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INFORMATION ON LEVELS OF ENVIRONMENTAL NOISE REQUISITE TO PROTECT PUBLIC HEALTH AND WELFARE WITH AN ADEQUATE MARGIN OF SAFETY

MARCH 1974

PREPARED BY
THE U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF NOISE ABATEMENT AND CONTROL

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number of people living in areas which are exposed to freeway and aircraft noise are taken from the EPA airport/aircraft noise report.[B-4] They were based on calculated noise contours and associated populations for a few selected situations which formed the basis for extrapolation to national values. The estimates for the number of people living in areas in which the noise environment is dominated by urban traffic were developed from a survey[B-5] conducted in Summer 1973 for EPA. The survey measured the outdoor 24-hour noise environment at 100 sites located in 14 cities, including at least one city in each of the ten EPA regions. These data, supplemented with that from previous measurements at 30 additional sites, were correlated with census tract population density to obtain a general relationship between L_{dn} and population density. This relationship was then utilized, together with census data giving population in urban areas as a function of population density, to derive the national estimate given in Table B-2.

These data on urban noise enable an estimate of the percentage urban population in terms of both noise levels and the qualitative descriptions of urban residential areas which were utilized in the Title IV EPA report to Congress in 1971.[B-6]

These estimates, summarized in Table B-3, show that the majority of the 134 million people residing in urban areas have outdoor L_{dn} values ranging from 43 dB to 72 dB with a median value of 59 dB. The majority of the remainder of the population residing in rural or other non-urban areas is estimated to have outdoor L_{dn} values ranging between 35 and 50 dB.

Indoor Sound Levels

The majority of the existing data regarding levels of environmental noise in residential areas has been obtained outdoors. Such data are useful in characterizing the neighborhood noise environment evaluating the noise of identifiable sources and relating the measured values with those calculated for planning purposes. For these purposes, the outdoor noise levels have proved more useful than indoor noise levels because the indoor noise levels contain the additional variability of individual building sound level reduction. This variability among dwelling units results from type of construction, interior furnishings, orientation of rooms relative to the noise, and the manner in which the dwelling unit is ventilated.

Data on the reduction of aircraft noise afforded by a range of residential structures are available.[B-7] These data indicate that houses can be approximately categorized into "warm climate" and "cold climate" types. Additionally, data are available for typical open-window and closed-window conditions. These data indicate that the sound level reduction provided by buildings within a given community has a wide range due to differences in the use of materials, building techniques, and individual building plans. Nevertheless, for

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FOREWORD

The Congress included among the requirements of the Noise Control Act of 1972 a directive that the Administrator of the Environmental Protection Agency "...develop and publish criteria with respect to noise..." and then "publish information on the levels of environmental noise the attainment and maintenance of which in defined areas under various conditions are requisite to protect the public health and welfare with an adequate margin of safety."

Not all of the scientific work that is required for basing such levels of environmental noise on precise objective factors has been completed. Some investigations are currently underway, and the need for others has been identified. These involve both special studies on various aspects of effects of noise on humans and the accumulation of additional epidemiological data. In some cases, a considerable period of time must elapse before the results will be meaningful, due to the long-term nature of the investigations involved. Nonetheless, there is information available from which extrapolations are possible and about which reasoned judgments can be made.

Given the foregoing, EPA has sought to provide information on the levels of noise requisite to protect public health and welfare with an adequate margin of safety. The information presented is based on analyses, extrapolations and evaluations of the present state of scientific knowledge. This approach is not unusual or different from that used for other environmental stressors and pollutants. As pointed out in "Air Quality Criteria"–Staff Report, Subcommittee on Air and Water Pollution, Committee on Public Works, U.S. Senate, July, 1968,

> The protection of public health is required action based upon best evidence of causation available. This philosophy was appropriately expressed by Sir E. B. Hill, 1962, when he wrote: "All scientific work is incomplete–whether it be observational or experimental. All scientific work is liable to be upset or modified by advancing knowledge. That does not confer upon us freedom to lower the knowledge we already have, or to postpone the action that it appears to demand at a given time. The lessons of the past in general health and safety practices are easy to read. They are characterized by empirical decisions, by eternally persistent reappraisal of public health standards against available knowledge of causation, by consistently giving the public the benefit of the doubt, and by ever striving for improved environmental quality with the accompanying reduction in disease morbidity and mortality. The day of precise quantitative

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Throughout this report, the words "identified level" are used to express the result of the inquiry mandated by Section 5(a)(2). The words "goals", "standards", or "recommended

the selected indicator of environment noise does not correlate uniquely with any specific effect on human health or performance. Admittedly, there are uncertainties with respect to effects in individual cases and situations. Such effects cannot be completely accounted for: thus, the necessity to employ a statistical approach.

Section 2 of the report addresses the details of characterizing and measuring human exposure to environmental noise. The equivalent sound level (L_{eq}) and a variation weighted for nighttime exposure (L_{dn}) has been selected as the uniform descriptor. The relationship of L_{eq} and L_{dn} to other measures in use is analyzed in Appendix A. Section 2 and Appendix B further detail the various human exposure patterns and give simplified examples of individual exposure patterns. The problem of separating occupational exposure from the balance of environmental exposure and the statutory responsibility for controlling occupational exposure is analyzed in Appendix F.

In Section 3, cause and effect relationships are summarized and presented as the basis and justification for the environmental noise levels identified in Section 4. Specifically, Section 3 develops conclusions with regard to levels at which hearing impairment and activity interference take place. These are discussed in terms of situational variation and the respective appropriateness of L_{eq} and L_{dn}. The factors providing for an adequate margin of safety and special types of noises are discussed. This section makes reference to material in Appendices C (on hearing loss), D (annoyance and activity interference) and G (special noises), which in turn rely upon material presented in EPA's document, Public Health and Welfare Criteria for Noise,[2] to which the reader is referred for more detailed information.

Section 4 discusses the levels of environmental noise requisite to protect public health and welfare for various indoor and outdoor areas in the public and private domain in terms of L_{eq} and L_{dn}. The summary table is supplemented by short explanations.

It is obvious that the practical application of the levels to the various purposes outlined earlier requires considerations of factors not discussed here. Although some guidance in this respect is included in Section 4, not all problems can be anticipated and some of these questions can only be resolved as the information contained in this report is considered and applied. Such practical experiences combined with results of further research will guide EPA in revising and updating the levels identified. In this regard, it should be recognized that certain of the levels herein might well be subject to revision when additional data are developed.

Section 2

ENVIRONMENTAL NOISE EXPOSURE

A complete physical description of a sound must describe its magnitude, its frequency spectrum, and the variations of both of these parameters in time. However, one must choose between the ultimate refinement in measurement techniques and a practical approach that is no more complicated than necessary to predict the impact of noise on people. The Environmental Protection Agency's choice for the measurement of environmental noise is based on the following considerations:

1. The measure should be applicable to the evaluation of pervasive long-term noise in various defined areas and under various conditions over long periods of time.

2. The measure should correlate well with known effects of the noise environment on the individual and the public.

3. The measure should be simple, practical and accurate. In principle, it should be useful for planning as well as for enforcement or monitoring purposes.

4. The required measurement equipment, with standardized characteristics, should be commercially available.

5. The measure should be closely related to existing methods currently in use.

6. The single measure of noise at a given location should be predictable, within an acceptable tolerance, from knowledge of the physical events producing the noise.

7. The measure should lend itself to small, simple monitors which can be left unattended in public areas for long periods of time.

These considerations, when coupled with the physical attributes of sound that influence human response, lead EPA to the conclusion that the magnitude of sound is of most importance insofar as cumulative noise effects are concerned. Long-term average sound level, henceforth referred to as equivalent sound level (L_{eq}), is considered the best measure for the magnitude of environmental noise to fulfill the above seven requirements. Several versions of equivalent sound level will be used for identifying levels of sound in specific places requisite to protect public health and welfare. These versions differ from each other primarily in the time intervals over which the sound levels are of interest, and the correction factor employed.

Equivalent A-weighted sound level is the constant sound level that, in a given situation and time period, conveys the same sound energy as the actual time-varying A-weighted sound.* The basic unit of equivalent sound levels is the decibel (see Appendix A), and the symbol for equivalent sound level is L_{eq}. Two sounds, one of which contains twice as much energy but lasts only half as long as the other, would be characterized by the same equivalent sound level; so would a sound with four times the energy lasting one fourth as long. The relation is often called the equal-energy rule. A more complete discussion of the computation of equivalent sound level, its evolution and application to environmental noise problems, and its relationship to other measures used to characterize environmental noise is provided in Appendix A.

The following caution is called to the attention of those who may prescribe levels: It should be noted that the use of equivalent sound level in measuring environmental noise will not directly exclude the existence of very high noise levels of short duration. For example, an equivalent sound level of 60 dB over a twenty-four hour day would permit sound levels of 110 dB but would limit them to less than one second duration in the twenty-four hour period. Comparable relationships between maximum sound levels and their permissible durations can easily be obtained for any combination, relative to any equivalent sound level (see the charts provided in Appendix A).

Three basic situations are used in this document for the purpose of identifying levels of environmental noise:

1. Defined areas and conditions in which people are exposed to environmental noise for periods of time which are usually less than twenty-four hours, such as school classrooms, or occupational settings.

2. Defined areas and conditions in which people are exposed to environmental noise for extended periods of time, such as dwellings.

3. Total noise exposure of an individual, irrespective of area or condition.

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*See Glossary for a detailed definition of terms. Note that when the term "sound level" is used throughout this document, it always implies the use of the A-weighting for frequency.

Three versions of equivalent sound level are used in this document in order to accommodate the various modes of noise exposure that occur in these situations. They are distinguished by the periods of time over which they are averaged and the way in which the averaging is done.

1. L_{eq} for an 8-hour period ($L_{eq(8)}$): This is the equivalent A-weighted sound level (in decibels relative to 20 micropascals) computed over any continuous time period of eight hours identified with the typical occupational exposure. As will be shown in later sections of this document, $L_{eq(8)}$ serves as a basis for identifying environmental noise which causes damage to hearing.

2. L_{eq} for 24-hour weighted for nighttime exposure (L_{dn}): This formula of equivalent level is used here to relate noise in residential environments to chronic annoyance by speech interference and in some part by sleep and activity interference. For these situations, where people are affected by environmental noise for extended periods of time, the natural choice of duration is the 24-hour day. Most noise environments are characterized by repetitive behavior from day to day, with some variation imposed by differences between weekday and weekend activity, as well as some seasonal variation. To account for these variations, it has been found useful to measure environmental noise in terms of the long-term yearly average of the daily levels.

In determining the daily measure of environmental noise, it is important to account for the difference in response of people in residential areas to noises that occur during sleeping hours as compared to waking hours. During nighttime, exterior background noises generally drop in level from daytime values. Further, the activity of most households decreases at night, lowering the internally generated noise levels. Thus, noise events become more intrusive at night, since the increase in noise levels of the event over background noise is greater than it is during the daytime.

Methods for accounting for these differences between daytime and nighttime exposures have been developed in a number of different noise assessment methods employed around the world, (see Appendix A). In general, the method used is to characterize nighttime noise as more severe than corresponding daytime events; that is, to apply a weighting factor to noise that increases the numbers commensurate with their severity. Two approaches to identifying time periods have been employed: one divides the 24-hour day into two periods, the waking and sleeping hours, while the other divides the 24 hours into three periods--day, evening, and night. The weighting applied to the non-daytime periods differs slightly among the different countries, but most of them weight nighttime activities by about 10 dB. The evening weighting, if used, is 5 dB.

An examination of the numerical values obtained by using two periods versus three periods per day shows that for any reasonable distribution of environmental noise levels, the two-period day and the three-period day are essentially identical; i.e., the 24-hour equivalent sound levels are equal within a few tenths of a decibel. Therefore, the simpler two-period day is used in this document, with daytime extending from 7 a.m. to 10 p.m. and nighttime extending from 10 p.m. to 7 a.m. The symbol for the 15-hour daytime equivalent sound level is L_d, the symbol for the 9-hour nighttime equivalent sound level is L_n, and the day-night weighted measure is symbolized as L_{dn}.

The L_{dn} is defined as the A-weighted average sound level in decibels (re 20 micropascals) during a 24-hour period with a 10 dB weighting applied to nighttime sound levels. Examples of the outdoor present day (1973) day-night noise level at typical locations are given in Figure 1.

3. L_{eq} for the 24-hour average sound level to which an individual is exposed (L_{eq} (24)): This situation is related to the cumulative noise exposure experienced by an individual irrespective of where, or under what situation, this exposure is received. The long-term health and welfare effects of noise on an individual are related to the cumulative noise exposure he receives over a lifetime.

Relatively little is known concerning the total effect of such lifetime exposures, but dose-effect relations have been studied for two selected situations:

a. The average long-term exposure to noise primarily in residential areas leading to annoyance reactions and complaints.

b. The long-term effects of occupational noise on hearing, with the daily exposure dose based on an eight-hour work day.

An ideal approach to identifying environmental noise levels in terms of their effect on public health and welfare would be to start by identifying the maximum noise not to be exceeded by individuals. However, the noise dose that an individual receives is a function of lifestyle. For example, exposure patterns of office workers, factory workers, housewives, and school children are quite different. Within each group the exposures will vary widely as a function of the working, recreational, and sleeping patterns of the individual. Thus, two individuals working in the same office will probably accumulate different total noise doses if they use different modes of transportation, live in different areas, and have different TV habits. Examples of these variations in noise dose for several typical life styles are provided in Appendix B. However, detailed statistical information on the distribution of actual noise doses and the relationship of these doses to long-term health and welfare effects is still missing. Therefore, a realistic approach to this problem is to identify appropriate noise levels for

places occupied by people as a function of the activity in which they are engaged, including a gross estimate of typical average exposure times.

From a practical viewpoint, it is necessary to utilize the wealth of data relating to occupational noise exposure, some of it, albeit, subject to interpretation, in order to arrive at extrapolations upon which the identification of safe levels for daily (24-hour) exposures can be based.

In the following sections of this report, the various modes of exposure to noise and the human responses elicited will be discussed, leading to the identification of appropriate noise exposure levels. In order to assist the reader in associating these levels with numerical values of noise for familiar situations, typical noise levels encountered at various locations are listed in Table 2. For further assistance, Figure 2 provides an estimate of outdoor noise levels for different residential areas.

Table 2
EQUIVALENT SOUND LEVELS IN DECIBELS NORMALLY OCCURRING INSIDE VARIOUS PLACES[6]

SPACE	L_{eq}(+)
Small Store (1-5 clerks)	60
Large Store (more than 5 clerks)	65
Small Office (1-2 desks)	58
Medium Office (3-10 desks)	63
Large Office (more than 10 desks)	67
Miscellaneous Business	63
Residences	
Typical movement of people – no TV or radio	40-45
Speech at 10 feet, normal voice	55
TV listening at 10 feet, no other activity	55-60
Stereo music	50-70

(+) These measurements were taken over durations typical of the operation of these facilities.

these indoor levels of 40 dB during the day and approximately 32 dB at night are consistent with the background levels inside the home which have been recommended by acoustical consultants as acceptable for many years, (see Table D-10).

The effects associated with an outdoor day-night sound level of 55 dB are summarized in Table 3. The summary shows that satisfactory outdoor average sentence intelligibility may be expected for normal voice conversations over distances of up to 3.5 meters; that depending on attitude and other non-level related factors, the average expected community reaction is none, although 1% may complain and 17% indicate "highly annoyed" when responding to social survey questions; and that noise is the least important factor governing attitude towards the area.

Identification of a level which is 5 dB higher than the 55 dB identified above would significantly increase the severity of the average community reaction, as well as the expected percentage of complaints and annoyance. Conversely, identification of a level 5 dB lower than the 55 dB identified above would reduce the indoor levels resulting from outdoor noise well below the typical background indoors (see Table 3) and probably make little change in annoyance since at levels below the identified level, individual attitude and life style, as well as local conditions, seem to be more important factors in controlling the resulting magnitude of annoyance or community reaction than is the absolute magnitude of the level of the intruding noise.

Accordingly, L_{dn} of 45 dB indoors and of 55 dB outdoors in residential areas are identified as the maximum levels below which no effects on public health and welfare occur due to interference with speech or other activity. These levels would also protect the vast majority of the population under most conditions against annoyance, in the absence of intrusive noises with particularly aversive content.

Adequate Margin of Safety

The outdoor environmental noise level identified in Table 3 provides a 5 dB margin of safety with respect to protecting speech communication. This is considered desirable for the indoor situation to provide for homes with less than average noise reduction or for persons speaking with less than average voice level. A higher margin of safety would be ineffective most of the time due to normal indoor activity background levels.

The 5 dB margin of safety is particularly desirable to protect the population against long-term annoyance with a higher probability than would be provided by the levels protecting indoor and outdoor speech communication capability alone. The 5 dB margin clearly shifts community response as well as subjective annoyance rating into the next lower

Table 3
SUMMARY OF HUMAN EFFECTS IN TERMS OF SPEECH COMMUNICATION, COMMUNITY REACTION, COMPLAINTS, ANNOYANCE AND ATTITUDE TOWARDS AREA ASSOCIATED WITH AN OUTDOOR DAY/NIGHT SOUND LEVEL OF 55 dB re 20 MICROPASCALS

TYPE OF EFFECT	MAGNITUDE OF EFFECT
Speech - Indoors	100% sentence intelligibility (average) with a 5 dB margin of safety
- Outdoors	100% sentence intelligibility (average) at 0.35 meters
	99% sentence intelligibility (average) at 1.0 meters
	95% sentence intelligibility (average) at 3.5 meters
Average Community Reaction	None evident; 7 dB below level of significant "complaints and threats of legal action" and at least 16 dB below "vigorous action" (attitudes and other non-level related factors may affect this result)
Complaints	1% dependent on attitude and other non-level related factors
Annoyance	17% dependent on attitude and other non-level related factors
Attitudes Towards Area	Noise essentially the least important of various factors

(Derived from Appendix D)

response category than would be observed for the maximum level identified with respect to speech communication alone. According to present data, this margin of safety protects the vast majority of the population against long-term annoyance by noise. It would reduce environmental noise to a level where it is least important among environmental factors that influence the population's attitude toward the environment. To define an environment that eliminates any potential annoyance by noise occasionally to some part of the population appears not possible at the present state of knowledge.

MAXIMUM EXPOSURES TO SPECIAL NOISES

Inaudible Sounds

The following sounds may occur occasionally but are rarely found at levels high enough to warrant consideration in most environments which the public occupies. For a more detailed discussion, see Appendix G.

Infrasound

Frequencies below 16 Hz are referred to as infrasonic frequencies and are not audible. Complaints associated with extremely high levels of infrasound can resemble a mild stress reaction and bizarre auditory sensations, such as pulsating and fluttering. Exposure to high levels of infrasound is rare for most individuals. Nevertheless, on the basis of existing data[2,7], the threshold of these effects is approximately 120 dB SPL (1-16 Hz). Since little information exists with respect to duration of exposure and its effects, and also since many of the data are derived from research in which audible frequencies were present in some amount, these results should be interpreted with caution.

Ultrasound

Ultrasonic frequencies are those above 20,000 Hz and are also generally inaudible. The effects of exposure to high intensity ultrasound is reported by some to be a general stress response. Exposure to high levels of ultrasound does not occur frequently. The threshold of any effects for ultrasound is 105 dB SPL[2]. Again, many of these data may include frequencies within the audible range, and results are, therefore, to be interpreted cautiously.

Impulse Noise

It is difficult to identify a single-number limit requisite to protect against adverse effects from impulse noise because it is essential to take into account the circumstances of exposure, the type of impulse, the effective duration, and the number of daily exposures, (see Appendix G).

Hearing

Review of temporary threshold shift data leads to the conclusion that the impulse noise limit requisite to prevent more than a 5 dB permanent hearing loss at 4000 Hz after 10 years of daily exposure is a peak sound pressure level (SPL) of 145 dB. This level applies in the case of isolated events, irrespective of the type, duration, or incidence at the ear. However, for duration of 25 microseconds or less, a peak level of 167 dB SPL would produce the same effect, (see Figure 4).

1. Duration Correction: When the duration of the impulse is less than 25 microseconds, no correction for duration is necessary. For durations exceeding 25 microseconds, the level should be reduced in accordance with the "modified CHABA limit" shown in Figure 4 and Figure G-1 of Appendix G.

2. Correction for Number of Impulses:

Number of impulses per day:	1	10	100	10^3	10^4	
Correction factor:	0	-10	-20	-30	-40	dB

(More detailed information is provided in Figure 4.)

Furthermore, if the average interval between repeated impulses is between 1 and 10 seconds, a third correction factor of -5 dB is applied. Thus, to prevent hearing loss due to impulse noise, the identified level is 145 dB SPL, or 167 dB peak SPL for impulses less than 25 microseconds, for one impulse daily. For longer durations or more frequent exposures, the equivalent levels are as shown in Figure 4.

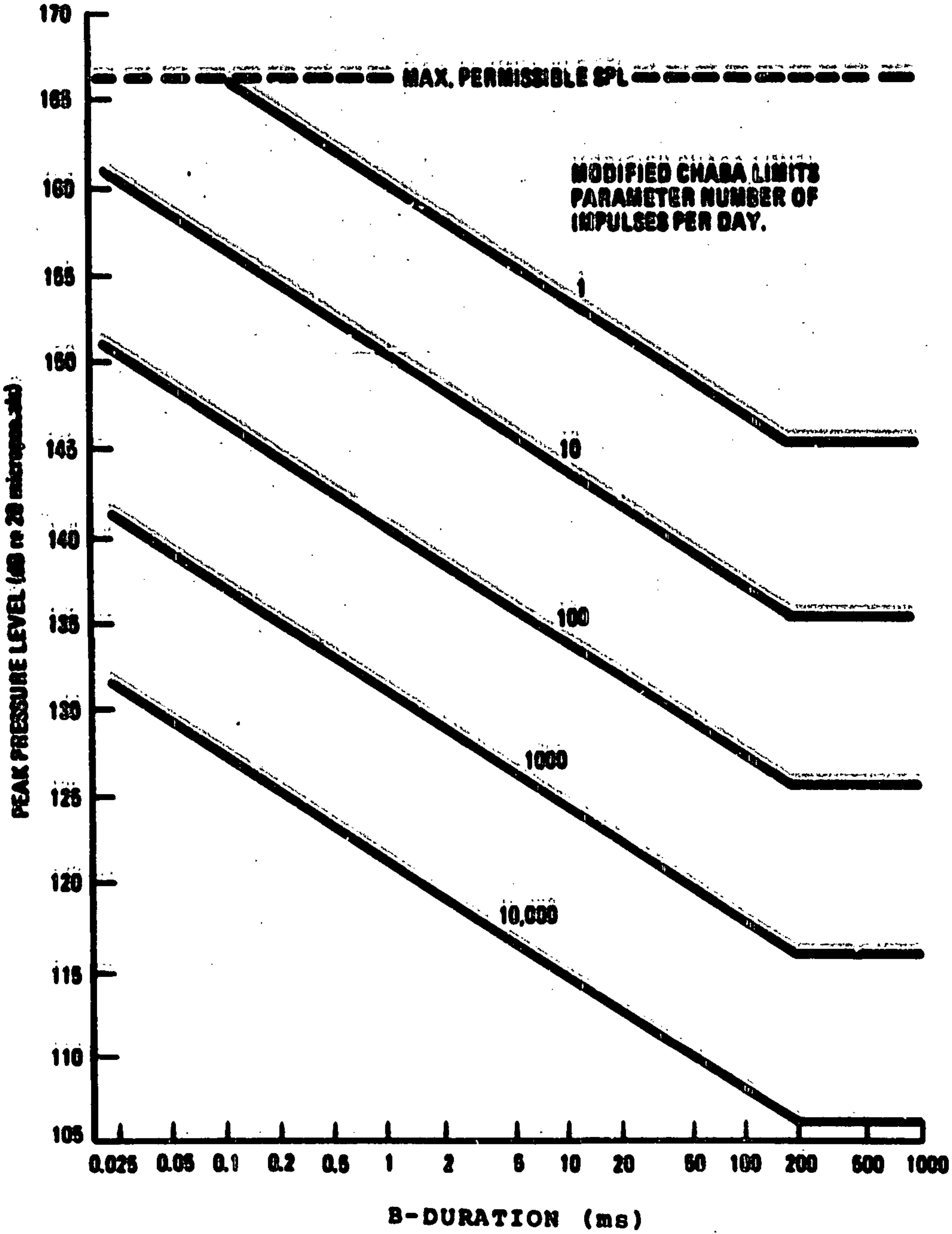

Figure 4. Set of Modified CHABA Limits for Daily Exposure to Impulse Noises Having B-Durations in the Range 25 Microseconds to 1 Second. (Parameter: number (N) of impulses per daily exposure. Criterion: NIPTS not to exceed 5 dB at 4 kHz in more than 10% of people.)

(Derived from Appendix G)

Non-Auditory Effects of Impulsive Sound

Impulses exceeding the background noise by more than about 10 dB are potentially startling or sleep-disturbing. If repeated, impulsive noises can be disturbing to some individuals if heard at all *(they may be at levels below the average noise levels)*. However, no threshold level can be identified at this time; nor is there any clear evidence or documentation of any permanent effect on public health and welfare.

Sonic Booms

Little or no public annoyance is expected to result from one sonic boom during the daytime below the level of 35.91 pascals (0.75 pounds per square foot) as measured on the ground (see Appendix G). The same low probability of annoyance is expected to occur for more than one boom per day if the peak level of each boom is no greater than:

$$\text{Peak Level} = \frac{35.91}{\sqrt{N}} \text{ pascals}$$

Where N is the number of booms. This value is in agreement with the equal energy concept.

Section 4

IDENTIFIED LEVELS OF ENVIRONMENTAL NOISE IN DEFINED AREAS

IDENTIFIED LEVELS

Table 4 identifies the levels requisite to protect public health and welfare with an adequate margin of safety for both activity interference and hearing loss. The table classifies the various areas according to the primary activities that are most likely to occur in each. The following is a brief description of each classification and a discussion of the basis for the identified levels in Table 4. For a more detailed discussion of hearing loss and activity interference, see Appendices C and D.

1. Residential areas are areas where human beings live, including apartments, seasonal residences, and mobile homes, as well as year-round residences. A quiet environment is necessary in both urban and rural residential areas in order to prevent activity interference and annoyance, and to permit the hearing mechanism to recuperate if it is exposed to higher levels of noise during other periods of the day.

An indoor L_{dn} of 45 dB will permit speech communication in the home, while an outdoor L_{dn} not exceeding 55 dB will permit normal speech communication at approximately three meters. Maintenance of this identified outdoor level will provide an indoor L_{dn} of approximately 40 dB with windows partly open for ventilation. The nighttime portion of this L_{dn} will be approximately 32 dB, which should in most cases, protect against sleep interference. An $L_{eq(24)}$ of 70 dB is identified as protecting against damage to hearing.

Although there is a separate category for commercial areas, commercial living accommodations such as hotels, motels, cottages, and inns should be included in the residential category since these are places where people sleep and sometimes spend extended periods of time.

2. Commercial areas include retail and financial service facilities, offices, and miscellaneous commercial services. They do not include warehouses, manufacturing plants, and other industrial facilities, which are included in the industrial classification. Although a level for activity interference has not been identified here (see footnote a), suggestions for such levels will be found in Table D-10 of Appendix D. On the other hand, a level of $L_{eq(24)}$ of 70 dB has been identified to protect against hearing loss.

Table 4

YEARLY AVERAGE* EQUIVALENT SOUND LEVELS IDENTIFIED AS REQUISITE TO PROTECT THE PUBLIC HEALTH AND WELFARE WITH AN ADEQUATE MARGIN OF SAFETY

	Measure	Indoor: Activity Interference	Indoor: Hearing Loss Consideration	To Protect Against Both Effects (b)	Outdoor: Activity Interference	Outdoor: Hearing Loss Consideration	To Protect Against Both Effects (b)
Residential with Outside Space and Farm Residences	L_{dn}	45		45	55		55
	$L_{eq(24)}$		70			70	
Residential with No Outside Space	L_{dn}	45		45			
	$L_{eq(24)}$		70				
Commercial	$L_{eq(24)}$	(a)	70	70(c)	(a)	70	70(c)
Inside Transportation	$L_{eq(24)}$	(a)	70	(a)			
Industrial	$L_{eq(24)}$(d)	(a)	70	70(c)	(a)	70	70(c)
Hospitals	L_{dn}	45		45	55		55
	$L_{eq(24)}$		70			70	
Educational	$L_{eq(24)}$	45		45	55		55
	$L_{eq(24)}$(d)		70			70	
Recreational Areas	$L_{eq(24)}$	(a)	70	70(c)	(a)	70	70(c)
Farm Land and General Unpopulated Land	$L_{eq(24)}$				(a)	70	70(c)

Code:

a. Since different types of activities appear to be associated with different levels, identification of a maximum level for activity interference may be difficult except in those circumstances where speech communication is a critical activity. (See Figure D-2 for noise levels as a function of distance which allow satisfactory communication.)

b. Based on lowest level.

c. Based only on hearing loss.

d. An $L_{eq(8)}$ of 75 dB may be identified in these situations so long as the exposure over the remaining 16 hours per day is low enough to result in a negligible contribution to the 24-hour average, i.e., no greater than an L_{eq} of 60 dB.

Note: Explanation of identified level for hearing loss. The exposure period which results in hearing loss at the identified level is a period of 40 years.

*Refers to energy rather than arithmetic averages.

3. Transportation facilities are included so as to protect individuals using public and private transportation. Included within this classification are commercial and private transportation vehicles. Identification of a level to protect against hearing loss is the only criterion

OTOLOGICALLY NORMAL. Enjoying normal health and freedom from all clinical manifestations and history of ear disease or injury; and having a patent (wax-free) external auditory meatus.

PEAK SOUND PRESSURE. The absolute maximum value (magnitude) of the instantaneous

THRESHOLD OF HEARING (AUDIBILITY). The minimum effective sound pressure level of an acoustic signal capable of exciting the sensation of hearing in a specified proportion of trials in prescribed conditions of listening.

ULTRASONIC. *Having a frequency above the audible range for man (conventionally* deemed to cut off at 20,000 Hz).

APPENDIX A

EQUIVALENT SOUND LEVEL AND ITS RELATIONSHIP TO OTHER NOISE MEASURES

Appendix A

EQUIVALENT SOUND LEVEL AND ITS RELATIONSHIP

DEVELOPMENT OF EQUIVALENT SOUND LEVEL

The accumulated evidence of research on human response to sound indicates clearly that the magnitude of sound as a function of frequency and time are basic indicators of human response to sound. These factors are reviewed here, and it is concluded that it is not necessary to invent a new concept for the purpose of identifying levels of environmental noise.

Magnitude

Sound is a pressure fluctuation in the air; the magnitude of the sound describes the physical sound in the air; (loudness, on the other hand, refers to how people judge the sound when they hear it). Magnitude is stated in terms of the amplitude of the pressure fluctuation. The range of magnitude between the faintest audible sound and the loudest sound the ear can withstand is so enormous (a ratio of about 1,000,000 to 1) that it would be very awkward to express sound pressure fluctuations directly in pressure units. Instead, this range is "compressed" by expressing the sound pressure on a logarithmic scale. Thus

Frequency Characteristics of Noise

The response of human beings to sound depends strongly on the frequency of sound. In general, people are less sensitive to sounds of low frequency, such as 100 hertz (Hz)*, than to sounds at 1000 Hz; also at high frequencies such as 8000 Hz, sensitivity decreases. Two basic approaches to compensate for this difference in response to different frequencies are (1) to segment the sound pressure spectrum into a series of contiguous frequency bands by electrical filters so as to display the distribution of sound energy over the frequency range; or (2) to apply a weighting to the overall spectrum in such a way that the sounds at various frequencies are weighted in much the same way as the human ear hears them.

In the first approach a sound is segmented into sound pressure levels in 24 different frequency bands, which may be used to calculate an estimate of the "loudness" or "noisiness" sensation which the sound may be expected to cause. This form of analysis into bands is usually employed when detailed engineering studies of noise sources are required. It is much too complicated for monitoring noise exposure.

To perform such analysis, especially for time-varying sounds, requires a very complex set of equipment. Fortunately, much of this complication can be avoided by using approach 2, i.e., by the use of a special electrical weighting network in the measurement system. This network weights the contributions of sounds of different frequency so that the response of the average human ear is simulated. Each frequency of the noise then contributes to the total reading by an amount approximately proportional to the subjective response associated with that frequency. Measurement of the overall noise with a sound level meter incorporating such a weighting network yields a single number, such as the A-weighted Sound Level, or simply A-level, in decibels. For zoning and monitoring purposes, this marks an enormous simplification. For this reason, the A-level has been adopted in large-scale surveys of city noise coming from a variety of sources. It is widely accepted as an adequate way to deal with the ear's differing sensitivity to sounds of different frequency, including assessment of noise with respect to its potential for causing hearing loss. Despite the fact that more detailed analysis is frequently required for engineering noise control, the results of such noise control are adequately described by the simple measure of sound level.

One difficulty in the use of a weighted sound level is that psychoacoustic judgment data indicate that effects of tonal components are sometimes not adequately accounted for by a simple sound level. Some current ratings attempt to correct for tonal components;

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*Hertz is the international standard unit of frequency, until recently called cycles per second; it refers to the number of pressure fluctuations per second in the sound wave.

for example, in the present aircraft noise certification procedures, "Noise Standards: Aircraft Type Certification," FAR Part 36, the presence of tones is identified by a complex frequency analysis procedure. If the tones protrude above the adjacent random noise spectrum, a penalty is applied beyond the direct calculation of perceived noise level alone. However, the complexities involved in accounting for tones exceed practicable limits for monitoring noise in the community or other defined areas. Consequently, EPA concludes that, where appropriate, standards for new products will address the problem of tones in such a way that manufacturers will be encouraged to minimize them and, thus, ultimately they will not be a

With respect to both simplicity and adequacy for characterizing human response, a frequency-weighted sound level should be used for the evaluation of environmental noise. Several frequency weightings have been proposed for general use in the assessment of response to noise, differing primarily in the way sounds at frequencies between 1000 and 4000 Hz are evaluated. The A-weighting, standardized in current sound level meter specifications, has been widely used for transportation and community noise description.[A-1] For many noises the A-weighted sound level has been found to correlate as well with human response as more complex measures, such as the calculated perceived noise level or the loudness level derived from spectral analysis.[A-2] However, psychoacoustic research indicates that, at least for some noise signals, a different frequency weighting which increases the sensitivity to the 1000-4000 Hz region is more reliable.[A-3] Various forms of this alternative weighting function have been proposed; they will be referred to here as the type "D-weightings". None of these alternative weightings has progressed in acceptance to the point where a standard has been approved for commercially available instrumentation.

It is concluded that a frequency-weighted sound pressure level is the most reasonable choice for describing the magnitude of environmental noise. In order to use available standardized instrumentation for direct measurement, the A frequency weighting is the only suitable choice at this time.* The indication that a type D-weighting might ultimately be more suitable than the A-weighting for evaluating the integrated effects of noise on people suggests that at such time as a type D-weighting becomes standardized and available in commercial instrumentation, its value as the weighting for environmental noise should be considered to determine if a change from the A-weighting is warranted.

the next. Thus, one cannot simply say that the noise level at a given location or that experienced by a person at that location is "so many decibels" unless a suitable method is used to average the time-varying levels. To describe the noise completely requires a statistical approach. Consequently, one should consider the noise *exposure* which is received by an individual moving through different noisy spaces. This exposure is related to the whole time-varying pattern of sound levels. Such a noise exposure can be described by the cumulative distribution of sound levels, showing exactly what percent of the whole observation period each level was exceeded.

A complete description of the noise exposure would distinguish between daytime, evening and nighttime, and between weekday and weekend noise level distributions. It would also give distributions to show the difference between winter and summer, fair weather and foul.

The practical difficulty with the statistical methodology is that it yields a large number of statistical parameters for each measuring location; and even if these were averaged over more or less homogeneous neighborhoods, it still would require a large set of numbers to characterize the noise exposure in that neighborhood. It is literally impossible for any such array of numbers to be effectively used either in an enforcement context or to map existing noise exposure baselines.

It is essential, therefore, to look further for a suitable single-number measure of noise exposure. Note that the ultimate goal is to characterize with reasonable accuracy the noise exposure of whole neighborhoods (within which there may actually exist a fairly wide range of noise levels), so as to prevent extremes of noise exposure at any given time, and to detect

[illegible]

masses of data for each location are not required, and may even be a hindrance, since one could fail to see the forest for the trees.

Equivalent Sound Level is formulated in terms of the equivalent *steady* noise level which in a stated period of time would contain the same noise energy as the time-varying noise during the same time period.

The mathematical definition of L_{eq} for an interval defined as occupying the period between two points in time t_1 and t_2 is:

$$L_{eq} = 10 \log \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p^2(t)}{p_o^2} \, dt \right] \quad \text{(Eq. A-2)}$$

where p(t) is the time varying sound pressure and p_o is a reference pressure taken as 20 micropascals.

The concept of Equivalent Sound Level was developed in both the United States and Germany over a period of years. Equivalent level was used in the 1957 original Air Force Planning Guide for noise from aircraft operations,[A-6] as well as in the 1955 report[A-7] on criteria for short-time exposure of personnel to high intensity jet aircraft noise, which was the forerunner of the 1956 Air Force Regulation[A-8] on "Hazardous Noise Exposure". A more recent application is the development of CNEL (Community Noise Equivalent Level) measure for describing the noise environment of airports. This measure, contained in the Noise Standards, Title 4, Subchapter 6, of the California Administrative Code (1970) is based upon a summation of L_{eq} over a 24-hour period with weightings for exposure during evening and night periods.

The Equivalent Noise Level was introduced in 1965 in Germany as a rating specifically to evaluate the impact of aircraft noise upon the neighbors of airports.[A-9] It was almost immediately recognized in Austria as appropriate for evaluating the impact of street traffic noise in dwellings[A-10] and in schoolrooms.[A-11] It has been embodied in the National Test Standards of both East Germany[A-12] and West Germany[A-13] for rating the subjective effects of fluctuating noises of all kinds, such as from street and road traffic, rail traffic, canal and river ship traffic, aircraft, industrial operations (including the noise from individual machines), sports stadiums, playgrounds, etc. It is the rating used in both the East German[A-14] and West German[A-15] standard guidelines for city planning. It was the rating that proved to correlate best with subjective response in the large Swedish traffic noise survey of 1966-67. It has come into such general use in Sweden for rating noise exposure that commercial instrumentation is currently available for measuring L_{eq} directly; the lightweight unit is small enough to be held in one hand and can be operated either from batteries or an electrical outlet.[A-16]

The concept of representing a fluctuating noise level in terms of a steady noise having the same energy content is widespread in recent research, as shown in the EPA report on Public Health and Welfare Criteria for Noise (1973). There is evidence that it accurately describes the onset and progress of permanent noise-induced hearing loss,[A-17] and substantial evidence to show that it applies to annoyance in various circumstances.[A-18] The concept is borne out by Pearsons' experiments[A-19] on the trade-off of level and duration of a noisy event and by numerous investigations of the trade-off between number of events and noise level in aircraft flyovers.[A-20] Indeed, the Composite Noise Rating[A-21] is a formulation of L_{eq}, modified by corrections for day vs. night operations. The concept is embodied in several recommendations of the International Standards Organization, for assessing the noise from aircraft,[A-22] industrial noise as it affects residences,[A-23] and hearing conservation in factories.[A-24]

COMPUTATION OF EQUIVALENT SOUND LEVEL

In many applications, it is useful to have analytic expressions for the equivalent sound level L_{eq} in terms of simple parameters of the time-varying noise signal so that the integral does not have to be computed. It is often sufficiently accurate to approximate a complicated time-varying noise level with simple time patterns. For example, industrial noise can often be considered in terms of a specified noise level that is either on or off as a function of time. Similarly, individual aircraft or motor vehicle noise events can be considered to exhibit triangular time patterns that occur intermittently during a period of observation. (Assuming an aircraft flyover time pattern to be triangular in shape instead of shaped like a "normal distribution function" introduces an error of, at worst, 0.8 dB). Other noise histories can often be approximated with trapezoidal time pattern shapes.

The following sections provide explicit analytic expressions for estimating the equivalent sound level in terms of such time patterns, and graphic design charts are presented for easy application to practical problems. Most of the design charts are expressed in terms of the amount (ΔL) that the level (L) of the new noise source exceeds an existing background noise level, L_b. ($\Delta L = L - L_b$). This background noise may be considered as the equivalent sound level that existed before the introduction of the new noise, provided that its fluctuation is small relative to the maximum value of the new noise level.

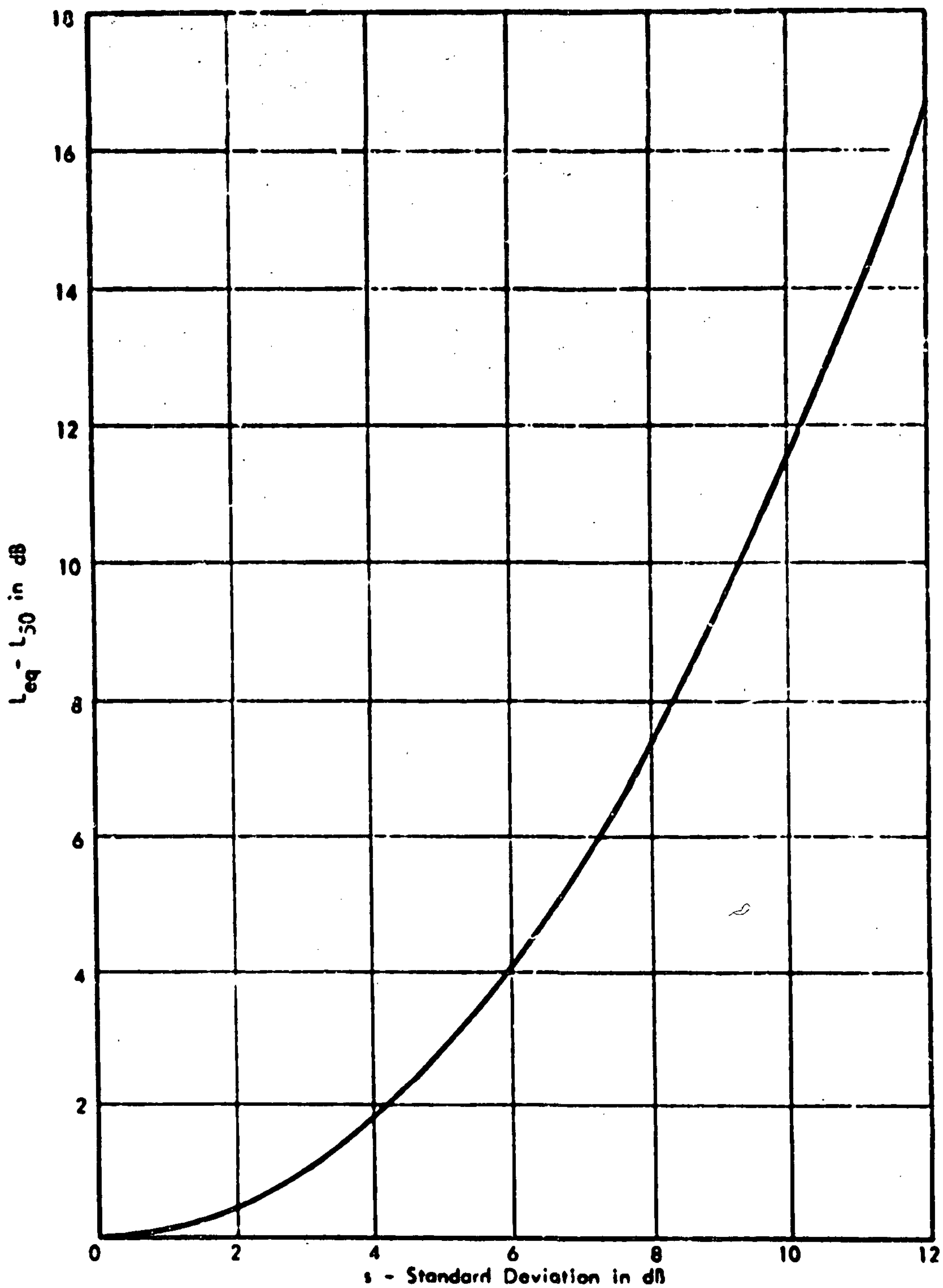

Figure A-4. Difference Between L_{eq} and L_{50} for a Normal Distribution Having Standard Deviation of s.[A-25] (See Equation A-14).

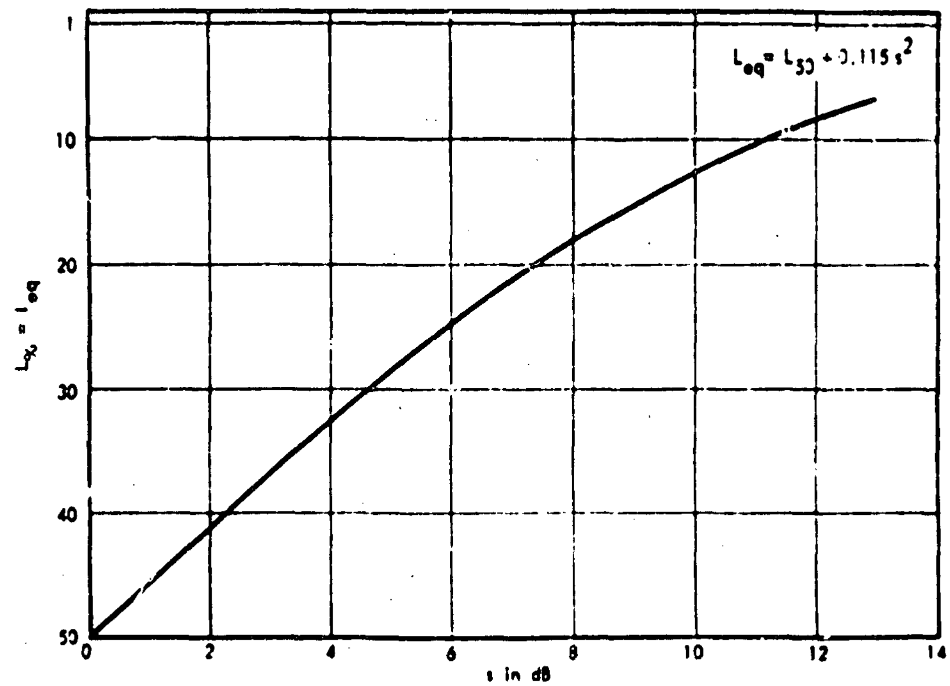

Figure A-5. Percentile of a Normal Distribution that is Equal to L_{eq}[A-25] (See Equation A-14 and Probability Function).

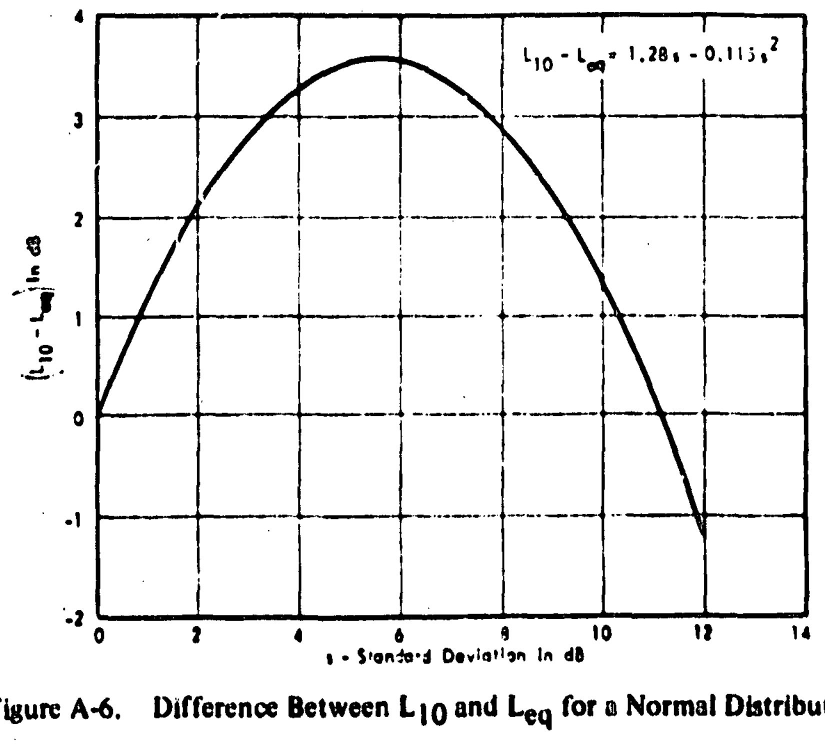

Figure A-6. Difference Between L_{10} and L_{eq} for a Normal Distribution[A-25]

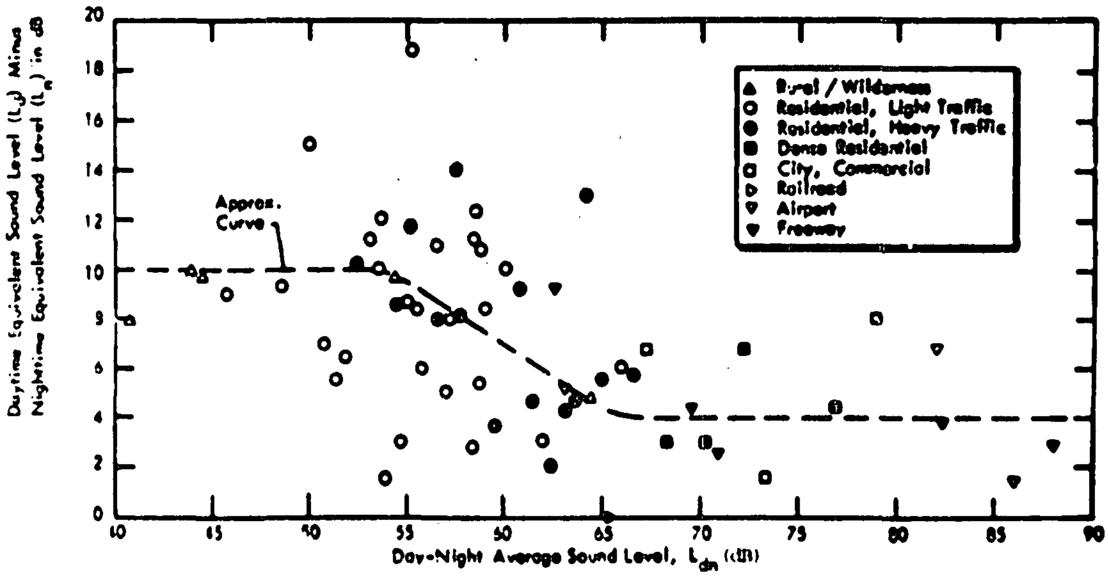

Figure A-7. Comparison of the Difference Between Day and Night Values of the Equivalent Sound Level with the Day-Night Average Sound Level, L_{dn} [A-25]

The effect of the weighting may perhaps be more clearly visualized if it is thought of as a method that makes all levels measured at night 10 dB higher than they actually are. Thus, as an example, if the noise level is a constant 70 dB all day and a constant 60 dB all night, L_{dn} would be 70 dB.

Methods for accounting for the differences in interference or annoyance between daytime/nighttime exposures have been employed in a number of different noise assessment methods around the world.[A-5] The weightings applied to the nondaytime periods differ slightly among the different countries but most of them weight night activities on the order of 10 dB;[A-24] the evening weighting if used is 5 dB. The choice of 10 dB for the nighttime weighting made in Section 2 was predicated on its extensive prior usage, together with an examination of the diurnal variation in environmental noise. This variation is best illustrated by comparing the difference between L_d and L_n as a function of L_{dn} over the range of environmental noise situations.

Data from 63 sets of measurements were available in sufficient detail that such a comparison could be made. These data are plotted in Figure A-7. The data span noise environments ranging from the quiet of a wilderness area to the noisiest of airport and highway environments. It can be seen that, at the lowest levels (L_{dn} around 40-55 dB),

L_d is the controlling element in determining L_{dn}, because the nighttime noise level is so much lower than that in the daytime. At higher L_{dn} levels (65-90 dB), the values of L_n are not much lower than those for L_d; thus, because of the 10 dB nighttime weighting, L_n will control the value of L_{dn}.

The choice of the 10 dB nighttime weighting in the computation of L_{dn} has the following effect: In low noise level environments below L_{dn} of approximately 55 dB, the natural drop in L_n values is approximately 10 dB, so that L_d and L_n contribute about equally to L_{dn}. However, in high noise environments, the night noise levels drop relatively little from their daytime values. In these environments, the nighttime weighting applies pressure towards a round-the-clock reduction in noise levels if the noise criteria are to be met.

The effect of a nighttime weighting can also be studied indirectly by examining the correlation between noise measure and observed community response in the 55 community reaction cases presented in the EPA report to Congress of 1971.[A-1] The data have a standard deviation of 3.3 dB when a 10 dB nighttime penalty is applied, but the correlation worsens (std. dev. = 4.0 dB) when no nighttime penalty is applied. However, little difference was observed among values of the weighting ranging between 8 and 12 dB. Consequently, the community reaction data support a weighting of the order of 10 dB but they cannot be utilized for determining a finer gradation. Neither do the data support "three-period" in preference to "two-period" days in assigning nondaytime noise penalties.

COMPARISON OF DAY-NIGHT SOUND LEVEL WITH OTHER MEASURES OF NOISE USED BY FEDERAL AGENCIES

The following subsections compare the day-night sound level with three measures utilized for airport noise, CNR, NEF, and CNEL, the HUD Guideline Interim Standards and the Federal Highway Administration standards:

Comparison of L_{dn} with Composite Noise Rating (CNR), Noise Exposure Forecast (NEF), and Community Noise Equivalent Level (CNEL)

CNR, NEF, and CNEL are all currently used expressions for weighted, accumulated noise exposure. Each is intended to sum a series of noise while weighting the sound pressure level for frequency and then adding appropriate nighttime weightings. The older ratings, CNR and NEF, are expressed in terms of maximum Perceived Noise Level and Effective Perceived Noise Level, respectively; each considers a day-night period identical to L_{dn}.

The measure CNEL itself is essentially the same as L_{dn} except for the method of treating nighttime noises. In CNEL, the 24-hour period is broken into three periods: day (0700-1900), evening (1900-2200), and night (2200-0700). Weightings of 5 dB are applied to the evening period and 10 dB to the night period. For most time distributions of aircraft noise around airports, the numerical difference between a two-period and three-period day are not significant, being of the order of several tenths of a decibel at most.

One additional difference between these four similar measures is the method of applying the nighttime weighting and the magnitude of the weighting. The original CNR concept, carried forward in the NEF, weighted the nighttime exposure by 10 dB. Because of the difference in total duration of the day and night periods, 15 and 9 hours respectively, a specific noise level at night receives a weighting of $10 + 10 \log \left(\frac{15}{9}\right)$, or approximately 12 dB in a reckoning of total exposure. Given the choice of weighting either exposure or level, it is simpler to weight level directly, particularly when actual noise monitoring is eventually considered.

The following paragraphs describe the method utilized to calculate CNR, NEF, and CNEL, as applied principally to aircraft sounds, together with the analogous method for calculating L_{dn}:

Composite Noise Rating Method (CNR)

The original method for evaluating land use around civil airports is the composite noise rating (CNR). It is still in wide use by the Federal Aviation Administration and the Department of Defense for evaluating land use around airfields (Civil Engineering Planning and Programming, "Land Use Planning with Respect to Aircraft Noise," AFM 86-5, TM 5-365, NAVDOCKS P-98, October 1, 1964). This noise exposure scale may be expressed as follows:

The single event noise level is expressed (without a duration or tone correction) as simply the maximum perceived noise level (PNL_{max}) in PNdB.

The noise exposure in a community is specified in terms of the composite noise rating (CNR), which can be expressed approximately as follows:

$$CNR = \overline{PNL}_{max} + 10 \log N_f - 12 \qquad \text{(Eq. A-16)}$$

where

$\overline{PNL}$ = approximate energy mean maximum perceived noise level (PNL) at a given point

$N_f = (N_d + 16.7\,N_n)$, where N_d and N_f the numbers of daytime and nighttime events, respectively.

The constant (-12) is an arbitrary constant, and the factor 16.7 is used to weight the nighttime exposure in the 9-hour night period on a 10 to 1 basis with the daytime exposure in the 15-hour daytime period.

Noise Exposure Forecast (NEF)

This method, currently in wide use, for making noise exposure forecasts utilizes a perceived noise level scale with additional corrections for the presence of pure tones. Two time periods are used to weight the number of flights (Galloway, W.J. and Bishop, D.E., "Noise Exposure Forecasts: Evolution, Evaluation, Extensions and Land Use Interpretations," FAA-NO-70-9, August 1970).

The single event noise level is defined in terms of effective perceived noise level (EPNL) which can be specified approximately by:

$$EPNL = PNL_{max} + \log \frac{\Delta t_{10}}{20} + F, \text{ (EPNdB)} \qquad \text{(Eq. A-17)}$$

where

PNL_{max} = maximum perceived noise level during flyover, in PNdB,

Δt_{10} = "10 dB down" duration of the perceived noise level time history, in seconds,

and

F = pure tone correction. Typically, $F = 0$ to $+3$ dB

Community noise exposure is then specified by the Noise Exposure Forecast (NEF). For a given runway and one or two dominant aircraft types, the total NEF for both daytime and nighttime operations can be expressed approximately as:

$$NEF = \overline{EPNL} + 10 \log N_f - 88.0 \qquad \text{(Eq. A-18)}$$

where

$\overline{EPNL}$ = energy mean value of EPNL for each single event at the point in question

N_f = same as defined for CNR.

Community Noise Equivalent Level (CNEL)

The following simplified expressions are derived from the exact definitions in the report, "Supporting Information for the Adopted Noise Regulations for California Airports." They can be used to estimate values of CNEL where one type of aircraft and one flight path dominate the noise exposure level.

Single event noise is specified by the single event noise exposure level (SENEL) in dB and can be closely approximated by:

$$SENEL = NL_{max} + 10 \log_{10} \tau/2 \qquad (dB) \qquad (Eq. A-19)$$

where

NL_{max} = maximum noise level as observed on the A scale of a standard sound level meter

and

τ = duration measured between the points of $(L_{max} - 10)$ in seconds. The effective duration is equal to the "energy" of the integrated noise level (NL), divided by the maximum noise level, NL_{max}, when both are expressed in terms of antilogs. It is approximately 1/2 of the 10 dB down duration.

A measure of the average integrated noise level over one hour is also utilized in the proposed standard. This is the hourly noise level (in dB), defined as:

$$HNL = \overline{SENEL} + 10 \log n - 35.6 \qquad (dB) \qquad (Eq. A-20)$$

where

$\overline{SENEL}$ = energy mean value of SENEL for each single event,

and

n = number of flights per hour

The total noise exposure for a day is specified by the community noise equivalent level (CNEL) in dB, and may be expressed as:

$$CNEL = \overline{SENEL} + 10 \log N_c - 49.4 \qquad (dB) \qquad (Eq. A-21)$$

where

$$N_c = (N_d + 3N_e + 10N_n)$$

or

$$= (12\bar{n}_d + 9\bar{n}_e + 90\bar{n}_n)$$

$N_d, \bar{n}_d$ = total number and average number per hour, respectively, of flights during the period 0700 to 1900

$N_e, \bar{n}_e$ = total number and average number per hour, respectively, of flights during the period 1900 to 2200

and

$N_n, \bar{n}_n$ = total number and average number per hour, respectively, of flights during the period 2200 to 0700

Day-Night Sound Level (L_{dn})

The following simplified expressions are useful for estimating the value of L_{dn} for a series of single event noises which are of sufficient magnitude relative to the background noise that they control L_{dn}:

Single event noise is specified by the sound exposure level (L_{ex}) measured during a single event. It can be closely approximated by:

$$L_{ex} \cong L_{max} + 10 \log_{10} \tau/2 \qquad \text{(dB)} \qquad \text{(Eq. A-22)}$$

where

L_{max} = maximum sound level as observed on the A scale of a standard sound level meter on the slow time characteristic

and

τ = duration measured between the points of (L_{max} - 10) in seconds

The day-night sound level may be estimated by:

$$L_{dn} = \overline{L_{ex}} + 10 \log N - 49.4 \qquad \text{(dB)} \qquad \text{(Eq. A-23)}$$

where

$\overline{L_{ex}}$ = the energy mean value of the single event L_{ex} values

N = $(N_d + 10N_n)$

or

N_d = total number of events during the period 0700 to 2200

and

N_n = total number of events during the period 2200 to 0700

There is no fixed relationship between L_{dn} or CNEL and CNR or NEF because of the differences between the A-level and PNL frequency weightings and the allowance for duration, as well as the minor differences in approach to day-night considerations. Nevertheless, one may translate from one measure to another by the following approximate relationship:

$$L_{dn} \doteq CNEL \doteq NEF + 35 \doteq CNR - 35 \qquad \text{(Eq. A-24)}$$

For most circumstances involving aircraft flyover noise, these relationships are valid within about a ± 3 dB tolerance.

Comparison of L_{eq} with HUD Guideline Interim Standards (1390.2 Chg. 1)

The interim HUD standards for outdoor noise are specified for all noise sources, other than aircraft, in terms of A-weighted sound level not to be exceeded more than a certain fraction of the day. Aircraft noise criteria are stated in terms of NEF or CNR.

The HUD exposure criteria for residences near airports are "normally acceptable" if NEF 30 or CNR 100 is not exceeded. A "discretionary acceptable" category permits exposures up to NEF 40 or CNR 115.

For all other noise sources, the HUD criteria specify a series of acceptable, discretionary, and unacceptable exposures. Since these specifications are similar to points on a cumulative statistical description of noise levels, it is of interest to compare the HUD criteria with L_{eq} for different situations. For discussion purposes, consider the boundary between the categories "discretionary-normally acceptable" and "unacceptable."

The first criterion defining this boundary allows A-weighted noise levels to exceed 65 dB up to 8 hours per 24 hours, while the second criterion states that noise levels exceeding 80 dB should not exceed 60 minutes per 24 hours. These two values may be used to specify two limit points on a cumulative distribution function, $L_{33.3}$ = 65 dB and $L_{4.2}$ = 80 dB. The relationship between L_{eq} and the HUD criteria may then be examined for different types of distribution functions, restricting the shape of the distribution only so that it does not exceed these two limit points.

Highway noise often has a random distribution of noise level, the distribution function being approximately normal in many instances. In this case, the relationship between L_{eq} and L_{10} is given by the expression:

$$L_{eq} = L_{10} - 1.28\,s + 0.115\,s^2 \qquad \text{(dB)} \qquad \text{(Eq. A-25)}$$

where s is the standard deviation of the noise level distribution. The difference between L_{10} and L_{eq} for normal distribution of sound level is plotted in Figure A-6. It can be noted that $L_{eq} = L_{10}$ -2 dB within ±2 dB, for s ranging from 0 to 11 dB. Highway noise rarely has a standard deviation of 11 dB; 2 to 5 dB is more typical.

Thus, setting L_{10} at 60 dB for highway noise impacting a sensitive outdoor space, we find that an L_{eq} value of 60 -2 = 58 ±2 dB would meet the most sensitive FHWA criterion.

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APPENDIX B

LEVELS OF ENVIRONMENTAL NOISE IN THE U.S. AND TYPICAL EXPOSURE PATTERNS OF INDIVIDUALS

APPENDIX B

LEVELS OF ENVIRONMENTAL NOISE IN THE U.S. AND TYPICAL EXPOSURE PATTERNS OF INDIVIDUALS

Levels of environmental noise for various defined areas are provided for both the outdoor and indoor situation. Examples are then used to illustrate how an individual's daily dose accumulates from the exposure to such noise levels.

LEVELS OF ENVIRONMENTAL NOISE

Outdoor Sound Levels

The range of day-night sound levels (L_{dn}) in the United States is very large, extending from the region of 20-30 dB estimated for a quiet* wilderness area to the region of 80-90 dB in the most noisy urban areas, and to still higher values within the property boundaries of some governmental, industrial and commercial areas which are not accessible to the general public. The measured range of values of day-night sound levels outside dwelling units extends from 44 dB on a farm to 88.8 dB outside an apartment located adjacent to a freeway. Some examples of these data are summarized in Figure B-1.

The dominant sources for outdoor noise in urban residential areas are motor vehicles, aircraft and voices. This conclusion has been found in several studies, including a recent survey [B-1] of 1200 people which is summarized in Table B-1.

The cumulative number of people estimated to reside in areas where the day-night sound level exceeds various values is given in Table B-2. In the areas where the L_{dn} exceeds 60 dB, the proportion between the number of people residing in areas where the outdoor noise environment is dominated by aircraft and those residing in areas where motor vehicles dominate is approximately one to four. This proportion is almost identical to the proportion found in the survey, previously summarized in Table B-1 where people were asked to judge the principle contributing sources of neighborhood noise. The estimates in Table B-2 of the

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*Measurement approximately 25 feet from a mountain waterfall on a small canyon stream in Wyoming gave an L_{dn} of approximately 65 dB.[B-2]

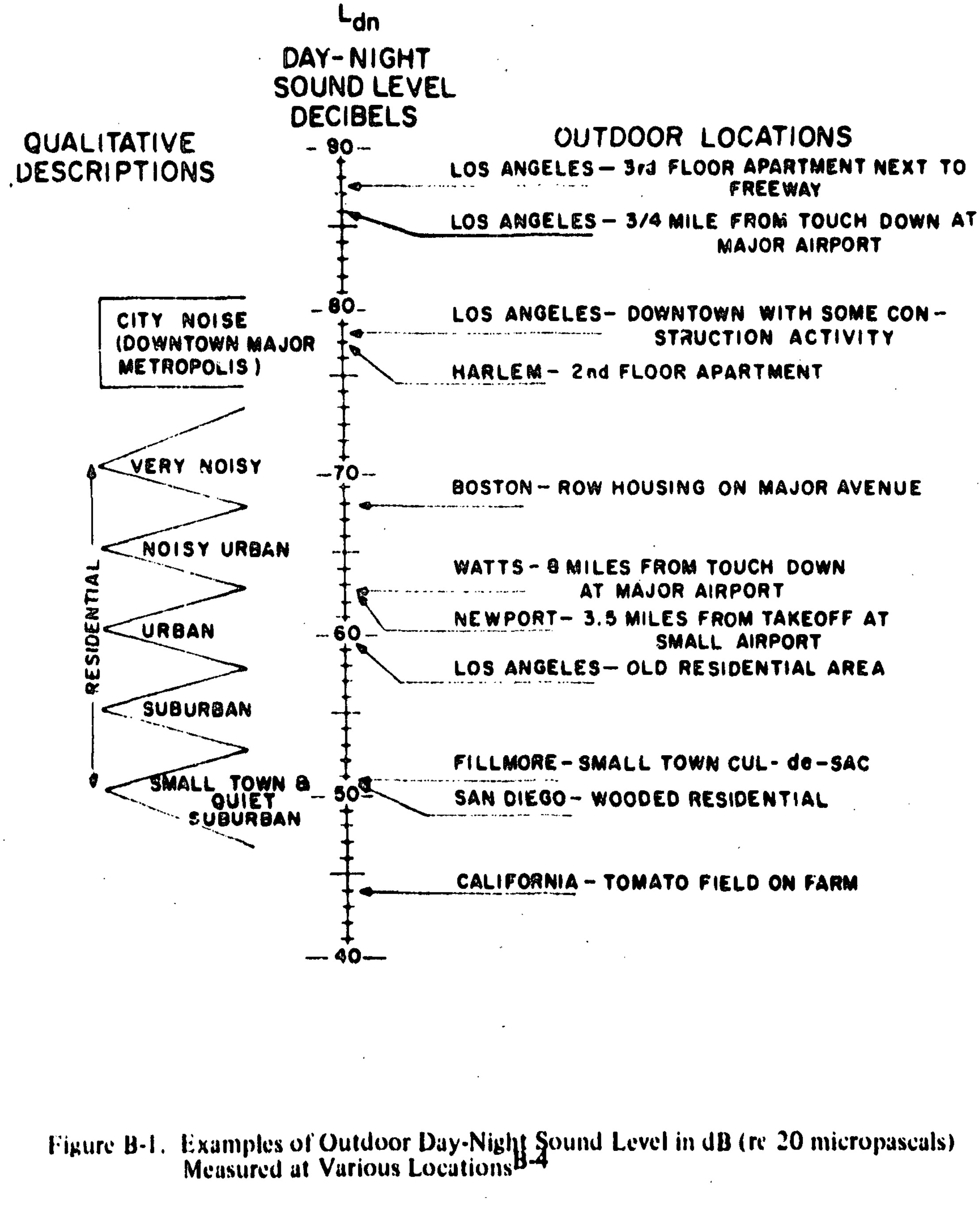

Figure B-1. Examples of Outdoor Day-Night Sound Level in dB (re 20 micropascals) Measured at Various Locations[B-4]

Table B-1
PERCENT CONTRIBUTION OF EACH SOURCE IDENTIFIED BY RESPONDENTS CLASSIFYING THEIR NEIGHBORHOOD AS NOISY (72% OF 1200 RESPONDENTS)[B-3]

Source	Percentage
Motor Vehicles	55
Aircraft	15
Voices	12
Radio and TV Sets	2
Home Maintenance Equipment	2
Construction	1
Industrial	1
Other Noises	6
Not Ascertained	8

Table B-2
ESTIMATED CUMULATIVE NUMBER OF PEOPLE IN MILLIONS IN THE UNITED STATES RESIDING IN URBAN AREAS WHICH ARE EXPOSED TO VARIOUS LEVELS OF OUTDOOR DAY/NIGHT AVERAGE SOUND LEVEL.[B-4,B-5]

Outdoor L_{dn} Exceeds	Urban Traffic	Freeway Traffic	Aircraft Operations	Total
60	59.0	3.1	16.0	78.1
65	24.3	2.5	7.5	34.3
70	6.9	1.9	3.4	12.2
75	1.3	0.9	1.5	3.7
80	0.1	0.3	0.2	0.6

number of people living in areas which are exposed to freeway and aircraft noise are taken from the EPA airport/aircraft noise report.[B-4] They were based on calculated noise contours and associated populations for a few selected situations which formed the basis for extrapolation to national values. The estimates for the number of people living in areas in which the noise environment is dominated by urban traffic were developed from a survey[B-5] conducted in Summer 1973 for EPA. The survey measured the outdoor 24-hour noise environment at 100 sites located in 14 cities, including at least one city in each of the ten EPA regions. These data, supplemented with that from previous measurements at 30 additional sites, were correlated with census tract population density to obtain a general relationship between L_{dn} and population density. This relationship was then utilized, together with census data giving population in urban areas as a function of population density, to derive the national estimate given in Table B-2.

These data on urban noise enable an estimate of the percentage urban population in terms of both noise levels and the qualitative descriptions of urban residential areas which were utilized in the Title IV EPA report to Congress in 1971.[B-6]

These estimates, summarized in Table B-3, show that the majority of the 134 million people residing in urban areas have outdoor L_{dn} values ranging from 43 dB to 72 dB with a median value of 59 dB. The majority of the remainder of the population residing in rural or other non-urban areas is estimated to have outdoor L_{dn} values ranging between 35 and 50 dB.

Indoor Sound Levels

The majority of the existing data regarding levels of environmental noise in residential areas has been obtained outdoors. Such data are useful in characterizing the neighborhood noise environment evaluating the noise of identifiable sources and relating the measured values with those calculated for planning purposes. For these purposes, the outdoor noise levels have proved more useful than indoor noise levels because the indoor noise levels contain the additional variability of individual building sound level reduction. This variability among dwelling units results from type of construction, interior furnishings, orientation of rooms relative to the noise, and the manner in which the dwelling unit is ventilated.

Data on the reduction of aircraft noise afforded by a range of residential structures are available.[B-7] These data indicate that houses can be approximately categorized into "warm climate" and "cold climate" types. Additionally, data are available for typical open-window and closed-window conditions. These data indicate that the sound level reduction provided by buildings within a given community has a wide range due to differences in the use of materials, building techniques, and individual building plans. Nevertheless, for

Table B-3
ESTIMATED PERCENTAGE OF URBAN POPULATION (134 MILLION) RESIDING IN AREAS WITH VARIOUS DAY-NIGHT NOISE LEVELS TOGETHER WITH CUSTOMARY QUALITATIVE DESCRIPTION OF THE AREA[B-3,B-4]

Description	Typical Range L_{dn} in dB	Average L_{dn} in dB	Estimated Percentage of Urban Population	Average Census Tract Population Density, Number of People Per Square Mile
Quiet Suburban Residential	48-52	50	12	630
Normal Suburban Residential	53-57	55	21	2,000
Urban Residential	58-62	60	28	6,300
Noisy Urban Residential	63-67	65	19	20,000
Very Noisy Urban Residential	68-72	70	7	63,000

planning purposes, the typical reduction in sound level from outside to inside a house can be summarized as follows in Table B-4. The approximate national average "window open" condition corresponds to an opening of 2 square feet and a room absorption of 300 sabins (typical average of bedrooms and living rooms). This window open condition has been assumed throughout this report in estimating conservative values of the sound levels inside dwelling units which results from outdoor noise.

The sound levels inside dwelling units result from the noise from the outside environment plus the noise generated internally. The internally generated noise results from people activity, appliances and heating and ventilating equipment. Twenty-four hour continuous measurements were made in 12 living rooms (living, family or dining room) in 12 houses during the 100-site EPA survey[B-5] of urban noise, excluding areas where the noise resulted from freeways and aircraft. The results, summarized below in Table B-5, show that the inside day-night sound level in these homes was the result of internally generated noise. In fact, the internal L_{dn} and L_d values were slightly higher than those measured outdoors, despite the fact that the average house sound level reduction appeared to exceed 18 dB. The pattern for the indoor sound levels varies significantly among the homes, as portrayed by the data in Figure B-2. The hourly equivalent sound levels have an average minimum of approximately

Table B-4

SOUND LEVEL REDUCTION DUE TO HOUSES* IN WARM AND COLD CLIMATES, WITH WINDOWS OPEN AND CLOSED[B-7]

	Windows *Open*	Windows *Closed*
Warm climate	12 dB	24 dB
Cold climate	17 dB	27 dB
Approximate national average	15 dB	25 dB

*(Attenuation of outdoor noise by exterior shell of the house)

Table B-5

COMPARISON OF INTERNAL AND OUTDOOR SOUND LEVELS IN LIVING AREAS AT 12 HOMES[B-7]

	Daytime Sound Level (L_d) in dB	Nighttime Sound Level (L_n) in dB	Day-Night Sound Level L_{dn} in dB
Outdoors:			
Average	57.7	49.8	58.8
Standard Deviation	3.1	4.6	3.6
Indoors:			
Average	59.4	46.9	60.4
Standard Deviation	5.6	8.7	5.9
Difference:			
Outdoors Minus Indoors	1.7	2.9	-1.6

where: $L(t_i)$ is the L_{eq} value for the appropriate time periods, (t_i) and the summation of all the t_i's must equal a total of 24 hours (i.e., $\sum_{i=1}^{n} t_i = 24$ hours (86400 sec.)).

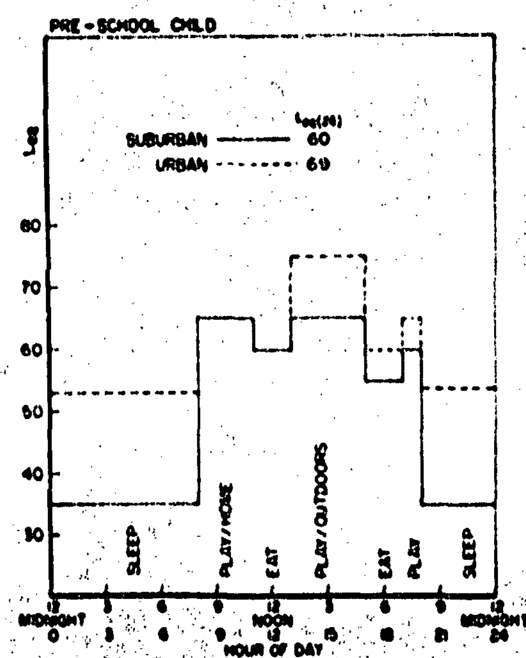

Figure B-7. Typical Noise Exposure Pattern of a Pre-School Child B-1, B-4, B-8, B-9

REFERENCES FOR APPENDIX B

B-1. Eldred, K.M., "Community Noise," Environmental Protection Agency NTID 300.3, December 1971.

B-2. Garland, W.L., Hanna, S.J. and Lamb, D.R., "Ambient Noise, Wind and Air Attentuation in Wyoming," Proceedings of Noise-Con 73, Washington, D.C., October 1973.

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B-5. Galloway, D. and Eldred, K., 100-Site Report, in preparation as a BBN Report for the Environmental Protection Agency.

B-6. "Report to the President and Congress on Noise," Environmental Protection Agency NRC 500.1, December 31, 1971.

B-7. "House Noise - Reduction Measurements for Use in Studies of Aircraft Flyover Noise," Society of Automotive Engineers, Inc., AIR 1081, October 1971.

B-8. "Transportation Noise and Noise from Equipment Powered by Internal Combustion Engines," Environmental Protection Agency NTID 300.13, December 1971.

B-9. "Noise from Construction Equipment and Operations, Building Equipment and Home Appliances," Environmental Protection Agency NTID 300.1, December 1971.

APPENDIX C

NOISE-INDUCED HEARING LOSS

APPENDIX C

NOISE-INDUCED HEARING LOSS

INTRODUCTION

A considerable amount of hearing loss data have been collected and analyzed. These data include measurements of hearing loss in people with known histories of noise exposure. Much of the analysis consists of grouping these measurements into populations of the same age with the same history of noise exposure and determining the percentile distribution of hearing loss for populations with the same noise exposure. Thus, the evidence for noise-induced permanent threshold shift can be clearly seen by comparing the distribution of a noise-exposed population with that of a relatively non-noise-exposed population.

Most of these data are drawn from cross-sectional research rather than longitudinal studies. That is, individuals or populations have been tested at only one point in time. Because complete noise-exposure histories do not exist, many conclusions are limited by the need to make certain hypotheses about the onset and progression of noise-induced hearing loss. Different hypotheses about the time history will lead to different conclusions even from the same data base, although the range of such conclusions is limited. Thus, in reaching conclusions about hearing loss, reliance is made on assumptions, hypotheses, and extrapolations which are not all universally accepted by the scientific community. However, attempts have been made to consider differing opinions and to insure that the methodology and conclusions in this section are in the mainstream of current scientific thought.

BASIC ASSUMPTIONS AND CONSIDERATIONS

In order to proceed further, it is necessary to make the following well-based assumptions:

1. Hearing shifts in the "non-noise-exposed" populations are attributable to aging and other causes rather than to noise exposure.

2. As individuals approach the high end of the distribution and their hearing becomes worse, they become less affected by noise exposure. In other words, there comes a point where one cannot be damaged by sounds that one cannot hear.

In addition, there are some important considerations necessary for the identification of a level to protect against hearing loss.

Preservation of High Frequency Hearing

The levels identified in this document for hearing conservation purposes are those which have been shown to provide protection from any measurable degradation of hearing acuity. This protection is provided even for those portions of the hearing mechanism which respond to the audiometric frequency at which noise-induced hearing impairment first occurs, namely 4000 Hz. The definition of hearing handicap originated by the American Academy of Opthalmology and Otolaryngology (AAOO), and currently incorporated in many hearing damage-risk criteria, is somewhat different from the definition used in this document. Hearing handicap, (and later, hearing impairment) was defined by a formula which used the average hearing level at 500 Hz, 1000 Hz and 2000 Hz.

Although hearing loss for frequencies above 2000 Hz is not treated as significant by most of the existing occupational hearing damage-risk criteria, the ability to hear frequencies above 2000 Hz is important for understanding speech and other signals. Despite the traditional use of the term "speech frequencies" to apply to 500, 1000 and 2000 Hz, useful energy in speech sound ranges from about 200 to 6100 Hz.[C-1] It has been known for many years that the equal discriminability point in the speech spectrum is at about 1600 Hz. That is, frequencies above 1600 Hz are equal in importance to those below 1600 Hz for understanding speech.[C-1] However, there are other reasons for preserving the frequencies above 2000 Hz. Higher frequencies are important for the localization and identification of faint, high-pitched sounds in a variety of occupational and social situations. Detection of soft, relatively high-frequency sounds can be especially important in vigilance tasks, such as those which may occur in the military. In addition, good hearing for the higher frequencies is important to hear everyday occurrences such as sounds indicative of deterioration in mechanical equipment, crickets on a summer evening, bird song, and certain musical sounds. In fact, high-fidelity sound reproducing equipment is often promoted on the basis of its fidelity up to 15,000 Hz, or even 30,000 Hz.

Any measurable hearing loss at any frequency is unacceptable if the goal is protection of health and welfare with an adequate margin of safety. For most environmental noise, protection at 4000 Hz will insure that all other frequencies are protected.[C-2] Thus, the 4000 Hz frequency has been selected as the most sensitive indicator of the auditory effects of environmental noise.

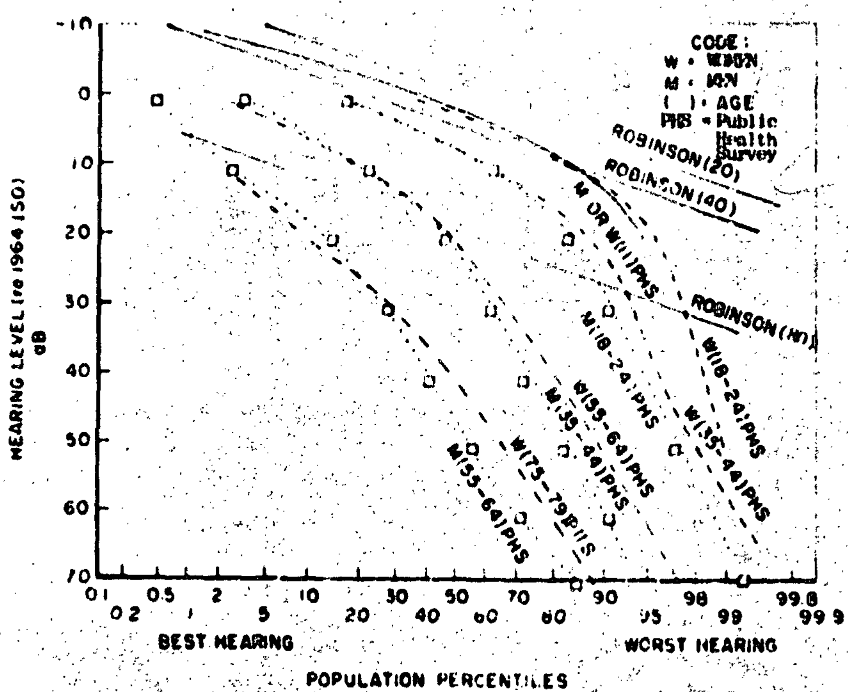


Figure C-1. Population Hearing Levels at 4000 Hz[C-4,C-5,C-6]

1. The hearing of a selected percentile of the population can be determined for various age groups. As displayed here, the higher the percentile point, the worse the hearing.

2. At age 11, there is no hearing difference due to sex,[C-6] but for the 18-24 age group, a definite difference is evident, with men's hearing considerably worse.

3. Considering that there is no evidence for any sex-inherent differences in susceptibility to hearing impairment, it is most likely that the differences displayed are due to noise exposure.

The Effect of Noise on Hearing

Table C-1 summarizes the hearing changes expected for daily exposures to various values of steady noise, for an eight-hour day, over 10- and 40-year periods.[C-7]

Four different measurement parameters are considered in Table C-1:

1. Max NIPTS: The permanent change in hearing threshold attributable to noise.

Table C-1
SUMMARY OF THE PERMANENT HEARING DAMAGE EFFECTS EXPECTED FOR CONTINUOUS NOISE EXPOSURE AT VARIOUS VALUES OF THE A-WEIGHTED AVERAGE SOUND LEVEL[C-7]

	75 dB for 8 hrs		
	av.0.5,1,2 kHz	av.0.5,1,2,4 kHz	4 kHz
Max NIPTS 90th percentile	1 dB	2 dB	6 dB
NIPTS at 10 yrs. 90th percentile	0	1	5
Average NIPTS	0	0	5
Max NIPTS 10th percentile	0	0	0

	80 dB for 8 hrs		
	av.0.5,1,2 kHz	av.0.5,1,2,4 kHz	4 kHz
Max NIPTS 90th percentile	1 dB	4 dB	11 dB
NIPTS at 10 yrs. 90th percentile	1	3	9
Average NIPTS	0	1	4
Max NIPTS 10th percentile	0	0	2

	85 dB for 8 hrs		
	av.0.5,1,2 kHz	av.0.5,1,2,4 kHz	4 kHz
Max NIPTS 90th percentile	4 dB	7 dB	19 dB
NIPTS at 10 yrs. 90th percentile	2	6	16
Average NIPTS	1	3	9
Max NIPTS 10th percentile	1	2	5

	90 dB for 8 hrs		
	av.0.5,1,2 kHz	av.0.5,1,2,4 kHz	4 kHz
Max NIPTS 90th percentile	7 dB	12 dB	28 dB
NIPTS at 10 yrs. 90 percentile	4	9	24
Average NIPTS	3	6	15
Max NIPTS 10th percentile	2	4	11

Example: For an exposure of 85 dB during an 8-hour working day, the following effects are expected:

Table C-1 (continued)

For the 90th percentile point, the Max NIPTS occurring typically during a 40-year work lifetime, averaged over the four frequencies of 0.5, 1, 2 and 4 kHz, is 7 dB; averaged over the three frequencies of 0.5, 1, and 2 kHz is 4 dB and 19 dB at 4 kHz. For this same 90th percentile point of the population, the expected NIPTS after only 10 years of exposure would be 6 dB averaged over the four frequencies, 2 dB averaged over three frequencies, and 15 dB at 4 kHz.

exposure that starts at age 20. Data from the 90th percentile point of the population will be used to extrapolate to higher percentiles.

2. NIPTS at 10 years: The entries on this row also apply to the 90th percentile point of the population for 10 years of exposure.

3. Average NIPTS: The value of NIPTS is averaged over all the percentiles for all age groups. (This figure differs by only a couple of decibels from the median NIPTS after 20 years of exposure for the entire population.)

The values in Table C-1 are arithmetic averages of data found in the reports of Passchier-Vermeer,[C-8] Robinson,[C-5] and Baughn.[C-9]

DERIVATION OF EXPOSURE LEVELS

Selection of the Percentile and Related Exposure Level

[illegible]

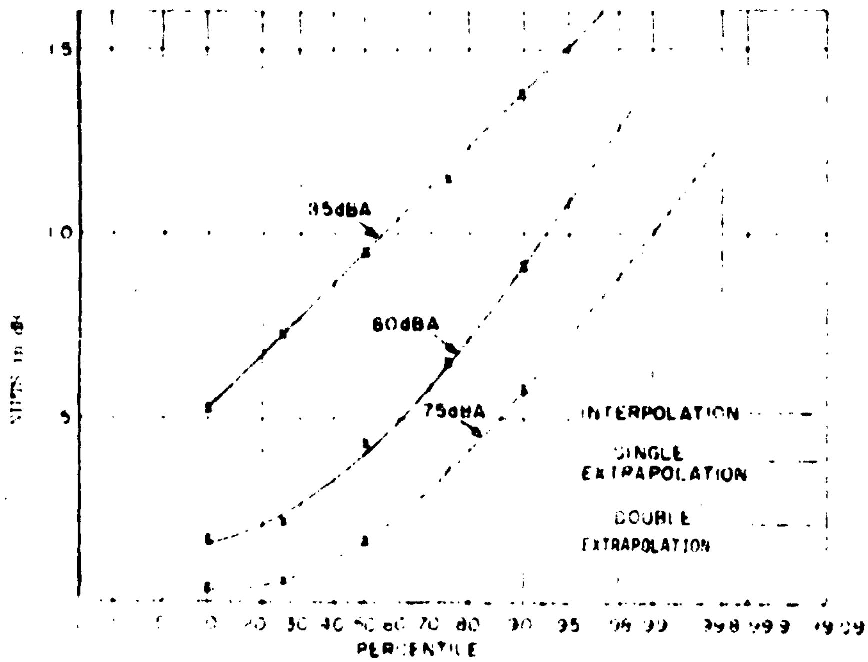


Figure C-2. NIPTS at 4000 Hz across Percentiles for Various 40-yr Exposure Levels[C-2]

for a given exposure level will approach an asymptote. In order for further hearing loss to be incurred above this critical percentile point, greater exposure levels must occur. In the extreme, a person who is totally deaf cannot suffer noise-induced hearing loss.

A study of the data provides a basis for a reasonable estimate of this critical percentile. Baughn's data gives an indication that the population with a hearing level greater than 60 dB after a 40-year exposure begins to become less affected by noise (Figures 9, 10, and 11 of ref. C-2). For example, if a person has a hearing loss greater than 75 dB, it is not reasonable to expect that an A-weighted noise of 75 dB (which normally means that only a level of 65 dB would be present at the octave band centered at 4000 Hz) will cause a further increase of the 75 dB loss. Next, it is necessary to determine the distribution of hearing levels of the non-noise-exposed population at age 60. The best data available are the hearing levels of 60 year-old women of the 1960-62 Public Health Survey.[C-4] While certainly some of the women in the sample may be noise exposed, the noise exposure of that population sample can be considered minor as compared to the apparent noise exposure of men. The data from the Public Health Survey predict the percentage of the population with hearing levels above 70, 75, and 80 dB.

Figure C-3 shows the exposure levels at which no more than 5 dB NIPTS at 4000 Hz will occur for various percentiles on the lowermost curve. The curve labeled PHS-4000 Hz

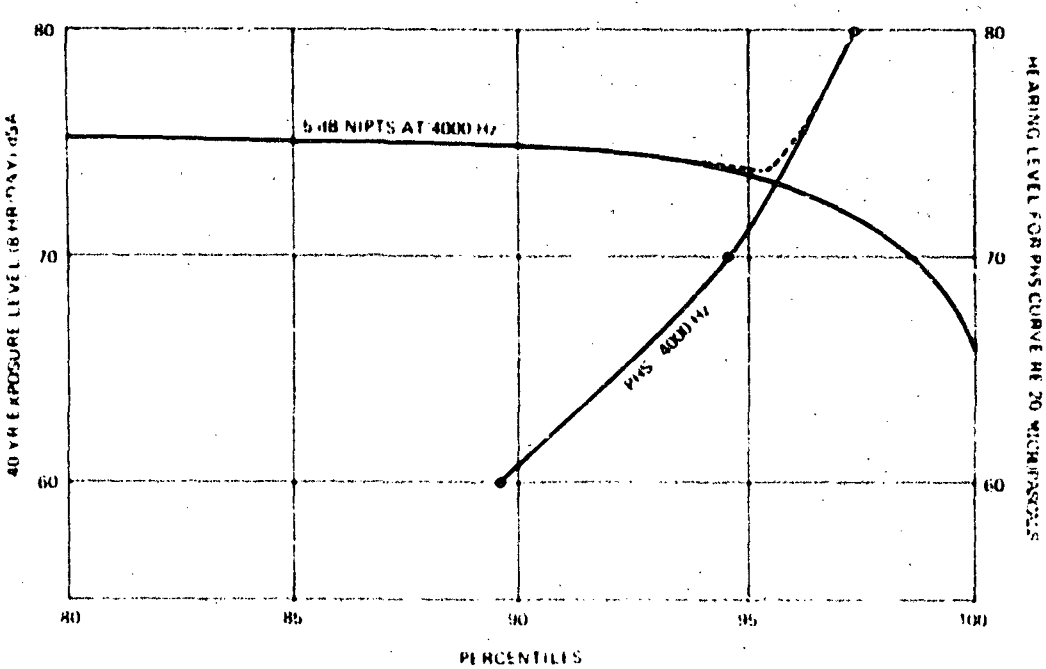


Figure C-3. Exposure Level and Hearing Level as a Function of Population Percentile, Showing the 5 dB NIPTS Curve Merging with the PHS 4000 Hz Curve

represents hearing levels by percentiles of the non-noise exposed population. If a noise level that cannot be heard by an individual is assumed not to change his hearing level, then the extrapolated 5 dB NIPTS curve of Figure C-3 cannot cross the curve labeled PHS. In fact, the 5 dB NIPTS curve must turn upward and merge with the PHS curve, shown in Figure C-3 by the dotted line. The point of merging is seen to be at approximately the 96th percentile and the exposure level required to protect this percentile from a shift of more than 5 dB is an $L_{eq(8)}$ of 72 to 74 dB, or approximately 73 dB. It may be concluded therefore, that a 40-year noise exposure below an $L_{eq(8)}$ of 73 is satisfactory to prevent the entire statistical distribution of hearing levels from shifting at any point by more than 5 dB. Generalizing from these conclusions, the entire population exposed to $L_{eq(8)}$ of 73 is protected against a NIPTS of more than 5 dB.

A similar analysis can be made for 5 dB and 10 dB NIPTS at the mid frequencies (Figure C-4). The upper PHS curve represents the better ear data for the average of 500, 1000 and 2000 Hz of both men and women from the Public Health Survey.[C-4] Both men and women are used since there is little difference due to sex and hearing levels for these frequencies. Considering that the curves will merge in the same manner as the 5 dB at 4000 Hz NIPTS and PHS curves, one can conclude that:

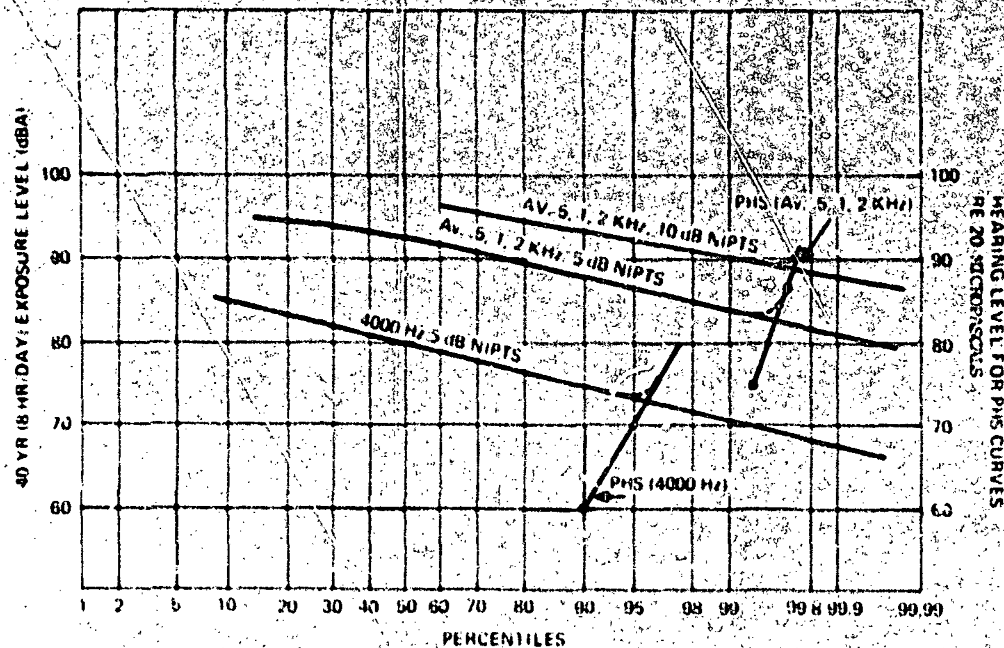


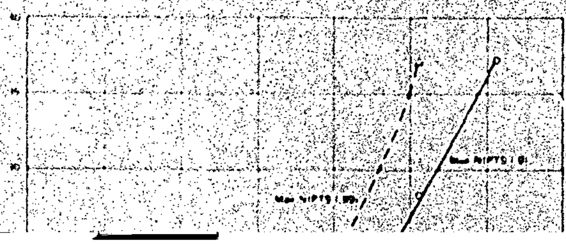
Figure C-4. Exposure Level and Hearing Level as a Function of Population Percent Showing Merging of Different NIPTS Curves with PHS Curves

1. $L_{eq(8)}$ of 84 dB will cause no more than a 5 dB shift at the critical percentile for the averaged frequencies 500, 1000 and 2000 Hz.

2. $L_{eq(8)}$ dB will cause no more than a 10 dB shift at the most critical percentile for the averaged frequencies 500, 1000 and 2000 Hz.

Although the data base used here is quite large, we cannot be absolutely certain that it is representative of the whole population. Any argument such as that presented above does not, in fact, provide 100% protection of the entire population. Obviously, there are a few individuals who might incur more than 5 dB NIPTS for an exposure level of 73 dB. There is the possibility that individuals might shift from lower to higher percentiles with a change in exposure level. In other words, there may be individuals who experience greater shifts in hearing level than those predicted here over periods of time much less than 40 years.

At this point, it may be useful to examine the same data in a slightly different way, without utilizing the concept of the critical percentile. Assuming that the NIPTS of the exposed population are distributed normally, the exposure levels which produce various amounts of NIPTS at the 50th and 90th percentiles may be extrapolated to levels which produce NIPTS at the 99th percentile. Using this extrapolation, Figure C-5 shows NIPTS as



Adjustments for Intermittency and Duration

The next step is to transpose this level into one which will protect public health and welfare, in terms of environmental noise exposure, with an adequate margin of safety. For this purpose, it is necessary to correct for intermittency and to extrapolate to 24 hours. In order to do this, two hypotheses are necessary—the TTS Hypothesis and the Equal Energy Hypothesis.

The TTS Hypothesis states that a temporary threshold shift measured 2 minutes after cessation of an 8-hour noise exposure closely approximates the NIPTS incurred after a 10- to 20-year exposure to that same level. There is a substantial body of data supporting this hypothesis.

The Equal Energy Hypothesis states that equal amounts of sound energy will cause equal amounts of NIPTS regardless of the distribution of the energy across time. While there is experimental confirmation and general acceptance of this hypothesis, certain types of intermittency limit its application.

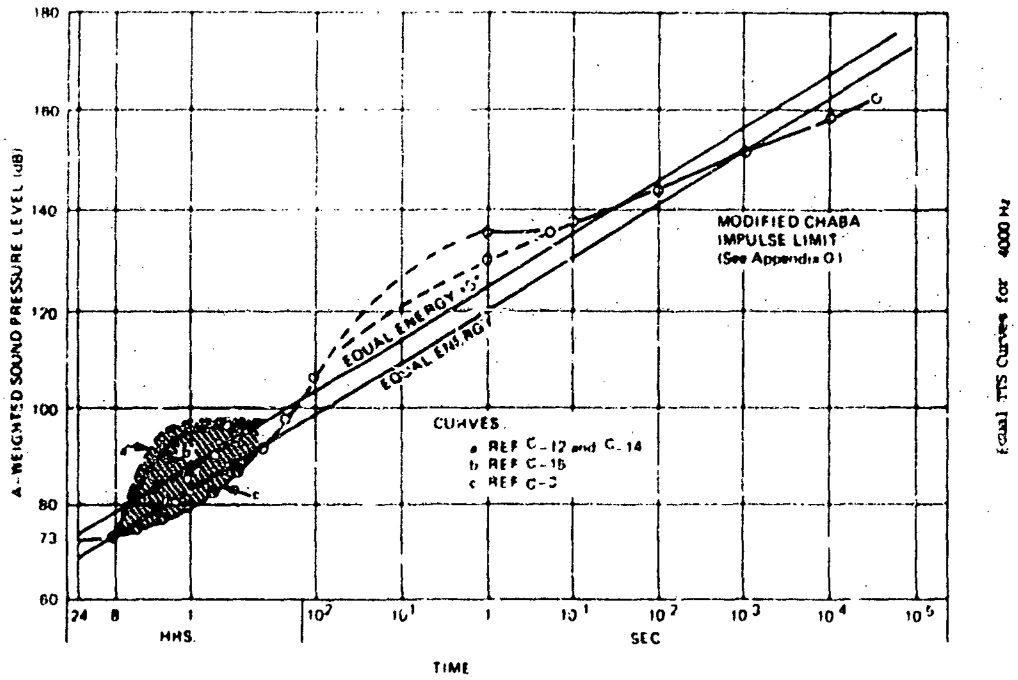
Intermittency

The equal energy concept is considered by some to be a conservative approach for short exposure periods. An alternative approach may be necessary because there is little direct evidence to show the effect of short exposure periods or intermittency on the development of NIPTS. This approach implies the use of temporary threshold shift as a predictor of NIPTS.

Even for a continuous noise, TTS is not predictable for all possible durations using the equal energy rule. The equal energy rule predicts, with reasonable accuracy, the TTS at 4000 Hz for durations of 8 hours down to about 30 minutes. Effects from durations shorter than this, however, are better predicted by a slight deviation from the equal energy rule. While equal energy provides for a 3 dB increase in exposure level for each halving of exposure duration, TTS for durations of less than 30 minutes are better predicted by greater intensities for each halving of time. For instance, TTS for durations of less than 15 minutes are better predicted by a 6 dB rather than a 3 dB increase. For an exposure of two minutes duration, the level required to produce an expected TTS at 4000 Hz would be approximately 10 dB greater than the level predicted by the equal energy concept.

Investigations of environmental noise patterns reported in the EPA document "Community Noise"[C-10] indicate that in most environments, noise fluctuates or is intermittent. Moreover, intermittent noise for a given L... having peak levels of 5 to 15 dB with the same energy.[C-11] Also, noise levels which are below 65 dB for 10 percent of the time tend to be less dangerous than continuous noise.[C-12] Therefore, intermittent noise as used in this document will be defined as noise which is below 65 dB for about 10 percent of each hour (i.e., L_{90} of less than 65 dB), with peak levels of 5 to 15 dB higher than the background. From the examples cited in "Community Noise", it is clear that most environmental noise meets these criteria. For this reason, the L_{eq} measured in many situations can be expected to produce less harmful effects on hearing than those depicted in Table C-1. Some correction factor is thus indicated for L_{eq} values describing noise expected in a typical environmental situation in which the exposure is relatively intense but intermittent in nature.

In order to determine an appropriate correction factor, Figure C-6 has been drawn. Using an exposure of 73 dB for 8 hours as a baseline, the sound pressure levels producing equal TTS_2 to be expected at 4000 Hz are plotted for durations of continuous noise as short as 1-1/2 minutes.[C-3] Plotted also (curve a), is the maximum intermittency correction suggested by "Second Intersociety Committee" [C-13] and discussed in the NIOSH criteria document.[C-11] This correction is for the mid frequencies. Recent work has indicated that for 4000 Hz the best intermittency correction to produce equal TTS_2 is represented by curve b.[C-14] The crosshatched area between the curves "a" and "c" signifies the area of uncertainty.



* With 5 dB correction for intermittency added

NOTE: Impulse noise is defined as L_{eq} - PEAK 9 dB. Shaded area indicates area of uncertainty

Figure C-6. Equal TTS Curves for 4000 Hz

In addition, TTS curves for impulse noise are included in Figure C-6. Appendix G contains the details of the modified CHABA limit and the conversion necessary to derive from the peak sound pressure level of a decaying impulse the continuous A-weighted noise of the same duration. The impulse noise data show that the equal energy concept is still a reasonable approximation for very short durations. While certainly it may be overly protective for some noise patterns, in general it predicts the effects of noise on hearing reasonably well. Prediction is improved, however, with a 5 dB allowance for intermittency.

The average correction for intermittency suggested by Figure C-6 is 5 dB (i.e., placing the origin of the equal energy line at 78 dB for 8 hours). This correction should be used only if the noise level between events is less than 65 dBA for at least 10 percent of the time ($L_{90} < 65$ dBA). Since most environmental noise exposures will meet this requirement during any 8-hour period, it is further suggested that environmental noise should be considered intermittent unless shown otherwise. Using the 5 dB correction factor, the area of uncertainty (crosshatched) of Figure C-6 is approximately bisected. Further support for such a 5 dB correction factor is found in a recent Swedish study where exposure to continuous noise of L_{eq} 85 to 90 caused a hearing loss which corresponded to an intermittent noise of L_{eq} 90 to 95. The authors conclude that a 5 dB correction factor is appropriate.[C-15]

For certain noise situations, a larger intermittency correction might be justified. However, the use of large corrections when only part of the total noise exposure pattern is known entails a considerably higher chance of error. Therefore, the use of correction factors higher than 5 dB for intermittency are not considered consistent with the concept of an adequate margin of safety.

Conversion of 8-Hour to 24-Hour Exposure Levels

The TTS after 24 hours of exposure generally exceeds that after 8 hours of exposure

1. Few, if any, of the various "classic studies" (e.g., those of Robinson, Baughn, and Passchier-Vermeer) are on comparable populations. In addition, some of the data are derived from populations for which noise exposure histories are sketchy, if not absent (e.g., the 1960-62 U.S. Public Health Survey data).

2. There are major questions regarding the comparability of the audiometric techniques used in the various surveys.

3. There are a great number of unanswered questions and areas of uncertainty with regard to the relationship of hearing thresholds to individual physiological and metabolic state. The role of the adequacy of the blood supply to the ear (and the possible influence of changes in that blood supply resulting from cardio-vascular respiratory disease or the process of aging), as well as the fundamentals of cellular physiology involved in adverse effects within the organ of Corti, simply cannot be stated with any degree of reliability at this time. There is some evidence that these non-noise related influences may be of major significance. Moreover, part of the adverse effect of noise on hearing may be attributable indirectly to these influences.

4. There are no large-scale longitudinal studies on hearing loss in selected and carefully followed populations, whose physical state and noise exposure has also been carefully detailed.

Accuracy of Estimated Effects

There is imperfect agreement among various studies as to the exact relationship between sound exposure level and noise-induced hearing loss. The range of error involved is on the order of 5 dB[C-2] when examining the difference between the values in any single study and the values presented in Table C-1. Furthermore, the intermittency correction of 5 dB is only an approximation. It has been proposed that a correction as high as 15 dB could be used in some cases. Thus, the true intermittency correction for a particular noise exposure situation could be from 0 - 15 dB.

The selection of alternative population percentiles to be protected would cause relatively small changes. For instance, there is only a 7 dB difference in protecting the 50th percentile against incurring a 5 dB hearing loss instead of the 96th percentile.

Using the assumption that the noise is of breadband character can lead to errors of 5 to 10 dB by which the risk of the sound exposure is underestimated. This could lead to greater possible errors if a substantial portion of the exposure is to noise with intense pure tone components. These conditions, however, are rare in the environmental situation.

It should be noted that this level would be too high to protect against other effects. (See Appendix D).

Contribution of Outdoor Noise to the Total Exposure in Residential Areas

A person's 24-hour exposure to outdoor noise will typically include both outdoor and indoor exposures. Since a building reduces the level of most intruding outdoor environmental noises by 15 dB or more (windows partially open), an outdoor L_{eq} will not adequately predict hearing effects, because the corresponding NIPTS estimates will be too high. Consider a situation where the average sound level is 70 dB outdoors and 55 dB indoors. The effective noise exposures for some of the possible exposure situations are:

24-hour L_{eq} in dB (assuming the noise is generated outdoors)

Indoor Time (55 dB)	Outdoor Time (70 dB)	Combined Indoor and Outdoor	Outdoor Only
24 hrs	0 hrs	55.0	
23	1	58.6	56.2
22	2	60.5	59.2
21	3	61.8	61.0
20	4	62.9	62.2
16	8	65.5	65.2
8	16	68.3	68.2
0	24	70	70

The 24-hour value of the combined L_{eq} is essentially unchanged from the outdoor value (less than one dB) by the indoor noise exposure, so long as the outdoor exposure exceeds 3 hours. Thus, as long as the criterion is established with respect to outdoor noise exposure exceeding 3 hours per day, the contribution of the indoor level of intruding outdoor noise may be neglected in computing the 24 hour L_{eq}. This conclusion does not depend greatly on the actual noise attenuation provided by the house so long as the attenuation is greater than 10 dB.

Relation of L_{dn} to L_{eq} in Residential Areas

Although in residential areas, or in areas where individuals may be expected to be present for prolonged periods of time, it would appear desirable for practical considerations to use only one measure of noise, such as L_{dn}, it may be misleading to do so. The difficulty arises from the fact that to relate hearing loss to noise exposure, the basic element to consider is the actual energy (not weighted) entering the ear during a twenty-four hour period. L_{eq} measures the [illegible]

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Appendix D

NOISE INTERFERENCE WITH HUMAN ACTIVITIES AND RESULTING OVERALL ANNOYANCE/HEALTH EFFECTS

Environmental noise may interfere with a broad range of human activities in a way which degrades public health and welfare. Such activities include:

1. Speech Communication in Conversation and Teaching.
2. Telephone Communication.
3. Listening to TV and Radio Broadcasts.
4. Listening to Music.
5. Concentration During Mental Activities.
6. Relaxation.
7. Sleep.

Interference with listening situations (items 1-4) can be directly quantified in terms of the absolute level of the environmental noise and its characteristics. The amount of interference in non-listening situations (e.g.,) is often dependent upon factors other than the physical characteristics of the noise. These may include attitude towards the source of an identifiable noise, familiarity with the noise, characteristics of the exposed individual, and the intrusiveness of the noise.

The combination of the various interference effects results in an overall degradation of

will vary with the type and amount of furnishings, carpets, drapes and other absorbent materials. It is generally least in bathrooms and kitchens and greatest in living rooms, with typical values ranging between 150 and 450 sabins. A typical value for living rooms and bedrooms is 300 sabins. For this value of absorption, the distance to the reverberant field from the talker is slightly greater than one meter, as stated above.

As shown in Figure D-1, the maximum sound level that will permit relaxed conversation with 100% sentence intelligibility throughout the room (talker-listener separation greater than approximately 1.1 meter) is 45 dB.

Outdoor Speech Interference Due to Steady Noise

The sound level of speech outdoors generally continues to decrease with increasing distance between talker and listener with the absence of reflecting walls which provide the reverberance found indoors. Figure D-2 presents the distances between talker and listener for satisfactory outdoor conversations, in different steady background noise levels (A-weighted), for three degrees of vocal effort. This presentation depends on the fact that the voice level at the listener's ear (outdoors) decreases at a predictable rate as the distance between talker and listener is increased. In a steady background noise there comes a point, as the talker and listener increase their separation, where the decreasing speech signal is masked by the noise.

The combination of level in the first column and duration in the second column are such as to maintain constant L_{eq} for each situation, 45 dB indoors and 60 dB outdoors. The third column gives the percent interference with sentence intelligibility that would apply if the noise were steady and continuous with the level indicated in column 1. The fourth column gives the percent interference for the cycled noise in each case.

The results for this extreme case indicate that no matter how extreme the noise fluctuation for the indoor case, on the average there is negligible speech interference for L_{eq} = 45 dB. On the other hand, with L_{eq} = 60 dB outdoors, the average speech interference tends to decrease as the fluctuations of the noise become more extreme. However, it should be recognized that if the duration of the intruding noise were to take place in one continuous period, and if its percentage interference (column 3) were equal to 100, then it would blot out all communication for the duration of its "on-cycle".

The following sections relating to activity interference, annoyance, and community reaction utilize equivalent sound level with a nighttime weighting (L_{dn}) which is discussed more fully in Appendix A. However, for the speech interference effects of noise, a similar measure without the nighttime weighting (L_{eq}) has been employed. To allow comparison between the various effects stated above, some relationships are necessary to allow at least approximate conversion from L_{eq} to L_{dn}. For indoor levels such as those described in Appendix A for various lifestyles, levels during the day are at least 10 dB higher than those during the night. Thus L_{eq} is virtually the same as L_{dn} for normal indoor situations.

For an outdoor L_{dn} of 55 dB or less, day time levels (L_d) are generally 8 dB higher than the nighttime levels (L_n). For this situation, L_{dn} is still quite close to L_{eq} during the day. The correction is less than one dB. For levels greater than L_{dn} 65 dB, the nighttime levels are generally only 4 dB less than during the day time. For these cases, L_{dn} is 3 dB higher than L_{eq} during the day.

For values of L_{dn} between 55 and 65, further interpolation is necessary using Figure A-7.

ACTIVITY INTERFERENCE

Activity interference due to noise is not new. The recent EPA document concerning public health and welfare criteria for noise[D-5] mentions an ordinance enacted 2500 years ago by the ancient Greek community of Sybaris, banning metal works and the keeping of roosters within the city to protect against noise that interfered with speech and might disturb sleep. History contains other examples indicating speech and sleep interference due to various types of noises, ranging from wagon noise to the noise of blacksmiths.

More recently, surveys have been conducted which further demonstrate that noise does interfere with various types of activity. For example, Figures D-5 and D-6, based on research done in England, give activity interference reported by the people who were disturbed by aircraft noise for various types of activities as a function of the approximate L_{dn} associated with noise from aircraft flyovers [D-14] (for explanation of the term L_{dn} see Appendix A). Thus, for an outside L_{dn} of approximately 55 dB, over 50% of the people who were disturbed reported some interference with TV sound, and 45% reported some interference with conversation. At the same level, about 45% reported that noise occasionally woke them up, while 30% claimed it sometimes disturbed their relaxation. The figures also indicate that at higher noise levels, greater percentages of people who were disturbed have reported activity interference.

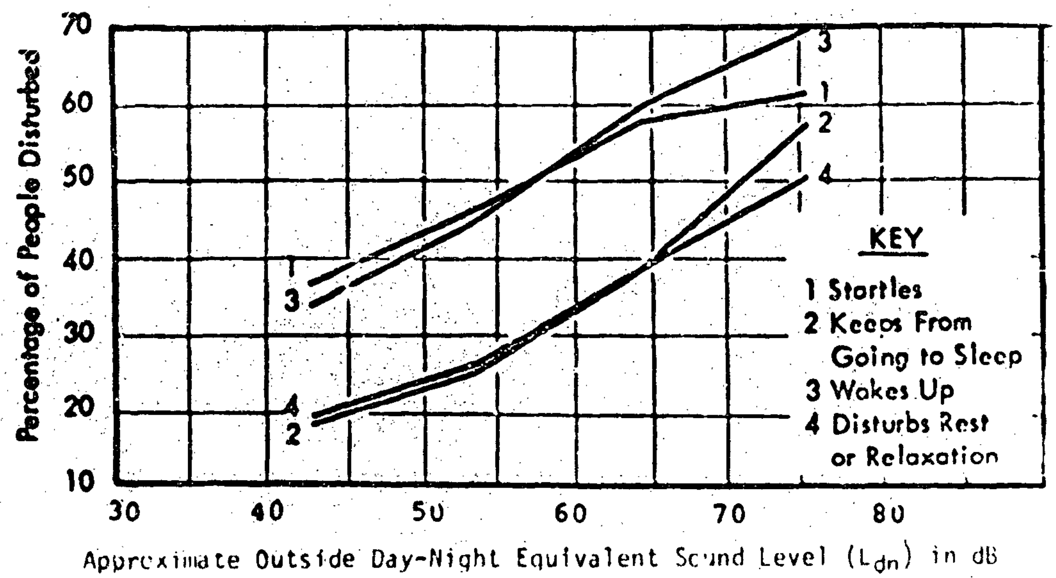


Figure D-5. Percentage of People Disturbed by Aircraft Noise for Various Types of Reasons Concerned With Rest And Sleep [D-6]

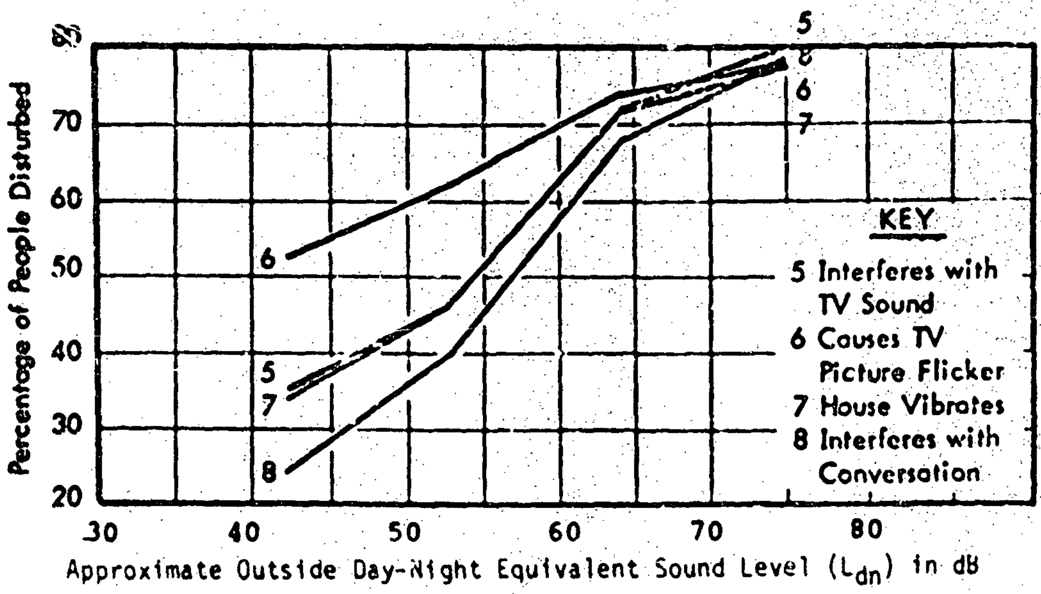


Figure D-6. Percentage of People Disturbed by Aircraft Noise for Various Types of Reasons Concerned with Domestic Factors[D-6]

Later research in the USA[D-7] provides the information on activity interference shown in Table D-4. This table gives the activity disturbance percentages of those who reported that they were *extremely disturbed* by the noise, which accounts in part for the low per-

Table D-4

PERCENT OF THOSE PEOPLE WHO WERE EXTREMELY DISTURBED BY AIRCRAFT NOISE*, BY ACTIVITY DISTURBED[D-7]

freeways, new industrial plants, and homeowner equipment, have created numerous community problems with environmental noise. These problems have provided significant data and insight relating to community reaction and annoyance and stimulated the development of several indices for measurement of the magnitude of intruding noises.

Various U.S. Governmental agencies began to investigate the relationships between aircraft noise and its effect on people in communities in the early 1950's. This early research resulted in the proposal of a model by Bolt, Rosenblith and Stevens [D-10] for

Table D-7

CORRECTIONS TO BE ADDED TO THE MEASURED DAY-NIGHT SOUND LEVEL (L_{dn}) OF INTRUDING NOISE TO OBTAIN NORMALIZED L_{dn} [D-3]

Type of Correction	Description	Amount of Correction to be Added to Measured L_{dn} in dB
Seasonal Correction	Summer (or year-round operation)	0
	Winter only (or windows always closed)	–5
Correction for Outdoor Noise Level Measured in Absence of Intruding Noise	Quiet suburban or rural community (remote from large cities and from industrial activity and trucking)	+10
	Normal suburban community (not located near industrial activity)	+5
	Urban residential community (not immediately adjacent to heavily traveled roads and industrial areas)	0
	Noisy urban residential community (near relatively busy roads or industrial areas)	–5
	Very noisy urban residential community	–10
Correction for Previous Exposure & Community Attitudes	No prior experience with the intruding noise	+5
	Community has had some previous exposure to intruding noise but little effort is being made to control the noise. This correction may also be applied in a situation where the community has not been exposed to the noise previously, but the people are aware that bona fide efforts are being made to control the noise.	0
	Community has had considerable previous exposure to the intruding noise and the noise maker's relations with the community are good	–5
	Community aware that operation causing noise is very necessary and it will not continue indefinitely. This correction can be applied for an operation of limited duration and under emergency circumstances.	–10
Pure Tone or Impulse	No pure tone or impulsive character	0
	Pure tone or impulsive character present	+5

Table D-8

NUMBER OF COMMUNITY NOISE REACTION CASES AS A FUNCTION OF NOISE SOURCE TYPE AND REACTION CATEGORY

Type of Source	Community Reaction Categories			Total Cases
	Vigorous Threats of Legal Action	Wide Spread Complaints	No Reaction or Sporadic Complaints	
Transportation vehicles, including:				
Aircraft operations	6	2	4	12
Local traffic			3	3
Freeway	1			1
Rail		1		1
Auto race track	2			2
Total Transportation	9	3	7	19
Other single-event or intermittent operations, including circuit breaker testing, target shooting, rocket testing and body shop	5			
Steady state neighborhood sources, including transformer substations, residential air conditioning	1	4	2	7
Steady state industrial operations, including blowers, general manufacturing, chemical, oil refineries, et cetera	7	7	10	24
Total Cases	22	14	19	55

There is no evidence in these 55 cases of even sporadic complaints if the L_{dn} is less than 50 dB.

ANNOYANCE

Annoyance discussed in this report is limited to the long-term integrated adverse responses of people to environmental noise. Studies of annoyance in this context are largely based on the results of sociological surveys. Such surveys have been conducted among residents of a number of countries including the United States.[D-6,D-7,D-15,D-16]

The short-term annoyance reaction to individual noise events, which can be studied in the field as well as in the laboratory, is not explicitly considered, since only the accumulating effects of repeated annoyance by environmental stimuli can lead to environmental even to the environment in general, which lead to fluctuations of each individual's attitude. The average group response does, to some extent, express the individual's response averaged over longer periods of his life. Therefore, this response reflects the effects most likely to affect his health over a longer time period.

A comparison of the results of three of the most prominent social surveys around airports are presented in the following paragraphs. These are the first and second surveys around London's Heathrow Airport,[D-6,D-15] and the Tracor study [D-7] around eight major airports in the United States. The noise level data reported for each survey were converted to outdoor day-night sound levels for the purpose of this analysis. In addition, data are presented from a survey of response to motor vehicles in U.S. urban areas.[D-18]

First London-Heathrow Survey

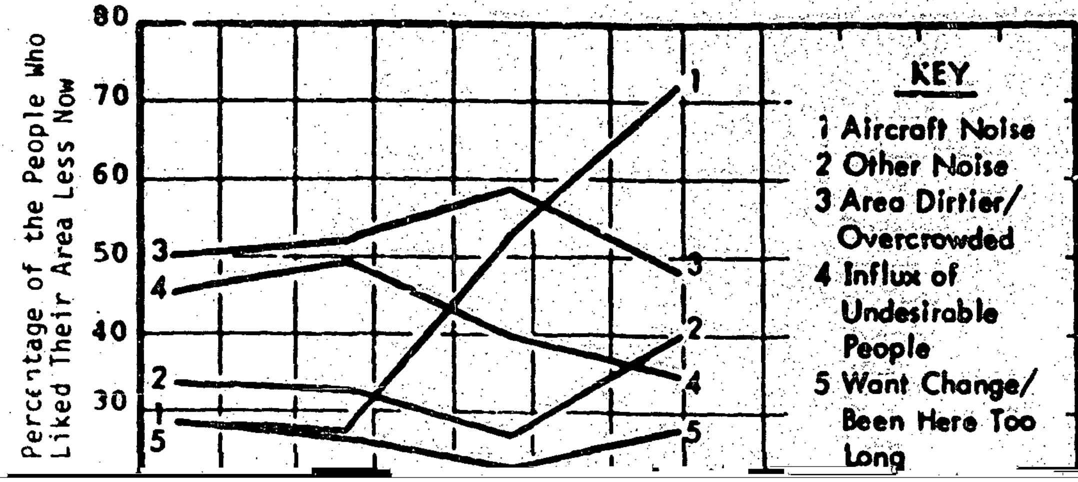
The first survey of about 2,000 residents in the vicinity of Heathrow airport was conducted in 1961 and reported in 1963.[D-6] The survey was conducted to obtain responses of residents exposed to a wide range of aircraft flyover noise. A number of questions were used in the interviews to derive measures of degrees of reported annoyance. Two results of this survey are considered here.

A general summary of the data, aggregating all responses on a category scale of annoyance ranging from "not at all" to "very much annoying," is plotted as a function of approximate L_{dn} in Figure D-9. This figure presents a relationship between word descriptors and day-night sound level.

Among the respondents in every noise level category, a certain percentage were classified in the "highly annoyed" category. This percentage of each group is plotted as a function of approximate L_{dn} on Figure D-10.

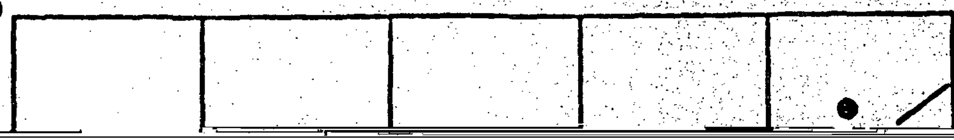
Comparison of the data on the two figures reveals that, while the average over the population would fit a word classification of "little annoyed" at an L_{dn} value of approximately 60 dB, more than 20% of the population would still be highly annoyed at this L_{dn} value.

In addition to the derivation of overall annoyance scales, this study examined the attitude of the people towards their area and their desire to move as a function of both noise level and several other factors. The results are summarized in Figs. D-11 and D-12. They indicate that when the approximate L_{dn} exceeded 66-68 dB, aircraft noise became the reason most often cited by those who either "liked their area less now than in the past" or "wanted to move". Further, the data indicate that aircraft noise was of little importance,



80
70
60
50
40
30
Percentage of the People Who Liked Their Area Less Now
KEY
1 Aircraft Noise
2 Other Noise
3 Area Dirtier/ Overcrowded
4 Influx of Undesirable People
5 Want Change/ Been Here Too Long

70



of Knudsen and Harris [D-21] in 1950. It is of interest to quote from the text to understand the reasoning used to develop the recommended levels:

> Acceptable Noise Levels in Buildings
>
> The highest level of noise within a building that neither disturbs its occupants nor impairs its acoustics is called the acceptable noise level. It depends, to a large extent, on the nature of the noise and on the type and customary use of the building. The time fluctuation of the noise is one of the most important factors in determining its tolerability. For example, a bedroom with an average noise level of 35 dB, with no instantaneous peak levels substantially higher, would be much

Table D-10

...TIONS OF SOUND LEVELS IN VARIOUS SPACES D-21 through D-38

Ashrae 1967 6 dB(A)*	Dennison 1970 7 dB(A)	Kryter 1970 8 dB(A)	Tokyo 1971 9 dB(A)	USSR 1971 10 dB(A)	Beranek 1971 11 dB(A)	Doelle 1972 12 dB(A)	Wood 1972 13 dB(A)	Rettinger 1973 14 dB(A)	Sweden (p-9) 15 dB(A)	Switzerland 1970 (p-4) 16 dB(A)	Czechoslovakia 1967 (p-10-11) 17 dB(A)	West Germany 1968 (p-12) 18 L_{eq} M-D
25-35		40		35	34-47	35-45	35	34-42	25	35-45	40	
30-40		40		35	38-47		40		25	35-45	40	
35-45		18			34-47			38-42		35-50	40	
35-45		38		35	34-47	35-54	30-40	42		35-50	40	
40-55		55		55	42-52	45-60	45-50	50		40-50	55	
25-45	40-45	35			38-47	30-45	40-45	46	40			
35-65	50-60	35-40		50	42-52	45-55	45-55	50				
35-55				60								
					52-61		55-65			45-55		
	65				66-80		60-75	70		50-60		
35-45		35		40	38-47	35	35-45	36	35	35-45		
40-50	40-50				47-56		45-50	42				
35-45		40			38-47	40-45	40-45	42			40	
30-45		40		25	34-47	40	40-45	38	25-35	25-35	35-40	
45-60							50-60	50				
35-45				60		60		46			60	
40-50						55-60	45-55	46				
30-40		38			30-42	35-45	35-45					
25-35		40		35	30-42	35-40	35-40	36-42				
25-35		28-35			21-30	25-35	30-35	34			35	
		40			42	35-40	35-40					
25-35		28			21-34	25-30	30	30				
25-35		28			21-34	30-35	35	34-36				
		28			21-34	35	25					
35-45		40		40		40	35-40	38				
30-40		33			30-34	30-35		34			35	
			35-45	35								35-45
			40-50	45								35-50
			50-60									40-55
			50-60									50-65
									55			

Appendix E

GENERAL EFFECTS OF NOISE NOT DIRECTLY USED IN IDENTIFYING LEVELS OF NOISE REQUISITE TO PROTECT PUBLIC HEALTH AND WELFARE

Although these possibly adverse effects were not used in identifying the noise levels in this document, employers or educational authorities should consider their influence since it might provide additional motivation to achieve the values seen in Table D-10 of Appendix D.

Effects of Noise on the Autonomic Nervous System and Other Non-Auditory Physiological Effects

From an environmental point of view, the most significant effects are those caused by sonic booms on the secondary components of structures. These effects include the breaking of windows and cracking of plaster. Effects such as these have led to the speculation that historical monuments and archeological structures may age more rapidly when exposed to repeated sonic booms. However, the levels identified in Appendix G to protect against adverse effects on public health and welfare are low enough to protect against damage to structures.

Appendix F

EPA's RESPONSIBILITY TO IDENTIFY SAFE LEVELS FOR OCCUPATIONAL NOISE EXPOSURE

Although the workplace is a vital component of the human environment, the Environmental Protection Agency does not have jurisdiction over most occupational health and safety matters. These matters have traditionally been the responsibility of the Departments of Labor and Health, Education and Welfare. Section 6(b)(5) of the Occupational Safety and Health Act of 1972 specifies that the Secretary of Labor, ". . . in promulgating standards dealing with toxic materials or harmful physical agents . . ., shall set the standard which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life . . . In addition to the attainment of the highest degree of health and safety protection for the employee, other considerations shall be the latest available scientific data in the field, the feasibility of the standards, and experience gained under this and other health and safety laws."

In contrast, section 5(a)(2) of the Noise Control Act of 1972 directs EPA's Administrator to "publish information on the levels of environmental noise, the attainment and maintenance of which in defined areas under various conditions are requisite to protecting the public health and welfare with an adequate margin of safety."

The words "public health and welfare" appear in a number of places in the Noise

Appendix G

IMPULSE NOISE AND SOME OTHER SPECIAL NOISES

IMPULSE NOISE

Impulse noise is defined in various ways [G-1, G-2, G-11] but generally means a discrete noise (or a series of such noises) of short duration (less than a second), in which the sound pressure level rises very rapidly (less than 500 ms, sometimes less than 1 ms) to a high peak level before decaying below the level of background noise. The decay is frequently oscillatory, because of sound reflections and reverberation (ringing) in which case the spectrum of the oscillation may also be important in determining the hazard to hearing. Some authors distinguish reverberant impulse noise as "impact" noise (typically produced by metal to metal impact as in industrial forging), to distinguish it from simple oligophasic impulses (typified by a gunshot in the open air).[G-1]

The peak sound pressure level (SPL) is an important but not the sole parameter determining hazard. Some typical values for disturbing or hazardous impulse noises are given in Table G-1.

NOTE: Peak SPL for impulses cannot be properly measured with a standard sound level meter, which is a time-averaging device. Oscillographic techniques must be used.

Table G-1

SOME TYPICAL VALUES OF PEAK SPL FOR IMPULSE NOISE
(in dB re 20 micropascals)

SPL	EXAMPLE
190+	Within blast zone of exploding bomb
160-180	Within crew area of heavy artillery piece or naval gun when shooting
140-170	At shooter's ear when firing hand gun
125-160	At child's ear when detonating toy cap or firecracker
120-140	Metal to metal impacts in many industrial processes (e.g., drop-forging; metal-beating)
110-130	On construction site during pile-driving

Effects of Impulse Noise on People

Cochlear Damage and Hearing Loss

Impulse noise can produce temporary (TTS) and permanent threshold shift (PTS). The pattern essentially resembles that produced by a continuous noise but may involve somewhat higher frequency losses (maximal at 4 to 6 kHz) and recovery from impulse-NIPTS can be more variable.[G-9] A blow to the head can have a similar effect. TSS (and, by inference, PTS) in man depends on many factors, the more important of which are reviewed in more detail later. Impulse noise (like continuous noise) can also be shown to produce pathological changes in the inner ear (cochlea) of mammals, notably destruction and degeneration of the haircells of the hearing organ, and atrophic changes in related structures. A quantitative relationship between the amount of visible damage to the cochlea and the amount of NIPTS has not yet been clearly established.[G-2, G-4, G-5]

Other Pathological Effects

Exposure to blast or to sustained or repeated impulsive airborne over-pressures in the range of 140 to 150 dB (239 to 718 pascals) or higher can cause generalized disturbance or damage to the body apart from the ear. This is normally a problem for military personnel at war (e.g., artillerymen firing field guns), and need not be considered further here. Transient over-pressures of considerable magnitude can be experienced due to sonic boom but are unlikely to be hazardous to the ear.

Startle and Awakening

Impulsive noises which are novel, unheralded, or unexpectedly loud can startle people and animals. Even very mild impulsive noises can awaken sleepers. In some circumstances (e.g., when a person is handling delicate or dangerous objects or materials), startle can be hazardous. Because startle and alerting responses depend very largely upon individual circumstances and psychological factors unrelated to the intensity of the sound, it is difficult to make any generalization about acceptable values of SPL in this connection. A high degree of behavioral habituation, even to intense impulse noises such as gunfire, is normally seen in animals and humans when the exposure is repeated, provided that the character of the stimulus is not changed.

Parameters of Impulse Noise Exposure

Impulse noise is characterized completely by the waveform and spectrum. Various summary parameters are also useful in characterizing an impulsive noise, these include:

1. Peak SPL (in dB re 20 micropascals)

2. Effective duration (in milliseconds or microseconds)

3. Rise time

In addition, the following are important for predicting the effects of the impulse on people:

4. Number of repeated impulses in a daily or other cumulative exposure

5. Intervals or average interval between repeated impulses (or rate of impulse occurrence)

6. Individual susceptibility to inner ear damage

7. Orientation of the ear with respect to the noise

8. Preceding or simultaneous exposure to continuous noise at TTS-producing levels

9. Action of acoustic reflex, if elicited

10. Audiometric frequency

In 1968, Working Group 57 of CHABA prepared a damage risk criterion for gunfire noise, based essentially on the work of Coles *et. al.*, [G-6] which included procedures to allow for repetition of impulses and some of the other parameters listed above.[G-1] Some modification has recently been proposed by Coles and Rice. [G-7] The CHABA proposal was intended to protect 95% of the exposed population.

Guidelines for Evaluating Hazard from Impulse Noise Exposure

Peak Level

The growth of TTS at 4 kHz with increase in peak level above 130 dB SPL of impulses (clicks) presented at a steady rate has been demonstrated by Ward *et. al.*[G-8] Based on TTS data from rifle shooters, Kryter and Garinther[G-18] estimated permanent hearing levels expected to result from daily exposure to a nominal 100 rounds of rifle shooting noise in selected percentiles. Their data are reproduced in Table G-2 below, showing the increasing hazard with increasing peak level and with increasing audiometric frequency up to 6000 Hz.

CHABA's 1968 Damage-Risk Criteria (DRC)[G-1] recommended limits to peak level as a function of impulse duration for a nominal exposure of 100 impulses per day at normal incidence (discussed below and shown in Figure G-1). These limits were intended to protect 95% of the people according to an implied criterion of NIPTS not exceeding 20 dB at 3 kHz or above, after 20 yrs. If 90% of the people were to be protected to a criterion of NIPTS not exceeding 5 dB at 4 kHz, it would be necessary to lower the CHABA limits by 12 dB (15 dB reduction to meet the more stringent criterion, assuming an approximately decible to decibel relationship in the range of interest [see Table G-2], less 3 dB elevation to apply the limit to the 90th percentile). This modified CHABA limit is shown in Figure G-1 by hatched lines.

Duration of Impulse

Hazard increases with the effective duration of impulses.[G-10] Impulse duration is defined according to the type of impulse (A, simple peak, or B, oscillatory decay); [G-1, G-6] and CHABA has recommended separate limits for A- and B-durations (Figure G-1). For effective durations much above 1 ms, a more stringent limit should be applied to reverberant oscillations (e.g., metallic impacts in industry or gunshots in a reverberant indoor range) than to simple A-type impulses (e.g., gunshots in the open). When the type of impulse cannot be determined, it is conservative to assume the B-duration.

Table G-2

ESTIMATED EXPECTED PERMANENT HEARING LEVEL (IN DB RE ASA:1951)
IN SELECTED PERCENTILES OF THE MOST SENSITIVE EARS
FOLLOWING NOMINAL DAILY EXPOSURE TO RIFLE NOISE
(DURING TYPICAL MILITARY SERVICE),

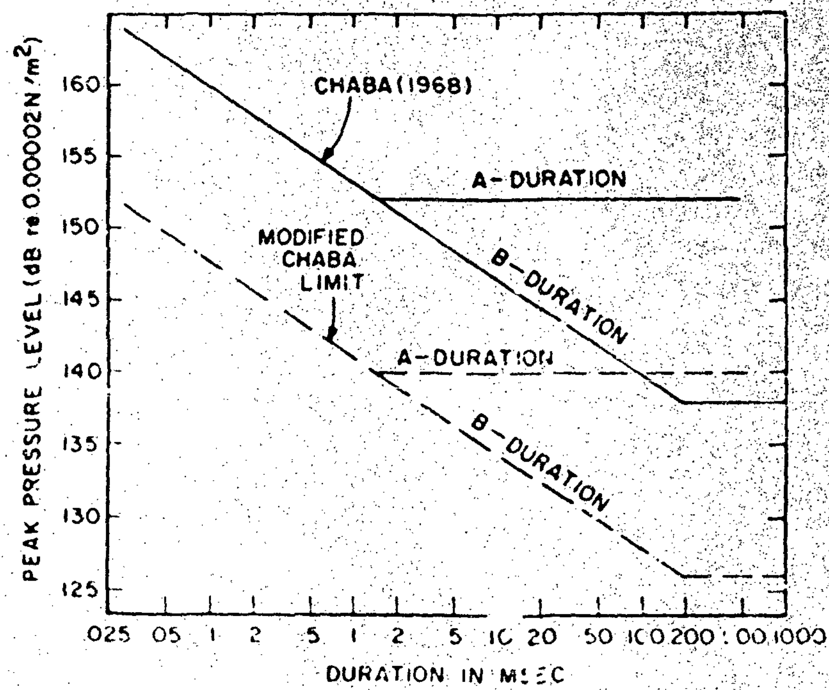


Figure G-1. The 1968 CHABA[G-1] Damage-Risk Criterion for Impulse Noise Exposure (solid lines) and a Proposed Modification (hatched lines). Peak Sound Pressure Level is Expressed as a Function of A- or B-Duration in the Range 25 Microseconds to 1 Second.[G-1]

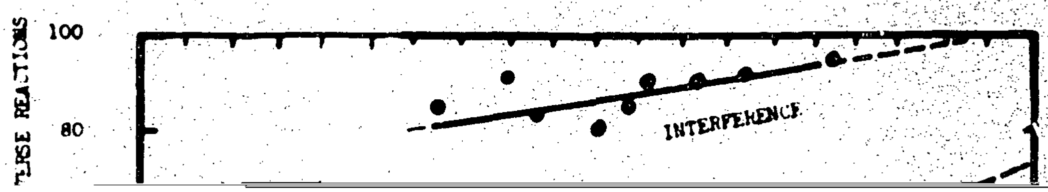
Rise Time

This parameter is usually correlated closely with peak pressure. Present evidence as to its effect on hearing risk is insufficient for allowance to be made for it in damage risk criteria.

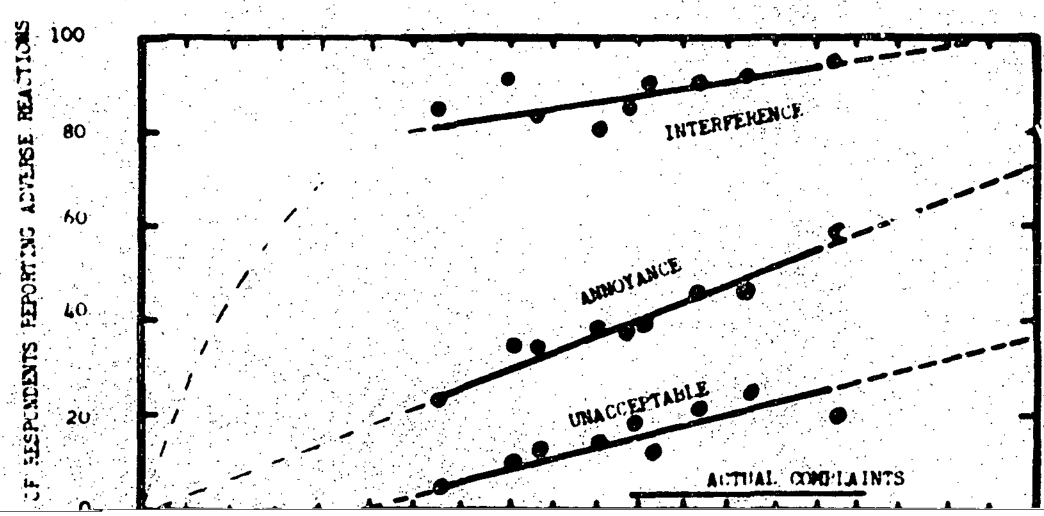
Spectrum (Or Waveform)

Impulses with largely high frequency spectral components (e.g., reverberant gunshots) are generally more hazardous to the hearing mechanism than predominantly low-frequency impulses (e.g., distance-degraded blast waves; sonic booms) of the same peak SPL. However, comparative data are as yet too scanty to serve as the basis of differential damage risk criteria.

6 month period. Some results of this study are summarized in Figure G-3. For eight sonic booms/day, there is clear evidence that the median peak overpressure must be well below 47.88 pascals (or 1 psf) if no annoyance is reported. When interviewed, part of the population considered eight sonic booms/day to be unacceptable. By extrapolation, the level at which eight sonic booms per day should be acceptable for the population is slightly less than 23.94 pascals (or 0.5 psf). But even at 23.94 pascals, approximately 20% of the population consider themselves annoyed by an exposure of eight sonic booms/day. Linear extrapolation of the annoyance data of Figure G-3 indicates that annoyance will disappear in the total population only when the 8 sonic booms per day are less than 4.79 pascals. A linear extrapolation is probably not entirely justified, however, as certainly for sonic booms much less than 4.79 to 9.58 pascals, a large percentage of the population is not even expected to sense the boom. The fact that the extrapolation must curve is best illustrated by the interference curve of Figure G-3. Unless the extrapolation is curved as shown, interference would be predicted for about 70% of the population even when the peak overpressure is zero, i.e., no boom at all.



6 month period. Some results of this study are summarized in Figure G-3. For eight sonic booms/day, there is clear evidence that the median peak overpressure must be well below 47.88 pascals (or 1 psf) if no annoyance is reported. When interviewed, part of the population considered eight sonic booms/day to be unacceptable. By extrapolation, the level at which eight sonic booms per day should be acceptable for the population is slightly less than 23.94 pascals (or 0.5 psf). But even at 23.94 pascals, approximately 20% of the population consider themselves annoyed by an exposure of eight sonic booms/day. Linear extrapolation of the annoyance data of Figure G-3 indicates that annoyance will disappear in the total population only when the 8 sonic booms per day are less than 4.79 pascals. A linear extrapolation is probably not entirely justified, however, as certainly for sonic booms much less than 4.79 to 9.58 pascals, a large percentage of the population is not even expected to sense the toom. The fact that the extrapolation must curve is best illustrated by the interference curve of Figure G-3. Unless the extrapolation is curved as shown, interference would be predicted for about 70% of the population even when the peak overpressure is zero, i.e., no boom at all.



So far the discussion has been about eight sonic boom exposures per day on a daily recurring basis. The more difficult question is how to interpret the effect on public health and welfare of sonic booms that are more infrequent than eight times per day. Kryter[G-25] provides a relationship which indicates that a sonic boom of 90.97 pascals once a day would be equal to 110 PNdB or a CNR of 98 dB. It further suggests that the level (which is proportional to P^2) should be reduced by one half (3 dB) for each doubling of number of occurrences. From Appendix A, L_{dn} is approximately related to CNR by L_{dn} = CNR -35 dB. Thus, a CNR of 98 equals an L_{dn} of 63 dB. If the sonic boom is made equivalent to an L_{dn} = 55 dB, so as to be consistent with the levels identified in the interference/ annoyance section of this document, the level of one daytime sonic boom per day must be less than 35.91 pascals. For more than eight sonic booms/day, the level should be less than 12.45 pascals or $\frac{35.91}{\sqrt{N}}$ pascals. This result is slightly lower than the data from Figure G-3. However, extrapolating the annoyance line in the figure suggests that the 12.45 pascals level of 8 booms would annoy only 8% of the people and more would find it unacceptable. Therefore, the relationship proposed is: daytime peak over-pressure per day = $\frac{35.91}{\sqrt{N}}$ pascals where N = number of sonic booms/day. Thus, the peak over-pressure of a sonic boom that occurs during the day should be no more than 35.91 pascals if the population is not to be annoyed or the general health and welfare adversely affected.

The standard sound level meter, which is a time-averaging device, will not properly measure the peak sound pressure level of sonic booms.

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