself, which (as usual for community noise) was varying over a range from 5 to 15 dB. The greater rate of attenuation with distance may be due to the interaction of the statistics of the speech signal and those of the background noise (the argument from Webster's data assumes steady-state background level), or due to the excess attenuation expected in the presence of a ground reflection.^{83,285/} Whatever the reasons for these differences, the experimental points define a surprisingly close relation between the existing A-Level and the distance at which understanding just becomes impossible, at each location. Estimates of the existing A-Levels made from the experimental curve, therefore, are good and are quite suitable for assigning sites to HUD's four acceptability categories, as shown at the top of Figure 39 and in Table IV of the Guidelines, reproduced here:

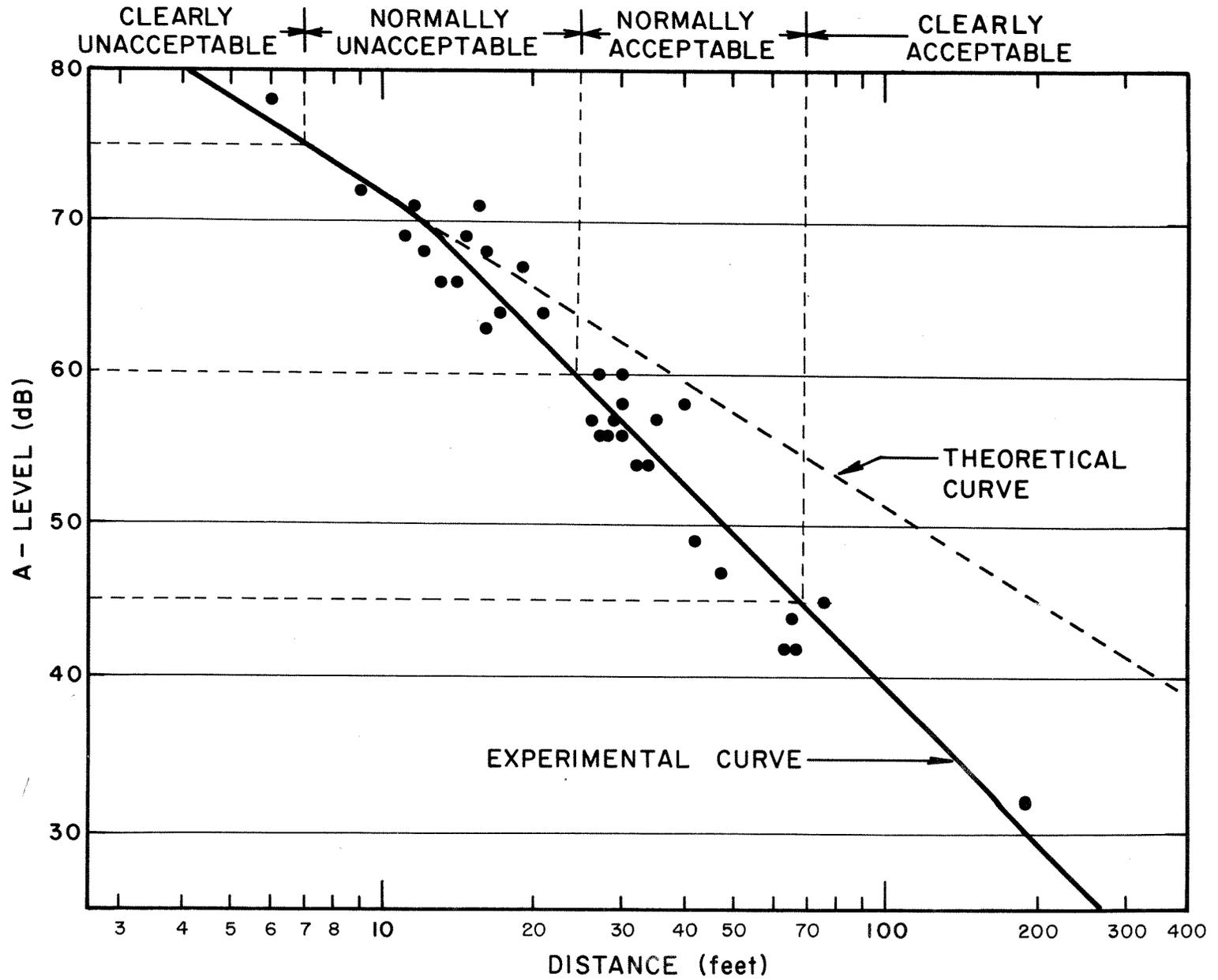


FIG. 39 THE "WALK-AWAY TEST"

Distance Where Understanding
Become Very Difficult

More than 70 ft.

26 to 70 ft.

7 to 25 ft.

Less than 7 ft.

HUD Acceptability
Category

Clearly Acceptable

Normally Acceptable

Normally Unacceptable

Clearly Unacceptable

APPENDIX A *

4. Standards

b. Interim Standards. The following interim standards are established. In applying these interim standards, projected noise exposures shall form the basis for decision.

- (1) External Noise Exposures: Sites for New Residential Construction (single or multifamily)

CHART: EXTERNAL NOISE EXPOSURE STANDARDS FOR NEW CONSTRUCTION SITES (Measurements and projections of noise exposures are to be made at appropriate heights above site boundaries)

GENERAL EXTERNAL EXPOSURES dB(A)	AIRPORT ENVIRONS	
	CNR ZONE	NEF ZONE
UNACCEPTABLE		
Exceeds 80 dB(A) 60 minutes per 24 hours	3	C
Exceeds 75 dB(A) 8 hours per 24 hours	(CNR greater than 115)	(NEF greater than 40)
(Exceptions are strongly discouraged and require a 102(2)C environmental statement and the Secretary's approval)		
DISCRETIONARY -- NORMALLY UNACCEPTABLE		
Exceeds 65 dB(A) 8 hours per 24 hours	2	B
Loud repetitive sounds on site	(CNR between 100 and 115)	(NEF between 30 and 40)
(Approvals require noise attenuation measures, the Regional Administrator's concurrence and a 102(2)C environmental statement)		
DISCRETIONARY -- NORMALLY ACCEPTABLE		
Does not exceed 65 dB(A) more than 8 hours per 24 hours		
ACCEPTABLE		
Does not exceed 45 dB(A) more than 30 minutes per 24 hrs.	1 (CNR less than 100)	A (NEF less than 30)

* Quoted from Ref. 292.

APPENDIX A (cont.)

(2) Interior Noise Exposures (for new and rehabilitated residential construction).

(Note: the standards listed below are performance standards. The means required for achieving them will depend on, among other things, the external noise levels, the equipment and layout used in the building, and the noise attenuation characteristics of the building's floors and walls. These standards assume open windows unless other provision is made for adequate ventilation.)

(a) "Acceptable":

Sleeping Quarters. For the present time, HUD field personnel should consider existing and projected noise exposure for sleeping quarters "acceptable" if interior noise levels resulting from exterior noise sources and interior building sources such as heating, plumbing, and air conditioning.

--do not exceed 55 dB(A) for more than an accumulation of 60 minutes in any 24-hour period, and

--do not exceed 45 dB(A) for more than 30 minutes during night time sleeping hours from 11 p.m. to 7 a.m., and

--do not exceed 45 dB(A) for more than an accumulation of eight hours in any 24-hour day.

APPENDIX A (cont.)

Other Interior Areas. HUD personnel should exercise discretion and judgement as to interior areas other than those used for sleeping. Consideration should be given to the characteristics of the noise, the duration, time of day, and planned use of the area.

(3) Insulation Between Dwelling Units

(a) "Unacceptable"

For multifamily structures, including attached single family units, floors and dividing walls between dwelling units having Sound Transmission Class (STC) of less than 45 are always unacceptable.

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