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Guidelines for Preparing Environmental Impact Statements on Noise

Committee on Hearing, Bioacoustics and Biomechanics

Assembly of Behavioral and Social Sciences

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GUIDELINES FOR PREPARING ENVIRONMENTAL IMPACT STATEMENTS ON NOISE

Report of Working Group 69
on
Evaluation of Environmental Impact of Noise

Committee on Hearing, Bioacoustics, and Biomechanics
Assembly of Behavioral and Social Sciences
National Research Council

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NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

Committee on Hearing, Bioacoustics, and Biomechanics

Working Group 69
on
Evaluation of Environmental Impact of Noise

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PREFACE

The guidelines proposed in this report are the result of the deliberations of the Committee on Hearing, Bioacoustics and Biomechanics (CHABA) Working Group 69 from 1972 to 1976, in response to a request in 1972 by the U.S. Environmental Protection Agency. The approaches selected for the various topics -- for noise environment documentation as well as noise impact quantification -- had to conform to legal requirements and to be acceptable to the potential users and the scientific community. They had to reflect a compromise between practicality, economy, and desired accuracy and specificity.

The technical approaches proposed underwent several significant changes during the period of the working group activity as a result of working group deliberations, public discussions, and presentations at national and international technical meetings. (90th meeting Acoustical Soc. Am. 1975, J. Acoust. Soc. Am. 58 Suppl. 1 (827-828) 1975; Internoise 77, Zurich, Switzerland 1977). As far as possible, the working group tried to be responsive to the numerous suggestions received through these mechanisms from government agencies, industries, and the scientific community. The proposed procedures were tried out by working group members and others, and shortcomings and gaps in our knowledge were identified. This led to joint working group research activities or to efforts by individual members. Many of these individual efforts, which had their roots in the working group activities, were conducted and sponsored under other government or private industry programs and have been separately published in the meantime. Similarly, some agencies, faced with the need for operational decisions, used concepts from this report in their publications; those publications are included among the references of this report.

For other sections of the report, such as the proposed measurement and assessment of impulse noise, coordination and agreement by several government agencies appeared desirable prior to completion of the final report. Such coordination was achieved and has already led to the official adoption of some of the proposed methods by several agencies. Similarly, close liaison was maintained between the working group and several writing groups working on related items under the American National Standards Institute (ANSI) Acoustical Standards Committees. In summary, the working group tried to be responsive to all potential users concerned and tried to reach consensus wherever possible.

The originally small membership of the working group (7) changed during its existence: early presentation of the approaches selected by the working group to the scientific community led to discussions, comments, and new research data, which made it desirable to include some of the key contributors or critics in the working group. In spite of this enlargement of the group to 13 members, however, it is still indebted to a large number of unlisted individuals who assisted the evolution of this report. To all of them our thanks.

Finally it is only fair to say that in a report as comprehensive and exploratory as this one, not all working group members agree with all details of the report. However, they all agree with its essential concepts and the general approaches and hope that the details will be worked out, corrected, and fall in place as experience with the proposed guidelines is gained. It was important for these guidelines to be published as soon as possible in order to assist in the adoption of a uniform national method for noise impact assessment.

Henning von Gierke, Chairman
CHABA Working Group 69 on Evaluation
of Environmental Impact of Noise

SUMMARY

Guidelines are proposed for the uniform description and assessment of the various noise environments potentially requiring an Environmental Impact Statement for Noise. In addition to general, audible noise environments, the report covers separately high-energy impulse noise, special noises such as ultrasound and infrasound, and the environmental impact of structure-borne vibration. Whenever feasible and practical, a single-number noise impact characterization is recommended, based on the new concept of level-weighted population: i.e., the summation over the total population of the product of each residential person times a weighting factor that varies with the yearly day-night average sound level outside the residence of that person. A sound-level weighting function for general impact and environmental degradation analysis is proposed, based on the average annoyance response observed in community response studies; this weighting function is supplemented by an additional weighting function at higher noise environments to quantify the potential of noise-induced hearing loss and general health effects. The evaluation of the environmental impact of vibration is derived from existing or proposed ISO standards. The report explains and justifies the procedures selected and gives examples of their application.

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I. INTRODUCTION

It is the policy of the United States Government to consider in all actions to be taken, and projects to be supported, their potential adverse impact on the environment. Both the long- and short-range implications of these actions for man's physical and social surroundings, for nature and for wildlife are to be considered. One potential adverse impact is a worsening of the noise environment caused by the action under consideration. To assess the amount of adverse impact, and to minimize or avoid it by alternate solutions, are purposes of Environmental Impact Statements (EIS). These guidelines will be of the greatest use if they are used during the planning of an action, not after the fact.

A. Purpose of the Guidelines

This report offers guidelines for the preparation of Environmental Impact Statements that deal with noise and vibration. It is intended to provide guidance for a wide variety of situations and needs; although most situations are addressed, it may not address some special conditions for which an environmental impact statement may be required.

The users of this document are envisioned to be:

1. Federal agencies. The legal requirements for preparing environmental impact statements are established and will be described in detail. Although individual agencies may have need for their own, more specific guidelines, it is hoped that this document will assist them in achieving nationwide consistency in dealing with noise problems, and will lead to objective and uniform evaluation and disposition of the noise impacts. In those cases where there is conflict with the guidelines of a Federal Agency, that Agency's guidelines would be expected to take precedence over those proposed in this document.

2. Individuals, industries, environmental groups, etc., who will use the proposed method voluntarily to investigate or assess an environmental noise problem. Such users are not bound by legal requirements, but it is hoped that they will follow these guidelines so as to provide a common basis for public understanding of what is meant by noise impact.

3. Individuals, industries, state and local governmental agencies that must comply with state or local requirements to prepare environmental impact statements. States or local governments may have their own requirements for preparing an EIS, but wherever specific guidance is lacking, it is strongly recommended that the method proposed in this document be used.

B. Administrative Procedures

1. Several states already have environmental impact review procedures; however, since these procedures differ from state to state and since more states are expected to develop such procedures, these procedures are not listed.

2. A guideline to the Federal environmental impact review process is given here in Table I-1.

C. Rationale of Noise Impact Assessment

The guidelines are based on the philosophy that, as much as possible, the technical approach, the descriptors of the noise environment, the measurement and prediction methods, as well as the evaluation criteria and techniques for impact assessment should be uniform and as simple as possible. It appears feasible to follow these principles in arriving at an objective, and for most situations quantitative, definition of the noise impact. This in turn allows quantitative tradeoff studies and comparison of the noise impact produced by different projects. In some cases this approach may be

TABLE I-1 FEDERAL ENVIRONMENTAL IMPACT REVIEW PROCESS

ENVIRONMENTAL IMPACT PROCESS	APPLICANT	SPONSOR AGENCY	REVIEW AGENCY	REPOSITORY
Phases in The EIS Project	Organization Seeking Funding	Organization Responsible for Fed. Proj.	Identified to Review EIS	Council On Environmental Quality
PHASE A BACKGROUND	A 1. Determine Resource Needs 2. Seek Federal Support 3. Contact Federal Agency 4. Time Variable			
PHASE B CONSULTATION		B 1. Describe Available Resources 2. Detail Program Requirements 3. Outline Impact Guidelines and Criteria 4. Time Variable		
PHASE C PREPARATION OF DRAFT EIS	C 1. Prepare Draft EIS 2. Submit Draft EIS 3. Time Variable (1-12 mos.)			
PHASE D REVEIW OF DRAFT EIS	D 1. Receives Comments on Draft EIS	D 1. Review Draft EIS 2. Approve Draft EIS 3. Circulate Draft EIS 4. Schedule Public Hearing (optional) 5. Time 1-3 months 6. Receive Comments On Draft EIS	D 1. Review Draft EIS 2. Prepare Comments on Draft EIS 3. Submit Comments on Draft EIS to Sponsor 4. Time 45 days; Possible Extension of 15 days	D 1. Receive Draft EIS 2. Publish Notice of Availability and Review Status In Federal Register 3. Permanently File Draft EIS
PHASE E PREPARATION OF FINAL EIS	E 1. Prepare Responses To Comments On Draft EIS 2. Prepares Final EIS	E 1. Prepare Response to Comments on Draft EIS 2. Prepare Final EIS 3. Circulate Final EIS 4. Time 90 Day Maximum	E 1. Review Final EIS 2. Submit Comments if Project Remains Unacceptable 3. Citizen Suit May Be Initiated 4. Time 30 Days	E 1. Receive Final EIS 2. Publish Notice of Availability and Review Status in Federal Register 3. Permanently File Final EIS
PHASE F RESOLUTION AND COMPLETION		F 1. May Modify or Abandon Project If EIS is Too Controversial		F 1. May Intervene If EIS is too Controversial

considered overly mechanistic. For such cases the traditional, non-quantitative description of the noise impact is not discouraged, particularly if it is provided in the discussion section in addition to the proposed quantitative impact assessment. Use of the day-night average sound level to quantify the potential for hearing loss is not intended to supersede those occupational hearing loss criteria currently being used by the military services and the Occupational Safety and Health Administration.

The preparation of an EIS on noise (Table I-2) is primarily concerned with the documentation and assessment of the changes in noise. The methods proposed in these steps are based on the work and the progress achieved over the last few years by interagency committees, recommendations of the National Academy of Sciences-National Research Council and other published studies. In particular, use of the day-night average sound level, officially adopted by several Government agencies since publication of the Environmental Protection Agency "Levels Document," (ref 1) is recommended as the common noise descriptor. A modification of the descriptor for impulse noise is based on the work of a CHABA working group (ref 2) and of an interagency task force (ref 3) on this subject.

The impact assessment/quantification methods recommended in these guidelines are further developments of the Fractional Impact Methodology used by EPA for assessing health and welfare effects of a noise environment. They are based on the health and welfare effects and noise-dependences derived in the EPA "Levels" document, with certain modification to reflect more recent data and analyses. A similar impact assessment method is proposed in these guidelines for quantifying the potential for loss of hearing at day-night average sound levels in excess of 75 decibels. The degree of loss of hearing and the severeness of the effects as a function of increasing noise levels are largely based on the generalized findings of the EPA "criteria" (ref 4) and "levels" (ref 1) documents.

TABLE I-2 PREPARATION OF AN EIS ON NOISE

Description of Project or Action

↓

Analyze Noise Environment

Does noise environment change?
Does exposed population change?

Are changes significant enough for detailed documentation?

↓

Measurement and Documentation of Noise/Exposed Population

a. Definition of Existing Noise/Exposed Population
b. Projection of Future Noise/Exposed Population
c. Change in Noise/Impact of Project

↓

Assessment of Impact

a. Health and Welfare Effects
b. Potential loss of hearing
c. Environmental Degradation

↓

Discussion and Analysis of Results
Justification for Impact or Consideration of Alternatives

A summary of the proposed noise descriptors and assessment methods to be discussed in this report is presented in Table I-3. These proposed measures, applicable to the majority of common audible noise, are simplifications and the recommendation for their use is not intended to discourage other additional approaches. However, we strongly recommend that the methods of these guidelines, as a minimum, be used to provide a common framework for comparison among different environmental noise assessments.

Because of the close relationship of noise to structural vibration these guidelines recommend that the EIS on noise include the assessment of any significant changes of the vibration environment. The criteria for the evaluation of vibration environments, reviewed briefly in Chapter VI are based on an international standard (ref 5) and proposed amendments.

D. Classification of Noise and Vibration Environments for the Purposes of these Guidelines

1. The types of noise and vibration environments considered are:

a. General audible noises. Audible noise that can be adequately described by either the average (equivalent) A-weighted sound level or its variation that includes a nighttime weighting, the day-night average sound level. For most practical cases this type of noise measure will adequately describe the noise environment, and much of the document concerns the evaluation of general audible noise.

Note: Although A-weighting is theoretically defined up to 20 kHz sound level meters may not give the desired accuracy for sound whose frequency is likely to exceed 15 kHz. In such situations additional measurements should be made with instrumentation having a flat response above 10 kHz.

Table I-3 SUMMARY OF PREPARATION OF A NOISE IMPACT ANALYSIS

TYPE OF ENVIRONMENT		TYPE OF CRITERIA	RECOMMENDED NOISE MEASURE	ASSESSMENT METHODOLOGY USED
GENERAL AUDIBLE NOISES (including low-level impulse noise)		Potential for loss of Hearing	Day-Night Average Sound Level	Population Weighted Loss of Hearing (PLH)
		Health & Welfare Effects on People $L_{dn} > 55$	a. Day-Night Average Sound b. Word Description	a. Sound Level Weighted Population (LWP) and Noise Impact Index (NII) b. Descriptions of the Effects
		Environmental Degradation/Improvement on People/Animals $L_{dn} > 35$		
SPECIAL NOISES	Large Impulse Sonic Boom Blast Artillery	Structural Damage	a. Peak Pressure b. Empirical Formulas c. Peak Acceleration (weighted)	a. 200 Pa limit outside b. Listing of predicted damage as to amount and type c. 1 meter/sec^2 inside
		Annoyance due to auditory stimulation and building vibration	Composite Day-Night Average Sound Level using C-Weighted Sound Exposure Level for Impulses	Sound Level Weighted Population (LWP) and Noise Impact Index (NII)
	Other	Other (infrasound, ultrasound, etc.)	Maximum Sound Pressure Level	Discussion of possible effects. No quantification made.
VIBRATION		Structural Damage	Peak Acceleration (weighted)	1 meter/sec^2 for most structures 0.5 meter/sec^2 for sensitive structures. 0.05 meter/sec^2 for certain ancient monuments
		Annoyance and Complaints	RMS Acceleration (weighted) versus time of exposure.	Uses no complaint level for threshold of any adverse effects. Some quantification possible using vibration impact index.

(For ultrasound evaluation a flat response from 10 kHz to 100 kHz is recommended.)

b. Special noises. Not all noises can be adequately evaluated by average sound levels. Examples of the special noises are: infrasound (frequency range of 0.1 to 20 Hz), ultrasound (frequency range above 20 kHz), certain types of impulsive noises such as sonic booms and blasts, and sounds that convey more information than random noise sources with comparable average sound levels, such as voices, warning signals, barking dogs.

c. Vibration. Procedures are included for evaluating the impact of vibration on man. While the main reason for their inclusion here is to account for vibration generated by airborne noise, the impact of certain types of vibration can be assessed whether the transmission paths are airborne or structureborne.

A summary of the types of noise and vibration environments and the measures, criteria and assessment methods to be discussed in this report is given in Table 1-3.

2. Types of environmental impacts with respect to time are:

a. Short term temporary changes. A short term temporary change is a change in the acoustical or vibrational environment that exists for less than six months. It does not require the degree of noise documentation and impact assessment specified for actions of longer duration.

b. Long term temporary changes. A long term temporary change is a significant change in acoustical or vibration environment that exists longer than six months, but less than ten years. It requires noise or vibrational documentation comparable to that for permanent changes, but does not require as extensive an analysis of impact on future land uses and populations. Examples of such actions are some highway construction projects, military weapon system evaluations, transit system relocations, limited use quarrying projects.

c. Permanent changes in acoustical or vibrational environments. A permanent change in acoustical or vibrational environment is one whose consequences are significant for more than ten years. Evaluations of such actions that would cause such a change require projections of up to a twenty year period (or the life of the project if less), and the assessment of these environments requires a projection of population and land uses affected by the environments over a twenty year period.

E. Structure of the Guidelines

The main document is divided into eight chapters and is supported by appendices with more detailed information and practical examples. The eight main chapters are:

I. Introduction - Introduces the guidelines, identifies potential users and the technical approach taken with respect to categorizing, measuring, describing and assessing the noise environments.

II. How much noise analysis is required - Provides guidelines to determine whether the proposed project is clearly so unlikely to cause a noise impact that no further analysis is warranted; for these cases the EIS will comprise a statement that such-and-such condition in the screening process is satisfied and no further documentation of the change in noise environment is needed.

III. Flow chart for noise impact analysis - Describes the procedure for noise analysis in the cases of non-trivial impact that are not eliminated in the screening step. A flow chart guides the process (with reference to the sections of this report where specific details are given for the separate steps) from the initial description of the project, through its various potential effects on the environment, to a final statement of environmental impact; provision is made for a comparison of the impacts of alternative schemes for the project; and nodal points in the flow chart are identified where the analysis may be stopped with a showing of "no change in noise impact."

V. Description and documentation of special noises and vibration - Provides the recommended measures for evaluating and documenting special noises and vibration.

VI. Noise and vibration criteria - Describes the bases from which the measured or predicted change in noise due to a proposed project will be deemed to cause an adverse or positive environmental impact: these concern the probability that the noise will interfere with human activities such as sleep, speech, use of television. etc.; will pose a threat to people's hearing; will damage structures, monuments, etc.; or will simply increase the noise environment above existing conditions.

VII. Quantifying the assessment of the environmental impact of noise - Defines sound level-weighted population, and noise impact index as general measures of noise impact on health and welfare, and a population-weighted loss of hearing as a measure of noise impact when day-night average sound level exceeds 75 decibels. Describes procedures for assessing special acoustical and vibrational environments.

VIII. Summary of noise impact analysis - Summarizes the analysis that might be expected in an environmental impact statement on noise for each branch of the flow chart described in Chapter 3.

Detached from the main document under a separate cover, there are three appendices included as a part of these guidelines. These appendices, especially appendices B & C have not been given the extensive working group review afforded the main document and should be treated only as supportive material to the main document. These three appendices are:

A. Some Acoustical Terms, Abbreviations, Symbols and Mathematical Formulations for Environmental Impact Statements.

This appendix provides a list of acoustical terms, definitions of those terms, and acceptable abbreviations and symbols for each of the terms. Mathematical equations that describe some of the terms are also provided.

B. Development of Weighting Functions.

This appendix provides the bases of the two weighting functions used in section VII of these guidelines.

C. Measurement of and Criteria for Human Vibration Exposure.

This appendix summarizes the effects of human whole body vibration, human annoyance and interference caused by building vibration and structural damage thresholds due to building vibration.

II. HOW MUCH NOISE ANALYSIS IS REQUIRED? - SCREENING

Some proposed projects will obviously cause a severe noise impact on their surroundings, others may obviously be so quiet as not to change the noise environment at all. In the first case there is no doubt that a full analysis of the noise impact is required; in the second case the EIS for noise would simply state, with minimal documentation, that no impact is expected.

About many projects, however, there will be a question as to whether their noise impact is significant enough that a full noise impact analysis is needed for the EIS. This chapter offers a screening test to determine how extensive a noise analysis is needed and, in particular, whether noise measurements are required to establish the existing noise exposure accurately. This last matter is important because such measurements can be expensive and time-consuming.

A. Basic Screening Chart

Figure II-1 presents the basic screening chart to determine whether or not a full Noise Environment Documentation will be required for the proposed project. It is based on the relation between the existing noise environment and the expected environment after the project is completed and in operation.

So long as the expected yearly day-night average sound level after the proposed project is completed is less than 40 decibels and the sound pressure level is never greater than 105 decibels in the frequency band from 1 to 100,000 Hz, the project is "screened out" at the start and no further noise analysis is needed, no matter what the existing noise level.

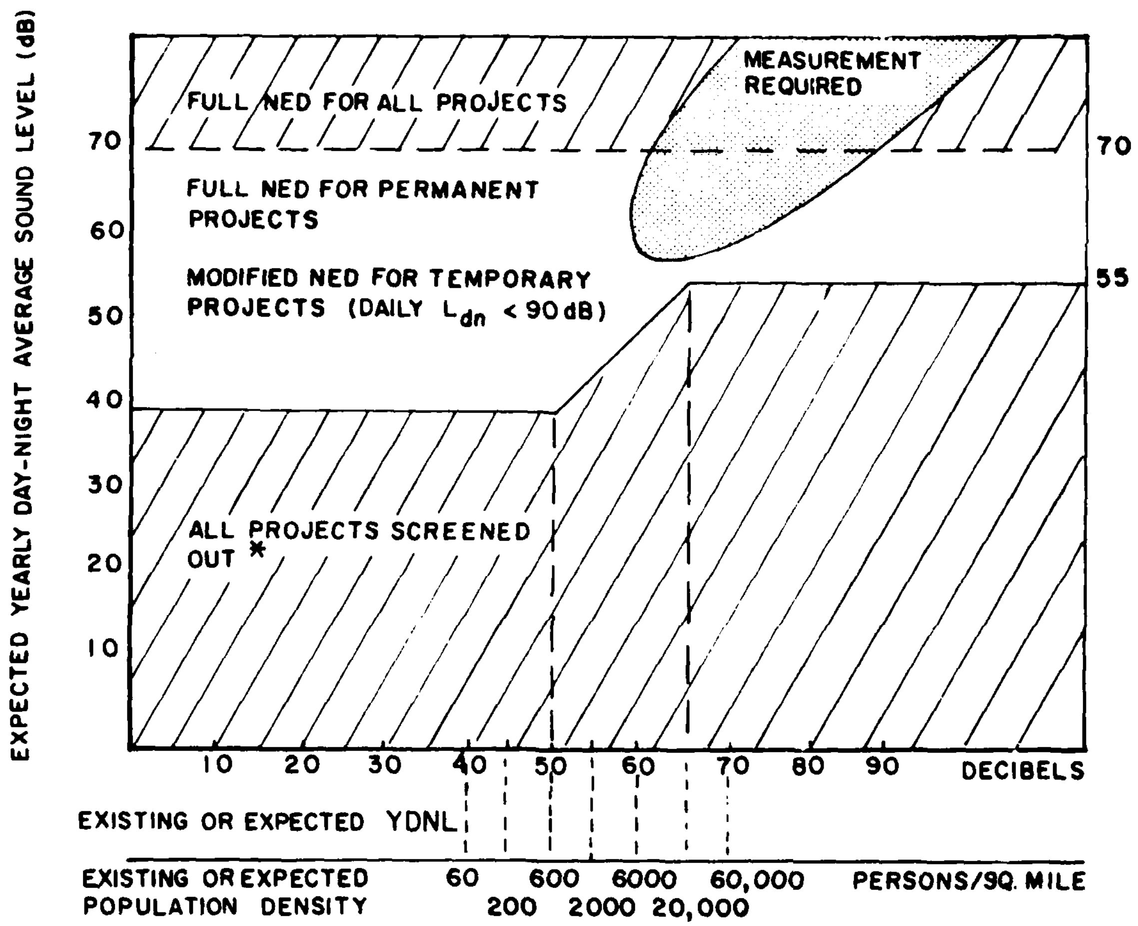

FIGURE II-1. Screening Diagram for the expected yearly day-night average sound level to determine whether or not full noise environment documentation (NED) is required. The shaded area in the upper righthand corner represents situations for which measurements, rather than estimates, of the existing noise are advised.

*The projects yearly day-night average sound level must not at any time include a peak sound pressure level greater than 105 dB with a band from 1 Hz to 100 kHz.

The EIS would simply state this fact; but it must also give a qualitative description of what effect this increase in noise level would have on people, wildlife, structures or monuments.

If the existing day-night average sound level (DNL) exceeds 50 dB, projects with expected after-completion levels above 40 dB may be screened according to the lower curve in the chart; for example, if the existing day-night average sound level is 60 dB, permanent projects with expected source levels under 50 dB are screened out. A project for which the expected noise level lies above the lower curve (permanent projects), or upper curve (temporary projects), requires a Noise Environment Documentation (NED), following through the flow chart described in Chapter III.

B. Determining the Existing Noise

There remains the question of whether a *measurement program* is needed to establish the existing noise environment with sufficient accuracy, or whether this environment can be adequately estimated by using the expected population density. The average relation of population density to DNL is shown on Figure II-1. For greater detail, refer to Table IV-1. (Note that the levels shown in that table are mean values for residential areas in urban areas that are not in the vicinity of an especially noisy existing source such as an airport, a freeway, a railroad, a switching yard, etc. If such a noise source exists, its contribution to the existing DNL should be estimated and then combined with the other background noise given in Table IV-1.)

III. FLOW CHART FOR NOISE IMPACT ANALYSIS

This section discusses a flow chart, Figure III-1, to provide guidance in carrying out the various parts of the Noise Environment Documentation (NED) and impact assessment needed for an environmental impact statement. There are three principal branches in the flow chart to be followed, depending on the nature of the potential impact of the proposed project; and there are "exit points" along each of the branches at which the analysis for that branch may stop without proceeding to the end, because it is clear that there is no significant increase with respect to the noise impact of concern on that branch. The goal is to find an exit point from each branch of the noise impact analysis as soon as possible, and thus to minimize the amount of analysis needed. At the right-hand edge of the flow chart there are four columns of boxes that will be checked to indicate the outcome of the analysis at each branch point. These columns will serve to summarize the noise impact analysis for the project, on the one hand, showing the stages at which exit points, if any, occurred, and will also call attention to aspects of the noise impact requiring explicit evaluation in the EIS, according to the methods of Chapters IV, V, and VII, in terms of the criteria described in Chapter VI. A summary of these methods, consistent with the flow chart, is provided in Chapter VIII.

The following discussion clarifies the various paths to be followed in the flow chart, and in the process, will also clarify the nature of the environmental impact statement itself. (Note: the letters and numbers that identify points along the flow diagram are NOT keyed to the heading and subheading numbers of this section.)

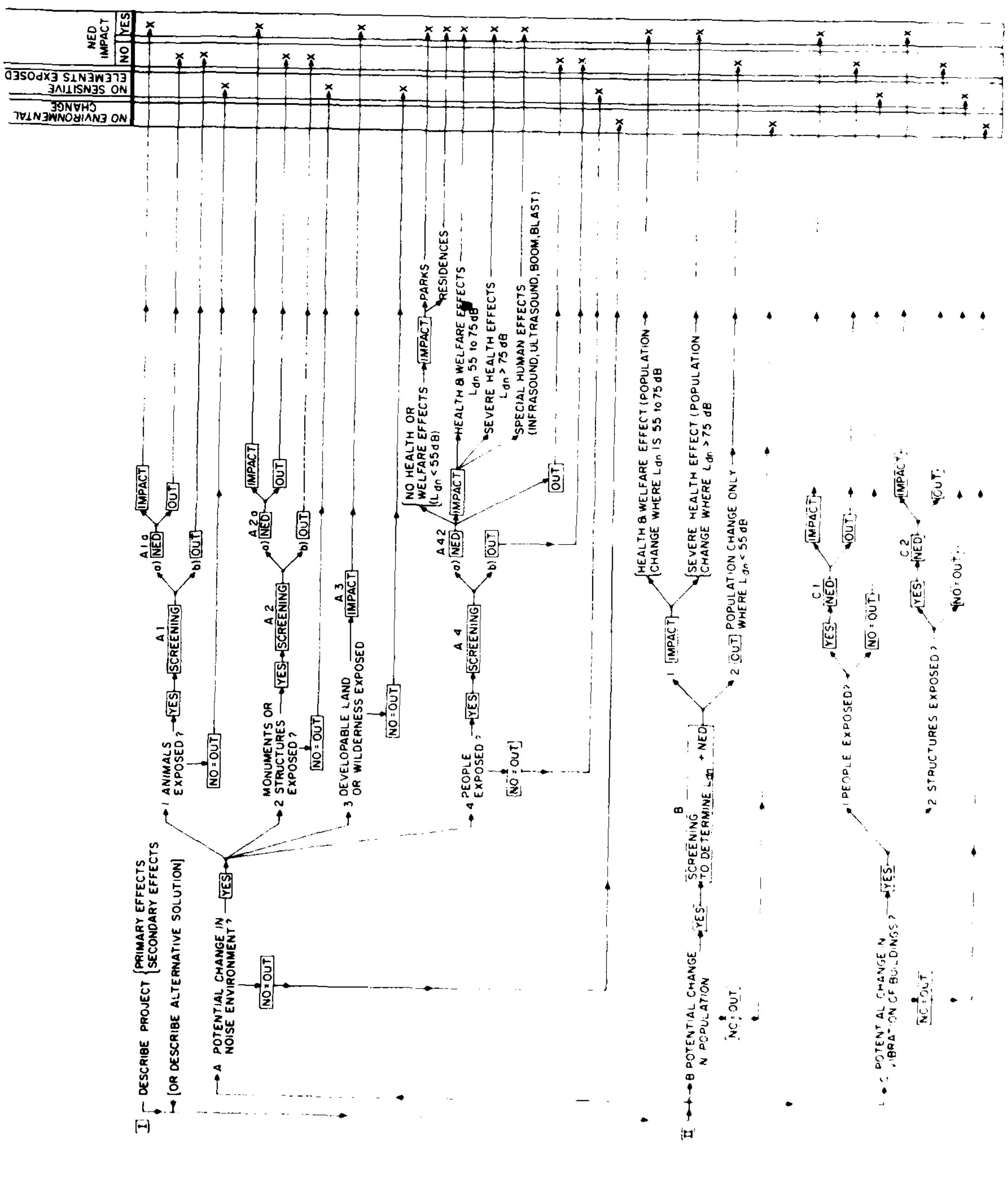

FIGURE III-1 FLOWCHART AND WORKSHEET

A. Description of the Project

The first step (I) is to give a general description of the proposed project, particularly emphasizing those aspects that are expected to contribute to noise impact on the environment. The project may involve changes in land planning, or plans for introducing, removing or replacing equipment, fixed or moving, or the promulgation of regulations, or the temporary noisy construction phase of an inherently quiet facility.

The expected noise impact either may be adverse, if the noise environment would be worsened by the project, (for example, by introducing a noisy plant into a quiet neighborhood, or by constructing residences in a noisy area), or it may be beneficial if the environment would be improved (as by the introduction of anti-noise regulations, or the replacement of a noisy facility by a quiet one).

Both the short term and long term effects expected from the project should be described. For example, the construction of a new airport or highway in a sparsely settled region would have as its initial impact an increase in noise that would affect relatively few people. However, it must be expected that unless proper land use planning and implementation occurs, the new facility will attract new people and business which would increase the nearby population density. Thus, the ultimate noise impact may be significantly greater than that projected on the basis of the initial effect alone. To evaluate an action over time, it is suggested that a time interval of 20 years be used in evaluating permanent action. Thus, the initial impact and the expected impact after 20 years should be evaluated. To present a complete picture, the impact after 5, 10, and 15 years might also be presented. When comparing the impact between projects or alternatives or when establishing economic cost/benefit ratios, the average impact over a 20 year period may be used.

When the flow chart analysis has been worked through for a project and at the end it is determined that the noise impact of the project will be significant, a number of alternative approaches must be proposed. Each of these modified plans must be analyzed, beginning again at step 1, with a description of the project as modified. There will thus be a flow chart worked out for each of the alternative schemes. Each of the worksheets, by its summary columns of checked boxes, will indicate what aspects of the noise impact of that alternative need explicit consideration in the EIS; and a comparison of these columns will facilitate choosing the project alternative with the least noise impact on the environment.

B. Is There Any Potential Increase In Noise Impact At All?

The first branch point in the flow chart occurs at II, where it must be determined whether there is any potential noise impact at all to be expected of the proposed project. Branch A should be followed if the project will in any way change the present noise level; either an increase or decrease in noise level must be evaluated. Branch B should be followed if the effect of the project is to change the population distribution, which might move people into or out of existing noise-impacted areas. Branch C should be followed if the project will cause a change in vibration in buildings. At each of the points A, B or C, if the project will have no increase in impact at all, you will follow the "NO=OUT" route and the analysis for that branch is complete; in that case, check the "NO" box at the right-hand side of the page, under "NO ENVIR. CHANGE."

1. Examples to illustrate which branch(es) of the flow chart to follow:

-- A project that entails a change in land use may cause only a change in the existing noise in an area, so only Branch A would be followed; on the other hand, it may only involve relocation of some of the population, in which case only Branch B would be followed. If the project is expected to cause (or diminish) vibration, Branch C would be followed. Most land use changes, however, will involve a combination of A, B and C.

-- A project involving the installation of new equipment, or the replacement of old equipment, is likely to require analysis of only branches A and/or C, since no population shift is likely to be involved.

-- A project that consists of a new regulation, or a change in an existing regulation, might follow either A or B. For example, a new regulation reducing the noise output of heavy trucks would change the noise along a highway, and thus Branch A should be followed. (Secondary effect: it is conceivable that when people realize that the highway is quieter as a result of this regulation, there may be additional residential development resulting in an increase in population. Such a case would involve Branch B, as well). On the other hand, a change in the noise policy of the Department of Housing and Urban Development may alter the distribution of future dwellings among neighborhoods with different levels of existing noise; such a regulation would change the population exposed to noise without affecting the noise anywhere, and hence would warrant analysis along Branch B.

-- A new airport, whose primary effect would be increased noise levels in the neighborhood, might impact only wildlife to begin with (Branch A.1), or only monuments or structures (Branch A.2), or only presently undeveloped land that could be spoiled for later residential development by the airport noise (Branch A.3) or it might impact an existing community (Branch A.4). The magnitude of the impact on the land, following Branch A.3, would be quite different for a prospective airport where land is purchased around the proposed site for controlled leasing to non-noise-sensitive activities as compared to one where such precaution was not taken. This difference would be reflected in the EIS for a time 10 to 20 years in the future.

-- A project that causes a change in the interior noise of aircraft cabins or a change in the noise insulation of automobile bodies would be analyzed on a path along Branch A, since it changes the noise environment in "existing spaces" with definable existing population.

RULE OF THUMB:

If the primary effect is to change the noise, follow A. If the primary effect is to move people, follow B.

2. "OUT" because of no environmental change. If exit points have been found in each of the locations A, B and C at branch point II, the noise analysis need not proceed further; a check mark will be placed in the three boxes in the column labelled "No environmental change" at the right of the page and the noise analysis is finished. The environmental impact statement on noise will simply state this fact. Otherwise, the analysis continues in the branches in which no exit point has been found at II.

C. Are Any Sensitive Elements Exposed To The Change In Noise?

Even if there is a change expected in the noise environment because of the introduction of the proposed project, it could happen that the location of the project (e.g., the Antarctic) or the mode of installation (e.g., remote and underground) is such that no sensitive elements are exposed to the new noise. This possibility accounts for a second set of exit points in branches A and C.

If no wildlife is exposed (point A.1), no monuments or structures are exposed (point A.2), no developable land is exposed (point A.3) or no people are exposed (point A.4), the noise analysis would exit at one or more of these points, and the corresponding boxes would be checked in the column at the right labelled "No sensitive elements exposed."

If all six such boxes are checked, the noise analysis is complete, and a statement to this effect is included in the EIS. Wherever an exit point has not been found, the noise analysis continues in that branch.

D. Screening

In cases where a change in the noise is expected and furthermore there will be sensitive elements exposed to this change, or where there will be no change in the existing noise but people will be moved from quiet to noisy areas or vice versa, then the noise analysis proceeds with the screening step of Chapter II. This step may demonstrate that the potential change in noise impact is actually negligible.

If the anticipated day-night average sound levels are below the screening levels in any branch, take the permitted exit routes at points A.1.b., A.2.b, A.4.b, or B.2 on the flow chart, and check the appropriate boxes on the right side of the sheet. Include a suitable statement in the EIS concerning elimination by screening for these phases of the noise impact analysis.

E. Noise Environment Documentation (NED)

1. Permanent changes. For non-temporary changes in the acoustical environment, all phases of the noise impact analysis that have not found an exit point by this time must be continued on to provide a full Noise Environment Documentation (NED).

Different methods for predicting the expected average sound levels and the corresponding noise impact are appropriate for different types of project and different kinds of noise sources. These NED procedures are described in detail in Chapters IV and V.

The result of the NED for each branch of the flow chart (worked out for each project or alternative) will result in a determination of degree of "IMPACT" according to Chapter VII. If the immediate or future noise environment due to the proposed project does not increase the impact, "OUT" is the conclusion. In this case, the appropriate box(es) are checked at the right of the worksheet and a statement is included in the EIS that, upon detailed analysis of the change in noise impact, none was found.

2. Temporary changes. Temporary changes which cause daily day-night average sound levels greater than 90 decibels in areas not under control of the project must also continue on to provide full noise Environmental Documentation. Temporary changes in which the daily DNL is less than 90 dB may modify, simplify or eliminate full Noise Environment Documentation as is reasonable when considering the scope of the proposed action or project. Suggested simplified procedures for quantifying the Impact of Temporary Actions are given in Chapter VII.

F. Statement of the Degree of Impact of the Project Noise or Vibration Environment

If a change in impact is found in any branch, refer to the criteria of Chapter VI and the methods for quantifying impact in Chapter VII; and based on the noise or vibration found in the analysis, prepare a statement of the expected impact caused by the noise or vibration environment of the project upon the people, wildlife, structures or land that will be affected. This statement is the heart of the required environmental statement (EIS). Wherever a significant increase in noise or vibration impact is found in the foregoing analysis, several alternative schemes must be explored that will reduce the degree of noise or vibration impact. Each of these will form the basis of a new flow chart worksheet, and will result in an alternative statement of noise impact. In effect, this requirement amounts to a "feedback loop" connecting the end of the flow chart procedure back to the beginning.

With respect to people exposed to noise, emphasis should first be placed on reducing the amount of potential loss of hearing. When this severe health effect is minimized, priority is then given to minimizing public health and welfare effects. Finally, the amount of degradation or improvement should be assessed.

G. Uncertainties in the Noise Analysis

There will almost always be areas of uncertainty in the noise impact analysis, usually because of the unavailability of needed factual information: the projected future traffic volume for a proposed freeway may be uncertain, the noise of a not-yet-built device may be only approximately known, the population estimated to be exposed to various sound levels from the project may be subject to error, etc. In all cases, a discussion of the probable uncertainties in the analysis must be provided in the EIS. Perhaps the most suitable approach for this purpose is to take the upper and lower bound for each of the uncertain quantities that enter into the analysis, and group the "most favorable" and "least favorable" bounds of these quantities together to arrive at two estimates of the environmental noise impact: the best and worst cases that together bracket the range of likely actual results of proceeding with the proposed project.

IV. DESCRIPTION AND DOCUMENTATION OF GENERAL AUDIBLE NOISE ENVIRONMENTS

A. Introduction

The purpose of an acoustical section in an Environmental Impact Statement (EIS) for a proposed project is to describe any change in the impact of noise on people and communities expected as a result of some action.

The "action" may be building of a new refinery, development of a new mine, construction of a road, use of a new piece of machinery, etc.; it may involve the enlargement or the reduction in size of an existing facility; or an effort to make a given facility more quiet; it may be the promulgation and enforcement of a new noise abatement regulation; or, with no change in the noise environment, it may entail a change in land-use or population density in a neighborhood. Any proposed change that will significantly affect either (a) the amount of noise generated or (b) the number of people exposed to it, will change the environmental noise impact; such a change is a "project" subject to the preparation of an EIS with respect to noise.

The noise impact may be calculated by the use of the methods described in Chapter VII; the corresponding expected response of the people may be estimated by reference to the criteria of Chapter VI.

This chapter describes the basic measures for evaluating and documenting the noise environment both before and after some action or project.

Several kinds of noise have been extensively studied, particularly the noise of transportation, and procedures have been developed for calculating day-night average sound levels based on types of noise source, and operational considerations. Procedures for dealing with the noise of specific sources such as aircraft near airports, roadways, railroads are available (for instance the draft joint services planning noise manual-reference 11) and no difficulty is anticipated in adapting them for the purposes of these guidelines.

B. Description of Environmental Noise

1. Noise measures for use in Environmental Impact Statements (EIS). The primary measure for describing noise in an EIS is the day-night average sound level, abbreviated as DNL, and symbolized as L_{dn}. The unit for DNL is the decibel. Average sound level is numerically equal to the value of steady sound level that would convey the same mean-square A-weighted sound pressure level as does the actual time-varying sound in the same time period. Average sound level is also called equivalent continuous sound level or equivalent sound level.

The day-night average sound level is a 24-hour average sound level in which nighttime noise levels occurring between 2200 and 0700 are increased by 10 dB before calculation of 24 hour average.

The day-night average sound level for a given calendar day should be composed of the nighttime average sound levels occurring between 0000 and 0700 hours and between 2200 hours and 2400 hours of that calendar day.

Long term environmental impact is evaluated by the yearly day-night average sound level, symbolized as L_{dny} and abbreviated as YDNL.

Day-night average sound level is the primary measure of a noise environment that affects a community over an entire 24-hour day. In some instances it is desirable to assess the effect of a noise environment on an activity of shorter duration, such as interference with speech in a classroom or office. In these instances it is useful to consider the average sound level over the time period of interest, for example one hour or an 8-hour work period. The average sound level over a specified period of time is abbreviated as TAVL, where T is the time interval of interest, and symbolized as L_T or sometimes as $L_{eq(T)}$. Simplified abbreviations for hourly average sound level and eight hour average sound level are 1 HAVL and 8 HAVL respectively, symbolized as L_h and L_{8h}. Similarly, a 15 minute or 30 second average sound level would be abbreviated by 15 minute AVL or 30 second AVL, symbolized as L_{15m} and L_{30s}.

It is often useful to describe the cumulated sound produced by a single event, such as an aircraft flyover, or the passage of a motor vehicle or train. The appropriate sound measure for such event is the A-weighted sound exposure level, abbreviated as SEL and symbolized as L_{AE}. It is a measure of accumulated, not average, sound energy.

All of the levels used in an EIS are expressed in decibels; the reference sound pressure is 20 micropascals. Precise mathematical descriptions of these measures are provided in Appendix A.

2. Determine the population affected by the noise of the proposed project. In preparing an environmental impact statement, it is required that the noise impact of a number of alternatives be assessed. Among these alternatives is included the option of not going ahead with the project at all.

For each of the alternatives that involves the introduction of some form of new noise source, the affected population is defined by that population experiencing sound levels produced by the new noise source above a specified YDNL. This specified YDNL will be called the base YDNL.

Normally, the base YDNL will be 55 dB consistent with the lower threshold for health and welfare effects as indicated in Table I-3 and justified in the Levels Document and in Chapter VI on criteria of this report. But the base YDNL may be lower in order to assure that the range between highest residential YDNL to the lowest residential YDNL investigated is at least 20 decibels. In any case, the base YDNL will never be greater than 55 dB. When several alternatives are compared, a same common YDNL must be used for all alternatives. In such cases, the base YDNL for all alternatives will be determined by the alternative that has the highest residential day-night average sound level. No person exposed to project day-night average sound levels less than the base YDNL (for any of the alternatives) would ever be regarded as impacted by the project, and hence his pre-project noise impact is considered neligible.

There are actions that do not add new noise sources, but only change the noise output of existing sources. In these cases, the changed source should be treated as a new source for purposes of determining the affected population.

There are actions that will move people into noisy areas. For these cases, the affected population will be that population that is moved into an area in which the existing YDNL is greater than 55 dB.

There are actions which affect large segments of the population that are not easily related to specific areas. Laws and regulations that directly affect mobile noise sources are examples of such actions. For actions affecting regulation of noise sources in general, the affected population might best be described as the total population experiencing day-night average sound levels above 55 decibels from such sources. For actions affecting source control for equipment operators, the affected population might be only the users of the specific noise source. In the final analysis, the preparer of an EIS for such actions must use his judgement. In all cases, a detailed rationale as to how the affected population was determined should be included in the EIS.

3. Determining the yearly day-night average sound level. Noise environments produced by new noise sources must be estimated by an acceptable engineering procedure. Procedures approved by various federal agencies are available for a number of typical situations, including aircraft, motor vehicles, railroads, construction equipment and other noise sources.

Where the introduction of a new noise is anticipated and an existing approved procedure is not available, an engineering description of the procedure employed in the EIS analysis must be provided in adequate detail for technical evaluation of its acceptability.

If the EIS relates to the altered use of an area exposed to an existing noise that is not expected to change, specifications of the noise environment used in the analysis should be based upon estimates or measurements of the present environment.

If the EIS relates to the introduction of new noise sources within an existing environment, or if a change in the quantity or nature of existing noise sources is expected, both the present and future noise environment should be predicted.

Various methods are available for defining the existing noise environment at a location. One method is to determine it by direct measurement.

If the present average sound levels are already high, so that noise impact of a new project will not be much greater, or may be even less than the impact from the existing noise environment, it may behoove the applicant to conduct a measurement program, so as to predict the noise impact more accurately. Such a program may entail substantial expense, but it may be warranted in view of the project requirements.

Where the existing noise environment is dominated by major noise sources such as airports, highways, railroads, power plants, factories or other situations where well-defined predictive models are available, the existing noise environment may be predicted using current source and operational data.

Where no dominant source of this nature is present, the existing noise environment may be considered to be caused primarily by local automotive traffic noise. For these instances the day-night average sound level may be estimated on the basis of population density in accordance with the values listed in Table IV-1. It should be noted that the yearly day-night average sound levels may be as much as 10 decibels less than or greater than the values listed in Table IV-1, depending upon local street layout and traffic flow conditions. The values in Table IV-1 are representative of space average values over areas of the order of 1 km^2 (0.4 sq. mile), or larger, for typical urban conditions. The basis for the values in Table IV-1 is the equation $\left[L_{dn} = 10 \log \rho + 22 \text{ dB}\right]$; where ρ is population density in people per square mile. Interpolations in Table 1 may be made by the above formula for population densities between 20 persons/sq mile to 20,000 persons per square mile. For purposes of estimating the existing noise in relation to permanent changes in areas with population density greater than 20,000 persons/sq mile, the day-night average sound level should be taken as 65 dB. Higher estimates of the background noise by the use of 10 log ρ + 22 dB requires specific justification such as direct measurements or detailed calculations based on existing noise sources.

TABLE IV-1

Typical Values of Yearly Day-Night Average Sound Level for Various Residential Neighborhoods Where There is No Well Defined Sources of Noise Other Than Usual Transportation Noise

Description	Population Density (People/Sq. Mi.)	L_{dn} - dB
Rural (undeveloped)	20	35
Rural (partially developed)	60	40
Quiet Suburban	200	45
Normal Suburban	600	50
Urban	2000	55
Noisy Urban	6000	60
Very Noisy Urban	20000	65

When an existing noise environment is to be determined by direct measurement, it will be necessary to make measurements at a number of locations and over a time period sufficient to establish a credible baseline for use in the EIS. The number of measurement locations and their geographic disposition will depend on the extent of the impact expected to be produced by the project.

Measurement periods and the time intervals between them should be determined by the characteristics of the existing noise. If the existing noise is expected to be substantially the same from day to day, measurements during a single typical 24-hour period may be adequate; locations where the noise is caused primarily by well-established motor vehicle traffic patterns are an example. In other situations where strong daily, weekly, monthly, or seasonal effects occur, it may be necessary to measure for a number of different daily periods suitably chosen to account properly for these variations.

The most reliable temporal data are obtained by techniques that approach continuous measurement of the sound level over the time period in question. In some instances it may be reasonable to obtain measurements over only fractions of the total time--e.g., several minutes per hour. However, any measurement method used to approximate continuous measurement of DNL must be justified by adequate technical reasons and data to show the accuracy of the procedure when applied to the specific noise sources affecting the noise environment being described.

Population estimates for residential areas identified in the analysis may be taken directly from census tract data, local master plans, or by counting residential units identified on aerial photographs of the area. Non-residential populations may be estimated from industrial, commercial, or public facility employee statistics; student enrollments and employee statistics can be used to estimate school populations. Population estimates should strive to identify total populations within ± 10 percent of the true population.

When the present and future average sound levels are determined and the population defined, the methods of Chapter VII should be used to establish the degree of impact of the noise environment.

4. Basic data presentation.

a. Necessary tables - As a minimum the data characterizing the noise impact should be tabulated in a set of summary tables. Typical examples are included as Tables IV-2 and IV-3. For a given time the areas and population are to be listed against the yearly day-night sound level (YDNL) at increments not greater than five decibels (5 dB):

(1) for the YDNL without the project's existence;

(2) for the YDNL due solely to the project action;

(3) for the YDNL due to all sources including the project action.

NOTE: All three tables may not always be necessary, especially if there are insignificant differences between any two of the tables.

If the tables are properly constructed, the total population and/or land area for each of the three conditions will be equal. For each condition the total land area, residential area, residential population, industrial/commercial land area, and all special situations should be listed as a function of level of exposure in increments of 5 dB, or smaller. Normally, the increment will be a constant number of decibels (e.g. 5 dB), but it is acceptable to change the increment for one of the conditions and thus keep either the residential population or the land area increments constant.

The tables should include enough YDNL increments such that all residential populations, industrial, commercial land and special situations experiencing a YDNL above 55 dB are included.

Increments below an YDNL of 55 dB should also be included where necessary to insure that the increments cover a 20 to 25 dB range below the highest YDNL to which a residential area is exposed due to the project or action alone. In no event, however, is it necessary to list YDNL below 35 dB.

The column headings will typically include: total land area, industrial/commercial land area, residential land area, residential population and special situations. (Depending upon local conditions, different classifications of land use may be appropriate).

(1) Total land area. All land area within the specified levels.

(2) Industrial/commercial land area. All land not considered as residential or associated with special functions. This land area would include farm land, undeveloped land, industrial plants, and similar uses.

(3) Residential land. All land associated with a residential population. May include land actually zoned commercial or industrial. For residences on farm lands, approx 1 acre should be considered as residential land for each separate residence.

(4) Residential population. The number of people in an area who sleep for four or more hours per day in a residential area.

(5) Special situations. Those situations which must be highlighted or treated separately in order to represent the impact properly. Situations of this category can be religious facilities, outdoor auditoriums, schools, precision laboratories, hospitals, etc. The detail to which each special situation should be discussed will depend on the size of the project and the size of the area being evaluated. Special situations should be combined as necessary to keep the total number of special situations within reason (normally less than 20 or 30 items).

Tables IV-2 and IV-3 demonstrate one useful approach to the listing of special situations. Each special situation is numbered and this number is used in the special situation column to indicate the corresponding YDNL for that situation. In these listings the recommended criterion level such as those recommended by Table VI-1 is included for each situation (see Chapter VI for details). The number of exposed people for each situation should also be listed. At some location the population does not remain constant from day to day, week to week, or month to month. Examples of such places are churches, parks, and stadiums. In such situations the population entered in the special situation table is the time weighted average number of people present during the year. This number should be calculated by summing the products of the number of people using a facility, multiplied by the number of hours these people are present in the facility during a year, and dividing by the total number of hours in a year. Similarly, the average number of people can be calculated for only the daytime, nighttime, or both. The concept of average number should not be used for residential areas.

Formats other than that used in Tables IV-2 to IV-5 may be appropriate and may be used, however, the information conveyed to the reader should be effectively the same or greater.

At the bottom of the tables the values of Level Weighted Population, the Noise Impact Index and the Population Weighted Potential Loss of Hearing are shown. The meaning of these measures are discussed in Chapter VII.

b. Necessary figures and maps - For a defined area surrounding projects such as airports, factories, highways, electrical plants, a map or drawing should be presented if possible with contours representing constant values of yearly day-night average sound level. In general, the decibel increments between contours should be consistent with the tables as discussed above. Other contours may be presented as needed. There should be a set of contours for each of the alternative studies; however, it is not necessary to provide a set of contours for each column in the basic data tables. Any short term temporary project for which the day-night average sound level is expected to exceed 90 dB for more than 1 day should be described by contours of DNL at 5 dB intervals starting upward from 75 dB.

c. Necessary data points with respect to time - For each alternative of a permanent project or action, a separate set of tables as outlined above (paragraph IV B.4.a) should be prepared for (1) the first year of the commencement of the project and (2) the last year before the end of the project (or at the 20 year point, whichever is shorter) and (3) for the worst case year if such a year is not the first or last year. In many cases, only one table will be required because the conditions with respect to time can be expected to remain reasonably constant. By "reasonably constant," it is meant that the change in exposed population will be small enough so any resulting errors are consistent with the error in the overall analysis.

Table IV - 2a Sample of Data Presentation

PROJECT X - 1982 NOISE ENVIRONMENT

Without Project X Operation

Basis: 1977 Noise Measurements
1982 Population Estimates

YDNL (dB)	TOTAL LAND AREA (Sq km)	INDUSTRIAL/ COMMERCIAL LAND AREA (Sq km)	RESIDENTIAL LAND AREA (Sq km)	RESIDENTIAL POPULATION	SPECIAL SITUATIONS (See Table 2d)
>70	0	0	0	0	-
65-70	2	2	0	0	9
60-65	82	80	2	10,000	10,11,13,19
55-60	284.8	262.5	20.8	35,000	5,18,22
50-55	77	14.7	62.2	39,550	1,2,3,4,7,8,12,14 15,16,17,20,21
TOTAL	445.8	349.2	85.0	84,550	

Level Weighted Population (LWP) = 13293

Noise Impact Index (NII) = .157

Population Weighted Potential Loss of Hearing (PLH) = 0

Table IV - 2b Sample of Data Presentation

PROJECT X - 1982 NOISE ENVIRONMENT

Project X Sources Only

YDNL (dB)	TOTAL LAND AREA (Sq km)	INDUSTRIAL/ COMMERCIAL LAND AREA (Sq km)	RESIDENTIAL LAND AREA (Sq km)	RESIDENTIAL POPULATION	SPECIAL SITUATIONS (See Table 2d)
>85	.8	0	0	0	-
80-85	2.0	1.5	.5	100	1
75-80	5.0	4.0	1.0	450	2,3,4
70-75	13.0	8.0	4.50	4000	5,6,7,8
65-70	36.0	20.0	16.0	30000	9,10,11,12,13
60-65	100	69.7	30.0	40000	14,15,16,17,18
55-60	289	246.0	33.0	10000	19,20,21,22
	445.8	349.2	85.0	84550	

Level Weighted Population (LWP) = 34949

Noise Impact Index (NII) = .413

Population Weighted Potential Loss of Hearing (PLH) = .4 decibels for 550 people

Table IV - 2c Sample of Data Presentation

PROJECT X - 1982 NOISE ENVIRONMENT

Project X Sources and Existing Sources Combined

YDNL (dB)	TOTAL LAND AREA (Sq km)	INDUSTRIAL/ COMMERCIAL LAND AREA (Sq km)	RESIDENTIAL LAND AREA (Sq km)	RESIDENTIAL POPULATION	SPECIAL SITUATIONS (See Table 2d)
>85	.8	0	0	0	-
80-85	2.0	1.5	.5	100	1
75-80	5.0	4.0	1.0	450	2,3,4
70-75	17.0	10.0	6.5	4500	5,6,7,8,9,13
65-70	40.0	22.0	18.0	33000	10,11,12,18
60-65	105	67.7	37.0	42000	14,15,16,17,22,19
55-60	276	244	22.0	4500	20,21
	445.8	349.2	85.0	84550	

Level Weighted Population (LWP) = 36631

Noise Impact Index (NII) = .433

Population Weighted Potential Loss of Hearing (PLH) = .4 decibels for 550 people

Table IV - 3d Sample of Data Presentation Problem Two

SPECIAL SITUATIONS FOR PROJECT Y HIGHWAY

		Average* Population Day	Night	Area Sq km	CL**	Comments
1.	School	1000	80	.0039	60	There is a large night school enrollment of approx 400 students from 2000 hrs to 2300 hrs.
2.	Church	100	-	.0026	60	The property is for sale and may be razed.
3.	Playground	500	-	.0078	70	
4.	Park	10	-	.0648	60	
5.	Office Building	267	-	.0016 sq km	70	
6.	Office Building	267	-	Included in Commercial Area	70	
7.	Office Building	266	-		70	

$$\text{* Average Population} = \frac{\Sigma \text{ People x Hours}}{\text{Number daytime or nighttime hours in a year}}$$

Daytime (0800 hrs to 2000 hrs)
Nighttime (2000 hrs to 0800 hrs)

**CL - Criteria Level. The criteria levels correspond to those of Table VI-1 except where the acoustic insulation of the buildings is not typical.

Table IV - 3a Sample of Data Presentation

Problem Two

Land Areas and Populations for 1984 for Different Yearly Day-Night Sound Levels

Without Project Y Highway

Basis: 1976 Noise Measurements
1976 Population Estimates

YDNL (dB)	TOTAL LAND AREA (Sq km)	INDUSTRIAL/ COMMERCIAL LAND AREA (sq km)	RESIDENTIAL LAND AREA (Sq km)	RESIDENTIAL POPULATION	SPECIAL SITUATIONS
>65	0	0	0	0	-
60-65	.1213	.00466	.1166	212	5,6,7
55-60	.1575	0	.0784	201	1,2,3,4
TOTAL	.2788	.00466	.195	413	

Level Weighted Population (LWP) = 105

Noise Impact Index (NII) = .255

Table IV - 3b Sample of Data Presentation

Problem Two

Land Areas and Populations for 1984 for Different Yearly Day-Night Sound Levels

Project Y Highway Only

YDNL (dB)	TOTAL LAND AREA (Sq km)	INDUSTRIAL/ COMMERCIAL LAND AREA (Sq km)	RESIDENTIAL LAND AREA (Sq km)	RESIDENTIAL POPULATION	SPECIAL SITUATIONS
>80	0	0	0	0	-
80-75	.0078	0	.0078	3	-
75-70	.0242	.00078	.0117	30	1,3, 50% of 5
70-65	.0106	.0016	.009	45	50% of 5, 50% of 6
65-60	.0956	.0023	.0933	85	50% of 6,7
60-55	.1406	0	.0732	250	2,4
TOTAL	.2788	.00468	.195	413	

Level Weighted Population (LWP) = 126

Noise Impact Index (NII) = .304

Population Weighted Potential Loss of Hearing (PLH) = .2 decibels for 3 people

Table IV - 3c Sample of Data Presentation

Problem Two

Land Areas and Populations for 1984 for Different Yearly Day-Night Sound Levels

Project Y Highway and Existing Sources Combined

YDNL (dB)	TOTAL LAND AREA (Sq km)	INDUSTRIAL/ COMMERCIAL LAND AREA (Sq km)	RESIDENTIAL LAND AREA (Sq km)	RESIDENTIAL POPULATION	SPECIAL SITUATIONS
>80	0	0	0	0	0
80-75	.0163	0	.0065	24	3, 50% of 1
75-70	.0191	.0016	.0155	43	50% of 1,5
70-65	.0238	.0031	.0207	75	6,7
65-60	.1452	0	.0778	183	2,4
60-55	.0745	0	.0745	88	
TOTAL	.2789	.0047	.195	413	

LWP = 180

NII = .437

PLH = .2 decibels for 24 people

Table IV - 2d Sample of Data Presentation Problem One

SPECIAL SITUATIONS FOR PROJECT X

		Average* Population Day	Night	Area Sq km	CL**	Comments
1.	School	500	50	-	60	
2.	Church	63	-	-	60	Capacity-300 Persons
3.	(2) Schools	500	150	-	60	
4.	School	1000	300	-	55	Poor Acoustic Insulation
5.	Park w/wild life	11	-	0.5	60	
6.	Hospital	250	200	-	55	
7.	School	500	150	-	65	Good Acoustic Insulation
8.	Outdoor Stadium	542	-	-	70	Capacity-10,000 Persons
9.	Hotel	200	300	-	60	
10.	(2) Schools	4000	200	-	60	
11.	School	500	150	-	55	Poor Acoustic Insulation
12.	Stadium & Football Field	1286	-	-	70	Capacity-54,000 Persons
13.	Nursing Home	200	200	-	55	
14.	Park w/Picnic Grounds & Camping	74	15	0.3	60	
15.	Hospital	250	250	-	55	
16.	(2) Schools	500	150	-	60	
17.	School	1000	50	-	55	Poor Acoustic Insulation
18.	Indoor Arena	119	-	-	65	Capacity-4,000 Persons
19.	Library	225	-	-	60	Capacity 600
20.	(2) Schools	1000	100	-	60	
21.	Park w/Lake (Fishing, Swimming, etc)	27	-	10.0	60	
22.	School	500	150	-	65	Good Acoustic Insulation

* Average Daytime (0700-1800) Population = $\frac{\Sigma \text{ People x Time in Hours}}{\text{Numer Daytime Hrs. in a Year}}$

Average Nighttime (1800-0700) Population = $\frac{\Sigma \text{ People x Time in Hours}}{\text{Number Nighttime Hrs. in a Year}}$

**CL - Criteria Level. The criteria levels correspond to those of Table VI-1 except where the acoustic insulation of the buildings is not typical.

V. DESCRIPTION AND DOCUMENTATION FOR SPECIAL NOISES AND VIBRATION

A. High Energy Impulse Noise

1. Introduction. The assessment of special noises can present unusual problems, since in many cases, the appropriate techniques and measures are applicable only to particular situations. For example, with respect to damage by blast to certain types of buildings, it is possible to predict the damage in terms of non-acoustic parameters, such as effective distance and the amount of explosive charge. Moreover, the significance of the noise impact cannot always be quantified for the same categories of effects suggested for general audible noises. Whereas low-level impulse noise is accounted for as part of normal general audible noise, high energy impulses require additional measurements for application of a slightly modified impact assessment method recommended in Chapter VII. In many situations an individual interpretation of the criteria in Chapter VI is required.

2. Description of high-energy impulsive sounds.

a. Background - Day-night average sound level is the primary descriptor for environmental noise on the basis of people's perception of audible sound. High-energy impulsive sounds, such as those produced by sonic booms, quarry blasts, or artillery fire, in addition to the high-level audible sound, can excite noticeable vibration of buildings and other structures. These induced vibrations - caused by airborne sound or transmitted through ground or structures - may generate additional annoyance, beyond that due to simple audibility of the impulse, because of "house rattling" and "startle," as well as additional contributions to interference with speech or sleep.

It has been general practice in the past to describe such high-energy impulsive sounds in terms of the peak sound pressure in a wide frequency band. While the peak pressure may be satisfactory for assessment of impulses in a restricted range of peak pressures and durations, it is not sufficient as a general description for use in measurement or prediction of the combined environmental effects of impulses having substantially different pressure-time characteristics. Use of the peak pressure is also unwieldly or misleading when a succession of impulses, sometimes overlapping, must be evaluated.

The noise measure recommended in these guidelines for assessing the environmental impact of high-energy impulse noise is the C-weighted sound exposure level, abbreviated as CSEL, symbolized as L_{CE}. (Restrictions on its use are noted in b. below). This measure should be used for impulsive sounds that have peak pressures greater than about 105 dB. Impulsive sounds with smaller peak pressure are assumed to elicit normal auditory responses and are assumed for most situations to be described adequately by the DNL. For impulses with peak pressures greater than 140 dB, assessment criteria based on actual physiological or structural damage should be also applied. In addition, the effects of groundborne vibration should be assessed (see Section C of this chapter).

b. Descriptors

(1) High-energy impulse - A high-energy impulse is defined as an event whose C-weighted sound exposure level, is greater than 85 dB in daytimes (07:00 to 22:00) or 75 dB at night (22:00 to 07:00) and for which the maximum C-weighted Sound Exposure Level in any 2-second time period is

10 dB greater than the C-weighted Sound Exposure Level in any contiguous 2-second period of the event.

> NOTE: This will mean that the peak sound pressure (flat response) will be greater than approximately 110 dB (85 dB plus an empirical constant of 25 dB) during the daytime or 100 dB at night. Furthermore an approximate evaluation of the impulse may be made with a standard sound level meter, meeting the Type I characteristics of ANSI S1.4-1971, employing C-weighting and "slow" meter characteristic. In order for the impulse to be considered "large" in the context of this procedure, it should produce a maximum meter reading in excess of 82 dB in daytime (or 72 dB at night). If the C-weighted sound exposure level is less than 80 dB for all impulses caused by an action, the action should be considered "screened out" regardless of the fact that some nighttime impulses might exceed 75 dB.

(2) Day-Night Average Sound Level Incorporating Impulse Noise - When impulse noise alone is used to compute DNL, the resulting average level is derived from the individual CSEL's and called C-weighted day-night average sound level, abbreviated as CDNL, and symbolized as L_{Cdn}. Assessment of the overall noise environment, combining the effects of impulsive sounds described by CDNL derived from measurements or predictions, is made in terms of a composite day-night average sound level. The contribution of the impulses, in terms of CDNL (C-weighted), is added, logarithmically, to the DNL (A-weighted) of other sources to obtain the composite DNL for the combination.

B. Other Special Noises

1. Description of infrasound.

a. Background - Infrasound is defined as sound in the frequency range from .1 to 20 Hz. The measurement of infrasound must be made with instrumentation having an uniform frequency response in this range. However, in evaluating a noise that is composed of both infrasound and higher frequency sound, the higher frequency sound must also be measured for proper assessment of the infrasound, because sounds above 20 Hz can mask the infrasonic sounds.

b. Measurement - Measurement of infrasound should be made using instrumentation that has a flat response (± 3 dB) for frequencies from .1 Hz to 1000 Hz.

2. Description of ultrasound.

a. Background - Ultrasound is defined as sound at frequencies between 20 kHz and 100 kHz. Seldom is ultrasound an environmental problem and, unless the level is expected to exceed 105 dB, it can be ignored in an Environmental Impact Statement.

b. Measurement - Measurement should be accomplished by instrumentation with flat response (± 3 dB) from 10 kHz to 100 kHz.

3. Noises that have an adverse effect through their information content.

Primarily, voice communication (live, amplified or recorded) that crosses residential boundaries at high levels should be classified under this category. There is no formal method for assessing the impact of such sounds; each case must be assessed on its particular merits. It is recommended, however, to mention how, as a result of the proposed action, the intrusion of understandable voices into some area might cause loss of privacy and consequent undesirable effects. The actual content of the typical messages or words should be stated along with the number of people that are impacted.

C. Description of Building Vibration for Evaluation of the Effect on Inhabitants

1. Introduction. Vibration of structures may be due to airborne acoustical waves or solidborne vibration. Most problems caused by airborne impulse noise, when building vibrations are caused as a side effect of the primary auditory stimulus, should be accounted for by the procedures of

paragraph A above. Nevertheless, at certain times it may be necessary to assess separately the vibration caused by such sources. Groundborne vibration which is quite likely to accompany some mining, construction, and other industrial activities usually requires special evaluation. A method to evaluate human response to vibration inside buildings is presented which should be used to evaluate the impact of such activities. The method applies to the frequency range between 1 and 80 Hz and is based on an approved ISO standard (reference 5) and its proposed amendments.

2. Measurement. For continuous vibration environments, rms acceleration should be measured along 3 orthogonal axes, one axis of which is normal to the surface being measured. The acceleration will be weighted to account for the dependence of human reaction on frequency by use of a low pass filter with a corner frequency of 5.6 Hz (see Figure V-1). This accounts for the fact that human sensitivity to acceleration decreases over the frequency range under consideration; above 10 Hz this decrease is approximately proportional to frequency. The assessment of the impact should be against greatest acceleration on any of the three axes used.

For building measurements for which the criteria of Chapter VI are to be used, the measurements should be taken on the floor at a point that has the maximum amplitude of all the reasonable points of entry of the vibration to the human occupants. Normally this point may be assumed to be at the mid-span or center of a room.

For impulsive shock the measurement should be the same as for the continuous vibration measurement, except that the peak acceleration, not the rms value, should be used. The duration for impulsive shock excitation will be determined by either the time the acceleration of an event exceeds .01 m/sec^2 or by the time the acceleration is within one-tenth the peak value. Whichever gives the shorter duration should be used.

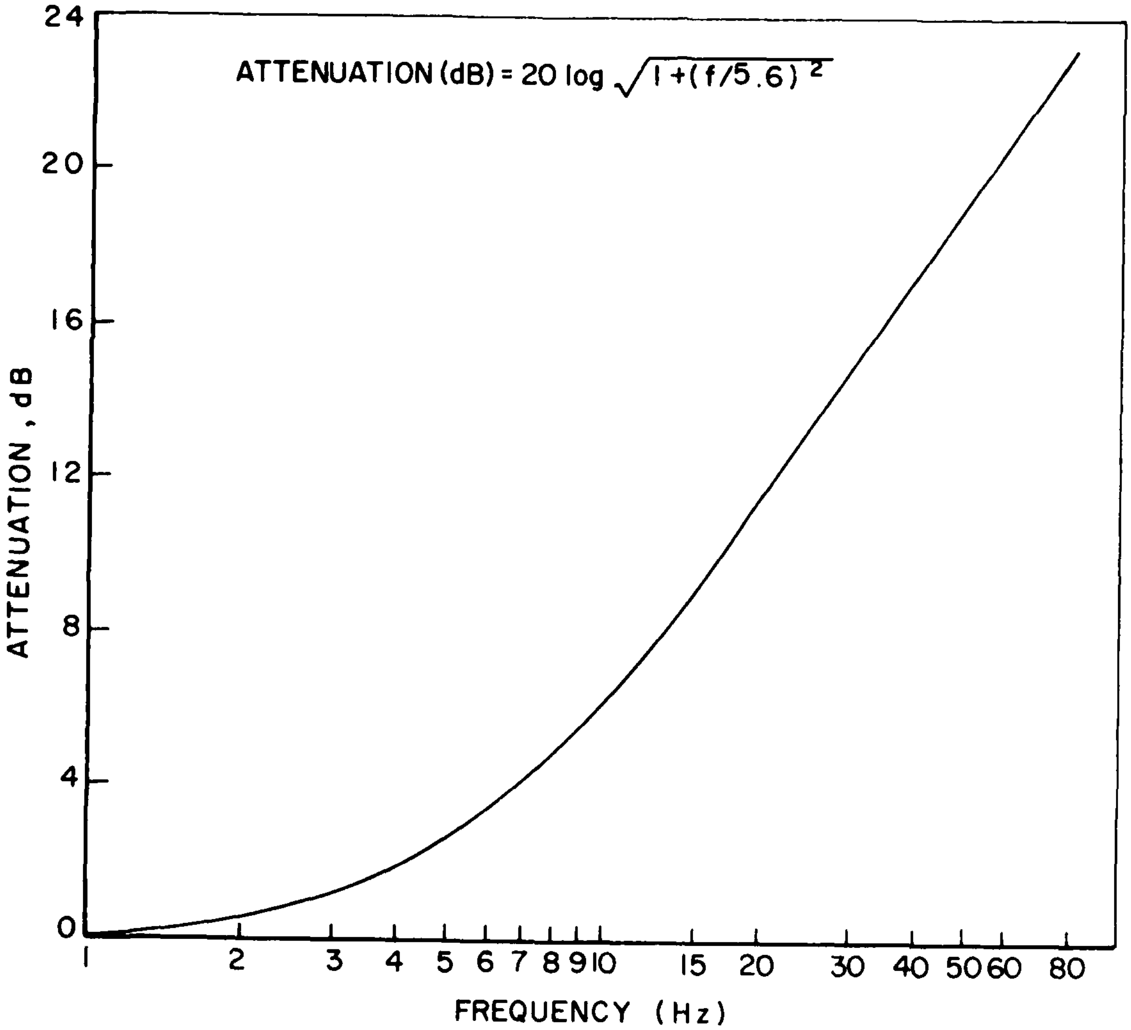

Figure V-1. Weighting characteristic for building vibration in terms of human response for the frequency range 1 to 80 Hz.

Note: Electrical network for low frequency cutoff below 1 Hz and high frequency cutoff above 80 Hz not yet standardized.

VI. NOISE AND VIBRATION CRITERIA

A. Introduction

The criteria summarized in this chapter are used as the basis for quantification of the impact of a change in noise environment described in Chapter VII. This chapter also provides tables that summarize the expected effects on people for various day-night average sound levels. These tables allow the preparer of an environmental impact statement to make an explicit statement as to the expected impact of any day-night average sound level.

The criteria presented in this chapter are not to be considered all-inclusive; and additional information should be used depending on the scope and magnitude of the environmental change. The EPA Criteria and Levels documents can be consulted as an additional reference source as well as any other applicable information.

B. Human Noise Exposure Criteria to be used for the EIS

1. Public Health and Welfare

As the primary criterion for evaluating the impact of noise on people, the effect on "public health and welfare" has been selected. The EPA levels document asserts that no significant effects on public health and welfare occur, for the most sensitive portion of the population and with an adequate margin of safety, if the prevailing day-night average sound level is less than 55 decibels. Interference with speech communication with general well-being and with sleep, as expressed in terms of general annoyance produced by the noise environment, were accepted as indications of effects on public health and welfare. The same criteria are proposed here as the basis for environmental impact assessment. This allows human response (expressed as percentage of a population highly annoyed) to be characterized by a single functional relationship of the noise environment. This approach leads to the statements that a day-night sound level of 55 decibels in residential areas will result in negligible impact on public health and welfare and that the degree of impact will increase as the day-night average sound level increases.

This is not to say that all individuals have the same susceptibility to noise; they do not. Even groups of people may vary in their response to noise, depending on previous exposure, age, socio-economic status, political cohesiveness and other social variables. In the aggregate, however, for residential locations, the average response of groups of people is quite stably related to a cumulative exposure to noise as expressed in a measure such as DNL. The response of interest is the general adverse reaction of people to noise, which includes speech interference, sleep interference, desire for a tranquil environment, and the ability to use telephones, radio, and television satisfactorily. A measure of this response is the percentage of people in a population that feels high annoyance about noise of a specified level.

For schools, offices, and similar spaces where ease of speech communication is of primary concern, the same relationship can be used to estimate the potential average response of people, as a group again, ignoring individual variations from person to person.

Discussions of the relationships between noise and human response are provided in the EPA "Levels" and "Criteria" reports. These relationships can be used to specify, for a variety of spaces and land uses, the average sound levels at a site that would provide acceptable acoustical environments. If these levels are not exceeded, negligible impact with respect to health and welfare on the community due to environmental noise can be expected.

Specific noise criteria for various land uses or occupied spaces are listed in Table VI-1. Note that these criteria are all specified in terms of the outdoor noise levels, even though the noise-sensitive activity in question is usually indoors. The sound level reduction for typical building construction was used to translate from acceptable indoor environments to acceptable outdoor environments, since in any practical environmental impact study it is the outdoor noise levels that can be most readily predicted.

A summary of the expected effects of noise on human activities for outdoor day-night average sound levels of 55, 65 and 75 dB, in terms of interference with speech communication, community reaction, annoyance and attitude towards area is provided in Tables VI-2 to VI-4. Basic information in these tables on speech intelligibility, and general community reaction was derived from reference 1. The relationships given in reference 1 between noise environment and annoyance have been modified in the light of a substantially increased set of data subsequently available.

Data used to relate annoyance to noise environment in the "levels" report was based on two social surveys around airports in the United States and England. Data have now been analyzed from 19 social surveys associated with aircraft, urban traffic, freeway traffic, and railroad noise. (See Appendix B). These data, when intercompared on an uniform basis, allow

TABLE VI-1 Criterion for Outdoor Sound Levels for Analysis of Environmental Noise Impact for Various Land Uses

Observor	Land Use	L_{dn} (dB)	L_{eq} (dB)
1	Residential (1)	55	
2	Hospital (1)	55	
3	Motel, Hotel (1)	60	
4	School Buildings & Outdoor Teaching Areas (1)		60
5	Church (2)		60
6	Office Buildings (2)		70
7	Theater (3)		70
8	Playgrounds, Active Sports		70
9	Parks		60
10	Special Purpose Outdoors Areas		*

NOTE: The assumed average outdoor/indoor sound-level reduction, for each land use, is keyed to the numbers in parentheses above:

(1) 15 decibels - windows open

(2) 25 decibels - windows closed

(3) 35 decibels - windows closed

Where knowledge of the specific structure indicates an actual sound level reduction differing from these values, the criterion level may be altered accordingly.

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*For outdoor amphitheaters, or other critical land uses requiring special consideration, the hourly average sound level (L_h) due to the new intruding noise should not be allowed to be higher than 5 dB below the existing hourly average sound level in the absence of speaking in the amphitheater.

TABLE VI-2 Summary of Human Effects for Outdoor Day-Night Average Sound Level of 55 Decibels

Type of Effects	Magnitude of Effect
Speech - Indoors	No disturbance of speech 100% sentence intelligibility (average) with a 5 dB margin of safety
- Outdoors	Slight disturbance of speech with: 100% sentence intelligibility (average) at 0.35 meter or 99% sentence intelligibility (average) at 1.0 meter or 95% sentence intelligibility (average) at 3.5 meters
Average Community Reaction	None; 7 dB below level of significant "complaints and threats of legal action" and at least 16 dB below "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
High Annoyance	Depending on attitude and other non-acoustical factors, approximately 5% of the population will be highly annoyed.
Attitudes Towards Area	Noise essentially the least important of various factors

TABLE VI-3 Summary of Human Effects for Outdoor Day-Night Average Sound Level of 65 Decibels

Type of Effects	Magnitude of Effect
Speech - Indoors	Slight disturbance of speech 99% sentence intelligibility (average) with a 4 dB margin of safety
- Outdoors	Significant disturbance of speech with 100% sentence intelligibility (average) at 0.1 meter or 99% sentence intelligibility (average) at 0.35 meter or 95% sentence intelligibility (average) at 1.2 meters
Average Community Reaction	Significant; 3 dB above level of significant "complaints and threats of legal action" but at least 7 dB below "vigorous Action" (attitudes and other non-acoustical factors may modify this effect)
High Annoyance	Depending on attitude and other non-acoustical factors, approximately 15 percent of the population will be highly annoyed.
Attitudes Towards Area	Noise is one of the most important adverse aspects of the community

TABLE VI-4 Summary of Human Effects for Outdoor Day-Night Average Sound Level of 75 Decibels

Type of Effects	Magnitude of Effect
Speech - Indoors	Some disturbance of speech Sentence intelligibility (average) less than 99%
- Outdoors	Very significant disturbance of speech with: 100% sentence intelligibility not possible at any distance or 99% sentence intelligibility (average) at 0.1 meter or 95% sentence intelligibility (average) at 0.35 meter
Average Community Reaction	Very severe; 13 dB above level of significant "complaints and threats of legal action" and at least 3 dB above "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
High Annoyance	Depending on attitude and other non-acoustical factors, approximately 37% of the population will be highly annoyed.
Attitudes Towards Area	Noise is likely to be the most important of all adverse aspects of the community

a much more definitive relationship to be developed between percentage of the population highly annoyed and average noise level. The data further confirm previous assumptions that the statistical relationship between population annoyance and average noise level is essentially independent of the type of noise source.

The generalized annoyance function derived from the 19 surveys differs from that used in reference 1 primarily at the lower values of average noise level where the new function indicates somewhat lower percentages of the population being highly annoyed. The reasons for these differences are discussed in detail in reference 6 . A comparison of the generalized annoyance function with those reported previously is given in Figure VI-1. The generalized annoyance function is used in Chapter VII of these guidelines to derive the average sound level weighting function to arrive at a quantitative procedure for assessing the noise impact produced by audible sound.

2. Severe health effects.

For exposure to an average sound level above 75 dB, the possibility of effects other than speech interference and annoyance exist and should be assessed. Noise-induced hearing loss can begin to occur as the average sound levels exceed 75 decibels. Other noise-induced physiological effects and/or changes may occur. However, a firm causal link between community noise and extra-auditory disease has not been established at this time. Therefore, this document proceeds on the assumption that protection against noise-induced hearing loss is sufficient to protect against severe extra-auditory health effects. However, one has to keep in mind that as the

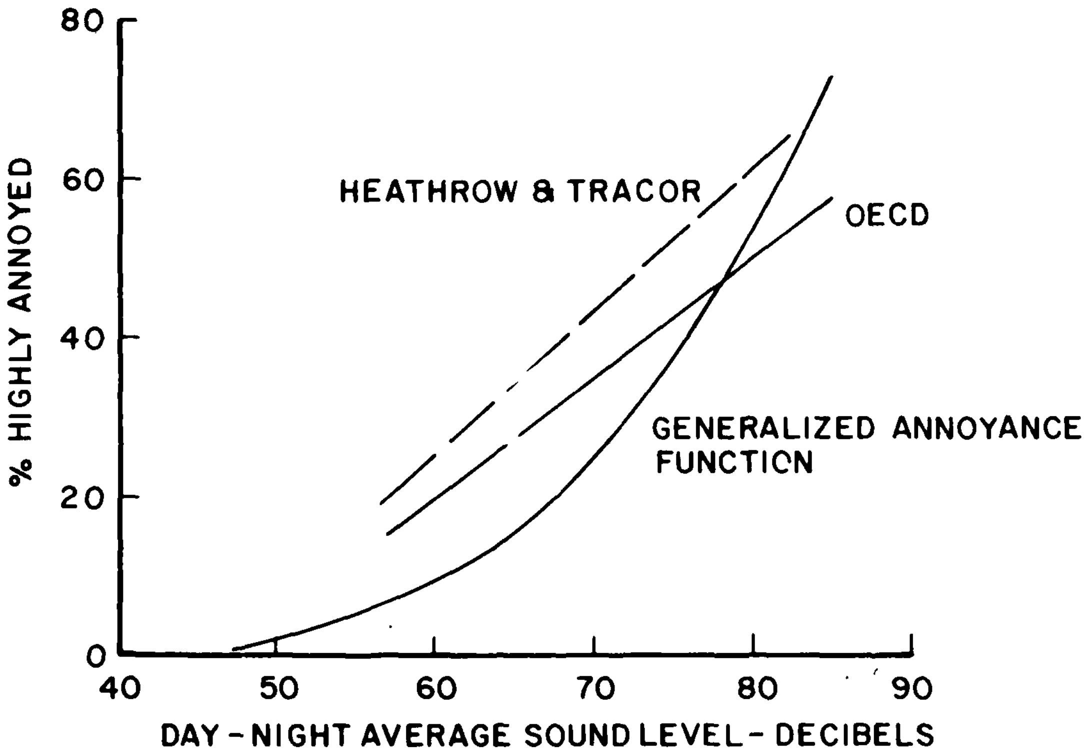

Figure VI-1. Comparison of Generalized Annoyance Function with Previously Published Functions Derived from Social Surveys Around Airports.

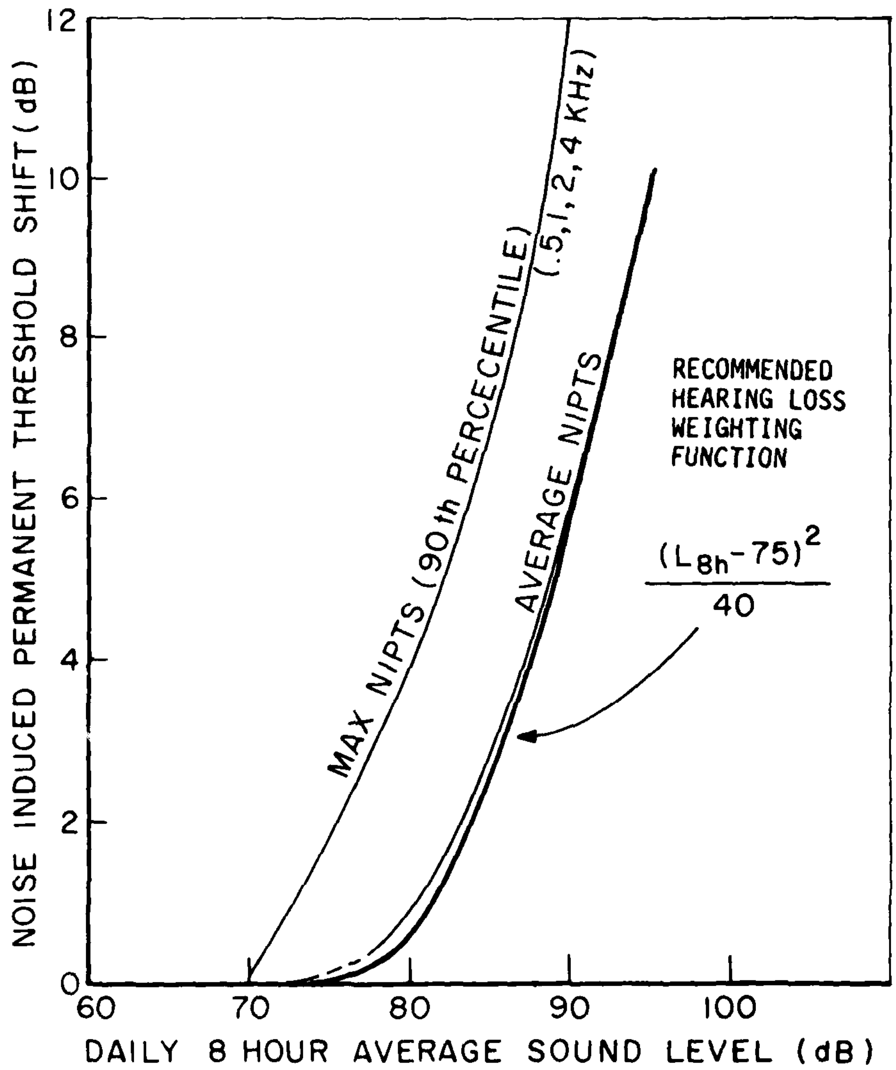

Figure VI-2. Potential hearing damage risk for daily exposure to 8 hour average sound levels. The curves predicts noise induced permanent threshold shift (NIPTS) in octave bands (.5, 1, 2, 4 kHz) for 8-hour exposure at various continuous noise levels. The eight hour average sound level can be replaced by DNL with negligible error if a person spends the remaining 16 hours out of 24 in L_{eq} of 70 dB or lower.

average noise level increases above 75 decibels so does the probability that other health effects in addition to noise induced hearing loss might become important. The adverse effect of noise on hearing rapidly accelerates as the noise exposure increases and it is reasonable to use expected noise induced hearing loss as a basis for assessment of severe health effects. As with public health and welfare effects, it is desirable to quantify the exposure of individuals to different levels by a single number.

Using the data of Table C-1 of the levels document, the average change in threshold of hearing of an exposed population for an average of four different audiometric frequencies over a 40-year exposure period is shown by the average noise induced permanent threshold shift (NIPTS) curve of Figure VI-2. As can also be seen, a simple formula closely approximates the average NIPTS curve. This formula is used in Chapter VII as the basis for quantification of severe health effects in these guidelines. It is also useful to look at individual susceptibility to noise induced hearing loss. Therefore it is recommended that the NIPTS for the most sensitive 10% of the population after 40 years of exposure also be considered. This curve is the Max NIPTS 90th Percentile curve of Figure VI-2. Other descriptions of the effect of noise exposure on hearing are contained in the EPA "Levels" report.

3. Degradation of the environment.

Even in areas where no people are presently living, a significant increase in noise over the existing conditions will constitute a noise impact. The environment may be degraded either because the increased noise affects wildlife or monuments, or because it destroys the tranquility of a wilderness area to which urban dwellers wish to go for an escape from city noise, or because it makes the area unsuitable for future residential or other noise sensitive development. In each case, some of the value of our national natural resources is lost; the quality of the environment is lowered. As a supplement to any numeric quantification, a word description of the environmental impact should be stated in terms of the expected change from the present conditions.

Quantification of the degradation of the noise environment when the day-night average sound level is below 55 decibels is proposed to be made with the same generalized annoyance weighting function defined in Chapter VII, even though no significant health or welfare effects are considered to exist below 55 decibels. In these instances, the small, but finite percent of population highly annoyed is considered a measure of environmental degradation.

4. Effects of special noises.

a. High energy impulsive sounds - (Sonic Booms, Artillery and Blasting Impulsive Noise). The Oklahoma City sonic boom study (ref 7) is the primary basis for the procedure proposed for the assessment of large impulsive sounds. The population was questioned if they were annoyed, and if so, if they were very annoyed, moderately annoyed or little annoyed. The percent very annoyed best matches the highly annoyed described in Figure VI-1. The percent very annoyed versus the average level of sonic boom per day are plotted on Figure VI-3.

b. Infrasound - (.1 Hz to 20 Hz) A summary from references 1 and 8 of infrasound effects is presented in Figure VI-4. To summarize the criteria, it is suggested that infrasound

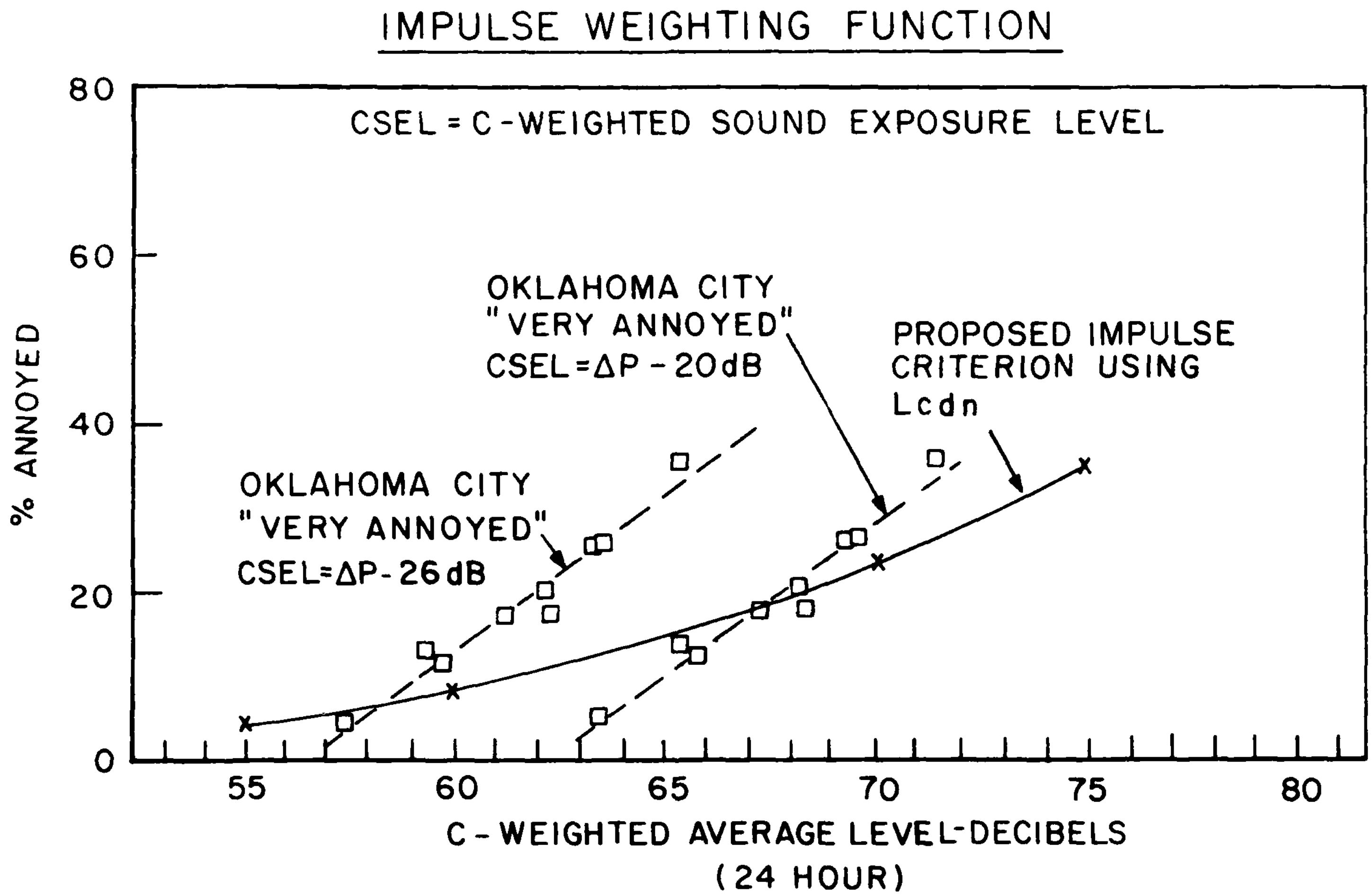

Figure VI-3. The relationship between 8 sonic booms per day and annoyance is plotted for the Oklahoma City Study. C-weighted Sound Exposure Level (CSEL) has been measured to be 20 to 26 dB below the peak pressure (ΔP). The two "very annoyed" curves plotted for both ΔP-26 and ΔP-20 form the boundaries for the proposed relationship between annoyance and C-weighted day night sound level.

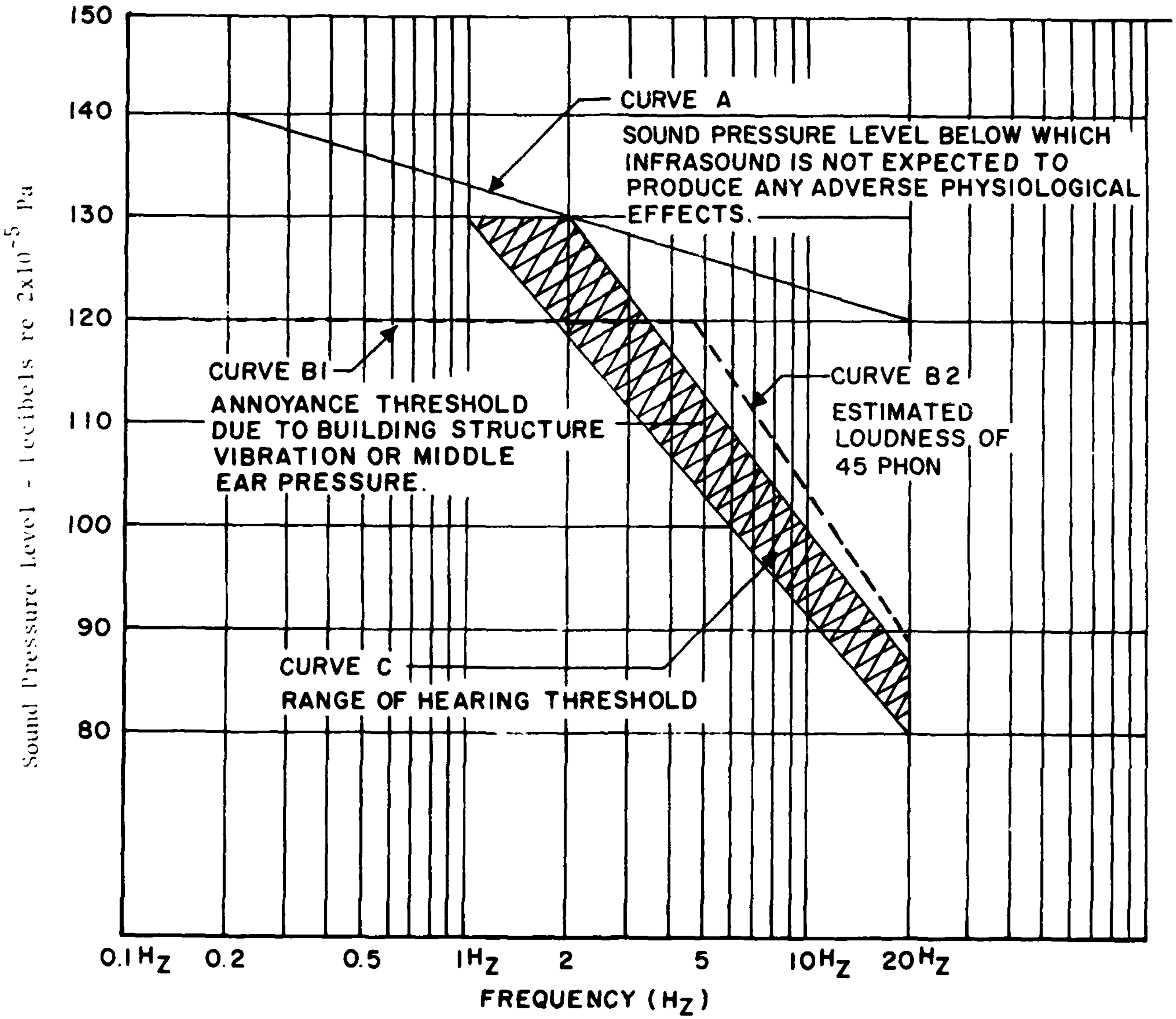

FIGURE VI-4. INFRASOUND CRITERIA

exposures for less than 1 minute should be below the following values:

0.1 Hz to 5 Hz...120 dB

5 Hz to 20 Hz...120 dB - 30 log $\frac{f}{5}$ eqn. VI-1

For exposures longer than 1 minute and less than 100 minutes, the levels should be reduced by (10 log t) dB where t is time of exposure in minutes. Exposure longer than 100 minutes should use the 100 minute limits. In other words, exposures 20 dB less than the one minute criteria should be regarded as having no impact, regardless of exposure time. The 100 minute criteria basically insures that the infrasound is inaudible. Assessment of the effects if this criteria is exceeded is not contained in these guidelines and will require further research and investigation.

c. Ultrasound - Ultrasound noise levels below 105 dB at frequencies above 20 kHz are considered to have no significant impact. Noise levels above 105 decibels should be reported in the EIS and individually evaluated based on specific research studies.

C. Vibration Criteria

1. Background

The criteria presented in this chapter for the acceptability of vibration inside structures are primarily based on the existing and the proposed ISO standards. The ISO proposed standard is included in Appendix C. The vibration criteria presented in this chapter are intended to be primarily for residential type structures. No differentiation is made as to the types of residential areas, i.e., city center, urban or rural. Correction factors are presented in Table VI-5 for non-residential type of structures. Not all types of buildings are classified, but common sense should suggest the most appropriate classification.

Offices and workplaces may in many cases require vibration levels as low as residential areas if any adverse reactions are to be avoided. In certain critical areas, such as operating rooms and laboratories and possibly research laboratories, standards rooms, tool rooms and the like, even lower vibration exposures levels may be required than indicated by Table VI-5. The acceleration values that are specified to cause less than 1% complaints are near or at the perception threshold level of vibration during normal activity and should serve as a realistic threshold of any adverse reaction to the vibration. The percentage of complaints likely to occur for higher levels of vibration are shown in Figure VI-5.

2. Human response to vibration.

The overall vibration that will not cause an adverse impact for any condition and time period corresponds to rms acceleration values below $3.6 \times 10^{-3} m/s^2$, evaluated by means of the weighting described in Chapter 5.

a. For hospital operating areas and other such critical areas, no higher levels should be permitted without analysis and justification of the acceptability of such levels.

b. For residential and other similar areas, continuous acceleration of greater values are normally expected to cause virtually no complaints (less than 1%). Even greater acceleration values could be permitted for shorter times during the daytime (0700 to 2200 hours), as indicated by Table VI-5 and Figure VI-6. Similarly, the maximum value of the impulsive shock excitation that is expected to cause virtually no complaints can be

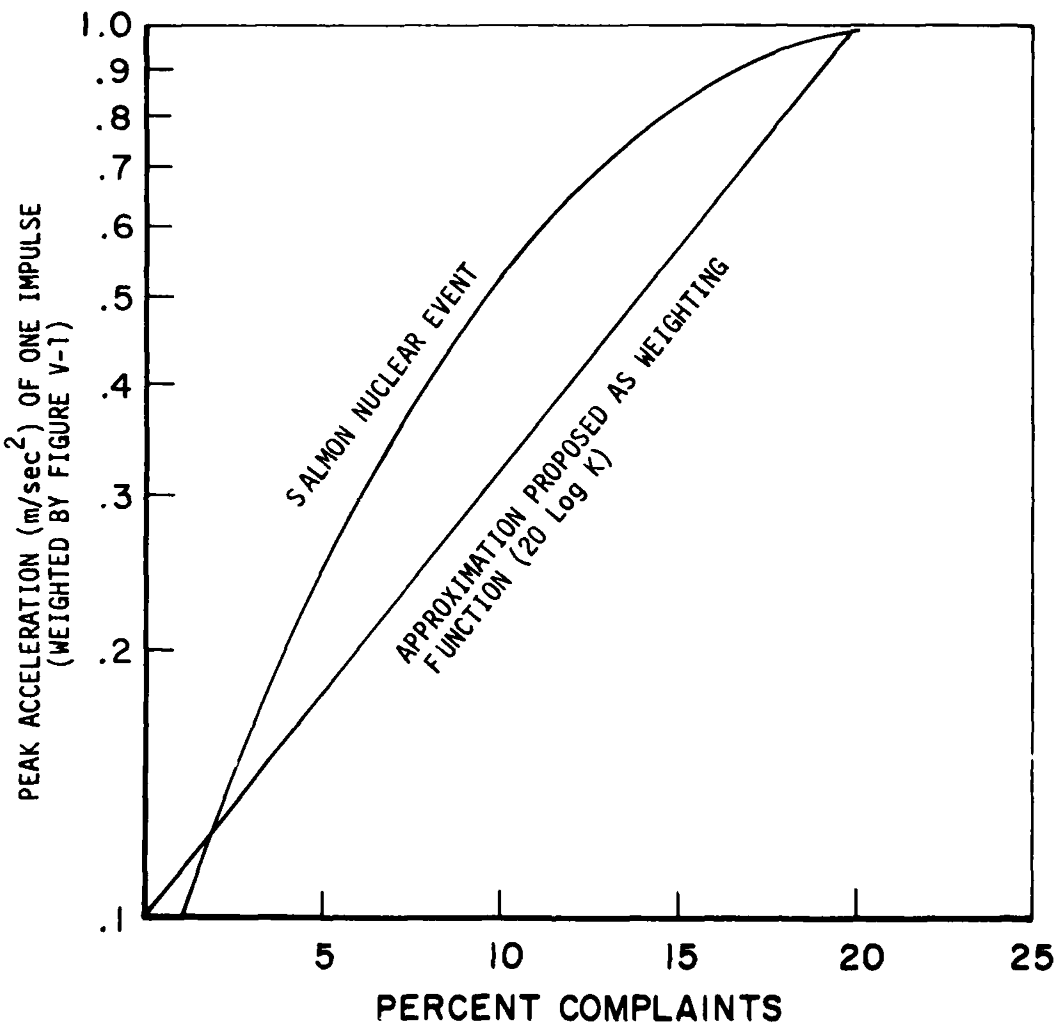

Figure VI-5. Percentage of population complaining (example of exposure to one event from reference 10)

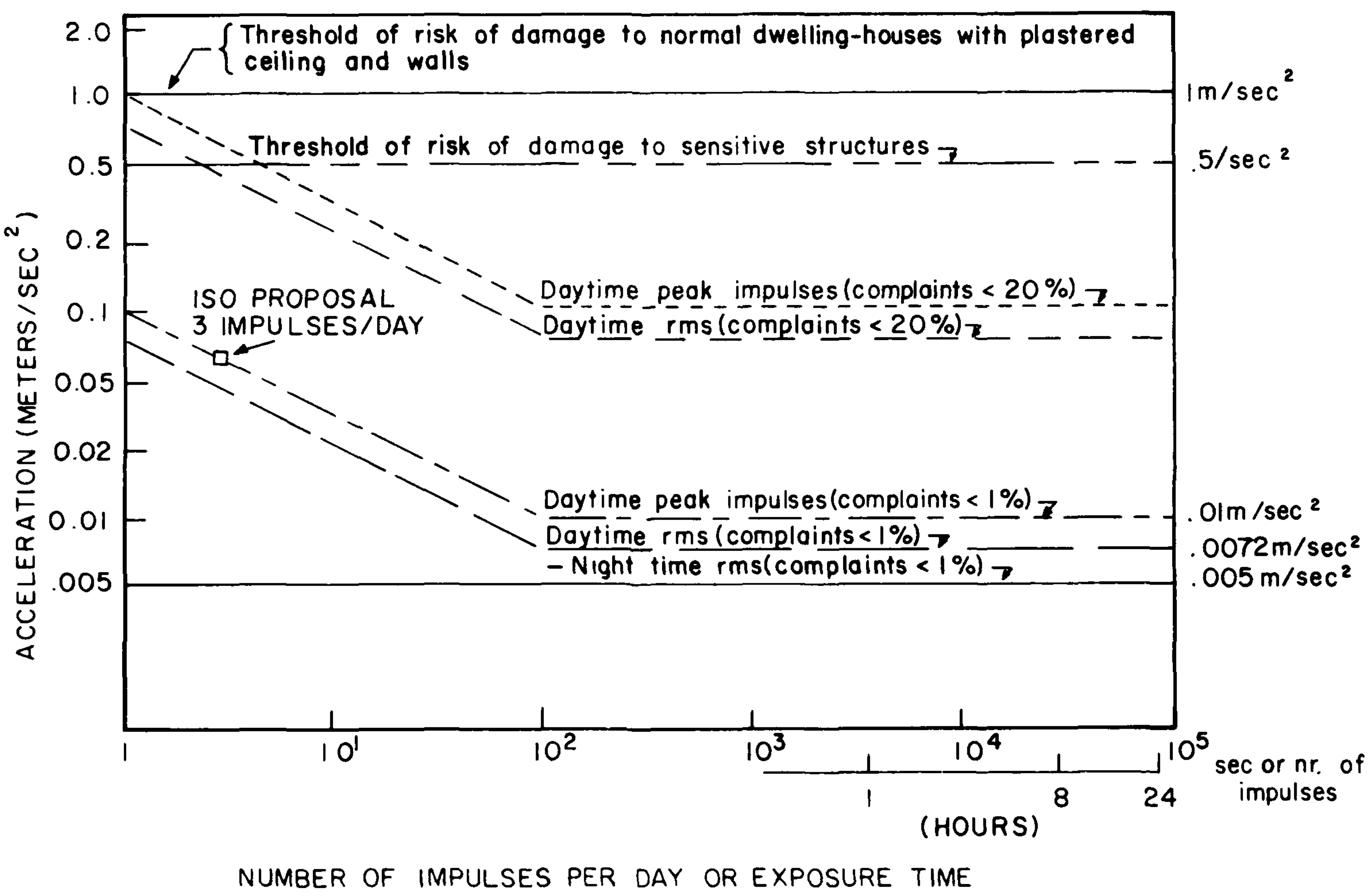

Figure VI 6. Vibration Criteria for Residential Areas

TABLE VI-5

BASIC THRESHOLD ACCELERATION VALUES FOR ACCEPTABLE VIBRATION ENVIRONMENTS

Daytime is 7 am to 10 pm. Nighttime is 10 pm to 7 am.

All Values are Meters/Sec^2

Type of Place	Time of Day	Continuous or Intermittent rms Acceleration	Impulsive Shock Excitation Peak Acceleration
Hospital Operating Rooms and Other Such Critical Areas	Day	.0036	.005
	Night	.0036	.005
Residential	Day	$\frac{.072}{\sqrt{t}}$	$\frac{.1}{\sqrt{N}}$
	Night	.005	.01
Office	Anytime	$\frac{.14}{\sqrt{t}}$	$\frac{.2}{\sqrt{N}}$
Factory and Workshop	Anytime	$\frac{.28}{\sqrt{t}}$	$\frac{.4}{\sqrt{N}}$

t = duration seconds of vibration, for durations greater than 100 sec, use t as 100 sec.

N = is the number of discrete shock excitations that are one sec or less in duration. For more than 100 excitations, use N=100.

raised, dependent on the number of such impulses during the daytime. (See Table VI-5 and Figure VI-6). For residential areas or other areas where people sleep, the nighttime peak acceleration should be less than .01 m/sec^2 at any time and the continuous rms acceleration should be below .005 m/sec^2 if no complaints are to occur.

c. For office type spaces, the threshold at which no adverse effects occur is twice the daytime residential rms or peak value. No distinction is made between daytime and nighttime exposure.

d. For factory and similar type spaces, the threshold at which no effects occur is 4 times the daytime residential values. No distinction is made between daytime and nighttime exposure.

D. Structural Damage Criteria for Noise and Vibration

1. Background.

It is normally considered that the most sensitive parts of a structure to airborne noise or overpressure are the structure's windows, although in some cases it may be plastered walls or ceilings. Such noise or large pressure waves also introduce building vibration in addition to that due to ground motion. Thus the effects of airborne sound on structures may need to be evaluated in terms of vibration criteria as well as in terms of criteria based on peak overpressure. For most airborne sound, however, evaluation of the peak overpressure is sufficient to determine the threshold of possible damage. On the other hand, for some types of underground blasting and when the building is close to the blast site, the vibration is transmitted essentially through the ground. In this case the vibration inside the house must be predicted and evaluated according to the vibration criteria.

2. Structural damage criteria for airborne noise.

a. Blast noises - For blast noises, the probability of broken windowpanes should be estimated. Empirical formulas given below allow an estimate of "safe" distances from the blast, beyond which window damage is negligible. They include sufficient safety factors to take into consideration such variables as wind direction, atmospheric temperature gradients, windowpane shape and sizes, etc. These formulas(ref 9) are newly proposed and are somewhat tentative. Therefore a monitoring program might be recommended to identify any damage, or lack of it, actually caused by an explosion. For surface explosions, window breakage in residential type structures is expected to be negligible (less than 50% probability of even one broken pane) if the equivalent weight of high explosive (WHE) in kilograms is less than that specified by the more appropriate of the following two conditions:

(1) Population clusters

If the population is non-uniformly distributed, but is clustered, then each population cluster, including the nearest residence, should be checked. The amount of WHE for any cluster should be less than 328 R^3/N where R is the distance in kilometers from the explosion to the center of a cluster of residences and N is the number of people residing in that cluster with the provison that N must always be at least 4.

(2) Uniformly distributed population

If the population is reasonably uniformly distributed, then the amount of WHE should be less than 40 R^3, where R is the distance in kilometers to the nearest residence.

NOTE: the use of these formulas requires some judgement as to what constitutes a population cluster and what constitutes a reasonably uniform distribution. In some cases, both formulas might be checked and the one that predicts the least allowable amount of WHE used.

For explosives buried deeper than 1.4 meter per $(Kg)^{1/3}$, the peak amplitude will be attenuated by at least a factor of 5. For such underground explosions the preceding formulas need to be adjusted as follows:

(1) Population clusters

The amount of WHE should be less than 26430 R^3/N.

(2) Uniformly distributed population

The amount of WHE should be less than 3200 R^3.

For explosive charges greater than those determined by the above formulas, the peak overpressure should be predicted and the number of broken windows estimated. The statistical estimator (Q) for the number of "average typical" panes broken is:

$$Q = 1.56 \times 10^{-10} N(PK^*)^{2.78}$$

where N = number of people exposed (assuming 19 panes per person) and PK* is the peak-to-peak amplitude of the pressure variation (in pascals) at ground level.

For convenience of measurement, the peak-to-peak pressure amplitude reflected at ground level (PK*) may be used. The conversion between the peak free air pressure (ΔP) and PK* given by the relation:

$$PK^* = 2.7\ \Delta P.$$

NOTE: However, the peak pressure may be amplified by a factor of 5 as the result of refraction, ducting, and focusing; therefore, in the "worst case" condition the number of broken panes, Q, may be multiplied by a factor as high as $(5)^{2.78}$ or 88 to obtain Q_{max}. Atmospheric meteorological effects can increase this factor further.

In addition, for peak pressures (ΔP) above 140 dB (200 Pa), structural damage other than window damage may occur. Measurement or prediction of vibration should be accomplished.

b. Sonic boom and artillery fire - The amount of window damage can be estimated by calculating Q and Q_{max} for the expected peak pressure (see preceding Blast section). These formulas, however, should be used only for peak pressure levels above 130 dB. Above 140 dB, structural damage should also be assessed by prediction or measurement of vibration levels in the exposed structures.

c. Continuous sounds - Above sound pressure levels of 130 dB, there is the possibility of structural damage due to excitation of structural resonances for infrasound, as well as low and medium frequency sound. While certain frequencies (such as 30 Hz for window breakage) might be of more concern than other frequencies, one may conservatively consider all sound lasting more than 1 sec above a sound pressure level of 130 dB (1 Hz to 1000 Hz) as potentially damaging to structures.

3. Safe levels of vibration with respect to structures.

A structural vibration velocity of 2 in/sec has commonly been used as the safe limit, and certainly vibrations above this value will have a very adverse environmental impact. Note that, except for frequencies below

3 Hz, if the acceleration measured with the weighting network of Figure V-1 is less than 1 m/sec^2, then the velocity will be 2 in/sec or less. For frequencies from 10 Hz to 80 Hz a weighted acceleration of 1 m/sec^2 is essentially equivalent to a velocity of 1 in/sec. In most practical cases, in which the acceleration is made up of several frequency components, an acceleration of less than 1 m/sec^2 will also mean that the resultant velocity will be less than 2 in/sec, and possibly less than 1 in/sec, regardless of frequency. Therefore it is recommended that 1 m/sec^2 be used as the normally safe acceleration with respect to structural damage. Vibrations above this should be avoided, or special arrangements should be made with the owners of the exposed structures. Since some minor damage has occasionally been reported at vibration as low as 1 in/sec, (.5 m/sec^2 to 1 m/sec^2), exposures in the range between .5 m/sec^2 and 1 m/sec^2 should also be regarded as a potentially adverse exposure with respect to structural damage. Finally, the safe peak acceleration for ancient monuments or ruins should be considered as .05 m/sec^2. Higher exposure values for such ancient structures should not be considered safe without a detailed structural analysis.

E. Effect of Noise on Animals

Noise produces, in general, effects on animals similar to those it produces on humans. Hearing loss, masking of communication, behavioral and non-auditory physiological effects can occur. For example, sonic booms of sufficient magnitude have been shown to affect farm animals. Unfortunately, there is little data with which to relate long-term noise exposure to the well-being of animals, and in turn relate animal well-being to the general health and welfare of man. Nevertheless, the lack of a cause/effect relationship does not mean that animals may be ignored. For lack of proper data and in order to stay on the safe side, it is proposed to assume that the exposure level identified to protect man will also protect animals.

VII. QUANTIFICATION OF THE ENVIRONMENTAL IMPACT OF NOISE

A. General

The impact of a noise environment on people regularly experiencing that environment is the degree to which the noise interferes with various activities such as speech, sleep, listening to radio and TV, thus, the peaceful pursuit of normal activities, and the degree to which it may impair health, through, for example, the inducement of hearing loss. The impact of a particular noise environment is a function of both sound level and the size of the population experiencing a particular value of sound level. One method for describing the noise impact of an action requiring the preparation of a noise impact report is to tabulate the number of people regularly experiencing various sound levels as described in Chapter IV.

Sound levels produced by sources being considered in an environmental assessment will generally vary with distance from the source, sometimes over a large geographic area. As a consequence, people occupying different geographic areas will experience different sound levels. It is desirable to derive a single number which represents quantitatively the integrated effect of "impact" of the action on the total population experiencing the different sound levels. This single number quantification is defined below as the sound level weighted population, LWP. Sound level weighted population, together with the tabulations of populations experiencing sound levels of a specified value, constitute the minimum quantification of environmental impact of noise recommended in these guidelines. A useful second descriptor of noise impact is the noise impact index, NII, which is formed by the ratio of sound level-weighted population to the total population.

In some high level noise environments people will be exposed regularly to average sound levels in excess of 75 decibels. In these environments special consideration should be given to the potential for noise-induced loss of hearing. A measure is defined below, the population weighted hearing loss, PHL, which provides a measure of the average hearing loss that might be expected for the population under consideration.

B. Sound Level Weighted Population

Sound level weighted population is a single number representation of the significance of a noise environment to the exposed population. Several assumptions are made in this method of analysis:

1) Intensity of human response is one of several consequences of average sound level, depending upon the response mode of interest (annoyance, speech interference, hearing loss).

2) The impact of high noise levels on a small number of people is equivalent to the impact of lower noise levels on a larger number of people in an overall evaluation. Thus the properties of intensity (level of sound) and extensity (number of people affected by the sound) can be combined mathematically.

3) On the basis of these two assumptions one can ascribe differing numerical degrees of impact to different segments of the population of concern, depending on the average sound level.

These concepts have been embodied into a descriptive term called the fractional impact method. In this method, the "fractional impact" is the product of a sound level weighting value and the increment of population exposed to a specified sound level. Summing the "fractional impacts" over the entire population provides the sound level weighted population, LWP. That is:

$$LWP = \int P(L_{dn}) \cdot W(L_{dn}) \quad d(L_{dn}) \qquad \text{VII-1}$$

where $P(L_{dn})$ is the population distribution function, $W(L_{dn})$ is the day-night average sound level weighting function characterizing the severity of the impact as a function of sound level described below, and $d(L_{dn})$ is the differential change in day-night average sound level.

It is usually not necessary to use the integral form to compute LWP. Sufficient accuracy is usually obtained by taking average values of the weighting function between equal decibel increments, up to 5 decibels in size, and replacing the integrals by summations of successive increments in average sound level. See the example given below.

C. Noise Impact Index

Noise Impact Index, NII, is a useful concept for comparing the relative impact of one noise environment with that of another. It is defined as the sound level weighted population divided by the total population under consideration:

$$NII = \frac{LWP}{P_{Total}} = \frac{\int P(L_{dn}) \cdot W(L_{dn}) \, d(L_{dn})}{\int P(L_{dn}) \, d(L_{dn})}$$

where the functions are the same as described above in Section B.

D. Population Weighted Loss of Hearing

The population weighted loss of hearing, PLH, is a single number representation of the potential loss of hearing, i.e., the average change in hearing threshold level in decibels that would be expected from a population experiencing the various day-night average sound levels in excess of 75 decibels. This quantity is formed by the ratio of sound level-weighted population to total population (experiencing day-night average sound levels in excess of 75 decibels).

Similar to NII, PHL is computed in decibels as:

$$PHL = \frac{\int_{75}^{x} P(L_{dn})\ H(L_{dn})\ d(L_{dn})}{\int_{75}^{x} P(L_{dn})\ d(L_{dn})}$$

where $H(L_{dn})$ is the loss of hearing weighting function described below, $P(L_{dn})$ is the population distribution functions, and $d(L_{dn})$ is the differential change in day-night average sound level.
NOTE: PHL is in decibels since the weighting function of loss of hearing has not been normalized.

Again, the integral forms may be replaced by summation over successive increments of day-night average sound level. It is recommended that increments of day-night average sound level less than five decibels (e.g. 2 decibels) be used in calculating values of PHL.

NOTE: A term similar to the level weighted population may be calculated by using only the numerator of the above expression. While use of such a term is not recommended for residential areas, such a term could be useful for evaluation of regulations and other such actions. In the evaluation of the effect of noise on hearing for situations in which residential exposure is of no or minimal concern (e.g. exposure of passengers in transportation), the eight hour average sound level (L_{8h}) should replace the day-night average sound level in calculating the potential loss of hearing.

E. Sound Level Weighting Functions

Two different weighting functions are provided for use in the analysis of environmental noise impact, one for general application in the majority of analyses in which the overall impact of the noise on the "Health and Welfare" of residential populations is involved, and one for evaluating the potential for hearing damage when the day-night average sound level exceeds 75 decibels.

1. Sound level weighting function for overall impact analysis. In the majority of analyses the primary concern is the effect of a noise environment on the residential population living in the environment under consideration. The weighting function used for this form of analysis is based on the documented reaction of populations to living in noise impacted environments (see Chapter VI) and is numerically derived from social survey data relating the fraction of sampled population expressing a high degree of annoyance to various values of day-night average sound level. (See Appendix B.) The weighting function is arbitrarily normalized to unity at L_{dn} = 75 decibels. (However for specific applications, it is always possible by way of the appendix to translate the level-weighted population into the actual number of people highly annoyed by the environment under consideration.) Values of the function are listed in Table VII-1, and the function is plotted in Figure VII-1. The analytic expression for the function is:

$$W(L_{dn}) = \frac{\left[3.364 \times 10^{-6}\right]\left[10^{0.103L_{dn}}\right]}{\left[0.2\right]\left[10^{0.03L_{dn}}\right] + \left[1.43 \times 10^{-4}\right]\left[10^{0.08L_{dn}}\right]}$$

In a number of environmental noise assessments conducted by EPA an early form of population weighting has been used where the day-night average

TABLE VII-1

Sound Level Weighting Function for Overall Impact Analysis

The right hand column is included for convenience for finding the weighting of certain 5 dB increments.

L_{dn} -dB	$W(L_{dn})$	$\frac{W(L_{dn}) + W(L_{dn} + 5)}{2}$
35	0.006	0.010
40	0.013	0.021
45	0.029	0.045
50	0.061	0.093
55	0.124	0.180
60	0.235	0.324
65	0.412	0.538
70	0.664	0.832
75	1.000	1.214
80	1.428	1.697
85	1.966	2.307
90	2.647	

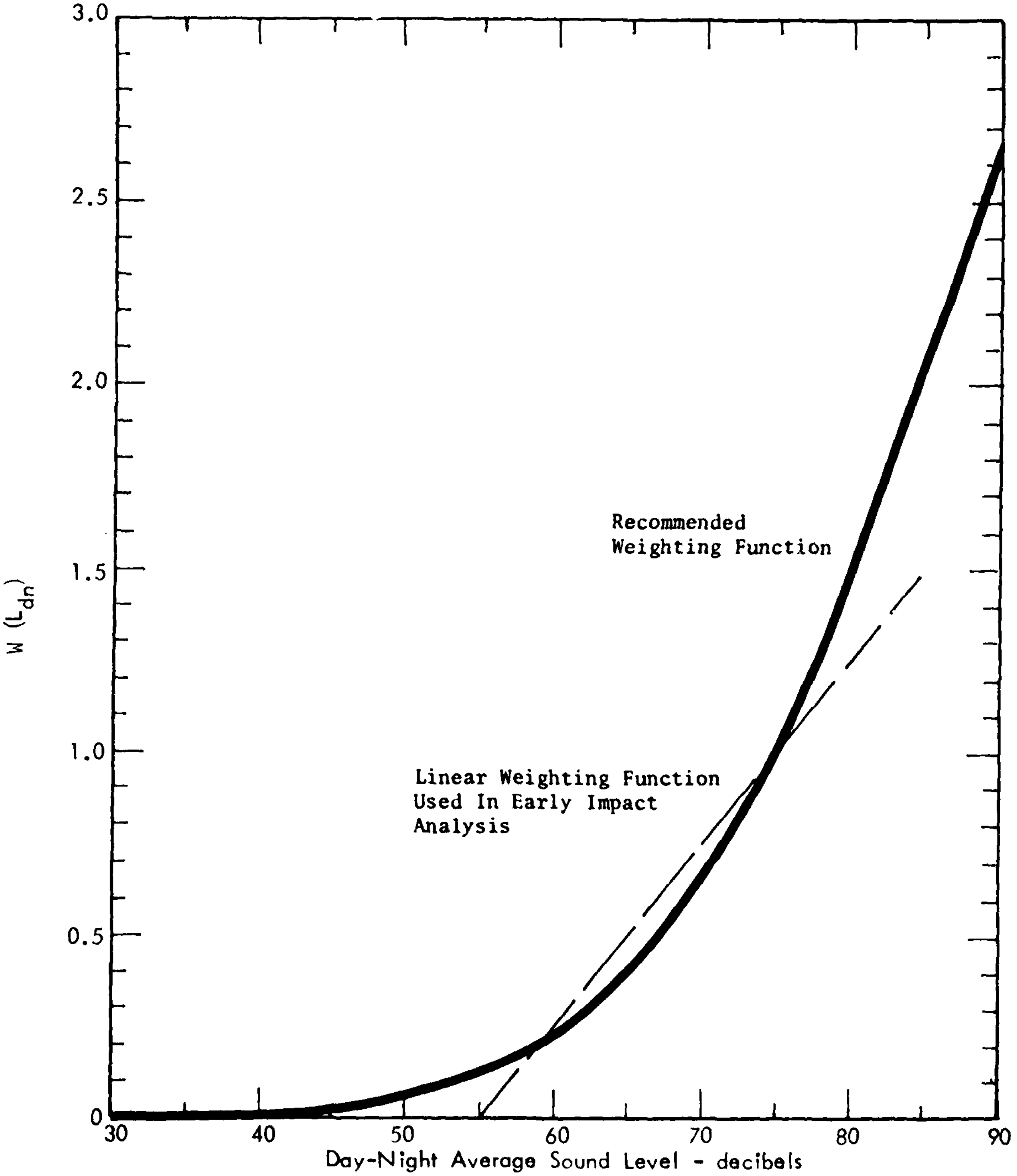

FIGURE VII-1. SOUND LEVEL WEIGHTING FUNCTION FOR OVERALL IMPACT ANALYSIS sound levels have ranged from 55 decibels, or higher, to 80 decibels. This weighting function was described as "fractional impact," FI, and has the form:

$$FI = 0.05\ (L_{dn} - 55)$$

This function is shown as the dashed line on Figure VII-1. It can be shown that, in the day-night average sound level range of 55 to 80 decibels, this linear weighting function will generate numerical values for level weighted population that differ only by the order of one percent from the more general weighting function, $W(L_{dn})$, in many applications.

2. <u>Weighting function for loss of hearing/severe health effects</u>. In those specialized environments where people are directly exposed, on a regular, continuing, long-term basis to day-night average sound levels above 75 decibels, there is a potential for producing noise-induced loss of hearing and other potentially severe health effects. The weighting function for loss of hearing/severe health effects, $H(L_{dn})$ or $H(L_{8h})$, is expressed as:

$$H\ (L_{dn}) = 0.025\ (L_{dn} - 75)^2$$

or $$H\ (L_{8h}) = 0.025\ (L_{8h} - 75)^2$$

Table VII-2

<u>Weighting Function for Loss of Hearing/Severe Health Effects</u>

L_{dn} or L_{8h} (dB)	$H(L_{dn})$ or $H(L_{8h})$ (in dB loss per ear)
75	0
76	0.025
77	0.100
78	0.225
79	0.400
80	0.625
81	0.900
82	1.225
83	1.600
84	2.025
85	2.500
90	5.625
95	10.0

3. Changes in level weighted populations and noise impact indices. A primary concern in an environmental noise assessment is a quantification of the effect of the action being assessed on the noise environment before and after the action was to take place. Two types of description of the effect of the action are useful (in addition to the always required description of populations experiencing various day-night average sound levels). The first descriptor is simply the numerical change in sound level weighted populations before and after the action, the change being an increase or decrease in sound level weighted population (or the neutral effect case, no change).

A second descriptor is the percent change in sound level weighted populations, where the effect of the action is expressed as the value of the sound level weighted population after the action, divided by the sound level weighted population before the change.

F. Example Computation of Level Weighted Population, Noise Impact Index, and Population-Weighted Loss of Hearing

An estimate of the U.S. urban population exposed to various day-night sound levels of traffic noise in excess of 55 decibels is provided in reference [1]. An example of the use of the day-night sound level weighting function applied to these data is shown in Table VII-3. The computation is performed by counting the population within successive 5 decibel increments of sound level, multiplying by the weighting function, then summing the weighted increments to obtain the sound level weighted population. The noise impact index is obtained by dividing the level weighted population by the total population. Note that, as in any noise impact analysis, the first requirement in the computation is to obtain the population distribution as a function of average sound level.

TABLE VII-3

Example of Level Weighted Population Computation
- Urban Traffic noise

L_{dn} -dB	Cumulative Population - millions	Incremental Population - millions	Weighting Function	Level Weighted Population - millions
80	0.1	0.1	1.695	0.17
75	1.3	1.2	1.203	1.44
70	6.9	5.6	0.832	4.66
65	24.3	17.4	0.538	9.36
60	59.6	35.3	0.324	11.44
55	97.5	37.9	0.181	6.86
Total	97.5			33.9

$$NII = \frac{33.9}{97.5} = 0.35$$

In a comparable manner, the expected change in population-weighted loss of hearing can be calculated for the same example, now using two decibel increments in the computation.

TABLE VII-4

Example of Population-Weighted Loss of Hearing
- Urban Traffic Noise

L_{dn} -dB	Cumulative Population - millions	Incremental Population-ΔP - millions	Weighting Function	$H(L_{dn}) \cdot \Delta P(L_{dn})$
81				
79	0.25	0.25	0.625	0.156
77	0.66	0.41	0.225	0.092
75	1.30	0.64	0.025	0.016
				0.264

$$PLH = \frac{0.264}{1.3} = 0.2 \text{ decibel}$$

An environmental assessment of this urban traffic noiseexample can be summarized as follows:

For the 97.5 million people in the urban portions of the United States who experience traffic noise in excess of a day-night average sound level of 55 decibels, the sound level-weighted population is 33.9 million, with a noise impact index of 0.35. For the 1.3 million of this population who experience day-night average sound levels in excess of 75 decibels, the average degradation in hearing acuity can be expected to be 0.2 decibel.

G. Assessment of Special Situations

The procedures described above are intended to apply most generally to the noise environment in most instances. Certain special situations arise, however, in which these methods are insufficient. In particular, high intensity impulsive sounds, infrasound, ultrasound, are not directly assessed by the procedures already described. These situations are described below.

1. High intensity impulsive sounds. The noise produced by sonic booms, artillery firing, blasting and similar activities is assessed in terms of C-weighted sound exposure level, as described in Section V. For these sounds, the composite day-night average sound level is computed as the logarithmic addition of the average sound level produced by the C-weighted sound exposure levels for the impulsive sounds and the A-weighted day-night average sound level produced by all other sources. The resulting composite day-night average sound level is then used in the assessment of impact exactly in the same manner as for non-impulsive sounds.

2. Infrasound. Infrasound is not normally an environmental problem, and when it does occur, usually higher frequency noises are present which

not only cause more of a problem, but which are properly assessed by day-night average sound level. However, the fractional impact method is not suitable for quantifying the impact infrasound itself. Instead, the qualitative impact is to be described; the effects that might occur at different sound levels are given in Section VI, Criteria.

3. Ultrasound. No quantification of the environmental impact of ultrasound is recommended. Rarely is ultrasound (except for some occupational situations, e.g., ultrasonic cleaners) an environmental problem of practical interest. Evaluation of ultrasound exposure above 105 dB requires additional investigation and research to evaluate the impact.

4. Temporary noise environnments. Screening methods for determining the degree of analysis required for consideration of temporary changes in noise environment have been discussed in Section III-E-2. For those situations in which a detailed analysis of the temporary noise environment is required, impact assessment is made in the same manner as for permanent noise environments by the use of sound level-weighted population and noise impact index calculations.

For both temporary and permanent noise environments the yearly average day-night average sound level should be used in computation of impact indices. In some instances it is useful to compute LWP and NII for two situations:

a) consider the temporary noise environment as if it were permanent, but also state its actual duration;

b) consider the temporary noise environment in terms of its contribution to the annual average day-night average sound level.

For example, consider a population of 1000 experiencing a temporary day-night average sound level of 70 decibels for nine months due to a construction project, after which the day-night average sound level drops to 60 decibels on a long-term basis. The following three situations would be described:

1. During the nine-month construction period itself, the level-weighted population is (0.664) (1000) = 664, and the noise impact index is 0.664.

2. The effect of the construction activity on annual average impact is obtained from the annual average day-night average sound level:

$$L_{dny} = 10\log_{10}\left[\left(\frac{9}{12} \times 10^{\frac{70}{10}}\right) + \left(\frac{3}{12} \times 10^{\frac{60}{10}}\right)\right] = 68.9 \text{ decibels}$$

For the year during which construction takes place the sound-level weighted population is 601 and the noise impact index is 0.601.

3. After construction is complete the sound level weighted population is 236 and the noise impact index is 0.236.

H. Assessment of the Impact of Vibration Exposure

1. General. There is a lack of data related to the assessment of the severity of the impact that results if the vibration guidelines proposed in this section are exceeded. It is recommended that the number of people exposed to vibration levels above the "no complaint" value (see Table VI-5) as well as the number of structures, if any, above the potentially structure damaging accelerations of 1 m/sec^2 and .5 m/sec^2 be estimated (see Section VI-D for structural damage). For a

specific action, therefore, contours of 1 m/sec^2, .5 m/sec^2 and appropriate "no complaint" acceleration value as determined by Table VI-5 should be predicted/measured. For example, if an action causes a steady vibration that lasts a total of 25 secs a day (during daytime hrs), the contour of .014 m/sec^2 should be evaluated ($.072/\sqrt{25} = .014$).

To evaluate alternative actions when the vibration values are above the "no complaint" values, the Vibration Weighted Population and the Vibration Impact Index as described below can be used.

2. <u>Vibration Impact Index - Vibration Weighted Population</u>. Figure VI-5 summarizes the complaint history from the Salmon Nuclear Event. For a single event the number of complainants for residential areas varies roughly as 10 log K (for peak acceleration range of 0.1 m/sec^2 to 1 m/sec^2), where K is the ratio of the observed acceleration to 0.1 m/sec^2. It is suggeste that this concept be tentatively broadened to apply to the vibration exposure to more than one impulse or to intermittent/ continuous exposures by defining K as the ratio of the actual acceleration to the recommended "no complaint" acceleration value. A term for the impact of vibration on residential areas can then be defined by using a vibration weighting function. This function is described by:

$$V(k) = 20 \log k$$

where k is ratio of the actual acceleration to the recommended no complaint acceleration values listed in Table VI-5 for a specified time period and where k is limited to values from 1 to 20.

A descriptor of the total vibrational impact of a project can be obtained by multiplying the number of people exposed to each vibrational condition by the vibration weighting function for that condition, finding the sum of these products, and then dividing this sum by the total number of residences. This results in an index that is similar to the Noise Impact Index, but that applies to vibration. This index is called the Vibration Impact Index (VII) and is found from:

$$VII = \frac{\int_1^k P(k)\ V(k)\ dk}{\int_1^k P(k)\ dk}$$

where V(k) is the vibration weighting function described above, P(k) is the population distribution function and dk is the differential change in k.

The related-Weighted Population (VWP) is defined as:

$$VWP = \int_1^k P(k)\ V(k)\ dk$$

Changes in VWP and VII can then be used to evaluate various alternatives and actions with respect to vibration.

VIII. SUMMARY OF NOISE IMPACT ANALYSIS

This chapter summarizes the analysis that might be expected in an environmental impact statement on noise for each branch (or element) of the flowchart described in chapter three that requires a full noise environment documentation. Discussion under each element should not necessarily be limited to the information and procedures proposed in this document, but should include all relevant material and use any other appropriate procedures. For some of the elements, additional references are suggested.

A. Elements under Potential Change in Noise Environment

1. Animals exposed. First, the changes in the noise environment should be described in detail. The extent of the necessary discussion about these changes will be very dependent on whether or not the exposure of any specified animals is a commonplace situation. Specific effects of the expected noise on endangered species, or abnormally high sound levels on domestic or wild animals should be discussed in detail. Material of the Criteria Document and the associated references might be consulted. Where both people and animals are impacted in the same areas, the assessment of the noise impact on people should be considered sufficient to assess the noise impact on animals.

2. Structures exposed. The noise environment should be described for each building or set of buildings in terms of maximum sound pressure levels. Either a worst case or a statistical estimate of the distribution of max levels should be provided. A discussion of the possible damaging effects of noise on structures or monuments is required. The chance that such effects could occur should be estimated. Finally, the significance of such damage, either in monetary and/or non-monetary terms should be reviewed.

3. Developable land. In evaluating effects of a permanent project at 20 years in the future, it might often be necessary to assess the impact on developable land. Data for the undeveloped and developed situation should be included in the summary tables required in Chapter IV. The amount of land that still could be developed after 20 years can be mentioned. In some cases, especially if the future population density cannot be predicted, a sound level weighted area could be calculated and used. The concept of developable land need not be discussed for temporary projects. Wilderness land should be an identified special situation as listed in the tables of Chapter IV. A word description of how the noise will affect the wilderness area should be provided.

4. People exposed - those levels under 55 dB but greater than 40 dB. The full Noise Environment Documentation will be required when the expected day-night average sound level of the project is such that the project is not screened out per Figure II-1. When full NED is required, summary tables suggested in Chapter IV should be constructed. Since the prediction and identification of noise sources becomes more difficult at levels below 50 dB, reasonable accuracy in these tables may be difficult to obtain. The change in level weighted population and Noise Impact Index can be used to describe the impact, but the interpretation of these indicies becomes less direct as the noise levels discussed are lowered. It should be mentioned that no health and welfare effects are expected to occur. A word description describing the general degradation caused by the change in the noise environment should be presented.

5. People exposed - some day night average sound levels above 55 dB. The data tables listed in Chapter VI should be completed and the level weighted population calculated for the residential population of each table.

For comparing the "before" and "after" day-night average sound levels of the same area or population, the absolute change in LWP as well as the percentage change in LWP can be used. If different noise sources or noise problems are compared with each other, the use of LWP as an absolute quantity and the use of the Noise Impact Index are recommended. For comparing the "before" and "after" changes in noise of different actions for different areas and/or populations, the LWP, change in LWP, NII, and % change in LWP are recommended; however, special emphasis should be placed on precisely defining the population/area considered when using these terms. A word description of the effect of the change in the noise environment on the special situations listed in the summary tables should be made. Of the special situations that are most likely to be the greatest impacted, the highest impact situation should be identified and discussed in reasonable detail.

As a final part of the assessment, a descriptive qualitative evaluation of the expected change in the acoustical environment should be made. This evaluation may be to some extent subjective and the opinion of the preparer, but it must be backed up with material that gives the opinion credibility. Previous experiences - if feasible in the same area - such as complaint listing, legal action, community surveys, with similar changes should be described.

6. People exposed - some day night average sound levels above 75 dB. In addition to the comments discussed in the preceding paragraph, the numbers of people exposed to day night average sound levels above 75 dB

should be given special attention. One descriptor, the population weighted loss of hearing can be used and the change and the percent change in PLH described. In residential areas, overemphasis of just the hearing loss consideration should be avoided. Instead emphasis should be placed on the possibility of severe health and welfare problems, using PLH as an indicator of the degree of severity. Finally, the effects on people of the highest DNL to which people are exposed should be discussed. The maximum Noise Induced Permanent Threshold Shift for the part of the population actually exposed on a daily basis to eight hour average levels above 75 decibels should be estimated (see Figure VI-2).

7. People exposed - special noises. For any special noise, enough Noise Environment Documentation must be provided to describe the noise environment for the population. As with general audible noise, tables such as those in Chapter IV may be needed. Except for large impulsive sound, only a word description of the effects of the special noise is recommended. The criteria of Chapter VI should be referenced, but in many cases additional reference material may be required. A discussion of previous experience with such noises must be made, if available. For high energy impulse noise, (see definition in Chapter V) the analysis can be carried further and the expected percent highly annoyed, and changes in this quantity, can be estimated as described in Chapter VI. The effects of high energy impulse noise may also be combined with general audible noise by use of a composite day-night average sound level.

B. Elements with a Potential Change in Populations

1. New population exposed to day night sound levels above 55 dB. The noise environment documentation required will consist of the development of

simplified summary tables as recommended in Chapter IV. Changes in the existing environment (before the change in population) introduced by the noise accompanying the population change should be used to define the final noise environment. Level weighted population from this environment can be compared to the LWP that would be calculated from the noise environment that would be predicted by Table IV-1. The Noise Impact Index should also be used in these situations and compared with the typical urban NII value calculated in Table VII-1. Unless there is evidence to the contrary, movement of an urban residential population into the area under evaluation can be assumed to be from an area with a NII of .35.

2. New population exposed to day-night sound levels above 75 dB. A complete noise environment documentation resulting in a summary table must be constructed similar to that of Chapter IV. An analysis similar to that of paragraph VIII-A.6 (people exposed - some day-night sound levels above 75 dB) should be made where a change in population results in exposures to a DNL greater than 75 decibels.

C. Potential Change in Vibration of Buildings

1. People exposed. The necessary NED should include documentation of the vibration environment such that the expected vibration acceleration values due to some action are provided for all residential areas, and other sensitive areas, in which the weighted acceleration exceed the "no complaint" level. The change in the vibration environment can be discussed by both using the average Vibration Impact Index for the exposed population and by listing the expected effects at the nearest residence. A discussion of the effects of the vibration environment on sensitive non-residential buildings is also needed.

2. Structures exposed. When structures are exposed to potentially damaging vibration, a description of the expected damage and the likelihood of such damage occurring should be provided for each type of structure. The information in Appendix C will be of some help in making this assessment, but often enough data will not be available to fully make this assessment. In such cases, a program for monitoring the actual damage, or lack of it, may be necessary.

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APPENDICES

GUIDELINES FOR PREPARING ENVIRONMENTAL IMPACT STATEMENTS ON NOISE

Report of Working Group 69
on
Evaluation of Environmental Impact of Noise

Committee on Hearing, Bioacoustics, and Biomechanics
Assembly of Behavioral and Social Sciences
National Research Council

APPENDIX A

Some Acoustical Terms, Abbreviations, Symbols and Mathematical Formulations for Environmental Impact Statements

1. Some Acoustical Terms

Some acoustical terms are defined here, which may be needed in the preparation of an environmental impact statement concerned with noise. They are arranged so as to bring near the top of the list those terms likely to be needed most frequently. It may be necessary to use abbreviations different than those listed above depending upon what other abbreviations are needed in a given context. A time period put in either an abbreviation or as the subscript to the symbol for level signifies an average A-weighted sound level during that time period.

1.1 sound level. The quantity in decibels measured by an instrument satisfying requirements of American National Standard Specification for Sound Level Meters S1.4-1971. Fast time-averaging and A-frequency weighting are understood, unless others are specified. The sound level meter with the A-weighting is progressively less sensitive to sounds of frequency below 1000 hertz (cycles per second), somewhat as is the ear. With FAST time averaging the sound level meter responds particularly to recent sounds almost as quickly as does the ear in judging the loudness of a sound.

1.2 noise level. Same as sound level, for sound in air. Some people use "noise" only for sound that is undesirable. A sound level meter does not, however, measure people's desires. Hence there is less likelihood of misunderstanding, if what is measured by a sound level meter is called sound level, rather than noise level.

1.3 decibel. A unit measure of sound level and other kinds of levels.

1.4 maximum sound level. The greatest sound level during a designated time interval or event. More specifically, it is the greatest FAST A-weighted sound level of the event.

1.5 peak sound level. The greatest instantaneous A-weighted sound level, during a designated time interval or event.

1.6 impulse sound level. In decibels, the exponential-time-average sound level obtained with a squared-pressure time constant of 35 milliseconds. The A-frequency weighting is understood.

1.7 fast sound level. In decibels, the exponential-time-average sound level measured with the squared-pressure time constant of 125 ms. The A-frequency weighting is understood.

1.8 slow sound level. In decibels, the exponential-time-average sound level measured with the squared-pressure time constant of one second. The A-frequency weighting is understood.

1.9 sound level exceeded x-percent of time. That sound level equalled or exceeded by a fluctuating fast sound level x-percent of a stated time period. L10, as a possible example, is a sound level exceeded 10% of 24 hours.

2.1 average sound level. A sound level typical of the sound levels at a certain place in a stated time period. Technically, average sound level in decibels is the level of the mean-square A-weighted sound pressure during the stated time period, with reference to the square of the standard reference sound pressure of 20 micropascals. Average sound level differs from sound level in that for average sound level, equal emphasis is given to all sounds within the stated averaging period, whereas for sound level an exponential time weighting puts much more emphasis on sounds that have just occurred than those which occurred earlier.

2.2 equivalent continuous sound level. Same as average sound level. The pertinent time period must be stated.

2.3 hourly average sound level. Average sound level, in decibels, over a one-hour time period, usually reckoned between integral hours. It may be identified by the beginning and ending times, or by the ending time only.

2.4 8-hour average sound level. Average sound level, in decibels, over an 8-hour period.

2.5 day average sound level. Average sound level over the 15-hour time period from 7 a.m. up to 10 p.m. (0700 up to 2200 hours).

2.6 night average sound level. Average sound level, in decibels, over the split nine-hour period from midnight up to 7 a.m. and from 10 p.m. to midnight (0000 up to 0700 and 2200 up to 2400 hours).

2.7 day-night average sound level. The 24-hour average sound level, in decibels, from midnight to midnight, obtained after addition of 10 decibels to sound levels in the night from midnight up to 7 a.m. and from 10 p.m. to midnight (0000 up to 0700 and 2200 up to 2400 hours).

2.8 yearly day-night average sound level. The day-night average sound level, in decibels, averaged over an entire calendar year.

2.9 day-night average sound level contour. A curved line connecting places on a map where the day-night average sound level is the same. If only one kind of contour is shown on the map the fact may be made known by a single legend, "Contours of day-night average sound level in decibels." In this case only the number of decibels need be marked on a contour.

3.0 sound exposure. Time integral of squared, A-frequency-weighted sound pressure over a stated time interval or event. The exponent of sound pressure and the frequency weighting may be otherwise if clearly so specified.

3.1 sound exposure level. The level of sound accumulated over a given time period or event. It is particularly appropriate for a discrete event such as the passage of an airplane, a railroad train, or a truck. Sound exposure level is not an average, but a kind of sum. In contrast with average sound level which may tend to stay relatively constant even though the sound fluctuates, sound exposure level increases continuously with the passing of time. Technically, sound exposure level in decibels is the level of the time integral of A-weighted squared sound pressure over a stated time interval or event, with reference to the square of the standard reference pressure of 20 micropascals (0.0002 microbar) and reference duration of one second.

3.2 sound exposure level contour. A curved line connecting places on a map where the sound exposure level of a discrete event is the same.

3.3 outdoor-indoor sound level difference. Difference, in decibels, between the average sound level outside a building, at a position two or more meters from the facade or roof as appropriate, and the space-time average sound level in a designated room, due to the outdoor sound. When the outdoor sound is caused by a moving vehicle it often suffices to measure the indoor sound only near the middle of the room.

3.4 slow C-weighted sound level. In decibels, the exponential time average sound level measured with the squared-pressure time constant of one second and the C-frequency weighting of the sound level meter.

3.5 8-hour average C-weighted sound level. Average sound level, in decibels, over a given 8-hour time period, measured with the C-frequency weighting.

3.6 C-weighted sound exposure level. In decibels, the level of the time integral of C-weighted squared sound pressure, with reference to the square of 20 micropascals and to one second.

4.1 instantaneous sound pressure, overpressure. Pressure at a place and instant considered, minus the static pressure there.

4.2 peak sound pressure. Greatest absolute instantaneous sound pressure in a stated frequency band, during a given time interval.

4.3 peak sound pressure level. In decibels, twenty times the common logarithm of the ratio of a greatest absolute instantaneous sound pressure to the reference sound pressure of twenty micropascals (0.0002 microbar).

4.4 sound pressure. Root-mean-square of instantaneous sound pressures over a given time interval. The frequency bandwidth must be identified.

4.5 sound pressure level. In decibels, twenty times the common logarithm of the ratio of a sound pressure to the reference sound pressure of twenty micropascals (0.0002 microbar). The frequency bandwidth must be identified.

4.6 (vibratory) acceleration. The rate of change of speed and direction of a vibration, in a specified direction. The frequency bandwidth must be identified.

4.7 (vibratory) acceleration level. In decibels, twenty times the common logarithm of the ratio of a vibratory acceleration to the reference acceleration of ten micrometers per second squared (nearly one-millionth of the standard acceleration of free fall). The frequency bandwidth must be identified.

Table A-1. Some Acoustical Terms, Abbreviations, and Symbols for Environmental Impact Statements

Item		Abbreviation	Symbol
1.1	(fast A-weighted) sound level	A	L_A, L
1.2	noise level (sound level)	A	L_A, L
1.3	decibel	DB	dB
1.4	maximum sound level	MXL	L_{max}
1.5	peak sound level	PKL	L_{Apk}
1.6	impulse sound level	ISL	L_{AI}
1.7	fast sound level	FA	L_{AF}
1.8	slow sound level	SA	L_{AS}
1.9	sound level exceeded x-percent of time	LX	L_x
2.1	average sound level, over time T	AVL	L_T
2.2	equivalent continuous sound level over time T	EQL	L_{eqT}
2.3	hourly average sound level	1HL	L_h
2.4	8-hour average sound level	8HL	L_{8h}
2.5	day (0700–2200) average sound level	DL	L_d
2.6	night (0000–0700 and 2200–2400) average sound level	NL	L_n
2.7	day-night average sound level	DNL	L_{dn}
2.8	yearly day-night average sound level	YDNL	L_{dny}
2.9	day-night average sound level contour	—	—
3.0	sound exposure	E	E
3.1	sound exposure level	SEL	L_{AE}
3.2	sound exposure level contour	—	—
3.3	outdoor-indoor sound level difference	SLD	D_A
3.4	slow C-weighted sound level	SCL	L_{CS}
3.5	8-hour average C-weighted sound level	8HCL	L_{C8h}
3.6	C-weighted sound exposure level	CSEL	L_{CE}
4.1	instantaneous sound pressure	ISP	p_i
4.2	peak sound pressure, in stated band	PKSP	p_{pk}
4.3	peak sound pressure level, in stated band	PKSPL	L_{pk}
4.4	sound pressure, in stated band	SP	p
4.5	sound pressure level, in stated band	SPL	L_p
4.6	(vibratory) acceleration, in stated band	VA	a
4.7	(vibratory) acceleration level, in stated band	VAL	L_a

5. Mathematical Formulations for the Descriptors to be used in an Environmental Impact Statement

5.1 Descriptors for general audible noise

5.1.1 Average sound level (L_{eq} or L_T)

$$L_T = 10 \log_{10}\left[\frac{1}{T}\int_0^T 10^{L_A(t)/10}\, dt\right] \qquad \text{A-1}$$

where: T is the length of the time interval, in seconds, during which the average is taken;

$L_A(t)$ is the time varying value of the A-weighted sound level during the time interval T.

Note 1: Average sound level may be calculated from the sound exposure levels of individual events occurring within the time interval T:

$$L_T = 10 \log_{10}\left[\frac{1}{T}\sum_{i=1}^{n} 10^{L_{AEi}/10}\right] \qquad \text{A-2}$$

where: L_{AEi} is the sound exposure level of the i-th event, out of a total of n events in time interval T in seconds, and L_{AE} is defined in 2.3.4

Note 2: When T is exactly one hour, L_T is referred to as an hourly average sound level.

5.1.2 Day-night Average Sound Level

$$L_{dn} = 10 \log_{10}\left[\frac{1}{86400}\left(\int_{0000}^{0700} 10^{[L_A(t)+10]/10}\, dt + \int_{0700}^{2200} 10^{L_A(t)/10}\, dt + \int_{2200}^{2400} 10^{[L_A(t)+10]/10}\, dt\right)\right] \quad \text{A-3}$$

Time t is in seconds, so the limits shown in hours and minutes are actually interpreted in seconds. It is often convenient to compute day-night average sound level from hourly average sound levels obtained during successive hours.

5.1.3 Yearly Day-night Average Sound Level

$$L_{dny} = 10 \log_{10} \frac{1}{365} \sum_{i=1}^{365} 10^{L_{dni}/10} \quad \text{A-4}$$

where L_{dni} is the day-night average sound level for the i-th day out of one year.

5.1.4 Sound Exposure Level

$$L_{AE} = 10 \log_{10}\left(\frac{1}{t_o} \int_{t_1}^{t_2} 10^{L_A(t)/10}\, dt\right) \quad \text{A-5}$$

where t_o equals one second and $L_A(t)$ is the time-varying A-weighted sound level in some time interval t_1 to t_2.

The length of the time interval may be arbitrary, or it may simply be large enough to encompass all the significant sound of an event.

Note: The value of the above integral is usually approximated with sufficient accuracy by integrating $L_A(t)$ over the time interval during which $L_A(t)$ is between 10 decibels less than its maximum value and the maximum value, before and after the maximum occurs.

5.2 **Descriptor for high-energy impulses**

5.2.1 C-weighted Sound Exposure Level - L_{CE} - The mathematical description of C-weighted sound exposure level in decibels is:

$$L_{CE} = 10 \log \left[\frac{1}{t_o} \int_{-\infty}^{\infty} \frac{p_c^2}{p_o^2} \, dt \right] \qquad \text{A-6}$$

t_o = 1 second

p_c = C-weighted sound pressure

p_o = 20 μ Pa

Note: In practice the integral is often approximated by integration within the time during which the sound level of the event exceeds some threshold value such as 20 dB less than the maximum sound pressure level.

5.2.2 C-weighted Day Night Average Sound Level - L_{Cdn} -

Analogous to the A-weighted L_{dn}, with a nighttime penalty of 10 dB, the C-weighted day-night average sound level is:

$$L_{Cdn} = 10 \log \frac{1}{T_o} \left[15 \times 10^{\frac{L_{Cd}}{10}} + 9 \times 10^{\frac{L_{Cn} + 10}{10}} \right] \quad \text{A-7}$$

where T_o is 24 hours, L_{Cd} is the average C-weighted sound level over the daytime period of 0700 to 2200 hours, L_{Cn} is the C-weighted average level over the nighttime period of 2200 to 0700 hours.

The C-weighted average level is most easily calculated from the C-weighted sound exposure levels during the time of interest as follows:

$$L_{Cd} = 10 \log \frac{1}{15 \times 3600} \left[\sum_{i}^{n} 10^{\frac{L_{CEi}}{10}} \right] \quad \text{for } L_{CEi}: >85 \quad \text{A-8}$$

$$L_{Cn} = 10 \log \frac{1}{9 \times 3600} \left[\sum_{i}^{n} 10^{\frac{L_{CEi}}{10}} \right] \quad \text{for } L_{CEi}: >75 \quad \text{A-9}$$

where L_{CEi} is the C-weighted sound exposure level of the i-th discrete event.

APPENDIX B

Development of Weighting Functions

1. Introduction

Section VII introduces the concept of a single number measure of the degree of impact associated with a noise environment that extends over a sizable geographic area, in which different numbers of people experience different levels of day-night average sound level. A key element in this concept is the weighting function that purports to describe the degree of adverse response expected from a population exposed to a specified day-night average sound level. We describe below the considerations which lead to the development of the selected weighting functions.

2. Development of the Sound Level Weighting Function

2.1 Background

Numerous social surveys have been made to evaluate the form and degree of response by people to environmental noise. A wide variety of approaches to determine the mode of response have been used in these surveys, in an attempt to determine such effects as "intrusiveness," disturbance of speech communication or sleep, interference with radio or TV listening, and the overall response to the aggregate of all these effects, termed "annoyance." Essentially all of the surveys, up to the late 1960's, were made in the vicinity of airports with the aim of correlating aircraft noise environments with *community response*. Studies of the available surveys indicate that the concept of "percent highly annoyed" in the sampled populations provides the most consistent indicator of response of a community to a particular noise environment[1,2,3,4].

The first version of a weighting function relating annoyance to noise environment was proposed, based on the earliest survey data, by a working group of the Bioacoustics Panel of the U.S. Interagency Transportation Noise Abatement Program in 1972[5]. This result described "percent highly annoyed" as a function of Composite Noise Rating (CNR) by the following relationship:

$$\% \text{ Highly Annoyed} = 1.99 \text{ CNR} - 176 \qquad \text{B-1}$$

In essence, this relationship predicts no people highly annoyed at CNR = 88 (nominally L_{dn} = 53), with an increase of 20 percent of the population "highly annoyed" for each 10 decibel increase in average noise level. This weighting function was used in various analyses of aircraft noise by working groups of the Committee on Aircraft Noise of the International Civil Aviation Organization.

A second look at the relationship between annoyance and average noise level was taken by an EPA Task Group under the EPA Aircraft/Airport Noise Study in 1973[6]. In this study, social survey data from aircraft studies in the U.S. and England were combined to develop a relationship between "percent highly annoyed" and day-night average sound level. This function was expressed as:

$$\% \text{ Highly Annoyed} = 1.8\ (L_{dn} - 46) \qquad \text{B-2}$$

which indicates both a smaller slope and a lower intercept than equation (1). Reference 6 also noted a similar relationship developed in an OECD study[7] that used the relationship:

$$\% \text{ Highly Annoyed} = 2\ (L_{dn} - 50) \qquad \text{B-3}$$

This equation was also based on airport noise studies.

The use of relationships between annoyance and average sound level to define a weighting function for numerical evaluation of impact analyses was introduced in the "fractional impact" method developed initially for use in the analysis of highway noise problems[8]. This method took into account the data and recommendations both of Reference 6 and the EPA "Levels" report[9], which indicate that a community would not be expected to exhibit significant reaction at noise exposures of L_{dn} = 55 dB or below, but would be expected to show strong, organized reaction at L_{dn} = 75 dB and higher. Using these two anchor points, and the linear relationship of equations 1 to 3, a weighting function, "fractional impact," F.I., was defined to be zero at L_{dn} = 55 dB, and unity at L_{dn} = 75 dB, varying linearly with average sound level:

$$\text{F.I.} = 0.05\ (L_{dn} - 55) \qquad \text{B-4}$$

The weighting function for F.I. has been used by EPA in impact analyses of a number of potential regulatory actions.

Several features of equation B-4 are unsatisfactory. It is not likely that community response is adequately described with a linear function of average noise level over a wide range of levels. Even though the data from the individual social surveys are reasonably well fitted by linear regressions over the limited range of levels represented in the separate surveys, the individual survey results indicate that the rate of change of annoyance with sound level is greater at higher sound levels than at lower sound levels. Moreover, the choice of an arbitrary zero at L_{dn} = 55 dB is not easily justified. Finally, few data from noise sources other than aircraft were available at the time the original weighting functions were developed, and a weighting function derived only from aircraft-related social surveys may not be satisfactory for use in evaluating other sources of noise.

Fortunately, data from a number of social surveys associated with highway traffic noise, railway noise, urban traffic noise, and further aircraft studies have become accessible since the earlier analyses were made. Recently Schultz[10] has made a thorough study of the results of 19 surveys from 9 countries (including those previously considered for aircraft alone). In this analysis a careful attempt has been made to relate the different response scales used in the individual surveys to a common basis. In addition, a detailed review was made of the noise level data from the different noise measures used in each survey to obtain a reliable conversion to day-night average sound level.

2.2 "Universal" response curve for "percent highly annoyed"

The results of this synthesis show quite clearly that the best "fit" of response data to average sound level is provided by a curvilinear function; usually a cubic equation was used in the regression analyses. Further, 12 of the surveys, covering aircraft, railroads, urban traffic, and expressway traffic as noise sources, "clustered" closely around an average curve for the set of data, as shown in Figure B-1. The remaining 7 surveys showed similarly shaped annoyance/sound level functions, but deviated in differing detail from the 12 "clustering" surveys for various qualitative reasons discussed by the author. It is worth noting that the average of the "non-clustering" surveys was essentially the same as the average for the "clustering" surveys.

Based on these data, Schultz proposes a "universal" response curve relating "percent highly annoyed," (%HA), to day-night average sound level:

$$\%HA = 0.8553\ L_{dn} - 0.0401\ L_{dn}^{2} + 0.00047\ L_{dn}^{3} \qquad \text{B-5}$$

This expression represents the least-squares fit of percent highly annoyed to day-night average sound level for the "clustering" survey data.

2.3 Day-night average sound level population weighting function

In terms of its use as a weighting function for impact analysis, however, the cubic expression behaves awkwardly (e.g., goes negative) at sound levels below those used in the regression analysis. The shape of the function suggests that an alternate expression in the form of a power function would be preferable. Analysis shows, however, that a simple power function can be made to fit either the upper range of day-night average sound level (L_{dn} > 70 dB) or the lower range (L_{dn} < 60 dB), but not both.

More detailed study shows that the entire range of the function can be matched by combining two power functions, one controlling the lower range of sound levels, and the other the higher range (analogous to the voltage response of parallel capacitors in an electrical circuit). This can be demonstrated by the two linear approximations to the curvilinear function

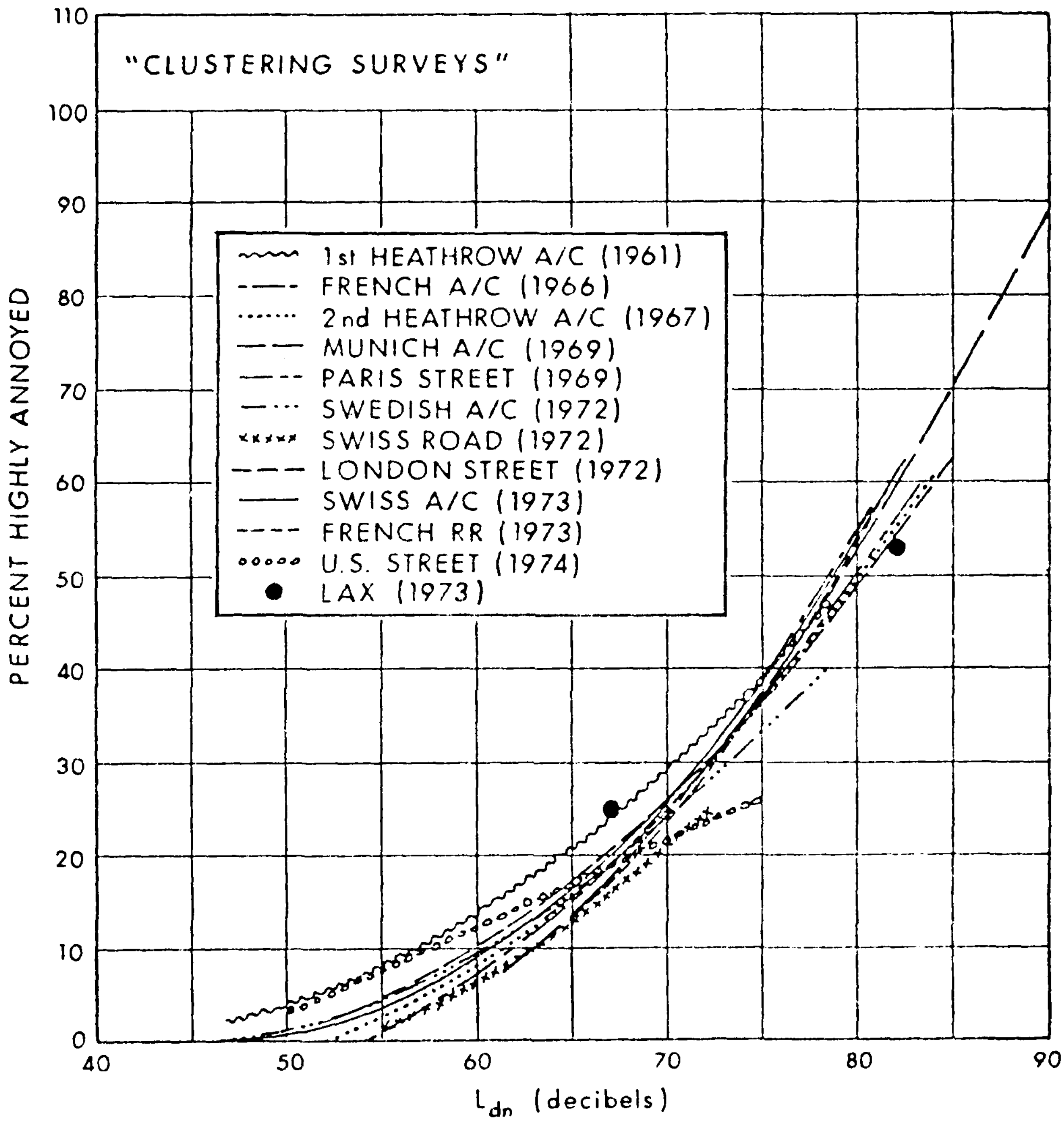

FIGURE B-1. SUMMARY OF ANNOYANCE DATA FROM 12 SURVEYS
DATA SHOW CLOSE AGREEMENT

plotted on a semi-logarithmic scale in Figure B-2. It is worth observing that the power function for the higher sound level range has the same rate-of-growth as a loudness function.

The two exponential functions indicated in Figure B-2 may be combined in a single expression, with an empirical choice of coefficients to achieve a best fit (less than one percent deviation) to equation 5. This expression is:

$$\%HA = \frac{\left(1.24 \times 10^{-4}\right)\left(10^{0.103L_{dn}}\right)}{\left(0.2\right)\left(10^{0.03L_{dn}}\right) + \left(1.43 \times 10^{-4}\right)\left(10^{0.08L_{dn}}\right)} \qquad \text{B-6}$$

The weighting function employed in Section VII is obtained by normalizing this expression to unity at L_{dn} = 75 dB, that is by dividing equation (B-6) by 36.9, the "percent highly annoyed" at L_{dn} = 75 dB.

$$\%HA = \frac{6582.9}{35.56 + 143} = 36.88$$

A listing of equation 6 devided by 36.9 in one-half decibel increments is provided in Table B-1.

3. Development of Weighting Function for Loss of Hearing

3.1 Background

There have been numerous studies conducted for the purpose of determining the long term effect of noise on the hearing ability of an exposed population. In particular, there have been three studies that have provided reasonable predictive models of the relationship between noise and changes in the hearing levels of the exposed population. The results are provided as changes in the statistical distribution of hearing levels. These changes are called Noise Induced Permanent Threshold Shifts (NIPTS). These studies are by Baughn[11], Passchier-Vermeer[12], and Robinson[13]. The results of these three studies were combined[14] and used in the EPA levels document[9]. Table B-1 is from the levels document and provides a summary of the expected NIPTS that would occur from a 40 year exposure beginning at an age of 20 years.

3.2 Development of weighting function for noise induced hearing loss

Inspection of the data in Table B-2 shows that as the average sound level of the exposure increases, there is a widening of the frequencies affected by the exposure. For instance at an 8 hour average sound level of 80, only the frequencies around 4000 Hz are affected while for an exposure

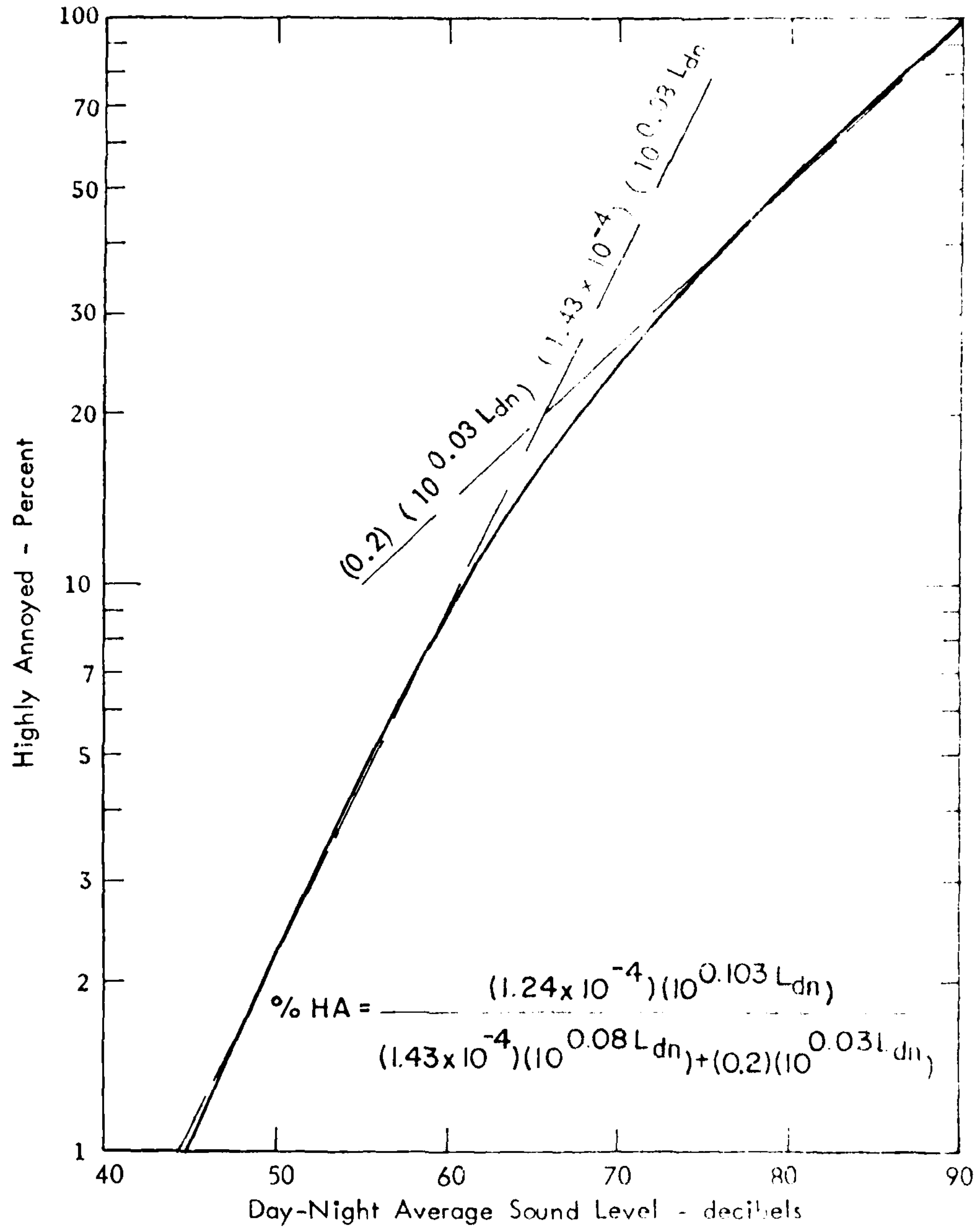

FIGURE B-2 POWER FUNCTION APPROXIMATION TO THE CUBIC EQUATION FOR RELATING ANNOYANCE TO DAY-NIGHT AVERAGE SOUND LEVEL

Table B-1. Weighting Function W(L_{dn}) Derived by Normalizing Equation B-6

L_{dn}	W(L_{dn})	L_{dn}	W(L_{dn})	L_{dn}	W(L_{dn})
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	58.0	0.1[illegible]	[illegible]	[illegible]42
36.5	0.007	58.5	0.19[illegible]	80.5	1.47[illegible]
37.0	0.008	59.0	[illegible].208	81.0	1.52[illegible]
37.5	0.009	59.5	0.221	81.5	1.57[illegible]
38.0	0.009	60.0	0.235	82.0	1.62[illegible]
38.5	0.010	60.5	0.250	82.5	1.68[illegible]
39.0	0.011	61.0	0.265	83.0	1.73[illegible]
39.5	0.012	61.5	0.281	83.5	1.79[illegible]
40.0	0.013	62.0	0.297	84.0	1.84[illegible]
40.5	0.014	62.5	0.314	84.5	1.90[illegible]
41.0	0.015	63.0	0.332	85.0	1.966
41.5	0.017	63.5	0.351	85.5	2.027
42.0	0.018	64.0	0.371	86.0	2.090
42.5	0.019	64.5	0.391	86.5	2.154
43.0	0.021	65.0	0.412	87.0	2.219
43.5	0.023	65.5	0.43[illegible]	87.5	2.286
44.0	0.025	66.0	0.456	88.0	2.355
44.5	0.027	66.5	0.479	88.5	2.425
45.0	0.029	67.0	0.503	89.0	2.497
45.5	0.031	67.5	0.528	89.5	2.571
46.0	0.034	68.0	0.554	90.0	2.647
46.5	0.036	68.5	0.580	90.5	2.724
47.0	0.039	69.0	0.607	91.0	2.804
47.5	0.042	69.5	0.636	91.5	2.885
48.0	0.046	70.0	0.664	92.0	2.968
48.5	0.049	70.5	0.694	92.5	3.054
49.0	0.053	71.0	0.725	93.0	3.141
49.5	0.057	71.5	0.75[illegible]	93.5	3.231
50.0	0.061	72.0	0.78[illegible]	94.0	3.323
50.5	0.066	72.5	0.8[illegible]	94.5	3.41[illegible]
51.0	0.071	73.0	0.855	95.0	3.51[illegible]
51.5	0.076	73.5	0.890	95.5	3.61[illegible]
52.0	0.082	74.0	0.92[illegible]	96.0	3.71[illegible]
52.5	0.088	74.5	0.96[illegible]	96.5	3.82[illegible]
53.0	0.094	75.0	1.000	97.0	3.92[illegible]
53.5	0.101	75.5	1.0[illegible]	97.5	4.03[illegible]
54.0	0.108	76.0	1.07[illegible]	98.0	4.14[illegible]
54.5	0.116	76.5	1.1[illegible]	98.5	4.26[illegible]
55.0	0.124	77.0	1.15[illegible]	99.0	4.38[illegible]
55.5	0.133	[illegible]	[illegible]	99.5	4.504
[illegible]	0.14[illegible]	78.0	[illegible]	100.0	4.62[illegible]
[illegible]	[illegible]	[illegible]		[illegible]	4.75[illegible]

of 95 dB, all the audiometric frequencies from 500 Hz to 6000 Hz are affected. As would be expected, the average of 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz does not show a uniform constant increase in loss with a rising exposure level, but instead increases at an accelerated pace with increasing average sound level. While use of the most sensitive frequency is proper for the determination of an absolutely safe daily average sound level, assessment of the relative impact of exposure to higher average sound levels requires that all audiometric frequencies be considered. Therefore the average of .5 kHz, 1 kHz, 2 kHz and 4 kHz is the recommended measure. Since each of the four frequencies describe the center of the preferred octave bands, there is no overlapping in octave bands as would be the case if 3000 Hz was included.

Having selected a method to handle the question of frequency, the next problem is time. One way to consider time is to select a point in time at which the relative impact will be described. Selection of such a point is somewhat arbitrary and not entirely meaningful. For instance one could argue that it is more important to describe the effects of noise when a person is middle-age, and not when a person is 60 years old. An alternative approach is to use the average NIPTS of the population during a normal working lifetime.

Averaging NIPTS with respect to time avoids arbitrarily selecting any one point in time and provides a realistic assessment of the overall effect of noise on hearing on a large population.

A grand averaging of the NIPTS with respect to frequency (.5 kHz, 1 kHz, 2 kHz, 4 kHz) and time (0 to 40 years of exposure) and percentiles (.1 to .9 percentiles) has been accomplished in Table B-2 for 8 hour AVL of 75 to 90 decibels. A similar value has been obtained for an 8 hour AVL of 95 decibels by using the data in reference 14. This grand average of the NIPTS data is listed in Table B-3. This NIPTS data, which is for one ear, can be very well described by the formula:

$$\text{Ave NIPTS} = (L_{8h} - 75)^2/40 \qquad \text{B-7}$$

The slight differences between eqn B-7 and the NIPTS data should be considered insignificant, especially in view of the fact that the values of Table B-2 have been rounded to nearest whole integer in any case.

The weighting function used in Section VII is obtained by using equation B-7. Since this equation is developed from averaging the effects of noise over frequency, time, and percentiles, it cannot estimate the effect on an individual at one audiometric frequency at one point of time. This equation should be used only to assess the average relative impact of exposure to different daily average sound levels.

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

1. Max NIPTS: The permanent change in hearing threshold attributable to noise. NIPTS increases with exposure duration. Max NIPTS is the maximum value during a 40-year exposure that starts at age 20.

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.)

TABLE B-2. SUMMARY OF THE PERMANENT HEARING DAMAGE EFFECTS EXPECTED FOR CONTINUOUS NOISE EXPOSURE AT VARIOUS VALUES OF THE A-WEIGHTED AVERAGE SOUND LEVEL C-7

TABLE B-3

L_{8h} dB	Ave (.5, 1, 2, 4 kHz) from Table D-2 dB	$(L_{8h} - 75)^2/40$ dB
75	0	0
80	1	.625
85	3	2.5
90	6	5.625
95	10	10

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APPENDIX C

Measurement of and Criteria for Human Vibration Exposure

1. Introduction

The criteria for vibration exposure in this appendix will address 3 types of effects. These three type of effects are: (1) whole body vibration of humans, (2) annoyance and interference caused by building vibration, and (3) structural damage from building vibration.

The existing state of knowledge is not complete in any of the above three areas; however, there are existing I.S.O. standards that have been approved or proposed. Summaries of these standards, along with other data, provide the content of this appendix. Some simplification of the proposed standards on building vibration and structural damage have been made in order to provide a simple, unified and reasonable method for assessing the effects of vibration.

2. Whole Body Vibration Criteria (Summary of Approved ISO Standard 2631-1974)

2.1 The Three Criteria for Evaluation of Whole Body Vibration

Experimental data show that there are various rather complex factors that determine the human response to vibration. Evaluation of all these factors is difficult at this time because of the paucity of quantitative data concerning mans perception of vibration and his response to it. Nevertheless, there is an international standard which does provide provisional guidance as to what is acceptable human exposure to vibration for some types of vibration.

In general, there are four physical factors of primary importance in determining the human response to vibration. These are intensity, frequency, direction, and exposure time of the vibration. The current International Standard for vibration addresses three main human criteria. These are:

1. Preservation of working efficiency
2. Preservation of health or safety
3. The preservation of comfort

For environmental problems the preservation of comfort is considered as the best criteria for evaluation of whether or not vibration significantly changes the environment.

2.2 Types of Vibration Transmissions.

The standard lists basically three kinds of human exposure to vibration, namely:

(a) Vibrations transmitted simultaneously to the whole body surface or substantial parts of it. This occurs when the body is immersed in a vibration medium. There are circumstances in which this is of practical concern; for example, when high intensity sound in air or water excites vibrations of the body.

(b) Vibration transmitted to the body as a whole through the supporting surface, namely, the feet of a standing man, the buttocks of a seated man or the supporting area of a reclining man. This kind of vibration is usual in vehicles, in vibrating buildings and in the vicinity of working machinery.

(c) Vibrations applied to particular parts of the body such as the head or limbs; for example, by vibrating handles, pedals, or head-rests, or by the wide variety of powered tools and appliances held in the hand.

It is also possible to recognize the condition in which an indirect vibration nuisance is caused by the vibration of external objects in the visual field (for example, an instrument panel).

The International Standard 2631, however, applies chiefly to the common condition (b) above; and, in particular, where the vibration is applied through the principal supporting surface to the body of a standing or seated man. In the case of vibrations applied directly to a reclining or recumbent man, insufficient data are available to make a firm recommendation; this is particularly true of vibration transmitted directly to the head, when tolerability is generally reduced. Tolerance may also be reduced when conditions (b) and (c) exist together. Provisionally, however, the limits for the standing or seated man may also be used for the reclining or recumbent man. It must be appreciated that some circumstances will arise in which the rigorous application of these limits would be inappropriate.

2.3 Direction of Vibration.

Rectilinear vibrations transmitted to man should be measured in the appropriate directions of an orthogonal co-ordinate system centered at the heart. The standard specifies separate criteria according to whether the vibration is in the longitudinal ($\pm a_z$) direction or transverse ($\pm a_x$ or a_y) plane. Accelerations in the foot (or buttocks) - to head (or longitudinal) axis are designated $\pm a_z$: acceleration in the fore-and-aft (anteposterior or chest-to-back) axis, $\pm a_x$; and in the lateral (right-to-left side) axis, $\pm a_y$. These axes are illustrated in Figure C-1.

2.4 Acceptable Whole Body Vibration.

The ISO standard identifies the 24 hr comfort level for rms pure (sinusoidal single) frequency or rms value in third octave band for random vibration as given in Table C-1. As long as the vibration levels are below the 24 hr levels, vibration should be considered to have no direct impact on an individual, regardless of the duration of the exposure. The standard does allow for increased exposure levels for shorter exposure times. Such a tradeoff is given by Table C-1 for 8 hr and 1 min exposures. For other exposure times and for the concept of a vibration dose, the basic standard should be consulted. For occupational and recreational situations, the values of Table C-1 can be raised by a factor of 3.15 (10 dB) to predict the boundary at which working efficiency may start to decrease. Increasing the acceleration listed in Table C-1 by a factor of 6.3 (16 dB) will give the boundary necessary for the preservation of health and safety. Thus the 1 min values of Table C-1 as multiplied by a factor of 6.3 provides the maximum recommended continuous acceleration to which an individual should be subjected. However, assessment of acceleration above the comfort levels listed in Table C-1 should be made only by direct reference to the ISO standard. In the ISO standard there are many considerations and limitations with respect to human exposure to acceleration that can cause reduced efficiency or health and safety problems.

3. Vibration Criteria for Occupants in Buildings. (Summary of 1976 draft addendum to ISO Standard 2631-1974)

3.1 Scope.

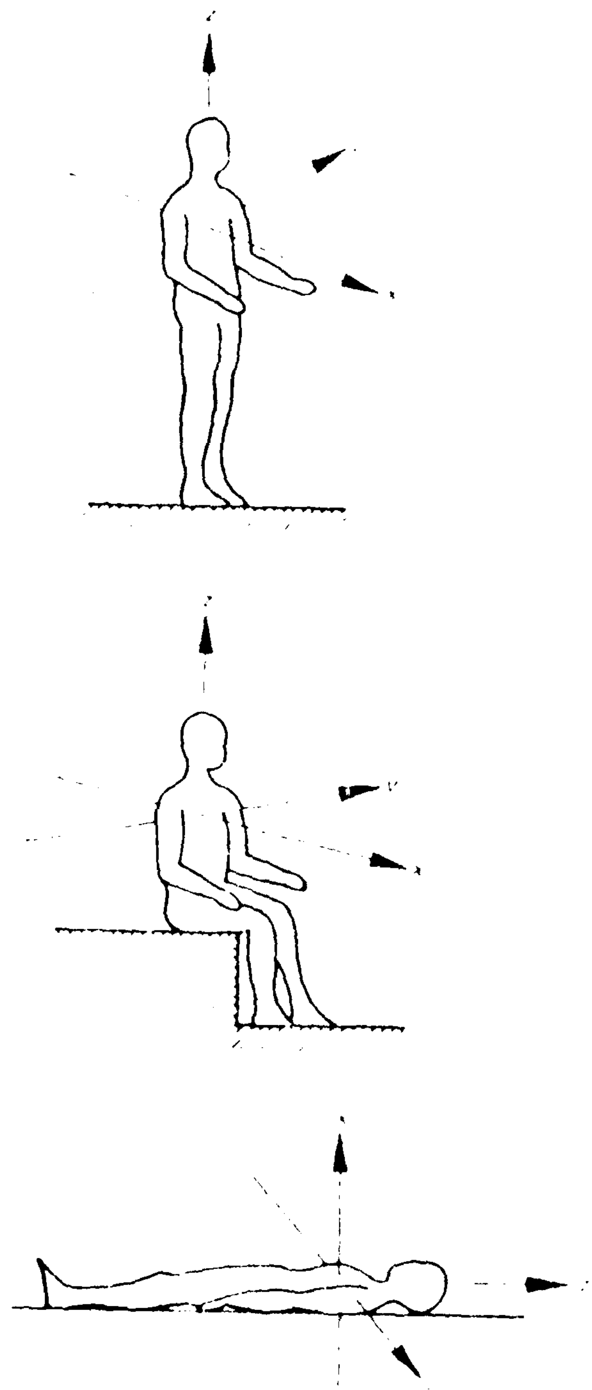
The proposed standard takes into account the following factors:

1. Type of Excitation - for example transient (shock) and/or steady vibration;

2. Usage of the Occupied Space in Buildings - for example hospital operating theatres, residential, offices and factories;

3. Time of Day;

4. Limits of Acceptability - in a proposal of this type there is no hard and fast line of acceptability, but guidance is given as to the level of complaint to be achieved at different levels of vibration. In cases where sensitive equipment or delicate operations impose more stringent limits than human comfort criteria, then the more stringent criteria should be applied.



a_x, a_y, a_z acceleration in the directions of the x, y, z axes

x axis back to chest

y axis right to left side

z axis foot (or buttocks) to head

Figure C-1 Directions of coordinate system for mechanical vibrations influencing humans

TABLE 1 - Numerical values of "comfort boundary" for vibration acceleration in the longitudinal, a_z, direction (foot (or buttocks)-to-head direction) (see figure) and in the transverse, a_x or a_y, direction (back-to-chest or side-to-side)

Values define the boundary in terms of rms value of pure (sinusoidal) single frequency vibration; of rms value in third-octave band for distributed vibration.

ACCELERATION m/sec

Frequency (Center Frequency of 1/3 Octave Band)	a_z			a_x or a_y		
	1 min	8 hr	24 hr	1 min	8 hr	24 hr
1	1.78	0.2	.07	0.63	0.07	.03
1.25	1.59	0.18	.06	0.63	0.07	.03
1.6	1.43	0.16	.06	0.63	0.07	.03
2.0	1.27	0.14	.05	0.63	0.07	.03
2.5	1.13	0.13	.04	0.79	0.09	.04
3.15	1.00	0.11	.04	1.0	0.11	.05
4.0	.89	0.1	.04	1.27	0.14	.06
5.0	.89	0.1	.04	1.59	0.18	.08
6.3	.89	0.1	.04	2.00	0.24	.10
8.0	.89	0.1	.04	2.54	0.29	.13
10.0	1.13	0.13	.04	3.17	0.36	.16
12.5	1.43	0.16	.06	3.97	0.44	.20
16.0	1.78	0.2	.07	5.08	0.57	.25
20.0	2.25	0.25	.09	6.35	0.71	.32
25.0	2.86	0.32	.11	7.94	0.89	.40
31.5	3.56	0.40	.14	10.00	1.13	.51
40.0	4.44	0.51	.18	12.70	1.43	.63
50.0	5.71	0.63	.23	15.87	1.78	.79
63.0	7.11	0.79	.29	20.00	2.25	1.00
80.0	8.89	1.0	.36	25.40	2.86	1.27

3.2 Characteristics of Building Vibration.

3.2.1 Direction of vibration

Because a building may be used for many different activites, standing, sitting and lying may all occur, hence vertical vibration of the building may enter the body as either Z axis, X axis or Y axis vibration, as shown in Figure C-1. The Standard is written for all three axes of vibration, however, in cases where it is not clear which direction to apply, it is often more convenient to consider the combined Standard detailed in Sections 3.3.4 below.

3.2.2 Random or multi-frequency vibration

Random or multi-frequency vibration represents a particular problem which fortunately does not often occur in buildings. There is evidence from research concerning the building environment to suggest that there are interaction effects between different frequencies of vibration. Under these circumstances and for random vibration, the proposed standard recommends an overall weighting method such as that in Section 3.3.4.

3.2.3 The characterization of impulsive shock and intermittent vibration

Continuous vibration of a repetitive nature is easy to identify and classify. The borderline between impulsive shock and intermittent vibration is difficult to define. Impulsive shock is characterized by a rapid build-up to a peak followed by decay, and is typically excited in buildings by blasting, forging presses or pile driving using an impact device. Intermittent vibration may only last a few seconds, but is characterized by a build-up to a level which is maintained for a considerable number of cycles. Examples of this in buildings would be traffic excited vibration and vibration generated inside a building by machinery starting up or on intermittent service. Pile driving by modern methods using vibrating columns would also be classified as continuous or intermittent vibration and not as impulsive shock.

The proposed standard recommends that impulsive shock created by forging presses or conventional pile drivers should be treated in a similar manner to continuous and intermittent vibration. Research has shown that vibration which only occurs at a specific instance, for example domestic building vibration by a passing bus, causes the same level of annoyance as continuous vibration.

Blasting which occurs only up to three times per day is a special case. The proposed standard recommends that building operations of this nature should never take place at night due to the disturbance and that during the daytime they should be limited to a small number of occurrences. The levels of vibration generated due to blasting are on an order of magnitude greater than traffic and general building vibrations, and can only be accepted on the basis of very limited exposure.

3.2.4 Classification of buildings and building areas

The criteria of classification are in the standard derived from the human reaction to vibration. In the home the highest standards are required, and this is characterized by an absence of detectable vibration. Under other conditions, such as offices and factories, there is some tolerance to vibration disturbance.

In the proposed Standard no differentiation has been made between different types of residential area, i.e. city centre, urban or rural. It is considered that similar standards should be met for all occupants of residential property. Some types of areas have not been classified, i.e. restaurants or places of entertainment, but common sense suggests the most appropriate classification - for example standards in a restaurant should be similar to those in residential property. It should be noted that certain entertainment areas in long span buildings present particular problems from self-generated vibration, such as that from dancing.

Hospitals have not been given more restrictive levels in general because there is some evidence that patients prefer to be in touch to some extent with the outside world, but operating theatres and laboratories should be considered as critical areas.

3.2.5 Measurement of vibration

The use of "root mean square" acceleration is recommended as the standard unit of measurement. If possible building vibration should be measured in acceleration terms, but in some cases it may be found necessary to measure in velocity or displacement due to equipment limitations. For these situations the vibration should be treated as sinusoidal and the appropriate correction factors, which are a function of frequency, used to transform either the measurement or the standard into compatible units.

In the case of impulsive vibration or shock the instantaneous peak value of velocity or acceleration is the preferred unit of measurement. A trace of the vibration should be obtained upon a suitable instrument and the peak level estimated. The motion should then be considered sinusoidal and the correction factors applied for the difference between peak and rms, and the frequency dependent factors used to transform either measurement or standard into compatible units.

If frequency analysis of the vibration is required, third octave filters are recommended. In certain circumstances it may be useful to analyse the vibration in terms of narrow fixed band width filters.

Measurement of vibration should be taken on the floor at the point of greatest amplitude, commonly found at mid-span. This should be close to the point of entry of vibration to the human subject. Measurement should be taken along the three orthogonal axes, and reference made to the appropriate human axis standard to determine whether limits have been exceeded. Alternatively the weighting network or combination curves (see Section 3.3.4) could be considered in relation to the worse case found.

In the case of impulsive shock caused by blasting, measurement may be made at the foundations to check for structural damage. It is also necessary to measure according to the technique given above in the areas of human habitation.

3.3 Characterization of Building Vibration and Acceptable Limits

3.3.1 Acceptable Limits.

All the following proposals are related to the recommendations for general vibration on humans given in Section 2. The presentation of information is in the form of a basic rating which is given for the most stringent conditions. From this basic rating a multiplication factor is then applied according to the tables for other more permissive situations.

The lowest basic rating has been defined in the area of the threshold of human perception. It is based upon research work completed up to the end of 1975.

Experience has shown in many countries that complaints of building vibrations in residential situations are likely to arise from occupants if the vibration levels are only slightly in excess of perception levels. In general the limits are related to the acceptance by the occupants and are not determined by any other factors such as short-term health and working efficiency. Indeed the levels are such that there is no possibility of fatigue or other vibration induced snydromes.

3.3.2 Head to Foot ("Z" Axis) Vibration Limits

For Z axis the recommended vibration values proposed by the standard is shown in Figure C-2. For frequencies between 4 Hz and 8 Hz the maximum acceleration (rms) is 5×10^{-3} m/s^2. At frequencies below 4 Hz the limit changes at 3 dB/octave. For frequencies greater than 8 Hz the limit increases by 6 dB/octave. For conditions other than the base curve a series of weighting factors apply and these are given in Table C-2. For example for residential property the weighting factor is two, hence at 4 to 8 Hz the maximum recommended rms acceleration for residential property by day would be 10^{-2} m/s^2.

3.3.3 Side to side or front to back (X or Y axis) vibration limits.

For X and Y axis human vibration a different base curve applies which is shown in Figure C-2. For frequencies from 1 - 2 Hz a maximum acceleration level of $3.6 \times 10^{-3} m/s^2$ will apply. At frequencies higher than 2 Hz the acceptable acceleration level will increase at 6 dB/octave. This means that for frequencies greater than 2 Hz a maximum rms velocity limit applies.

It will be noted that the standard for X or Y axis vibration is more severe than the Z axis case at low frequencies. This is due to the sensitivity of the human body towards sway at these low frequencies.

The table of weighting factors given in Table C-2 also applies to X or Y axis vibration.

3.3.4 Combined standard - recommended limits for undefined axis of human vibration exposure.

3.3.4.1 Worst case combination curve

In many situations the same building area may be used in both the lying and standing positions at different times of the day. If this is the case, then a combined Standard using the worst case combination of both the Z axis and X and Y axis conditions may be applied. This combination curve is shown in Figure C-2 and the same weighting factors given in Table C-2 still apply.

3.3.4.2 Proposed weighting network

The proposed standard also recommends a weighting network that closely approximates the combination curve. For routine measurement and evaluation of environmental vibration, this frequency weighting is recommended. The weighting function proposed for combined or random vibrations is given by:

$$G(J\omega) = \frac{1}{1 + \frac{J\omega}{11.2\pi}} \qquad \text{Eqn C-1}$$

where G (Jω) is the transmissibility of the filter, J represents the square root of -1, ω represents the exciting frequency.

This mathematical expression defines the electronic weighting filter of the low pass type. At low frequencies the transmissibility is zero, and at high frequencies attenuation is at 6 dB/octave. The corner frequency is 5.6 Hz.

Accuracy - ± 0.2 dB

TABLE C-2 Weighting Factors for Acceptable Building Vibration

Place	Time	Continuous or Intermittent Vibration & Repeated Impulsive Shock	Impulsive Shock Excitation with not more than 3 Occurrences per day
Hospital operating theatre & critical working areas	Day	1	1
	Night	1	1
Residential (minimum complaint level)	Day	2 3)	16
	Night	1.41	1.41
Office	Day	4 3)	128
	Night	4	128
Workshop	Day	8 3)	128
	Night	8	128

Weighting Factors above basic level of Curve shown in Figure C-2

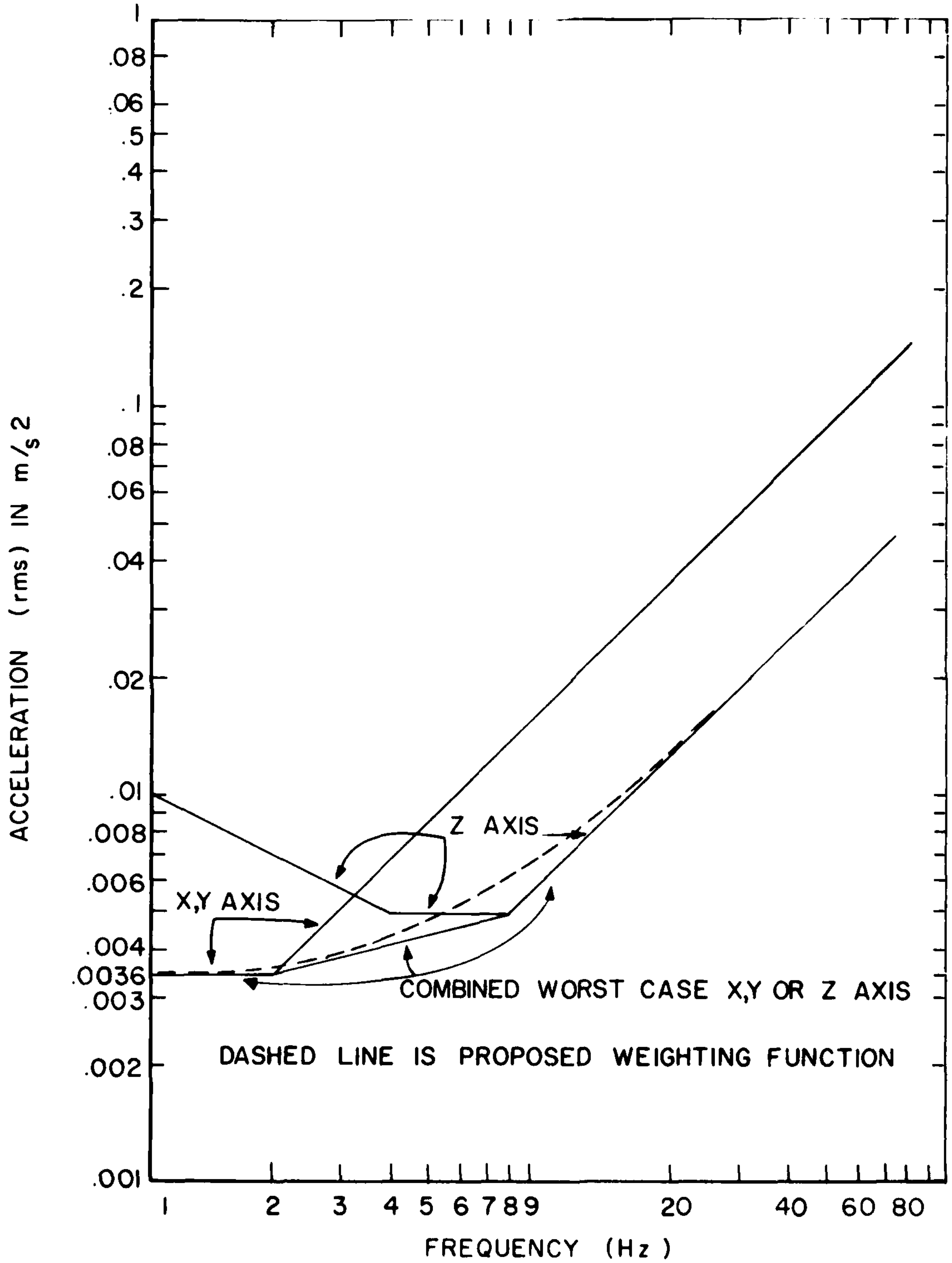


Figure C-2. Building vibration criteria for occupants in buildings. All curves are for hospital and critical working areas. See Table C-2 for proper scale factors.

Although the proposed standard recommends this function for preliminary investigations, for practical evaluations of the overall environmental impact of vibration on a community, the weighting function is a necessary and useful simplification, especially with respect to residential areas, that is not expected to introduce any significant errors.

4. Structural Damage from Building Vibration. (Summary of 1976 draft standard ISO/TC 108/SC 2/WG3

4.1 General considerations.

The proposed standard discusses the following general considerations:

Vibration in buildings (dwellings, offices, public buildings and factories) is of increasing general importance, especially since the distances between industrial areas with vibration exciting machines, blasts or other vibration sources and residential areas are decreasing. Traffic on roads and railroads also causes vibration troubles in nearby buildings.

Various methods of rating the severity of vibration in buildings and defining limits based on laboratory or field data have been developed in the past. However, none of these methods can be considered applicable in all situations and consequently none have been universally accepted.

In view of the complex factors required to determine the response of a building due to vibrations and in view of the paucity of quantitative data, this proposed Standard was prepared, first to facilitate the evaluation and comparison of data gained from continuing research in this field; and, second, to give provisional guidance as to acceptable values to avoid the risk of damage. The limits proposed are a compromise of available data. They satisfy the need for recommendations which are simple and suitable for general application. These limits are defined explicitly in numerical terms to avoid ambiguity and to encourage precise measurement in practice.

If the characteristics of the excitation vibration are known in relation to the severity, position and direction of the building response - this may be the case if the source of the vibration is within the building - and if the parts of the buildings or the whole building influenced by the vibrations can be idealized by a model, then it may be possible to estimate the severity of the dynamic stresses by calculation.

If vibrations are transmitted via the ground and the foundation into a building, it may be possible to estimate dynamic stresses based on vibration measurements.

In addition to simple vibration there may be other factors which influence vibration response (foundation conditions, dilatation due to temperature etc.) and which result in damage to buildings. No general method exists at present to take account into all such factors.

4.2 Categories of Damage.

The proposed standard provides several phases of damage which can occur, namely:

Category 1:

Threshold damage consists of visible cracks in non-structural members such as partitions, facings, plasterwalls (e.g. loose of mortar between pantiles etc.). As a guideline visible cracks may be taken as those of a width of 0,02 mm.

Category 2:

Minor damage consists of visible cracks in structural members such as masonry walls, beams, columns, slabs and no serious reduction in load carrying capacity.

Category 3:

Major damage consists of large permanent cracks in non-structural and structural members; settlement and displacements of foundations which may result in reduction of load carrying capacity.

The proposed standard applies chiefly to damage as described in categories 1 and 2. The limits of vibration specified in the standard were selected to avoid the exceeding of the threshold of damage, but does include data for estimating damage levels.

4.3 Measurement.

4.3.1 Frequencies

The proposed standard recommends the following frequency ranges:

1. In the case of vibration caused by shock and quarry blasting and the steady vibration of whole buildings: from about 1 Hz to about 100 Hz.

2. In the case of steady vibration of parts of a building, especially floor and wall vibrations: from about 10 Hz to about 100 Hz.

4.3.2 Measurement points

The standard recommends that for vibration caused by shock, especially quarry blasting, should be measured on the foundation structure parallel to its stiff-axes below ground level.

In only special cases are measurements of the floor vibration in vertical direction and the horizational vibration of the whole building recommended. When such floor vibration measurements are made, they should be made in a matter similar to that of section 3 of this appendix.

In the case of steady vibration (e.g. floor vibration, the vibration peak velocity v_{max} at the place of highest amplitude shall be determined. In floor vibration it is often the midspan, for whole building vibration it is often the upper floor in horizontal direction.

4.3.3 Measurement quantity.

Vibration can be measured by displacement, velocity or acceleration. It is desirable to measure the quantity that is most simply and generally related to damage as described below. While for steady vibration the proposed standard provides curves related to velocity from 10 Hz to 80 Hz (Figure C-3), it can be seen that for the frequency range of 10 to 80 Hz, acceleration as weighted by the function in Chapter 3 is for all practical purposes a measure of velocity. Plotting the weighted acceleration against actual blast damage data, see Figure C-4, the weighted acceleration provides a very reasonable fit to the data for frequencies below 10 Hz. For these reasons, the use of the weighted acceleration is proposed in the main sections of these guidelines for assessment of impact due to annoyance of building occupants and building damage.

For shock the proposed standard recommends using the vector sum of the maximum velocity along a set of orthogonal axis. The maximum velocity along an axis is that measured at any time during an event. Such an approach will be slightly more conservative than only using the maximum weighted acceleration along the worst case axis. However, the differences between the two approaches is not expected to be great (at the maximum they can only differ by a factor of the square root of 3.

4.4 Vibration boundaries with respect to damage categories.

4.4.1 Vibration caused by shock

In determining criteria for the onset of vibration damage to buildings, the proposed standard indicates a number of factors which can be effect the results which are recorded.

These include

- nature of the soil, clay, or rock, etc.
- stiffness of the building structure
- nature of the vibration, i.e. transient, intermittent, continuous, vertical, horizontal, etc.

With these uncertainties in mind, the proposed standard provides recommendations as to the maximum velocity to prevent damage for each of the three categories. These velocities are listed in Table C-3.

Table C-3

Limiting values of the vector sum of the maximum velocities (in three orthogonal axis) caused by quarry-blasting-vibration in dwellings and offices in good physical conditions

Category of Damage (See Section 4.2)	range v_R, onset of damage, in mm/s
1	3 . . . 5
2	5 . . . 30
3	100

These values are based on measured foundation vibration in the frequency range from about 3 Hz to about 100 Hz.

The standard cautions that:

(1) In the range between 30 mm/s and 100 mm/s the available data is not sufficient to define the nature of the damage without regard to the condition, type of structure and foundations.

(2) The limits apply only where differential settlement of the structure has not been excessive.

(3) Special consideration shall be given where buildings are situated on a slope or on soils which may be compacted or liquified by vibration.

(4) When large dynamic displacements are found to exist in the whole building or part of it then in addition to the recommended measuring points at the foundation additional measuring points located in the structure shall be used for the evaluation of potential building damage.

The standard recommends that the limits specified in Table C-3 be used for the evaluation of vibration effects caused by pile drivers and foregoing hammers when the time interval between two succeeding blows is so large that the vibration of the building due to one blow dissipates before the effects of the succeeding blow are observed. Dissipation is regarded as effective when peak particle velocities have decayed 1/5 from their maximum.

The standard proposed that the values specified in Table C-3 may also be used to evaluate the effects of vibration in buildings caused by traffic; however, when shakers and vibration pile drivers are the source of building vibration, the values given in Table C-3 should not be applied.

Finally, the standard recommends that for the evaluation of transient response of floors and walls, the vibration limits given for steady state vibrations may be used in a modified form. When there is no danger of fatigue the limits and values given in Figure C-3 may be increased by a factor of 2.

4.4.2 Steady vibration of buildings.

For steady building vibration, Figure C-3 summarizes the peak velocity boundaries between the different categories of damage.

4.5 Comparison of the recommendation of the proposed standard to the recommendations of the Section VI of these guidelines.

The proposed standard recommends that 6 mm/s (5 to 30 mm for shock) be considered as the upper limit of the threshold of damage. These velocities are considerably lower than the 2 in/sec (50.8 mm/sec) that has been commonly used in this country. Based on studies such as those shown in Figure C-4, reducing the threshold from 50 mm/sec to 5 mm/sec does not appear warranted, however, reduction of the threshold by a factor of 2 does seem reasonable. All of the data points of Figure C-4 will be covered by use of a velocity of 1 in/sec and it is this velocity that is recommended in the main EIS guidelines. Use of a weighted acceleration of 0.5 m/sec^2 is consistent with this velocity and is recommended.

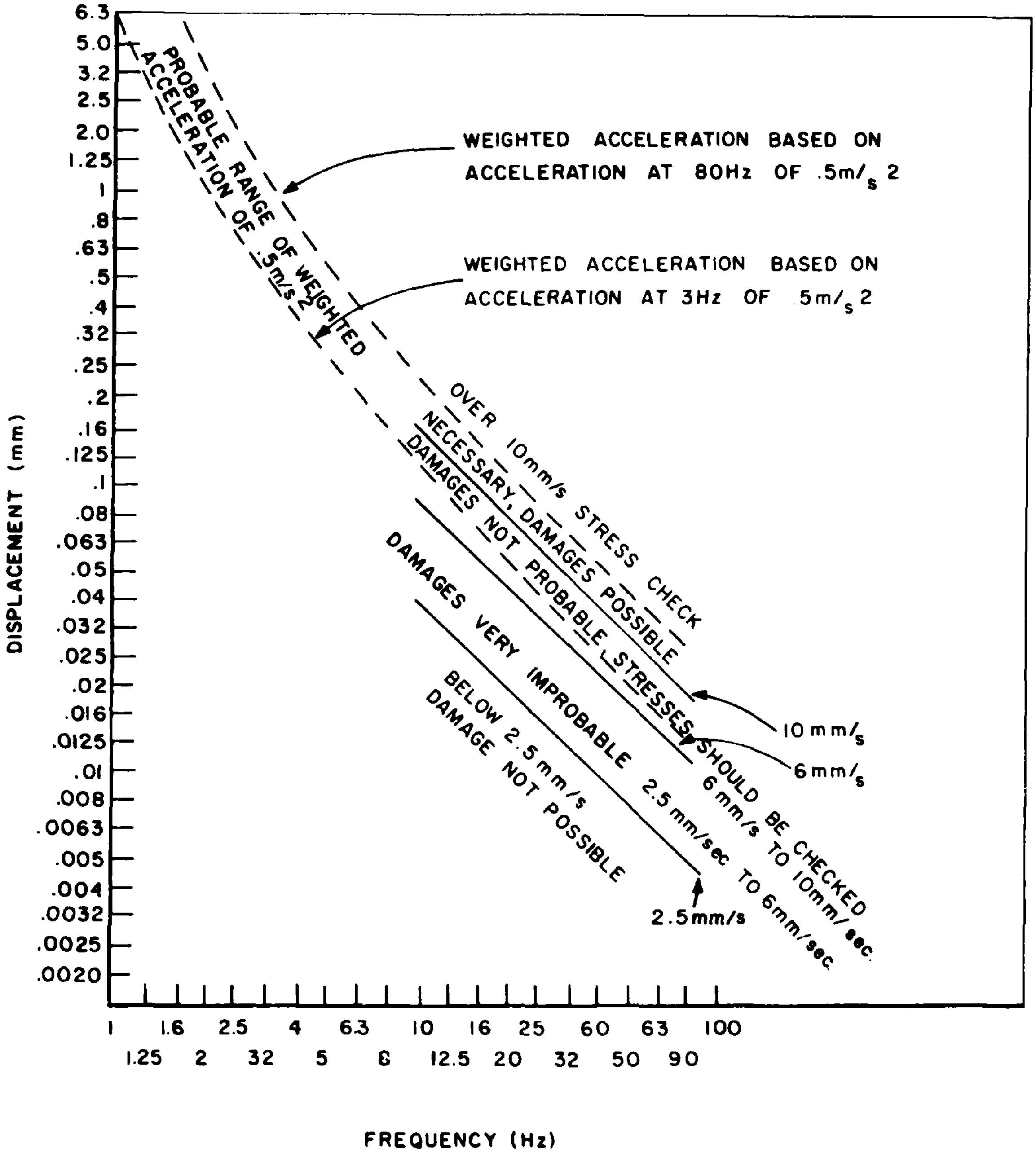


Figure C-3. Rough evaluation of vibrations of stationary floor vibrations by measurement of vibration displacements amplitude and frequency

Note: Amplitude is here the maximum absolute value of the displacement of the floor undergoing harmonic motion.

BLASTING VIBRATIONS AND THEIR EFFECTS ON STRUCTURES

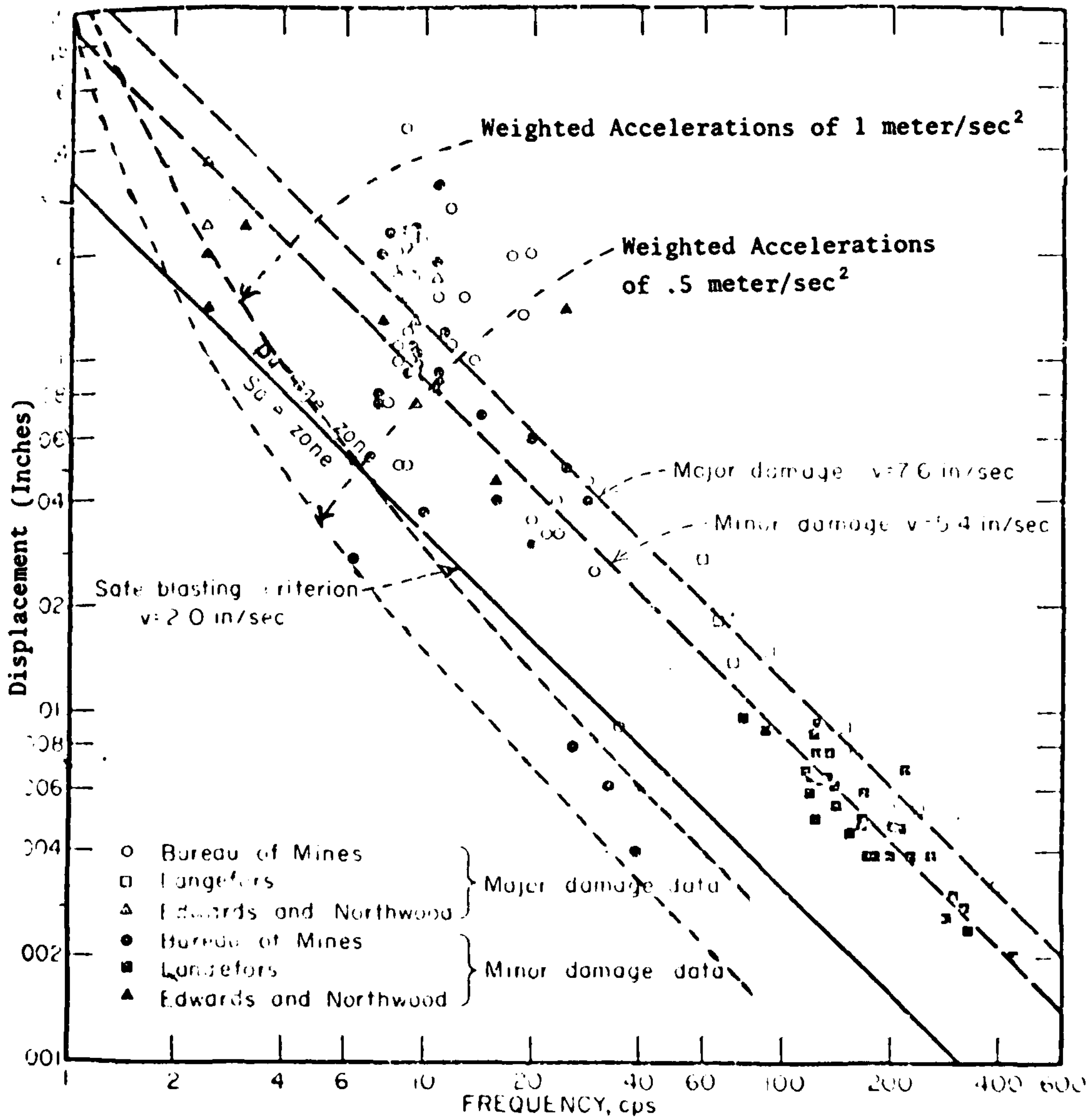


FIGURE C-4 - Displacement versus frequency, combined data with recommended safe blasting criterion.

Adapted from Bureau of Mines Bulletin 656.

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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13 ABSTRACT

Guidelines are proposed for the uniform description and assessment of the various noise environments potentially requiring an Environmental Impact Statement for Noise. In addition to general, audible noise environments, the report covers separately high-energy impulse noise, special noises such as ultrasound and infrasound, and the environmental impact of structure-borne vibration. Whenever feasible and practical, a single-number noise impact characterization is recommended, based on the new concept of level-weighted population: i.e., the summation over the total population of the product of each residential person times a weighting factor that varies with the yearly day-night average sound level outside the residence of that person. A sound-level weighting function for general impact and environmental degradation analysis is proposed, based on the average annoyance response observed in community response studies; this weighting function is supplemented by an additional weighting function at higher noise environments to quantify the potential of noise-induced hearing loss and general health effects. The evaluation of the environmental impact of vibration is derived from existing or proposed ISO standards. The report explains and justifies the procedures selected and gives examples of their application.

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