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A BASIS FOR LIMITING NOISE EXPOSURE FOR HEARING CONSERVATION

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13. ABSTRACT

A compilation of data is provided, with references to published work, which represents the present state of knowledge concerning the effects of continuous and impulsive noise on hearing. The danger to the ear of both occupational and non-occupational human exposure to noise is considered. Data are included or cited which enable quantitative predictions to be made of the risk to hearing in the American population due to noise exposure in any working or living context. Recommendations are made concerning the need to obtain more definitive data. Relevant aspects of noise measurement, the physiology of hearing, and theories explaining the effects of noise on the ear are discussed in appendices to the main report. This report deals solely with the effects of noise on hearing; other physiological or psychological effects of noise are not considered in the present document.

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PREFACE

The Biodynamics and Bionics Division of the Aerospace Medical Research Laboratory was given the responsibility, under an Interagency Agreement with the Environmental Protection Agency, to develop a document which would serve as a basis for limiting noise for hearing conservation. The preparation of this document was accomplished by the University of Dayton Research Institute (UDRI) under Contract F33615-72-C-1402, P00003. The Aerospace Medical Research Laboratory efforts in support of this project were included under Project 7231-03-16, "Auditory Responses to Acoustical Energy Experienced in Air Force Activities". Dr. J. C. Guignard and staff of UDRI compiled the main document, Appendices 1 through 11 and the Bibliography.

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Various material was provided by the consultants for incorporation into the document. Dr. J. H. Mills prepared the material for Appendix 12. Dr. Karl D. Kryter provided a paper, "Impairment to Hearing from Exposure to Noise", that has since been published in the May 1973 issue of the Journal of the Acoustical Society of America. For this reason Dr. Kryter's material has not been republished as part of this document. Dr. Daniel L. Johnson prepared supporting material, "Prediction of NIPTS Due to Continuous Noise Exposure", which will be published as a separate technical report identified as AMRL-TR-73-91 and EPA-550/9-73-001-B. Material was initially provided by the National Institute of Occupational Safety and Health (NIOSH). However, that material has not yet been released by NIOSH for publication. It is to be published in 1973 as NIOSH Technical Report TR 86, "NIOSH Survey of Occupational Noise and Hearing: 1968 to 1972" by Mr. Barry L. Lempert and Dr. Terry L. Henderson. In addition, Dr. William L. Baughn provided his work, "Relation Between Daily Noise Exposure and Hearing Loss Based on the Evaluation of 6,835 Industrial Noise Exposure Cases". This is available as AMRL-TR-73-53 or EPA-550/9-73-001-C.

At the University of Dayton, Miss Barbara McKenna assisted in the initial literature search and typed most of the preliminary draft. Miss Barbara Hartung assisted in completing the bibliography and typed the major part of the final report and its appendices.

This technical report is also identified as UDRI-TR-73-29.

CONTENTS

BACKGROUND

Good hearing is one of the most important of human senses. When it is lost or seriously impaired, one is not only disadvantaged socially but may be robbed of much potential as a wage-earner: handicap due to hearing loss is for many people as tragic as a disability resulting from major injury or serious illness, reducing the person's capacity to enjoy life to the full and to follow unfettered his or her chosen trade or profession.

Rarely, the hearing is deficient from birth or following a childhood illness; or it may be damaged during adult life by head injury or by disease affecting the ear or its connections with the brain. Moreover, some loss of sensitivity of hearing, particularly for high tones, is experienced by all adults as they grow older. This phenomenon (presbyacusis), the onset and progress of which shows considerable individual and demographic variation, is generally accepted to be a normal consequence of the human aging process, and to take place whether or not the ear is affected by disease, injury or noise.

Nevertheless, the most prevalent and avoidable cause of hearing loss is excessive noise exposure. Observations in animals as well as in man show that noise of sufficient intensity reaching the inner ear injures the hearing organ (the organ of Corti). The principal site of injury appears to be the hair cells of that organ. As the intensity of the noise and the time for which the ear is exposed to it are increased, a greater proportion of the hair cells are damaged or eventually destroyed. Because the function of the hair cells is to transduce the mechanical energy reaching the ear into electrical signals, which are then carried by the auditory nerves to the brain, progressive loss of hair cells is usually accompanied by progressive loss of hearing.

There is a great deal of individual variation in susceptibility to noise damage. However, any man, woman, or child whose unprotected ears are exposed to noise of sufficient intensity is in the long run likely to suffer some degree of permanent noise-induced hearing loss for which there is no foreseeable cure.

What constitutes a harmful level of noise depends on the effective duration of the noise exposure and the circumstances. Generally speaking, the greater the sound pressure level of the noise, the greater the danger to the unprotected ear, and the shorter the safe noise exposure time. In extreme cases, a damaging exposure to impulsive noise may be as brief as a few milliseconds: a few unfortunate young people are reputed to have suffered irreparable damage to their hearing from the sound of a few rounds of small-arms fire during their first day at the ranges. At the other end of the scale, prolonged exposures to comparatively moderate levels of noise, of the kind to be heard, for example, in factories, in vehicles, or in busy city streets, can cause hearing loss developing over the years in substantial numbers of susceptible people.

It remains an open question whether there is any absolute level of noise below which continuous exposure may be considered completely harmless for all ears. In this connection, it is important to bear in mind the fact that neither the loudness of a noise, nor the extent to which the noise causes discomfort, annoyance, or interference with human activity, are reliable indicators of its potential danger to the hearing mechanism. A noise loud enough to prevent verbal communication may be presumed to be hazardous to the ear, but the converse is not necessarily true.

Hearing damage can cause social problems, depending upon the severity of the loss. Such problems include difficulties with everyday communication and social integration, the pursuit of preferred employment, and for young people with hearing damage, education (Switzer and Williams, 1967).

The prevalence of hearing loss among workers in noisy industries has been recognized since ancient times; and a popular description of excessively loud noise is "deafening". Yet it is still not adequately appreciated by the general public that there is a causal link between noise exposure and hearing loss. If the hazard is understood, it is perhaps regarded by many people as a remote contingency, or as one having little consequence for those afflicted. It is possible, too, that while people exposed to intense noise frequently experience a substantial noise-induced temporary threshold shift (NITTS), sometimes accompanied by tinnitus (ringing in the ears), the fact that very often such symptoms of excessive noise exposure largely disappear within a few hours, if not minutes, may mislead the hearer into believing that no permanent damage is done by noise.

Clinical observations of noise-induced hearing loss have been reported over more than a century. However, the problem has received intensive study only during the past three or four decades. Since the second world war, substantial information has been gathered on the effects of noise (particularly industrial noise) upon the ear. Based variously upon the available data, numerous noise exposure limits have been established for the purpose of hearing conservation. Some of these have received national or international acceptance or standardization and some have been embodied in state legislation. An important present difficulty for the legislator, administrator or noise control engineer concerned with protecting human hearing against noise, however, is the fact that confusing and sometimes conflicting guidance is offered by the multiplicity of official or semiofficial standards, regulations or guidelines now in existence. In a recent review, Acton (1967) reported that at least 35 different hearing damage risk criteria, noise exposure limits or guidelines had been adopted or proposed by various authors.

Clearly, there is an urgent need for unification, which this document attempts to meet. It presents a current consensus of the majority of scientific opinion as to the incidence of noise-induced permanent threshold shift (NIPTS) to be expected in selected fractions of the American population. The conclusions reached in this report apply to both occupational and non-occupational exposure at work, in the home, in transportation, in recreation, or at large in the street and other public places.

The arrangement of this report is as follows: Section I (introduction) briefly sets out its main purposes and defines its scope. It is important to note in this connection that the present document deals only with the effects of noise on hearing: it is not concerned with annoyance or other adverse effects of noise. Section II presents some definitions crucial to the interpretation of the data given in the main sections which follow. Section III provides specific guidance to the selection of noise exposure limits for the purposes of hearing conservation. Section IV reviews certain factors influencing the incidence of NIPTS due to noise of a given type and exposure level. Section V contains some recommendations concerning the need for further research and field observation on noise-induced hearing loss, including the monitoring of the noise exposure and the hearing of the public; and concerning ways and means of increasing public awareness of the noise hazard and of promoting a wider acceptance and implementation of hearing conservation programs.

I. INTRODUCTION

I.1 Purposes of document

The goal of this document is threefold: (1) it attempts to arrive at a consensus (summarized in Section III) regarding the effects of noise exposure upon human hearing; (2) it evaluates the principal factors affecting the incidence of noise-induced hearing loss in various populations (Section IV); and (3) it makes recommendations (Section V) concerning noise exposure levels for the purpose of hearing conservation. Detailed treatments of relevant topics are given in the Appendices.

I.2 Scope of document

I.2.1 Population. While the principal findings here reported apply mainly to healthy adult American men and women of working age, having normal ears and hearing, some information is incidentally provided about noise exposure and hearing in children, in the aged, and in persons with abnormalities of the ear. "Normal hearing" is discussed in Appendix 2.

I.2.2 Varieties of noise. Data on their effects on hearing are presented for two main types of noise, namely, continuous and impulsive noise. These varieties of noise are further distinguished and defined in Sections II and III. "Noise" means airborne sound contained within the frequency range 16 Hz to 20,000 Hz (20 kHz). Oscillations outside that range (ultrasonics; infrasonics; vibration) are also considered briefly, inasmuch as they may affect the ear.

I.2.3 Ultrasonics; infrasonics; vibration. Appendix 10 provides information on the relatively minor auditory effects of ultrasound, infrasound and vibration.

I.2.4 Quantification of noise exposure. Although some other noise-measurement units are alluded to, this document in general adopts A-weighted sound level (in dBA) for the specification of continuous noise exposure levels; and peak sound pressure level (SPL) in decibels (dB) relative to the international standard reference zero of 0.00002 N/m^2 for impulse noises. When A-weighted sound levels are given in dBA, the use of international standard measurement techniques, instrumentation and weighting characteristics is assumed. Relevant standards are listed at the end of the Bibliography. Procedures for calculating equivalent continuous sound level (L_{eq}) in dBA, in the cases of untypical, interrupted or intensity-modulated steady-state noise exposure (see Section III.A) are given in Appendix 8. Appendix 8a may also be used to determine exposures in dBA from octave-band sound levels measured in decibels relative to 0.00002 N/m^2.

I.2.5 Measurement of hearing. When referred to in this document, hearing level or hearing threshold level (see definitions in Section II) is generally presumed to be, or to have been, determined by pure-tone audiometry using standardized instrumentation and procedures (see Appendix 6). Noise-induced permanent threshold shift (NIPTS) is defined as that part of hearing level ascribable to noise exposure, as opposed to other factors, such as aging, which also cause an elevation of the threshold. It should be borne in mind that hearing or hearing threshold level in decibels is customarily an average or a median value for a designated population or group of individuals and that, accordingly, a variance is implicitly associated with it. Sources of audiometric variance are discussed in Appendix 6.

I.2.6 Reference to noise-induced temporary threshold shift (NITTS) and tinnitus. The temporary effects of noise on hearing are frequently mentioned in some parts of this document and are discussed in some detail in Appendices 7 and 12 and by Johnson (1973) and Kryter (1973). The relationship between noise-induced temporary (NITTS) and permanent (NIPTS) threshold shift is still not entirely clear; however, it is generally agreed upon by most workers in this field that NITTS is a useful predictor of NIPTS in many circumstances of noise exposure. A presumptive relationship between them underlies many existing schemes for predicting the effects of exposure to noise, both continuous and impulsive.

I.2.7 Non-auditory physiological, psychological, and nuisance effects of noise. This document deals solely with the effects of noise on hearing. It does not provide data nor does it make recommendations concerning the limitation of noise exposure according to criteria other than those of hearing conservation.

II. DEFINITIONS

II.1 Definitions and Glossary

This section contains some definitions of important terms used later in the document. A more comprehensive Glossary of acoustical terms germane to the present work is given in Appendix 4.

II.2 Audible range (frequency range of human hearing)

The frequency domain of human hearing by air conduction may be taken as extending from 16 Hz to 20,000 Hz and to be contained between a lower boundary, namely, the threshold of audibility (see Glossary), and the upper boundary, namely, the threshold of pain in the ear. The threshold of audibility depends heavily upon frequency and has received international standardization (ISO, 1964).

II.3 Continuous noise

On-going noise which lasts for at least 500 ms, and which may last indefinitely, of which the level either does not vary by more than ±5 dB (constant or "steady-state" noise) or does not vary more rapidly than 40 dB in 500 ms in the case of level variations exceeding ±5 dB (fluctuating noise). Continuous noise which is interrupted by periods of subjective silence, or by periods of noise at levels below 55 dBA, may be described as intermittent noise (see Section III.A). Some examples of different kinds of continuous noise exposure are given in Table II.I.

II.4 Hearing level

In this document, hearing level means the difference in decibels between an individual or a group threshold of hearing (measured with a puretone audiometer at a specified test frequency or frequencies) and a specified standard reference zero, which is a function of audiometric frequency.* Positive values mean (as is usually the case) an elevation of threshold (poorer hearing). When hearing level is defined for a group the median and related centile values are customarily specified.

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* Strictly speaking, "hearing level" (HL) relates to ASA 1951, whereas a level related to ISO:1964 or ANSI:1969 should properly be called "hearing threshold level" (HTL). "Hearing level" is however an acceptable usage provided that the reference zero is clearly specified.

Table II-I. Varieties of continuous noise exposure.

Variety of Exposure	Description	Typical Examples
Steady-state	Single continuous daily exposure (typically 8 hours but may be shorter or longer) at a level constant within ±5 dBA.	Steady plant noise in factories. Steady urban noise. Sound of a waterfall. Shipboard noise. Noise inside vehicles or in aircraft in flight.
Fluctuating Noise	Noise is continuous but level rises and falls (rapidly or gradually) more than ±5 dBA during exposure.	Many kinds of processing or manufacturing noise. Traffic noise. Airport noise. Many kinds of recreational noise (eg, vehicle-racing; powered lawn-mowing; radio and TV).
Intermittent	Noise is discontinuous: ie, the level falls to immeasurable low or to non-hazardous levels between periods of noise exposure of which more than one affects the ear during the day. Note:this can be regarded as a special case of fluctuating noise (see Section III.A.3).	Many kinds of industrial noise (especially in construction work, shipbuilding, forestry, aircraft maintenance, etc.). Many kinds of recreational noise (eg, drag-racing; rock concerts; chainsawing). Light traffic noise. Occasional aircraft flyover noise. Many kinds of domestice noise (eg, use of electric appliances in the home). School noise.

II.5 Hearing risk

According to Robinson (1971) hearing risk is "that percentage of the population whose hearing level, as a result of a given influence (e.g., noise; age; pathological conditions of the ear) exceeds a specified value, minus that percentage whose hearing level would have exceeded the specified value in the absence of that influence, other factors remaining the same". Procedures for estimating risk due to noise exposure are given in Section III.

II.6 Impulsive noise

Impulsive noise in this document means intense transient noise of short duration (less than 500 ms), rapid growth (more than 40 dB in 500 ms) and often rapidly changing spectral composition (cf. steady-state noise). Two main types (A and B) are described (see Section III.B and Appendix 5). Typical sources of impulse noises are the discharge of firearms, hard impacts in industrial processes, shot-firing in mining or quarrying, and sonic boom.

II.7 Noise-induced permanent threshold shift (NIPTS)

The amount in decibels by which a hearing or hearing threshold level is permanently elevated as a result of noise exposure. It is assumed to be an addition to the increase in hearing level ascribed to aging or, in some individuals, otological causes. (The term noise-induced hearing loss is sometimes used loosely as a synonym.) See the definition of permanent threshold shift below.

II.8 Permanent threshold shift (PTS)

A permanent (irreversible) change in hearing level. It is measured in decibels at specified audiometric test frequencies or groups of frequencies.

II.9 Presbyacusis*

Permanent threshold shift (elevation), chiefly involving the higher audiometric frequencies above 2000 Hz but ultimately involving lower frequencies also, ascribed solely to advancing age (see Appendix 3). Note, it is presumed ultimately to affect all ears, regardless of otological health or noise exposure.

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* An alternate spelling, presbycusis, while etymologically incorrect, is in common use.

In otologically normal individuals or groups of specified age, standardized values (ISO, 1964) may be subtracted from measured or predicted hearing level in order to determine or estimate NIPTS. The term may also be applied to other manifestations of age-related loss of auditory efficiency, such as impaired discrimination of speech in noise.

II.10 Sociacusis

Permanent threshold shift ascribed to frequently unavoidable acoustic influences in the environment (e.g., urban noise) and not due either to aging or to occupational noise exposure. Loosely, non-occupational NIPTS.

II.11 Speech frequencies

Those audiometric test frequencies at which good hearing is held to be essential to spoken communication. Opinion is divided as to which frequencies should be so designated. Commonly, in clinical audiology (and notably in industrial practice in the United States), the determining frequencies, originally recommended by the American Medical Association, are 500, 1000 and 2000 Hz (see Appendix 1). In some foreign countries and in the state of California, hearing at 3 kHz is included in the assessment. Recent opinion argues strongly for the recognition of 4 kHz also as crucial to full speech reception, and especially to speech discrimination in a noisy background. When using the term "speech frequencies", therefore, it is important to specify tham numerically.

III. EFFECTS OF NOISE ON HEARING

III.A Continuous noise

III.A.1 Definition and varieties of on-going "continuous" noise

To most people "noise" means unwanted sound of a noticeable if not objectionable intensity which goes on for an appreciable time (seconds to hours), such as factory or office noise, or noise which is continuously or regularly present in the living environment such as traffic noise. When the quality and the intensity of the noise is practically constant (varying less than ±5 dBA) over an appreciable time (seconds or longer), it is often called "steady-state" noise. The use of that term implies that certain parameters or statistical properties of the noise do not change significantly over the interval of measurement or description: and such an assumption underlies the use of measurement techniques (including the use of sound level meters) based upon time-averaging the sound pressure at the measurement point. Continuous noise must be distinguished from the other main type of noise affecting man and the ear, namely, impulsive noise, which is defined and discussed in Section III.B below.

III.A.1.1 Temporal patterns of continuous noise. For descriptive and analytical purposes, continuous noise is, as a first approximation, assumed to be strictly steady-state, that is, to continue at a constant level (expressed in dBA), without interruption, for a designated daily exposure time. It is convenient to consider a typical industrial daily exposure of 8 hours, because such an exposure is suffered daily by millions of ears in the processing and manufacturing industries. Most of our knowledge of the effect of continuous noise upon the human ear comes from industrial audiological experience, as is brought out below, in Appendix 7 and in Johnson (1973). More ears are at risk from quasi-steady-state noise exposures of about 8 hours a day, 5 days a week for a working lifetime than from any other variety of noise exposure.

III.A.1.2 Non-steady-state (fluctuating or intermittent) continuous noise. Many ears are exposed at work, in transportation, or in supposedly resting or recreational periods to a variety of noises which are not continuous or which vary in intensity. Some varieties of non-steady-state exposure were summarized, with examples, in Table II.I in Section II. For purposes of evaluating the hazard of such noise to the ear, it is in many circumstances appropriate to determine an equivalent continuous sound level for fluctuating or intermittent noise. A computational procedure for carrying out this "noise-averaging" technique is referred to in Section III.A.3 below and a method set out in Appendix 8.

III.A.1.3 Relationship between on-going noise and hearing loss. There is a plethora of published information about the effects of long-term noise exposure upon the hearing of workers in the manufacturing and construction industries, as well as that of aviators and others in noisy occupations: several recent monographs and surveys have been published on this topic (Burns, 1968; Burns and Robinson, 1970; King, 1972; Kryter, 1970; Robinson, 1971). A recent survey by the National Institute of Occupational Seafety and Health (1972) contains a descriptive summary of some of the more important audiometric surveys carried our in the United States and abroad during the preceding decade. Certain important work, providing the basis of the conclusions reached below in the present document, is discussed in some detail in Appendix 7; cognate work is presented in Johnson (1973), Kryter (1973) and Mills (Appendix 12).

Temporary hearing loss (or noise-induced threshold shift, NITTS), lasting from a few seconds to several days or weeks can result from brief exposure to high sound levels or from day-long exposure to more moderate levels of continuous noise. Regular (day-by-day) exposure to such levels over a long period (days to years) can result in damage to the inner ear, associated with a sensorineural hearing loss (NIPTS) which is permanent and, so far as is presently known, incurable. It can only be prevented by protecting the ear from excessive noise exposure.

NIPTS is usually preceded by, and may at any time be accompanied by, a NITTS attributable to fatigue of the hearing organ. The typical pattern seen in the audiogram is a maximum loss in the range 4000 to 6000 Hz, with a somewhat smaller loss (initially) at the higher test frequencies. Because the loss is sensorineural, it is seen in both air- and bone-conduction audiograms.

III.A.1.4 Tinnitus associated with occupational NIPTS. Tinnitus (ringing in the ears) may be, at first, the only symptom in many cases of occupational hearing loss; and it is fairly frequently associated with the condition. Chadwick (1970) has reported an incidence of 30% in one industrial survey in Britain. Tinnitus is not necessarily diagnostic of noise-induced damage to the ear, however, for the symptom is also associated with other disorders of the ear or auditory nervous system, unrelated to noise exposure.

Chadwick (1970) has also commented that many patients with occupational NIPTS notice new symptoms only upon changing from one noisy job to another; or from a noisy job to a quiet one, possibly because they have adapted to or learned to cope with any handicaps due to the noise in a familiar situation.

III.A.1.5 Relationship between daily occupational (8-hour) exposure to steady-state noise and NIPTS. The following paragraphs refer to procedures for predicting the risk or amount of hearing loss to be expected from occupational-type noise exposure. The predictive data summarized here in Section III.A and used by Johnson (1973) are derived from an international triad of studies in the field of industrial noise-induced hearing loss, namely, the work of Baughn (1966, 1973), Passchier-Vermeer (1968, 1971) and Robinson (1968, 1971). These methods may be used to predict the effect upon hearing at selected centiles of the adult population of daily 8-hour exposure to steady-state distributed noise at levels in the range 75 to 90 dBA, sustained over periods up to 50 years. Further details of industrial audiological experience and related research germane to this section are given, with references, in Appendix 7 and in Johnson (1973). The three predictive methods summarized in the following paragraphs have been selected because (1) they permit calculation of NIPTS for designated percentiles of the adult population; (2) although they are based mainly upon the audiometric test frequencies 500, 1000 and 2000 Hz ("speech frequencies") currently accepted as essential to the evaluation of hearing impairment by most otologists in the United States, they also include data permitting the inclusion of 4000 in the assessment; and (3) they show fair agreement with one another. These aspects are considered in detail by Johnson (1973).

III.A.1.6 Method and data of Passchier-Vermeer (1968; 1971). Passchier-Vermeer (1968; 1971) has analyzed the audiometric data from several surveys of industrial hearing loss. Making allowances for presbyacusis, she has published (1968) procedures with graphs for determining the noise-induced part of hearing level evaluated as a function of daily noise expsoure for the 25th, 50th and 75th centiles of a working population. In 1969 and 1971, she published some additional data including 10th and 90th centile estimates. Her methods and results, which are applicable to daily 8-hour exposures to industrial-type noise up to 100 dBA, are summarized in Appendix 7 and discussed in Johnson (1973). Appendix 7 also contains an explanation of certain approximations (such as those used to obtain 10th and 90th centile values) and extrapolations introduced in that Appendix to the present document.

III.A.1.7 Method of Robinson (1968; 1971; Robinson and Cook, 1968). Robinson has devised an idealized method for predicting hearing loss resulting from noise exposure. His method is based on a unique mathematical relationship (the hyperbolic tangent) between noise exposure and NIPTS, which is adjusted parametrically for population centile and audiometric frequency. The method applies to otologically normal adults exposed to industrial noise for 8 hours per day over a period ranging from 1 month to 50 years. It yields estimates of the percentages of the exposed population who may develop NIPTS as a function of noise exposure (noise "immission"). Robinson's method can be criticised on the grounds that it is based upon a single although substantial study of otologically screened British industrial workers*; and that the mathematical niceness of the predictive theory may not be entirely justified by the realities of industrial audiometric data and their sources of variance. Robinson's (1971) specific definition of "risk" (to hearing) was defined in Section II above. His predictive method and certain modifications of it are described in more detail in Appendix 7 and Johnson (1973).

III.A.1.8 Method of Baughn. Baughn (1966, 1973) has amassed data from extensive industrial audiometric studies in the United States. His work provides insight into how NIPTS develops at various centile points as a result of typical industrial noise exposure in the range 78 to 92 dBA. The prediction of NIPTS may in some respects be too high, however, owing to a probable contamination of the data by residual TTS and masking in the circumstances in which the audiometry was conducted**.

III.A.1.9 Averaging NIPTS predictions over the three "industrial" methods. A summary chart of certain predictions which can be made concerning NIPTS and risk by combining the predictions of Baughn, Passchier-Vermeer and Robinson (see Johnson, 1973) is presented in Table III.A-I. More detailed tables in that report show NIPTS predicted using the three methods for continuous noise levels in the range 75 to 90 dBA. Johnson (1973) also provides a further explanation of the rationale and method adopted to yield these averages. A brief explanation of the terms used in Table III.A-I is given below.

III.A.1.10 Calculation of speech impairment risk (SIR). Kryter (1973) has proposed an alternate method for evaluating noise exposure in terms of speech impairment risk. The method leads to a generally more pessimistic view of noise hazard than the predictive methods outlined above. Critical comment on Kryter's proposal has received simultaneous publication (Cohen, 1973; Davis, 1973; Lempert, 1973; Ward, 1973). See also Johnson (1973).

III.A.1.11 Evaluative parameters of NIPTS.

(1) Maximum NIPTS (90th percentile). This is defined as the maximum value of NIPTS reached during 40 years of noise exposure after the age of 20 for the centile designated, namely, the 90th (i.e., 90% of the population do not exceed the stated value of NIPTS).

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* Hinchcliffe's (1959) data are used for the presbyacusis correction.

** In some measurements, only 20 minutes' recovery from the industrial noise was allowed before testing.

(2) NIPTS (90th percentile) at 10 years. The expected NIPTS after ten years of exposure during adult life is not exceeded by 90% of the population.

(3) Average NIPTS. The gross average value of NIPTS obtained by averaging over a 40-year exposure duration and also over all the population percentiles. Note: this figure differs by only a couple of decibels from the median NIPTS value after 20 years of exposure.

(4) Maximum Hearing Risk. Hearing risk is defined as the difference between the percentage of people with a specified hearing handicap in a non-noise exposed (but otherwise equivalent) group. The hearing risk varies with exposure duration and the Maximum Hearing Risk is defined as the peak value (largest difference) that occurs during the 40 years of exposure. Normally, but not always, this peak value occurs after 40 years of exposure.

III.A.2 Duration of exposure longer or shorter than 8 hours

III.A.2.1 Exposures to continuous noise exceeding 8 hours. An equivalent continuous sound level (L_{eq}) in dBA may be calculated for varying exposure times, based upon a nominal daily exposure of 8 hours (see Appendix 8). For that duration only, the equivalent continuous sound level, L_{eq}, is numerically equal to the average measured sound level in dBA. As in the case of unbroken steady-state exposures lasting less than 8 hours (see below) the nomogram in Appendix 8 may be used to find L_{eq} for uninterrupted steady-state exposures of more than 8 hours. Thus, for a continuous 24-hour exposure, L_{eq} is 4.8 dB greater than for an 8-hour exposure to the same noise (this can be approximated to 5 dB). Expressed another way, the hazard to hearing from a continuous 85 dBA noise lasting 24 hours is similar to the hazard of an 8-hour exposure to 90 dBA, provided of course that the noise is steady-state, broadly distributed in frequency, fairly uniform in spectrum without substantial discrete tonal components, and free from any significant addition of impulse sounds (see Section III.B).

An exposure exceeding 24 hours may be treated as an indefinite exposure. Allowances for level fluctuations in continuous noise, for intermittency (interruptions), and for the significant presence of simultaneous tonal components or impulses during prolonged exposure may be considered to obey rules similar to those which govern these allowances in the case of exposures shorter than 8 hours (see below).

III.A.2.2 Exposures to continuous noise for periods less than 8 hours. The risk to hearing in the case of daily exposures to on-going noise for periods (minutes to hours) less than 8 hours can also be evaluated by calculating an

Table III.A-I Summary of effects predicted for continuous noise exposure at selected values of A-weighted* sound level. Figures in parentheses show the audiometric test frequencies (in kilohertz) included in the evaluation.

	Speech (.5,1,2)	Speech (.5,1,2,4)	4 kHz
75 dBA for 8 hours			
Max NIPTS (90%-ile)	1 dB	2 dB	6 dB
NIPTS at 10 yrs (90%-ile)	0	1	5
Average NIPTS	0	0	1
Max Hearing Risk**	N/A	N/A	N/A
80 dBA for 8 hours			
Max NIPTS (90%-ile)	1 dB	4 dB	11 dB
NIPTS at 10 yrs (90%-ile)	1	3	9
Average NIPTS	0	1	4
Max Hearing Risk**	5%	N/A	N/A
85 dBA for 8 hours			
Max NIPTS (90%-ile)	4 dB	7 dB	19 dB
NIPTS at 10 yrs (90%-ile)	2	6	16
Average NIPTS	1	3	9
Max Hearing Risk**	12%	N/A	N/A
90 dBA for 8 hours			
Max NIPTS (90%-ile)	7 dB	12 dB	28 dB
NIPTS at 10 yrs (90%-ile)	4	9	24
Average NIPTS	3	6	15
Max Hearing Risk**	22.3%	N/A	N/A

* Values given are arithmetic averages obtained from predictions using the methods of Baughn, Passchier-Vermeer and Robinson (Johnson, 1973).

** 25 dB ISO Fence or Hearing Handicap (re: ISO: 1964). Averaged from the methods of Baughn and Robinson (see Johnson, 1973).

equivalent continuous sound level, L_{eq}, as explained in Appendix 8, provided that the noise is approximately steady-state. The calculation of L_{eq} normalizes the daily exposure to a duration of 8 hours for the purposes of entering the tables given in Section III.A.1.

III.A.3 Allowances for level fluctuation or interruption of noise

III.A.3.1 Fluctuating level in on-going noise. The International Organization for Standardization (ISO, 1971) in its current Draft Recommendation (ISO/DR 1999) for assessing noise exposure at work recommends a method which embodies the A-weighted "equal-energy" rule, namely, the computation of an equivalent continuous sound level, L_{eq} (see Appendix 8 and the nomogram therein), in dBA. This method is probably the best available method of predicting the effect of noise on hearing in the case of continuous noise of which the level fluctuates slowly (seconds to hours)* during the working day; and it may, with circumspection, be extrapolated to cover distributed noise of fluctuating level which goes on for longer than the typical working exposure of 8 hours.

The arbitrary ISO (1971) protective weighting of 10 dBA for impulsiveness in the noise may be more questionable. Recent work by Passchier-Vermeer (1971) has indicated that this figure may not be realistic in the case of distributed industrial noise with impulsive components, although her work does in general confirm the validity of the equivalent level method based on "equal-energy" in the case of on-going noise with slow but not impulsive fluctuations. Findings by Cohen, Kylin and LaBenz (1966) in an occupational setting have indicated that, in some circumstances, combined exposure to continuous and impulsive noise might be less noxious than exposure to similar continuous noise alone. Such a paradoxical effect might be attributable to a difference in the protective action of the acoustic reflex (see Appendix 9), although this is at present speculative. Impulsive noises must be evaluated separately and specifically using appropriate measurement techniques, for reasons given in Section III.B.

III.A.3.2 Intermittent noise. It is reasonable to treat intermittent exposure to steady-state non-impulsive noise as a special case of fluctuating level. For by "intermittent" noise is generally meant merely a substantial change in level from some potentially hazardous level, if not to silence, at least to a very low level (below 55 dBA).

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* The fluctuation in level must be non-impulsive, i.e., slow enough to be followed by a standard sound level meter on the "slow" setting.

Such intermissions are known to be protective, probably by allowing recovery of normal physiological function in the auditory system. Because there is no evidence for a threshold of noxiousness of noise so far as the hearing organ is concerned, it is desirable that the noise during any period of relative quiet should be measured, and included in the computation of L_{eq}. "Intermittent" noise may thus be treated in the same way as noise of varying level, and equated analytically with continuous noise for the purpose of predicting hazard or risk.

III.B Impulsive noise

III.B.1 Definition and varieties of impulsive noise. Elaborating the definition given in Section II, impulsive noise is one or more transient acoustical events, each of which lasts less than 500 ms and has a magnitude (change in sound pressure level) of at least 40 dB within that time. A single impulse may be heard as a discrete event occurring in otherwise quiet conditions; or it may be superimposed upon a background of continuous noise. Impulsive noise may be characterized by the following basic parameters:

1. Peak sound pressure level (in dB re 0.00002 N/m^2)*
2. Duration of the event (in milliseconds or microseconds)
3. Rise and decay time
4. Type of waveform (time-course)
5. Spectrum (in the case of oscillatory events, Type B)
6. Total energy of the event (impulse)
7. Number of impulses in a cumulative exposure
8. Intervals or average interval between impulses

III.B.1.1 Types of waveform. Coles and others (Coles *et al*, 1968; Coles & Rice, 1971) have distinguished two main varieties of acoustic impulse affecting the ear. These are described in Appendix 5. In many instances, however, impulsive noises are not readily classifiable into one of these simple categories: considerable caution must be exercised in evaluating the hazard according to the tentative criteria presently recommended. It is important to appreciate that impulse noises can only be described, distinguished as to type, and properly measured by means of oscillographic techniques. It cannot be done using a conventional sound level meter, even on the "fast response" setting of the instrument. In the "Type A" impulse,

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* For reasons connected with measurement practice in the English-speaking countries, the over-pressures associated with sonic booms in aerospace operations are customarily expressed in pounds/ft^2 (psf) relative to atmospheric pressure. Although deprecated, this convention is adhered to in the present document when citing data expressed in psf by other authors.

there is a rapid rise to a peak SPL followed by a decay to a negligible magnitude. In the classical "Friedländer" type of event, a subsequent negative pressure wave occurs, of much smaller magnitude. In evaluating the hazard due to this type of impulse only the duration of the positive part of the event is counted as the duration of the impulse. In the single "Type B" (oscillatory) event, the duration is taken as being the time for the envelope to decay to a value 20 dB below the peak. The acoustic effect of an impulse can be greatly modified by the circumstances of exposure (e.g., the presence of reverberant surroundings).

III.B.2 Effect of peak sound pressure level and duration of impulses. Most of our knowledge of the aural hazard due to impulse noise, and practically all the data systematically relating exposure parameters to threshold shift, comes from studies of the effects of gunfire on the ear, with some supporting evidence from industrial data. The evidence for the conclusions here presented is reviewed in Appendix 1.

III.B.2.1 Incidence of NIPTS as a function of peak SPL. An estimate of hearing damage risk following daily exposure to a nominal 100 rounds of gunfire (rifle) noise at 5-second intervals is shown in Table III.B-I (Kryter & Garinther, 1965). An important assumption implicit in these data is that a given TTS_2 (TTS measured at 2 minutes) will eventually lead to an equal amount of NIPTS.

Referring to the CHABA criterion, Kryter and Garinther (1965) agreed that a tolerable exposure for 90% of the people using military type rifles would be 100 rounds/day at peak SPL not exceeding 150 dB at the ear; or 160 dB if the criterion of protection was to be 75% of the people. Commenting on the data of Coles et al (1968), Kryter (1970a) has presented a unifying table in which, using certain empirical rules of conversion, TTS data of Coles and other sources are corrected to a common set of nominal exposure conditions similar to those cited above. Kryter's (1970a) table, including corrections to be used to predict probable damage due to gun noise in 25% of people, is reproduced below (Table III.B-II).

III.B.2.2 Effect of duration of impulses. The present state of knowledge indicates that a hazard exists, and accordingly that ear protection should be mandatory, when isolated Type A noise exposures (e.g., gunshots) exceed a peak sound pressure level of 150 dB* at the ear for more than 5 ms regardless of rise time, spectrum, or the presence of oscillatory transients.

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* A maximum permissible peak of 140 dB is prescribed by the Occupational Safety and Health Act, 1970. The validity of a limit specified in terms of level alone has been questioned by McRobert and Ward (1973).

Table III.B-I. Estimated expected permanent hearing level (in dB re ASA:1951) in selected percentiles of the most sensitive ears following nominal daily exposure to rifle noise (during typical military service), namely, 100 rounds at about 5 second intervals (Kryter & Garinther, 1965).

Peak SPL* (dB)	Percentile exceeding HL	Audiometric test frequency (Hz) 1000	2000	3000	4000	6000
170	10	25	35	70	85	90
	25	15	25	55	65	70
	50	0	10	35	45	50
165	10	16	20	62	60	67
	25	9	10	32	45	52
	50	0	0	12	25	47
160	10	15	16	25	45	60
	25	7	8	18	35	45
	50	0	0	0	15	25
150	10	10	15	15	35	50
	25	3	4	8	25	40
	50	0	0	0	10	20
140	10	0	5	10	30	45
	25	0	2	2	18	30
	50	0	0	0	5	10

* at the ear, grazing incidence.

Substantially lower values must be regarded as limiting in the case of repetitive Type A or Type B impulse noise exposures of the kind sustained in industry (McRobert & Ward, 1973). As the duration decreases below 5 ms, higher peak values may be tolerable; but an absolute maximum of 165 dB SPL for isolated impulses of short duration (below 3 ms) has been suggested as a limiting level exceeding which is likely to lead to cochlear damage in at least 50% of ears (see Acton, 1967; Coles et al, 1968; Kryter & Garinther, 1965; Rice & Coles, 1965).

The figure of 165 dB SPL absolute maximum for single impulses is considered overconservative by some authorities in relation to extremely brief exposures. The work of Loeb and Fletcher (1968), for example, has shown that substantially higher peaks may be tolerable by a majority of ears provided that the duration of each impulse is very brief (less than

Table III.B-II. Threshold Shift From Gun Noise* (Adapted from Kryter, 1970a)

Study**	Peak SPL Grazing to ear	Listening Condition	No. of Rounds	TTS_2 or HL_2 (Av 1, 2 & 3 Kilohertz) Equaled or Exceeded by 25% of People: Measured	Corrected to 100 Rounds by Adding 20 log 10 No. Rounds	No. of Subjects
Coles & Rice	160 dB	Open field	10-50	7 dB	19 dB	20
	160 dB	Reverberant	10-50	10 dB	22 dB	20
	159 dB	Open field	20-50	7 dB[1]	19 dB	20
	159 dB	Reverberant	20-50	19 dB[1]	31 dB	20
Elwood et al	161 dB	Open field	20	7 dB[2]	20 dB	12
	173 dB	Open field	1	7 dB[2]	47 dB	12
Acton et al	138 dB	Open field	100	0 dB	0 dB	19
	138 dB	Reverberant	100	5 dB[3]	5 dB	19
Murray & Reid	159 dB	Open field	100	...	20 dB[4]	?
	176 dB	Open field	10	5 dB	27 dB[5]	1
	181 dB	Open field	...	17 dB	48 dB	1
Smith & Goldstone	158 dB	Open field	25	5 dB	17 dB	30
Kryter & Garinther, weapon D	159 dB	Open field	100	10 dB	10 dB	30
Kryter & Garinther, weapon B	168 dB	Open field	100	22 dB	22 dB	36
Kryter & Garinther, weapon A	173 dB	Open field	100	55 dB	55 dB	8

* TTS_2 or HL_2 average of 1, 2 and 3 kHz as found in or estimated from various studies of threshold shift from gun noise, one to ten seconds or so between impulses.

** References in Kryter (1970a).

1 TTS data were not given at 1 kHz; average for 1, 2 and 3 kHz was taken to be the TTS at 2 Hz.

2 Data were given as TTS average of 2 to 6 Hz; this multiplied by 0.3 was taken as TTS average 1, 2 and 3 kHz.

3 Authors stated that "noise approached an auditory hazard for about 5% of people."

4 Estimated from authors' statement that 159 peak SPL "commonly" (taken to mean in 50% of people) caused 40 dB peak TTS - after 100 rounds or more.

5 Average 512 to 8,192 Hz TTS_{15} corrected to TTS_2 by adding 10 dB and then to average TTS_2 at 1, 2 and 3 Hz by multiplying result by 0.5.

100 microseconds). Moreover, Coles and Rice (1970, 1971) have suggested allowing 172 dB SPL for single impulses of 100 microseconds' duration; and over 180 dB for impulses of less than half that duration (irrespective of pulse shape). This may be overlenient. There is no evidence that such levels are safe for a majority of ears, no matter how brief the exposure. A simplified statement of the limits of safety recommended by Coles and Rice (1971) is given in the following Table III.B-III. (The diverging DRC for "A" type noises is included for comparison but is not recommended here.)

Table III.B-III. Damage risk criterion for impulse noise (nominal exposure: 100 impulses) as a function of duration of the impulse (adapted from Coles & Rice, 1971).

Duration (seconds)	10^{-4}	10^{-3}	10^{-2}	10^{-1}	1.0
Max. safe SPL for 90% of ears (dB re 0.00002 N/m^2)	172	163	157	150	144
Cole's limit for "A" type spikes	172	163	162	162	162

III.B.3 Allowance for repeated impulses

CHABA Working Group 57 has recently arrived at an empirical weighting factor for reducing permissible levels of exposure when multiple impulse noises are heard. Essentially, the current recommendation of that Working Group is to add or subtract 2 decibels from permissible values for each halving or doubling, respectively, of the number of impulses (or 5 dB for every tenfold change in the total number in a series of impulses). A related rule which, although less linear, may be more realistic in form, is that of Coles and Rice (1971), shown in Table III.B-IV. It is probable, however, that the factors of -20 dB and more for 1000 impulses and upwards given in this table may be overconservative (McRobert & Ward, 1973).

Table III.B-IV. Suggested correction factors for number of similar impulse noises, relative to zero for a nominal exposure of 100 impulses (approximated from Coles & Rice, 1971).

Number of impulses	1	10	100	1000	10^4	10^5
Correction factor (dB)	+15	+10	0	-20	-30	-35

III.B.4 The question of high-frequency hearing losses due to impulse noise

Coles (1971) and Loeb and Fletcher (1968) have drawn attention to the fact that, although hearing loss due to many kinds of intense short-lived or impulsive noise appear audiometrically identical with loss due to continuous noise (showing the characteristic audiometric notch at 4000 Hz and progressive upward spread), certain kinds of impulsive noise, such as gunfire, are not uncommonly associated with a substantial immediate TTS and potential permanent loss at higher frequencies (6 to 8 Hz and upward). This may be associated with particular parameters of the noise exposure, such as extremely rapid rise and high peak level (Coles, 1971).

Such high-frequency loss is not predicted, or is not treated as significant, by many of the existing damage risk criteria or methods of hazardous noise exposure evaluation, which are narrowly restricted to "speech frequencies" below 4000 Hz. High-frequency sensitivity can however be important for several purposes in life, such as the reception of speech heard against a background of noise (Hirsh, 1973); the localization and identification of faint, high-pitched sounds in a variety of occupational (including military) and social situations; and the appreciation of many human and environmental sounds (e.g., music; birdsong; orienting sounds and so on). High-frequency hearing loss associated with impulse noise exposure (Hodge & McCommons, 1966; Loeb, Fletcher & Benson, 1965) should accordingly, in our view, be prevented whenever practicable (Loeb & Fletcher, 1968).

III.B.5 Factors influencing hazard due to impulse noise

There is no unequivocal evidence that a practical distinction need be made between the sexes or between age groups when predicting hearing damage risk due to impulse noise as it is here defined. Nor does any definitive evidence exist for a significantly different degree of susceptibility to impulse-noise-induced PTS in the case of children or persons with otological abnormality. Factors generally influencing susceptibility to NIPTS due to noise in general are considered further in Section IV and the appendices referred to in that section.

III.B.6 Combined exposure to on-going noise with added impulsive noise; allowance for impulsiveness

When impulsive noise exposure takes place at the same time as continuous noise, the hazard of each element to the hearing mechanism should be evaluated separately (so far as it is possible to distinguish them in the measurement) against its respective criterion. A conservative approach is then to treat combined hazards as simply additive. For example, if at a given centile of the population at risk, a continuous noise exposure were predicted to cause NIPTS of 10 dB; and a concurrent impulse noise exposure were predicted to produce 5 dB of NIPTS, then the combination may be predicted to produce 15 dB of NIPTS at that centile. Alternately, some authorities might argue in favor of a logarithmic rule which would be somewhat less conservative.

IV. FACTORS INFLUENCING INCIDENCE OF NIPTS

IV.1 Varied action of different factors

Factors either influencing (+) the incidence of NIPTS or known to be essentially unrelated to it are listed in Table IV-I. Table IV-I shows that some factors appear to increase the risk of NIPTS while others decrease it; and that some, while they may be significant factors determining group hearing levels measured in population surveys, show no clear evidence of being related causally to NIPTS. Supporting evidence for the effects summarized in Table IV-I is referred to in Appendices 1-3, 7 and 9-11, and in Johnson (1973).

Table IV-I. Effect of various factors on incidence of NIPTS. The symbol (?) means present evidence is equivocal or lacking.

FACTOR	INCREASES	DECREASES	NO SIGNIFICANT EFFECT
Age	?	?	
Sex			+
Nationality			+
Race			+
Physiological state:			
i. General health	?	?	
ii. Activity			+
iii. Defensive mechanisms*		+	
Prolonged exposure	+		
Interrupted or modulated exposure		+	
Ear protection		+	
Adverse environments:			
i. Vibration + noise	?	?	
ii. Hypoxic states	?	?	
iii. Ototoxic drugs	?	?	
"Public awareness"		+	

* Principally the acoustic reflex: effect depends greatly on the individual and the noise exposure.

IV.2 Factors increasing the risk of NIPTS

The only factor known to increase the likelihood of a person developing NIPTS is increased exposure to hazardous noise. The influence of duration of exposure has been summarized in Section III. Although it is possible that the older ear may be more susceptible than the younger ear (see Appendix 3), such a phenomenon is difficult to distinguish epidemiologically and the question of age-enhanced susceptibility to NIPTS remains open. It is a tenable but unproven hypothesis that certain defects or diseases of the ear, or a poor general state of health, might increase predisposition to NIPTS. This is mentioned again in Appendices 7 and 9. There is some evidence (Misrahy et al, 1961; Dayal et al, 1971; Falk, 1972) that certain ototoxic drugs may act synergistically with noise to damage the hearing organ.

IV.3 Factors mitigating risk

Physiologically, the acoustic reflex is known to protect the hearing against noise. The degree of activation of the reflex, however, and the amount of protection which it affords varies with individuals and the character of the noise exposure. The variability of the acoustic reflex makes it difficult to assess its protective value in practice or to make allowance for it in predictive models. The action of the acoustic reflex is discussed in Appendix 9.

The use of artificial ear protection (earplugs, earmuffs and kindred devices) decreases the risk of NIPTS substantially but this again is a difficult factor to allow for in predictive formulae, because the use of ear protection (especially in non-occupational noise exposure situations) is neither universal nor uniform. In this connection, however, it is reasonable to presume that, as the population at large is made increasingly aware of the hearing hazard from noise, the public response (e.g., use of ear protectors; noise-avoidance) will be reflected in a decreasing incidence of NIPTS attributable to environmental noise.

IV.4 Factors not directly affecting susceptibility to NIPTS

Certain intrinsic factors have been observed to influence group hearing levels measured in public health and industrial surveys. Notable among these factors is sex (women frequently having been found to have better hearing, age for age, than men), with smaller correlations showing up in relation to other demographic factors such as race and social and economic status (Glorig et al, 1954; Glorig & Roberts, 1965; Roberts & Cohrssen, 1968). There is no conclusive evidence, however, that differences in sex, race or national origin are associated with any inherent predisposition to noise-induced hearing loss (see Appendix 2). These factors may accordingly be disregarded when formulating hearing damage risk criteria or noise exposure limits.

V. CONCLUSIONS AND RECOMMENDATIONS

V.1 Noise exposure hazardous to the hearing

Sufficient basic data now exist to enable the risk to hearing from specified noise exposures to be predicted on a statistical basis. There is however a need to reevaluate the question of what constitutes a real or "significant" noise-induced hearing loss. Hitherto, in the case of continuous, spectrally distributed noise (the commonest variety in urban and industrial settings), this question has been considered only in the context of occupationally related hearing loss. Now it has to be considered in the wider social context of possible damage to the hearing from environmental noise to which the general population may be exposed, either voluntarily or unwittingly, in the course of day to day living.

Such an extension of the preventive concepts worked out over many years of industrial hearing conservation raises new administrative questions concerning the social and ethical criteria by which hearing conservation standards (i.e., statements recommending noise exposure limits in various living and working contexts; and as to the percentage of the population to be protected against a specified amount of NIPTS) should be set. It must be recognized that decisions of this kind necessarily become even more arbitrary than they have been hitherto in the area of hearing conservation at the "speech frequencies" when the hearing is daily threatened by regular occupational exposure to noise. It is, for instance, inherently more difficult to define acceptable margins of safety governing the selection of exposure limits to protect general populations against non-occupational exposure; for such populations differ much more widely than, say, a relatively homogeneous group of industrial workers (presumed all to be adults below the age of retirement) in regard to their health, range of susceptibility to NIPTS, life-style (determining circumstances of noise exposure) and the personal and social significance of any hearing loss which may be sustained.

Such difficulties notwithstanding, however, the present report provides basic information from which predictions of hazard to the hearing from a variety of noise (both occupational and non-occupational) can be made. The principal data were summarized in Section III: justifications for the use made of the data are to be found elsewhere in this report (expecially in Appendix 7) and in Johnson (1973), the companion report. The main conclusions to be drawn are set out below. Kryter (1973) has presented an alternate approach to the prediction of risk to hearing ("Speech Impairment Risk").

V.1.1 Continuous noise exposure. The present consensus is that, in the case of daily exposure to continuous noise without strong tonal components, a level of 75 dBA sustained for 8 hours (or 70 dBA for 24 hours) per day is the threshold for detectable noise-induced permanent threshold shift (NIPTS): exceeding that threshold may cause NIPTS exceeding 5 dB in up to 10% of the people after a cumulative noise exposure of 10 years. This hearing change is predicted for the most sensitive audiometric frequency, namely, 4000 Hz. At the conventional speech frequencies (0.5, 1 and 2 kHz), the threshold may be 10 dB higher, that is, 85 dBA for a daily exposure of 8 hours. In the case of daily noise exposure for cumulative durations other than 8 or 24 hours, an equivalent continuous sound level (i.e., an effective level normalized to an 8-hour exposure) may be calculated, using the method set out in Appendix 8, in order to evaluate the risk.

V.1.2 Impulsive noise. Detectable effects upon hearing may be expected to result in a minority of people (<10%) from exposure to impulses exceeding a peak sound pressure level as low as 125 dB (grazing incidence at the ear) for more than 3 milliseconds; and a level of 150 dB SPL exceeded for more than 3 milliseconds may be taken to be the threshold of hazard for many purposes, depending upon the duration, number, rate and pattern of repetition, character and spectrum of the impulses (see Section III.B). With certain provisos, isolated exposures up to 165 dB peak SPL may be permissible in some circumstances when the impulse duration is very brief (less than 1 millisecond). Note: impulsive noises must be identified and measured using an oscillographic analytical technique in order to evaluate the hazard properly: an ordinary sound level meter is not suitable to the purpose.

V.2 Need for further research into the relationship between noise exposure and NIPTS

The following areas are considered to be in urgent need of investigation.

(i) Patterns of NITTS and NIPTS and their interrelationships in man associated with continuous noise exposures extending beyond the conventional 8-hour working duration of daily occupational exposure (ethical investigations of the effect of continuous exposure of up to 24 hours and longer in man should be included).

(ii) The significance of high-tone (above 2000 Hz) losses of hearing in relation to speech discrimination.

(iii) The effect of interruption and fluctuation in level of continuous noise exposure upon the growth of NITTS and NIPTS in man.

(iv) Susceptibility to NITTS and NIPTS as a function of age (including childhood).

(v) Hazard due to impulseive noise as a function of character, number, rate and pattern of repetition and spectrum of impulses. Here, particularly, NIPTS and cochlear damage pattern studies in animals are necessary to supplement impulse-NITTS observations in human subjects.

(vi) Appraisal of the hearing hazard of non-occupational exposures to noise, both continuous and impulsive.

V.3 Need for public noise monitoring and audiometric supervision

V.3.1 Noise monitoring of the environment. Public exposure to noise at work, in transportation, in the community, in recreation areas, and in the home can be estimated from proper measurements of the noise at representative sites and should be redetermined at appropriate intervals. Detailed and reliable information about exposure levels and the temporal pattern of exposure is crucial to the evaluation of environmental noise hazards. Existing techniques of noise monitoring in the vicinity of aerospace operations, highways, and industrial sources of noise serve as models in this connection.

V.3.2 Noise-exposure monitoring of the population. Properly selected and instructed voluntary random samples of designated sections of the population, otologically screened, should be provided with personal noise dosimeters (see Appendix 5), in order to evaluate their personal noise-exposure histories at appropriate intervals.

V.3.3 Monitoring audiometry and otological supervision. The same subjects should be tested (in properly controlled conditions) at intervals not exceeding 6 months, in order to follow up any hearing changes associated with their measured or estimated noise exposure and advancing age. The audiometric test frequencies used should span at least the range 500 to 8000 Hz. Children from the age of 7 years should be included in the survey.

V.4 Information and education

V.4.1 Education and protection of the public. There is a real need to raise public awareness (and indeed that of many physicians, engineers and administrators) regarding the hazard of environmental noise to the hearing mechanism. Programs designed to educate the public about noise hazards can be envisaged, perhaps along the lines of present television programs and advertisements concerning such matters as domestic and highway safety, the prevention of disease and of alcohol and drug abuse, and the care of the natural environment. There is much to be said for encouraging the public to regard a periodic hearing test as a desirable and routine part of health care throughout life. Such hearing tests are desirable irrespective of whether or not the person is knowingly exposed to hazardous noise at work or during his or her recreational pursuits. The tests might usefully be introduced routinely at school with a view to their continuation on a voluntary basis throughout adult life.

V.4.2 Warning notices. Graphic posters and warning notices can be used to reinforce public awareness in specific situations (e.g., at work or in certain recreational settings such as shooting ranges) where the noise is hazardous to the hearing. It is essential that such posters or notices be forcefully drawn and that they convey a clear instruction when protection of the ears is required. A British warning notice for use in industry (Department of Employment, 1972), reproduced in Figure V-1, is one of the most effective that we have seen in this connection. It is intended to be displayed at the entrances to noise-hazardous areas; or, with modified wording, to be affixed to dangerously noisy machines. For more general use in public areas, the wording "Protect Your Ears" might be more suitable.

Figure V-1. Warning notice against hazardous noise. Color: black inscription on a yellow field. (Department of Employment, 1972)

Appendix 1

EXISTING HEARING DAMAGE RISK CRITERIA AND PROCEDURES FOR EVALUATING NIPTS

A1.1 The origin of the "AAOO" rule for evaluating hearing handicap

A widely used formula for determining the amount of occupationally related hearing impairment to be deemed significant for purposes of compensation was devised by a committee of the American Academy of Ophthalmology and Otolaryngology in 1959. The basis of the formula was the contention that the arithmetical average hearing threshold level for pure tones at 500, 1000 and 2000 Hz gives the best estimate of hearing for everyday speech. It was implicitly assumed that, because hearing for speech is particularly important, hearing above 2000 Hz being of less social value need not be included in the assessment. According to the formula, impairment is nil until an AHL of 25 dB (the "low fence") is exceeded; and is total above a "high fence" of 92 dB AHL (ISO, 1964). Between the fences, a simple linear relationship between loss and impairment is assumed, so that 1.5% impairment is calculated for every decibel increase in AHL (giving 100% or total impairment at the high fence). In the case of loss mainly affecting one ear, impairment is based arbitrarily upon a 5:1 weighting ratio between the good and bad ears (a person with one normal and one totally deaf ear being deemed for purposes of compensation to be approximately 15% impaired).

This formula replaced earlier methods for evaluating hearing within the audiometric range (eg, Fletcher's "Point Eight" Rule); and has itself been the subject of proposed modifications. These have included the use of higher audiometric frequencies (notably 3000 Hz as is recommended by British otologists) and the inclusion of some form of speech audiometry in the evaluation.

Some years ago, when the Committee on Conservation of Hearing of the American Academy of Ophthalmology and Otolaryngology (AAOO) first adopted this relatively simple rule. It was tailored fairly specifically to the assessment of hearing handicaps in audiological patients presumed to be suffering from occupationally-related NIHL. The AAOO rule was essentially a simplification of the somewhat clumsy Fowler-Sabine Scale formerly recommended by the AMA in the

1940's. An important (some would say regretable) departure from the Fowler-Sabine formula was the dropping of 4000 Hz from the assessment: The AAOO evaluation is based only on the audiometric frequencies 500, 1000 and 2000 Hz, considered to be sufficient for the understanding of everyday speech in quiet conditions. Thus AAOO takes no account of high-frequency hearing, which may nevertheless be valuable in the appreciation of nonverbal sounds as well as the discrimination of speech in noise. As a compromise, some authorities, including the state of California, include 3000 Hz in the assessments. The rule retained the Fowler-Sabine weighting factor of 5:1 in cases of essentially monaural impairment; and similarly, AAOO made no allowance for any benefit obtainable from a hearing aid. Controversially, it also made no allowance for presbyacusis, a factor which is still a matter of arbitrary ruling which varies from state to state (Fox, 1972; Van Atta, 1970).

AAOO set the "high fence" of total (100%) handicap at 92 dB hearing level (ref. ISO, 1964), averaged for the 3 "speech" frequencies (a level of affliction at which the patient can barely hear very loud speech at a socially acceptable distance). Beginning handicap was set at a "low fence" of 25 dB (ref. ISO, 1964) at which level a hearer is just beginning to have difficulty understanding everyday speech. The simple AAOO rule presently states that, over the range of quantifiable handicap, 1½% of handicap is counted for each decibel rise in hearing threshold level above the low fence. Some otologists consider the low fence (an arbitrary "zero" for handicap) to be placed unfairly high from the viewpoint of the afflicted.

A1.1.1 <u>The meaning of "handicap"</u>. High <u>et al</u> (1964) have pointed out that two people with identical hearing impairment, as determined by pure tone audiometry, do not necessarily suffer the same degree of handicap as indicated by self-assessment using a questionnaire. The self-reporting type of instrument developed by those authors for the self-assessment of hearing handicap illustrates well, in its questionnary examples of everyday hearing difficulty, what handicaps can mean to the individual in social contexts.

A1.2 Criteria and limits of noise exposure

That there is a time/intensity "trade-off" for hazardous steady-state noise is well established; but this has been embodied in existing criteria in different ways. For the trade-off is not a simple one. Differing theories underlie the various criteria for the assessment of hearing risk currently in use. The picture is complicated by intermittent noise exposure, which is frequently the case in practice. Evidence from TTS experiments generally supports the view that the effect of intermittent exposures to high levels of noise separated by relative quiet is less than the effect of the same total noise exposure received unbroken (Ward, 1963). Moreover, the production of a given TTS by continuous noise requires progressively less time as the exposure level is increased.

A1.2.1 The "CHABA" criterion. The CHABA damage risk criterion was based on such observations. Its principal assumption is that, for a given octave band of noise, all noise exposures producing the same TTS_2 are equally likely to produce a given PTS (Kryter et al, 1966). This DRC, in which the trade-off between time and intensity varies (eg, between 2 and 7 dB per doubling of time for the 1200-2400 Hz band), represented a departure from the simple adoption of the "equal-energy" rule (3 dB per doubling of time) seen in earlier criteria (such as AFR 160-3, 1956). The resulting differences between DRC's are illustrated in Table A1-I which compares simply the limiting values for continuous exposure at 1200-2400 Hz in CHABA and AFR 160-3. The latter is more conservative.

Table A1-I. Comparison of CHABA DRC and AFR 160-3

Exposure time	8h	4h	2h	10 min	5 min	
CHABA	85	87		105	112	dB
AFR 160-3	85	88	91		105	dB

The 5 dB rule adopted under the Walsh-Healey Act in 1969 appears to have been an expedient compromise: it has some justification in that it in effect makes an allowance for intermittency.

A1.2.2 Criteria and exposure limits for steady-state noise. There is generally firm agreement that, for typical 8-hour everyday exposures to continuous industrial noises, levels below 80 dBA for most hearers may be innocuous but that, as the noise level increases, an increasing number of people are put at risk and the average magnitude of hearing loss grows commensurately. This picture is well supported by a number of substantial audiometric surveys of industrially exposed people in the United States and elsewhere (Baughn, 1966; Passchier-Vermeer, 1968; Robinson, 1968) (see Section

IIIA and Appendix 7). Based on such evidence, a recent DRC, provided for in 1969 under the Walsh-Healey Act governing the welfare of workers under public contracts, was adopted in the United States which allows 90 dBA for continuous 8-hour exposures. This arbitrary (administrative) limit may result in appreciable NIPTS (more than 15 dB at 4 kHz) in a majority (at least 50%) of workers but presumably will permit compensable damage to occur in relatively few cases.

A1.2.3 "AAOO" and cognate rules. It is a basic premise of these criteria that the chief (a rigorous interpretation might say the sole) function of human hearing is to receive speech signals. Arguing that telephoned speech (band-limited to some 300 to 3000 Hz) is generally intelligible, Fletcher (1929) introduced his "point-eight" rule for evaluating hearing damage in accordance with this philosophy. There was born the practice of averaging hearing levels at 500, 1000 and 2000 Hz. (Fletcher's original rule presumed damage to have begun as soon as these levels reached zero--i.e., there was no "low fence"--but not to be complete until the average had reached 125 dB, an unrealistic "high fence". A reconsideration led eventually to the modifications embodied in the AAOO rule.)

The AAOO and cognate rules attempt, inter alia, to find pragmatic answers to the following questions (Ward, 1970):

1) How much hearing loss must occur before the person affected notices any difficulty?

2) What values of hearing loss constitute complete loss of hearing?

3) What is the relative importance of different audiometric frequencies?

4) How important is it to have two working ears?

A1.2.4 The Intersociety Committee (1970) Guidelines. A group of professional associations* concerned with industrial noise recently (Intersociety Committee, 1970) revised some previously published (1967) guidelines intended "...to aid industrial management and official agencies in establishing effective hearing conservation programs." The document has also defined

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* The American Academy of Occupational Medicine; American Academy of Ophthalmology and Otolaryngology; American Conference of Governmental Industrial Hygienists; Industrial Hygiene Association; and Industrial Medical Association.

hearing impairment as an average threshold level in excess of 15 dB, ASA-Z24.5 (1951) (equivalent to 25 dB, ISO: 1964) at 500, 1000 and 2000 Hz. The guidelines were intended to prevent that portion of permanent hearing loss due to occupational exposure to continuous noise.

The evaluation of noise in dBA using standard meters and procedures was recommended by the Committee, as was the determination or estimation of the total time and temporal distribution of noise exposure "throughout the working day". The guidelines, subject to revision, contain numerical data and procedures for rating the auditory hazard of occupational noise exposure in terms of risk as a function of age, noise level and exposure time. The Committee in 1970 deemed 90 dBA for 8 working hours of steady-state noise experienced day after day to be a "reasonable objective for hearing conservation", with a permissible increase of 5 dBA* (up to a permissible maximum of 115 dBA) for each halving of exposure time. It was pointed out explicitly that the rating procedure applies only to groups, not to individuals.

The document included some general guidance on methods of noise control for hearing conservation in industry; and some recommendations concerning audiometry in industrial settings. The audiometric frequencies recommended by the Intersociety Committee for routine testing were 500, 1000, 2000, 3000, 4000 and 6000 Hz. The guidelines are subject to triennial review and revision.

A1.3 Use of A-weighted decibels

The Intersociety Committee on Guidelines for Noise Exposure and Control, influenced mainly by the work of Baughn (1966) in the USA and Robinson (1968) in the United Kingdom, decided to recommend the use of dBA to yield a single-number rating of continuous noise hazard (Mercer,1968). This unit, as recommended in the present document, has a number of advantages. These advantages include convenience of measurement using standard sound level meters; and the fact that a measurement in dBA can readily be related to the ISO standardized NR numbers using the approximate difference of 5 decibels (dBA ≐ NR + 5). Measurements on the A-weighting scale, however, may possibly underestimate hazard to hearing when the noise contains strong tonal components (Mercer, 1968; Acton, 1967) or a markedly uneven spectrum. Measurements using other weighting characteristics (eg, C-weighting) may have uses in the complete evaluation of the hearing hazard due to some kinds of noise (see Appendix 5).

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* cf the "Equal Energy rule.

A1.4 Indices of Cumulative Noise Exposure

A1.4.1 Robinson's "sound-immission" rating. Robinson (1968, 1971; Robinson & Cook, 1968) has contended that NIHL is expressible in terms of a composite noise exposure measure (noise of sound "immission") which is proportional to the total frequency-weighted sound energy received by the ear over a designated exposure period. Robinson & Cook (1968) have presented industrial hearing level and noise exposure data in support of this predictive model valid for 8-hour daily exposures in the range 1 to 600 months (50 years) to industrial type noise at levels that range from 75 to 120 dBA.

Based on recent British survey data relating hearing levels to continuous industrial-type noise exposure, a predictive method has been presented by Robinson (1968, 1971) for estimating the magnitude of NIPTS to be expected in designated fractions of an otologically normal population due to known or predicted noise exposure. Assuming that the noise is of the same general type as that found in manufacturing industries, where the worker's ear is exposed throughout every shift to a fairly constant (steady-state) assault, Robinson's formula may be used to determine the A-weighted noise immission level, E_A, as a measure of the total equivalent exposure.* Noise immission level is defined by Robinson according to the formula:

$$E_A = L_A + 10 \log (T/T_o),$$

where L_A is the A-weighted sound level of the noise in dBA, T is the duration of exposure in calendar years (up to 50) and T_o is the reference duration of 1 year. Robinson maintains that this is the measure of total noise exposure that uniquely determines NIPTS.

Certain important assumptions underlie Robinson's method, namely:

1) The noise is "reasonably steady" (sic) and continuous (8h/day) and does not exceed 120 dBA. Its spectrum may be undefined within the slope limits of ±5dB/octave (i.e., there are no prominent spectral peaks or tonal components in the noise).

2) The ear is exposed 5 days per week for a working life between 1 month and 50 years.

3) The ear is otologically normal but subject to normal aging (Note: Robinson makes use of Hinchcliffe's (1959) data to correct for presbyacusis).

* cf L_{eq}, the equivalent continuous sound level (Appendix 8)

Robinson recommends the "equal-energy" rule for extension to cover shorter exposures (less than 8h/day and less than 5 days/ week). His method permits entry into the noisy occupation at any specified age. Prior experience can be allowed for if the noise exposure is known to have been similar to the occupational exposure in question. No allowance is made for breaks in noisy employment; or for noise outside work (non-occupational exposure).

Granted the above assumptions, Robinson (1971) uses the following formula to predict the distribution of hearing levels (H'(p) for selected centiles) in a working population whose ears are subject only to occupational noise exposure of the kind described, and presbyacusis. Hearing level is predicted for the range 500 Hz to 6000 Hz.

$$H'(1) = 27.5 \left(1 + \tanh \frac{E_A - \lambda(f) + u(p)}{15} + u(p)\right) + F(N)_3,$$

in which:

E_A is A-weighted noise immission level;

$\lambda(f)$ is an audiometric frequency-weighting parameter;

U(p) is a distributional term given by:

$$u(p) = 6\sqrt{2} \ . \ erf^{-1}\left(\frac{p}{50}-1\right),$$

where p is the centile of population for which H' equals or exceeds H'(p) (high centile values being associated with noise resistant ears); and

F(N) is a further term taking empirically determined values according to audiometric test frequency and the sample age in years (N):

$$F(N) = \begin{cases} 0 \text{ when } N \leq 20 \\ c(f) \ . \ (N-20)^2 \text{ when } N > 20 \end{cases}$$

(20 years of age is a nominal age of entry into noisy employment of the young worker without presbyacusis.) The frequency-dependent values of C and λ (in dB) are given in the following table.

Table A1-II. Values of the parameter λ and C

Frequency (kHz)	0.5	1	2	3	4	6
C	0.0040	0.0043	0.0060	0.0080	0.0120	0.0140
λ (dB)	130.0	126.5	120.0	114.5	112.5	115.5

It may be noted that Robinson (1971) incidentally defines "risk" as that percentage of population whose hearing level, because of some specific influence such as noise, age or disease (or a combination), exceeds a specified value, minus that percentage of the population whose hearing would have exceeded the same value in the absence of the influence in question (assuming other factors to remain the same).

A1.5 The question of the adequacy of conventional "speech frequencies" assessment

Harris (1965) has contended that the widely adopted convention of using the average pure-tone auditory sensitivity at 500, 1000 and 2000 Hz to predict a person's ability to understand everyday speech may not be adequate when, as is often the case, the speech is of poor quality, interrupted, distorted or noise-masked. From a study of speech intelligibility among 52 subjects with sensori-neural hypoacusis, listening to various kinds of degraded speech, he concluded that a better assessment of hearing disability for realistic everyday speech is obtained when the audiometric frequencies 1, 2 and 3 kHz are used instead, as is the convention in British practice. This supports a finding of Kryter, Williams & Green (1962), who reported that the triad 2, 3 and 4 kHz was the best predictor of speech reception for phonetically balanced words (not sentences) in subjects with high-tone hearing losses. Kryter and his co-workers (1962) showed that some speech tests and methods of hearing evaluation hitherto adopted introduce a bias which is apt to lead to underestimation of the importance of auditory acuity at frequencies above 2 kHz. Some authorities, notably the state of California, already include 3000 Hz in the assessment of disability.

A1.6 Impulsive Noise

Impulsive noises have a very high peak level and a short duration. Examples are the sound of gunfire or explosions, impacts in industrial processes (eg, drop-forging), and sonic booms. The peak pressure produced at the ear from firing a self-loading rifle, for instance, can exceed 160 dB for 5 ms. The noise hazard may be greatly modified and sometimes enhanced by many factors, including the surroundings in which the weapon is used. Kryter (1970a) has defined an impulse as a change of sound pressure of at least 40 dB within half a second (500 ms): conversely, he deems steady-state noise to be present when the overall SPL changes less than 40 dB between successive 0.5 sec intervals. Kryter has adduced evidence from his own and other recent work to show that TTS_2 at 4000 Hz and, by implication, the risk of NIPTS, can in many circumstances be predicted with fair accuracy from a knowledge of the peak overpressure, spectral composition and number of impulses. For the noise of gunfire, Kryter maintains that damage risk to hearing can be evaluated from the peak overpressure and number of impulses. An important assumption implicit in these data was that a given TTS_2 would eventually lead to an equal NIPTS.

Some procedures proposed by Kryter (1970a) and others for predicting specifying damage risk to hearing due to gunfire and similar noises were summarized in Section IIIB. The risk to hearing from such noise depends primarily upon the peak overpressure and the number of impulses experienced; and to some degree upon the spectral and temporal characteristics of the noise. Although, in general terms, the pattern of NIHL produced by impulsive noise is similar to that produced by steady-state noise, namely, loss beginning and advancing most rapidly at 4 kHz and above, the different stimulus parameters call for rather different criteria and methods for evaluating impulse noise. For this reason, it should be noted, the current ISO Recommendation (ISO, 1971) on the assessment of occupational noise-exposure for hearing conservation purposes states specifically that the method is not applicable to such noises.

A1.6.1 Impulse noise: measurement and evaluation. Coles (1970; Coles et al, 1968; Coles & Rice, 1971) has distinguished three commonly encountered types of impulse noise, designated as follows:

Type (A) occasional, widely separated, rapidly decaying impulses (eg, gunfire or imtermittent impact or explosive noise)

Type (B) repetitive but still discrete impulses having a peak-to-background level of at least 6 dB and impulse rates of 0.5 to 10/sec. (eg, many industrial processes, such as blanking, manual hammering, etc.)

Type (C) rapidly repetitive noises (repetition rate greater than 10/sec) with a ration of peak to minimum level generally less than 6 dB. This type of noise is very common in industry (eg, pneumatic hammering, riveting).

Because of instrumental lag and nonlinearity, ordinary sound level meters, whether used on the A-scale or for octave-band analysis, are generally quite unsuitable for evaluating Type (A) and (B) noises, although some authorities have recommended the use of meters set to read dBA with the "slow" response, corrected by +10 dBA for impulsiveness. Possibly this might be valid for some varieties of Type (B) noise (Coles, 1970). Oscillographic measurements (and the use of appropriate DRC's) are proper to the evaluation of discrete impulsive noises. By contrast, Coles (1970) maintains that Type (C) noises, approximating as they do steady-state noise, are validly measured using the A-weighting scale of a conventional sound level meter. Coles (1970) has recently reported some proposed modifications of his DRC for impulsive noise (Coles et al, 1968 ; Coles & Rice, 1969, 1971) including a variable correction factor spanning some 50 dB for the number of impulses per exposure in the range 0 to 10^5 impulses. (See Section IIIB.)

A model procedure for measuring impulsive noise from cap guns has been published by the Department of Health, Education and Welfare (Food and Drug Administration) (Federal Register, 36 (134), 13030, July 13, 1971).

A1.6.2 Impulse noise and TTS. In 1962, Ward argued that damage risk criteria for impulsive noise should best be expressed in terms of the number of impulses rather than exposure time per se. The importance of number of impulses has more recently been brought out by Coles et al (1968; 1970) as noted above. Ward's (1962) argument was based on his observation that the TTS in the range 500 to 13,000 Hz (and, by implication, the PTS) produced by impulse noise is relatively independent of the interval between pulses--at least for intervals in the range 1 to 9 seconds (a 30-second interval, however, apparently permitted slight recovery between stimuli.

A1.6.3 Impulses with an oscillatory component. When the Impulse contains an oscillatory component ("Type B" of Coles and Garinther, 1968), the assumptions of Kryter (1970a) applying to simple, Type A gun noise may require modification; and spectral information may be needed in the evaluation of hazard, in addition to a knowledge of the peak pressure, number and temporal spacing of impulses (Coles et al, 1968; Kryter, 1970a; Ward, 1962; Ward et al, 1968 (CHABA); Ward, Selters and Glorig, 1961). Oscillatory waveforms can be recorded when guns are fired in reverberant areas; and from sources of impulsive noise other than gunfire. It has been argued (Muirhead, 1960) that even spike impulses must generate an oscillatory component upon entering the ear, by exciting the resonances of the ear canal and middle ear structures. This would in part explain the general similarities between the patterns of threshold shift produced by both impulsive and distributed steady-state noise. A single,universal limit of impulse noise exposure, based solely upon peak pressure, is unlikely to be satisfactory for hearing conservation purposes (McRobert & Ward, 1973).

Appendix 2

HEARING IN THE AMERICAN POPULATION

A2.1 "Normal hearing"

Hearing normally means being able to detect sounds in the audio-frequency range, namely, 16 Hz to 20,000 Hz (20 kHz), at levels which lie at or within 10 decibels of the normal threshold of hearing and below the threshold of aural pain in human beings (those boundaries define the domain of normally audible sounds heard by air conduction). Many otologists define normal hearing more narrowly as the ability to respond appropriately to human speech (the spectral components of which are contained largely in the frequency range 250 to 4000 Hz) in average everyday conditions: others dispute so restrictive a definition, however.

There is no evidence that the domain of hearing varies significantly between normal human populations around the world. The average or median normal threshold of hearing for pure tones and the corresponding reference zero for audiometers have received international standardization (ISO, 1961, 1964). The upper boundary of normally audible sound (threshold of aural pain) has not yet received such definitive recognition but is commonly considered to be about 135 dB SPL, a value which is largely independent of frequency (BENOX, 1953).

It is of interest to note that the typical average level of conversational speech without undue vocal effort, measured at a customary speaking distance of 1 meter from the speaker is about 65 dB SPL. Peak intensities of vocal sounds usually exceed the average level by about 6 dB. A range of individual variation of some 20 dB about the 65 dB SPL average is to be expected in the normal speech of different speakers.

A2.1.1 Audiological uniformity of the population. There is no inherent difference between the races comprising the population of the United States as regards hearing levels as a function of either age or noise exposure: human ears are much the same around the world. Public health surveys may however reveal demographic differences in hearing levels of adults of different races or social groups (Roberts and Bayliss, 1967). Such differences may be attributed to the effect of differing environmental influences, including non-occupational noise exposure (sociacusis).

A2.1.2 Hearing in children. Some 5% of school age children in the USA had deficient hearing according to a survey by Kodman and Sperrazzo in 1959. A similar incidence has been reported in the Lebanon by Mikaelian and Barsoumian (1971). There is no evidence that any substantial fraction of the hearing loss in American children (Eagles et al, 1963, 1967) is noise-induced. However, the possiblity exists that the child population experiences a significant risk from non-occupational (recreational and domestic) exposure to noise from such sources as noisy toys, including cap guns, regular firearms (either as a shooter or a bystander), pop music and recreational vehicles (see Appendix 11).

A2.1.3 Upper range of hearing in young people. Rosen and Rosen (1971) have published a comparative survey of the upper limits of hearing in school-age children and young people (aged 10 to 19 years) in several countries in Africa, Europe and North America. That survey suggests that the frequency range of "normal" hearing in that age group extends to at least 16 kHz (at which frequency, using a special audiometric technique, the authors obtained nearly 100% response in some of the groups); but that the percentage of children responding (ie, able to detect tones) falls off rapidly at higher frequencies. A response incidence of less than 50% was obtained from all but one of the nine test groups at 20 kHz. However, responses in the range 0 to 15% were obtained at 22 kHz; and responses greater than zero (up to 10% in Maba'an youngsters) in 4 groups even at 24 kHz. Fewer than 4% of a group of American (New York) children responded at that frequency. The prevalence of noisy toys and pursuits among children and young people in this country (Fletcher, 1972) may well be reflected audiometrically in those age groups (see Appendix 11).

Rosen and his co-workers have tentatively suggested that the differences in hearing level of children of different cultures may be linked with differences in susceptibility to atherosclerosis and coronary artery disease in later life. Rosen, Olin & Rosen (1970), citing work in Finland as well as their own studies, have also contended that a low saturated fat diet, said to protect against coronary artery disease, may also protect against sensorineural hearing loss.

A2.1.4 Limits of ultra high frequency hearing. Using a bone-conducting ultrasonic transducer in selected young adults (17 to 24 years of age) Corso (1963) also found that some hearing sensation exists above 20,000 Hz, above which frequency there is a fairly abrupt decrease in steepness of the threshold slope (which is steep--about 50 dB/octave--between 14 and 20 kHz). Corso found that some sensation persisted on bone conduction testing at high levels of stimulation at ultrasonic frequencies up to more than 95 kHz but it is very questionable whether this can be regarded as part of "hearing". There is little difference between the sexes in either sensitivity or range of sensation.

A2.2 Effect of "abnormal" ears on average hearing levels

Surveys of hearing levels in general populations can yield values which are poorer (less acute hearing) than those obtained from samples, from ostensibly similar populations, from whom subjects with certain audiological abnormalities (sometimes arbitrarily selected) have been weeded out by a selection procedure. This was observed by Parnell, Nagel & Cohen (1972) in their survey of the hearing of residents living near a jet airport, upon comparison of their subjects' actual hearing with the hearing predicted for the community from Public Health Service survey (Glorig and Roberts, 1965).

A2.3 Sources of variation

Apart from the question of changes in hearing with advancing age, individual and other factors, it is to be expected that some statistical variation in threshold will be seen even when a particular ear is retested audiometrically. The variation arises partly from intrinsic sources (eg, changes in the subject's physiological state) but a substantial source of variation in practice is imperfection in the way in which audiometry is conducted (see section on Audiometry, Appendix 6). Test-retest variance can, however, be kept to a minimum when serial audiograms are obtained in accordance with standard procedures, carried out under properly controlled conditions.

A2.3.1 Individual variation. Hearing surveys are always subject to possible bias because of the difficulties of sampling human populations. In voluntary public hearing surveys, for example, a substantial proportion of people selected to form a supposedly random sample of the adult American population may decline to be examined. One cannot know, in that event, whether or not those who will not be examined have group hearing levels similar to those who do participate. If for any reason those refusing do have different hearing as a group, then the survey cannot truly reflect the state of hearing of the population sampled. More reliable data are of course obtainable from "captive" (eg, industrial or military) populations, of whom every member can perforce be examined (Riley, 1961); but such populations do not represent the general population.

A2.3.2 Sex. From early teenage onwards, and particularly in the age range 25 through 65 years, women in industrial countries including the United States generally have better hearing than men. In the elderly, however, above age 75, the difference tends to become insignificant. Paradoxically, the rate of increase in hearing loss in men over 50 years of age declines, while increasing in women of the same age. Female employees have been found to have better hearing than male employees, even when they work side by side in noisy industries (Gallo & Glorig, 1964; Flodgren & Kylin, 1960; Dieroff, 1961). Selection processes and circumstantial factors have been postulated to account for this (eg, that the women were exposed less to non-occupational sociacoustic influences, such as small-arms noise; show a higher absentee rate--a questionable contention; and are freer to leave a job in which they find the noise level objectionable). A more reasonable explanation, however, may be that, in the industries involved, women benefited from more liberal and frequent rest periods than were alotted to men (Ward, Glorig and Sklar, 1961). The decline in differentiation between the hearing of the two sexes in old age may be linked with an enhanced aging effect upon the ear associated with post-menopausal changes in women (Glorig et al, 1954: Wisconsin State Fair Hearing Survey), although this is admittedly speculative.

Ward (1966) investigated various aspects of NITTS in relation to sex differences, finding that, whereas men were more susceptible to TTS following low frequency noise exposure (less than 700 Hz), they were less susceptible than women to high frequency (greater than 2000 Hz) exposures. Women also appeared to show a greater benefit (in terms of reduced TTS) from intermittency in the noise exposure. Ward has suggested another explanation for these findings, namely, that females have a more efficient acoustic reflex than males. However, evidence for sex-linked differences in the fragility of the hearing organ (or fatiguability of the auditory nerve by noise) proved to be negative in Ward's investigations.

Generally, it may be concluded that intrinsic differences between the sexes are of no practical significance in relation to hearing hazard in noisy environments, or in relation to the setting of hearing damage risk criteria.

Appendix 3

PRESBYACUSIS

A3.1 Hearing changes with age

The threshold of hearing rises, that is, the hearing becomes less sensitive, as a natural consequence of aging. This effect (presbyacusis) involves first and is most marked at the higher audiometric frequencies, above about 3000 Hz (Hinchcliffe, 1959). At least in urbanized western populations, presbyacusis appears to be more pronounced, age for age, in men than in women, but the difference may be associated with occupational factors and the differences between the sexes in the pattern of day to day activity involving noise exposure, rather than with the sex difference *per se* (Appendix 2). The loss of auditory sensitivity with advancing age is believed to be due to central neuronal attrition as well as to peripheral changes in the auditory system (König, 1957; Farrimond, 1962). Aging people are apt to have increasing difficulty in discriminating auditory signals and understanding speech heard against a background of noise. This may be due to an increasing susceptibility to masking by low frequency (below 500 Hz) noise, as well as to the loss of auditory acuity in the speech frequency range. Certain human groups, living in a simple manner in remote areas of the world where they are not exposed to the constant din of mechanized civilization, have been found to have unusually sharp hearing in comparison with urban populations of corresponding ages: in this connection particular attention has been given to the Maba'an people of the Sudan. But it is debatable whether such audiometric differences are due to the lack of noise exposure alone; for many factors (including cultural, genetic, dietary and general environmental differences) may underlie differences in the pattern of hearing found between dissimilar communities who are widely separated geographically and culturally (Rosen *et al*, 1968, 1971).

Although it has been suggested that older people are more susceptible to NIPTS (Kryter, 1960), it is debatable whether individual susceptibility to noise-induced hearing loss changes appreciably with age (Kup, 1966; Nowak & Dahl, 1971). Some authors have contended that young ears are more susceptible to noise-damage (more "tender") than older ones (Schwartz, 1963).

The evidence, however, is inconclusive, the findings in some studies having been confounded by non-occupational influences (eg, noise exposure in military service) which were not the same for the age-groups compared. Recent studies (Hülse & Partsch, 1970; Schneider et al, 1970) indicate that there is probably no causal relationship between age per se and susceptibility to NIPTS, at least in men of working age. This view is supported by the work of Loeb and Fletcher (1963).

That the effect of age on hearing is very difficult to distinguish audiometrically from the influence of noise exposure and related environmental variables is evident form data summarized by Burns and Robinson (1970) and from several studies dealing with or touching on noise susceptibility as a function of age.

A3.2 Presbyacusis in industrial experience and "presbyacusis corrections"

Glorig and Nixon's (1960) contention that aging and noise exposure alone determine group hearing levels in otologically healthy members of the general American population has received support from more recent data and from industrial experience in other Western countries, notably the United Kingdom (Burns & Robinson, 1970; Robinson, 1971). The audiogram in presbyacusis (when supposedly uncontaminated by noise-induced hearing loss) typically shows a gradual elevation in hearing threshold level, the effect being greater and positively accelerated towards the higher audiometric frequencies (Hinchcliffe, 1959; Glorig et al, 1957). Sufficient data now exist from large surveys of general population to permit average values ("presbyacusis corrections") to be standardized for application to group data from noise-exposed populations (see Table A3-I). Robinson (1968; 1971) contends that such corrections are beneficial to the data reduction, enabling the probability with which a portion of loss is due to aging to be predicted from a knowledge of the variance data.

Glorig and Nixon (1960) have restricted the definition of the term "presbyacusis" to hearing losses caused by physiological aging, and it is used in this sense in the present document, although some audiologists use it to embrace any sensorineural loss occurring in the elderly. It is important to appreciate the distinction between presbyacusis and sociacusis (see Appendix 2).

Glorig (1961) estimated a presbyacusis correction applicable to the three "speech frequencies" (500, 1000 and 2000 Hz) important in the assessment of disability due to occupational noise-induced hearing loss: his figures are shown below in Table A3-I to illustrate the magnitude of the effect. Other presbyacusis data, derived from industrial surveys (Passchier-Vermeer, 1968; Schneider et al, 1970) are shown in Table A3-II at the end of this Appendix. For comparison, the British data of Hinchcliffe (1959), which are used by Robinson (1971) in his predictive method (see Section IIIA and Appendix 7) are summarized in Table A3-III.

Table A3-I. Glorig's correction for AHL at 0.5, 1 and 2 kHz

Age (years)	25	30	35	40	45	50	55	60	65	70
Correction (dB)	0	+1	+1	+2	+2	+2	+3	+5	+7	+13

A3.2.1 Additivity of effect of age and noise. It is implicit in the use of presbyacusis corrections that the effects of age and noise on hearing age simply additive. As Hinchcliffe (1970) has remarked in a recent review, physiological aging is accompanied by degenerative changes affecting not merely the organ of Corti but the whole auditory system, including its central projections. This may explain some of the features of hearing handicaps typical of old age, such as loss of discrimination for normal, distorted and noise-masked speech, which are not amenable to prediction from pure tone audiometry alone. Rosen (1969) believes that degenerative arterial disease in particular is a major factor in the etiology of presbyacusis (especially its central component).

A3.2.2 Presbyacusis and audiometric prediction in the sensitive ear

It has been pointed out by von Schulthess and Huelsen (1968; von Schulthess, 1969) that, audiologically, the endogenous and exogenous factors causing the rise in hearing level with age are not distinguishable. One can only say that group hearing levels rise naturally with age (presbyacusis), due probably to both peripheral and central aging processes (Schuknecht, 1964; König, 1957); and that this effect is enhanced (in a way which for lack of other evidence is generally presumed to be additive) by noxious environmental, mostly acoustic influences (Glorig's "sociacusis") and specific exposures to excessive noise.

Table A3-II. Presbyacusis data. Upper register: Median age-induced hearing levels (non-noise-exposed men), rounded to nearest decibel. From: Passchier-Vermeer (1968).

Age	Frequency (Hz)							
(Years)	250	500	1000	2000	3000	4000	6000	8000
25	0	0	0	0	0	0	0	0
30	1	1	1	1	2	3	4	3
35	1	1	1	2	4	6	7	16
40	2	2	2	4	6	9	12	11
45	3	3	3	6	9	13	16	15
50	4	4	4	8	14	18	22	22
55	5	6	6	11	18	23	27	28
60	7	8	8	14	22	28	33	35
65	9	10	10	18	27	33	40	43
70	12	13	13	24	33	40	47	53
75	14	16	17	30	40	47	55	62

Comparative data derived from Schneider *et al* (1970), corrected to HL = 0 at Age 25

Age	Frequency (Hz)							
(Years)	250	500	1000	2000	3000	4000	6000	8000
25	-	0	0	0	0	0	0	0
30	-	0	1	1	3	3	4	2
35	-	1	1	3	5	5	7	5
40	-	1	2	4	8	9	10	9
45	-	2	3	6	12	14	14	13
50	-	3	5	8	15	18	19	19
55	-	4	7	12	20	25	25	25
60	-	6	9	16	27	32	33	36
65	-	8	12	22	34	42	42	50

Table A3-III. Hearing loss in decibels as a function of age in clinically normal female ears (random sample population). Median hearing loss is related to median threshold at 21.5 years of age (Hinchcliffe, 1959). Note: For the purposes of the present document, clinically normal female ears may be equated with non-noise exposed clinically normal male ears.

AGE (Years)	FREQUENCY (kHz) 0.125	0.25	0.5	1	2	3	4	6	8	12
18-24	0	0	0	0	0	0	0	0	0	0
25-34	0.5	1.0	0.5	1.0	0.5	1.5	3.5	3.5	3.0	5.0
34-44	2.5	2.0	2.0	2.0	2.5	5.5	5.5	6.0	7.0	15
45-54	5.0	3.5	4.0	4.5	5.0	9.5	12	12	23	40
55-64	9.0	6.5	7.0	5.5	8.5	14	20	22	23	63
65-74	10	10	10	12	15	19	22	34	42	70

Appendix 4

GLOSSARY*

ACOUSTIC REFLEX. The involuntary contraction of the muscles (stapedius and/or tensor tympani) of the middle ear in response to acoustic or mechanical stimuli.

ACOUSTIC TRAUMA. Damage to the hearing mechanism caused by a sudden burst of intense noise, or by blast. Note: The term usually implies a single traumatic event.

AIR CONDUCTION (AC). The process by which sound is normally conducted to the inner ear through the air in the external auditory meatus and the structures of the middle ear.

AMBIENT NOISE (RESIDUAL NOISE; BACKGROUND NOISE). Noise of a measureable intensity that is normally present in the background in a given environment.

AUDIBLE RANGE (OF FREQUENCY) (AUDIO-FREQUENCY RANGE). The frequency range 16 Hz to 20,000 Hz (20 kHz). Note: This is conventionally taken to be the normal frequency range of human hearing.

AUDIOGRAM. A chart, table or graph showing hearing threshold level as a function of frequency.

AUDIOMETER. An instrument for measuring the threshold or sensitivity of hearing.

AUDIOMETRY. The measurement of hearing.

AUDITORY TRAUMA. Damage to the hearing mechanism resulting in some degree of permanent or temporary hearing loss. Note: Auditory trauma may be caused by agents other than noise, eg, head injury; burns; sudden or excessive changes of atmospheric pressure (cf. acoustic trauma).

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* Some abbreviations commonly used in the literature on noise-induced hearing loss and hearing conservation are explained on page A4-10.

BASELINE AUDIOGRAM. An audiogram obtained on testing after a prescribed period of quiet (at least 12 hours).

BONE CONDUCTION (BC). The process by which sound is transmitted to the inner ear through the bones of the skull (cf. air conduction).

BROAD-BAND NOISE. Noise whose energy is distributed over a broad range of frequency (generally speaking, more than one octave).

CENTRAL HEARING LOSS. Hearing loss resulting from injury or disease involving the central auditory system in brain or from a psychoneurotic disorder. Note: Central hearing loss can occur in the absence of any damage or deficiency in the peripheral hearing mechanism.

CONDUCTIVE HEARING LOSS (CONDUCTIVE DEAFNESS). Hearing loss resulting from a lesion in the air-conduction mechanism of the ear.

CONTINUOUS NOISE. On-going noise whose intensity remains at a measurable level (which may vary) without interruption over an indefinite period or a specified period of time.

DAMAGE RISK CRITERION (DRC). A graphical or other expression of sound levels above which a designated or a general population incurs a specified risk of noise-induced hearing loss.

DEAFNESS. 100 percent impairment of hearing associated with an otological condition. Note: This is defined for medicological and cognate purposes in terms of the hearing threshold level for speech or the average hearing threshold level for pure tones of 500, 1000 and 2000 Hz in excess of 92 dB*.

DOSIMETER (NOISE DOSIMETER). An instrument which registers the cumulative occurrence of or exposure to noise exceeding a predetermined level at a chosen point in the environment or on a person. Note: The noise exposure may be integrated to yield a "dose" according to a specified rule, such as the "equal-energy" rule.

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* ISO, 1964.

EAR DEFENDER (EAR PROTECTOR). A device inserted into the ear canal or the entrance to it, or placed over the ear, in order to attenuate air-conducted sounds.

EARMUFF. An ear defender which encloses the entire outer ear (pinna). Note: Earmuffs are customarily mounted as a pair on a headband or in a helmet.

EARPLUG. An ear defender, having specified or standard acoustic characteristics, which upon insertion occludes the external auditory meatus. Note: Earplugs should be properly designed, made of suitable material, and correctly fitted to insure that they are acoustically effective and do not harm the ear.

FENCE. (Slang.) An arbitrary hearing level or hearing threshold level, greater than 0 dB, below which no hearing impairment is deemed to have occurred ("low fence") or at which complete (100%) hearing impairment is deemed to have occurred ("high fence").

FLUCTUATING NOISE. Continuous noise whose level varies appreciably (more than ±5 dB) with time.

FREE SOUND FIELD (FREE FIELD). In practice, a sound field in which the effects of spatial boundaries or obstacles are negligible.

HANDICAP (HEARING HANDICAP). The occupational and social difficulty experienced by a person who has a hearing loss.

HARD OF HEARING. Having more than zero but less than 100 percent impairment of hearing for everyday speech or for pure tones of 500, 1000 and 2000 Hz. Note: This is defined, according to various standards, in terms of an elevated hearing threshold level of which the elevation is less than that defining deafness.

HEARING CONSERVATION (HEARING CONSERVATION PROGRAM). Those measures which are taken to reduce the risk of noise-induced hearing loss.

HEARING DISABILITY. Hearing handicap prejudicing employment at full wages.

HEARING IMPAIRMENT. Hearing loss exceeding a designated criterion (commonly 25 dB, averaged from the threshold levels at 500, 1000 and 2000 Hz).

HEARING LEVEL. The difference in sound pressure level between the threshold sound for a person (or the median value or the average for a group) and the reference sound pressure level defining the ASA standard audiometric threshold (ASA: 1951). Note: The term is now commonly used to mean hearing threshold level (qv). Units: decibels.

HEARING LOSS. Impairment of auditory sensitivity: an elevation of a hearing threshold level.

HEARING THRESHOLD LEVEL. The amount by which the threshold of hearing for an ear (or the average for a group) exceeds the standard audiometric reference zero (ISO, 1964; ANSI, 1969). Units: decibels.

HEARING THRESHOLD LEVEL FOR SPEECH. An estimate of the amount of socially significant hearing loss in decibels. Note: This is measured by speech audiometry or estimated by averaging the hearing threshold level for pure tones of 500, 1000 and 2000 Hz.

IMPULSE NOISE (IMPULSIVE NOISE). Noise of short duration (typically, less than one second) especially of high intensity, abrupt onset and rapid decay, and often rapidly changing spectral composition. Note: Impulse noise is characteristically associated with such sources as explosions, impacts, the discharge of firearms, the passage of super-sonic aircraft (sonic boom) and many industrial processes.

INDUSTRIAL DEAFNESS. Syn. Occupational hearing loss.

INFRASONIC. Having a frequency below the audible range for man (customarily deemed to cut off at 16 Hz).

INTERMITTENT NOISE. Fluctuating noise whose level falls once or more times to very low or unmeasurable values during an exposure.

INTERRUPTED NOISE. Syn. Intermittent noise (deprecated).

MIXED HEARING LOSS. Hearing loss due to a combination of conductive and sensorineural deficit.

NARROW-BAND NOISE. A relative term describing the pass-band of a filter or the spectral distribution of a noise. Note: The term commonly implies a bandwidth of 1/3 octave or less (cf. Broad-band noise).

NOISE. Disturbing, harmful or unwanted sound.

NOISE EXPOSURE. The cumulative acoustic stimulation reaching the ear or the person over a specified period of time (eg, a work shift, a day, a working life, or a lifetime).

NOISE HAZARD (HAZARDOUS NOISE). Acoustic stimulation of the ear which is likely to produce noise-induced permanent threshold shift in some of a population.

NOISE-INDUCED HEARING LOSS (NIHL). A sensorineural hearing loss caused by acoustic stimulation.

NOISE-INDUCED PERMANENT THRESHOLD SHIFT (NIPTS). Permanent threshold shift caused by noise exposure, corrected for the effect of aging (presbyacusis).

NOISE-INDUCED TEMPORARY THRESHOLD SHIFT (NITTS). Temporary threshold shift caused by noise exposure.

NOISE LEVEL. Syn. Sound level (weighted sound pressure level). Note: The weighting should be specified.

NOISE LIMIT (NOISE EMISSION STANDARD). A graphical, tabular or other numerical expression of the permissible amount of noise which may be be produced by a practical source (eg, a vehicle or an appliance) or which may invade a specified point in a living or working environment (eg, in a workplace or residence) in prescribed conditions of measurement.

NOISE RATING (NR) NUMBERS (CONTOURS). An empirically established set of standard values of octave-band sound pressure level, expressed as functions of octave-band center frequency, intended as general noise limits for the protection of populations from hazardous noise, speech interference and community disturbance. Note: The NR number is numerically equal to the sound pressure level in decibels at the intersection of the so-designated NR contour with the ordinate at 1000 Hz.

NOISE SUSCEPTIBILITY. A measure of the degree of predisposition to noise-induced hearing loss, particularly of an individual compared with the average.

NON-ORGANIC HEARING LOSS (NOHL). That portion of a hearing loss for which no otological or organic cause can be found. Hearing loss other than conductive or sensorineural.

NONSTEADY NOISE. Noise whose level varies substantially or significantly with time (eg, aircraft fly-over noise). (Syn: fluctuating noise.)

NORMAL THRESHOLD OF HEARING. Syn. Standard audiometric threshold.

OCCUPATIONAL HEARING LOSS. A permanent hearing loss sustained in the course of following an occupation or employment. Note: While noise is usually presumed to be the cause, other causes are possible (eg, head injury).

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

PEAK SOUND PRESSURE. The absolute maximum value (magnitude) of the instantaneous sound pressure occurring in a specified period of time.

PERCENT HANDICAP. Syn. Percent impairment of hearing.

PERCENT IMPAIRMENT OF HEARING (OVERALL) (PIHO). The estimated percentage by which a person's hearing is impaired, based upon audiometirc determinations of the hearing threshold level at 500, 1000 and 2000 Hz (cf. Percent impairment of hearing for speech).

PERCENT IMPAIRMENT OF HEARING FOR SPEECH (PIHS). An estimate of the percentage by which a person's hearing is impaired, particularly at the frequencies (500, 1000 and 2000 Hz) deemed important for the perception of speech. Note: The scale 0 to 100% is arbitrarily set to correspond linearly with a standard range of values of hearing threshold level for speech in decibels, customarily 25 to 92 dB re ISO: 1964. The percent impairment of hearing increases by approximately 1.5% for each decibel of elevation of the estimated hearing threshold level for speech (average of 500, 1000 and 2000 Hz).

PERCEPTIVE HEARING LOSS. Syn. Sensorineural hearing loss.(Obs.)

PERMANENT HEARING LOSS. Hearing loss deemed to be irrecoverable.

PERMANENT THRESHOLD SHIFT (PTS). That component of threshold shift which shows no progressive reduction with the passage of time when the putative cause has been removed.

PERSISTENT THRESHOLD SHIFT. Threshold shift remaining at least 48 hours after exposure of the affected ear to noise.

PRESBYACUSIS (PRESBYCUSIS). Hearing loss, chiefly involving the higher audiometric frequencies above 3000 Hz, ascribed to advancing age.

PSYCHOGENIC OVERLAY. Syn. Non-organic hearing loss. (Deprecated.)

RISK. That percentage of a population whose hearing level, as a result of a given influence, exceeds the specified value, minus that percentage whose hearing level would have exceeded the specified value in the absence of that influence, other factors remaining the same. Note: The influence may be noise, age, disease, or a combination of factors.

SEMI-INSERT EAR DEFENDER. An ear defender which, supported by a headband, occludes the external auditory meatus at the entrance to the ear canal.

SENSORINEURAL HEARING LOSS. Hearing loss resulting from a lesion of the cochlear end-organ (organ of Corti) or its nerve supply.

SOCIACUSIS. Elevation of hearing threshold level resulting from or ascribed to non-occupational noise exposure associated with the general social environment and exclusive of elevation associated with aging.

SOUND PRESSURE LEVEL (SPL). 20 times the logarithm to the base 10 of the ratio of the sound pressure in question to the standard reference pressure of 0.00002 N/m^2. Units: decibels (dB).

SPEECH AUDIOMETRY. A technique in which speech signals are used to test a person's aural capacity to perceive speech in prescribed conditions of testing.

SPEECH DISCRIMINATION. The ability to distinguish and understand speech signals.

STANDARD AUDIOMETRIC THRESHOLD. A standardized set of values of sound pressure level as a function of frequency serving as the reference zero for determinations of hearing threshold level by pure-tone audiometry.

STAPEDIUS REFLEX (STAPEDIAL REFLEX). (Likewise, tensor tympani reflex.) The reflex response of the stapedius (likewise, tensor tympani) muscle to acoustic or mechanical stimulation. Commonly, synonymous with acoustic reflex.

STEADY NOISE (STEADY-STATE NOISE). Noise whose level varies negligibly within a given period of time.

TEMPORARY THRESHOLD SHIFT (TTS). That component of threshold shift which shows a progressive reduction with the passage of time after the apparent cause has been removed.

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

THRESHOLD OF FEELING (TICKLE). The minimum effective sound pressure level of an auditory signal capable of exciting a sensation of feeling or tickle in the ear which is distinct from the sensation of hearing.

THRESHOLD OF PAIN (AURAL PAIN). The minimum sound pressure level of an auditory signal which is capable of eliciting a sensation of pain in the ear as distinct from sensations of feeling, tickle or discomfort.

THRESHOLD SHIFT. An elevation of the threshold of hearing of an ear at a specified frequency or average value of frequency. Units: decibels.

TINNITUS. Ringing in the ear or noise sensed in the head. Onset may be due to noise exposure and persist after a causative noise has ceased, or occur in the absence of acoustical stimulation (in which case it may indicate a lesion of the auditory system).

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

WEIGHTING (FREQUENCY WEIGHTING). The selective modification of the values of a complex signal or function for purposes of analysis or evaluation, in accordance with prescribed or standardized rules or formulae. Note: This may be done by computation or by the use of specified weighting networks inserted into electronic instrumentation so as to transform input signals.

ABBREVIATIONS

AAOO	American Academy of Ophthalmology and Otolaryngology
AC	Air Conduction
AFR	Air Force Regulation
AHL	Average Hearing Level
AI	Articulation Index
AMA	American Medical Association
ANSI	American National Standards Institute (formerly USASI)
BC	Bone Conduction
CHABA	Committee on Hearing and Bio-Acoustics
dBA	A-weighted decibel (decibels). Also written dB(A).
DRC	Damage Risk Criterion
E_A	Noise immission level
EPA	Environmental Protection Agency
HL	Hearing Level
HTL	Hearing Threshold Level
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
L_A	A-weighted sound level
L_{A50}	A-weighted sound level exceeded 50% of the time
L_{eq}	Equivalent continuous sound level
L_{NP}	Noise Pollution Level
NIHL	Noise-Induced Hearing Loss
NIOSH	National Institute for Occupational Safety and Health
NIPTS	Noise-Induced Permanent Threshold Shift
NITTS	Noise-Induced Temporary Threshold Shift
NPL	Noise Pollution Level (also National Physical Laboratory in England,
NR	Noise Rating
OSHA	Occupational Safety and Health Act
PB	Phonetically Balanced
PTS	Permanent Threshold Shift
RMS	Root Mean Square
SIL	Speech Interference Level
SIR	Speech Impairment Risk
SPL	Sound Pressure Level
SRT	Speech Reception Threshold
TS	Threshold Shift
$TS_{4\infty}$	TS at asymptote at 4 kHz
TTS	Temporary Threshold Shift
TTS_2	TTS determined 2 minutes after cessation of exposure

Appendix 5

PHYSICAL MEASUREMENT AND DESCRIPTION OF NOISE HAZARDOUS TO THE EAR

A multiplicity of acoustical units and measurement techniques are at present in use in the United States and around the world. The choice of unit and method of measurement is usually determined mainly by the criterion of interest (eg, hearing hazard; annoyance) but, even within the specific province of hearing hazard, several methods of rating noise are available; and more than one procedure has achieved national or international standardization.

A5.1 Units and procedures for on-going (continuous) noise

A5.1.1 Principles of measurement. On-going noise in most situations is nearly always measured with a sound level meter, an instrument which responds to the pressure oscillations (sound waves) in the air at the point of measurement in the sound field. Many kinds of sound level meter exist: measurements should be made using instruments which conform to current national or international standards prescribing the characteristics, method of calibration, precision, etc. of such instruments (see bibliography below). An important feature of the sound level meter is that it contains electronic networks which perform a time-averaging integration of the instantaneous pressure signal, using a time-constant selected to resemble the integrative function of the human ear and to permit reading of a reasonably stable averaged sound level on the meter. Two options, "fast" and "slow" response, are customarily provided in commercial instruments. The "slow" response is normally used when evaluating noise hazardous to the hearing. It is important to appreciate that the time-averaging feature of the sound level meter renders it unsuitable for measuring impulsive noises or bursts of noise lasting less than half a second (see Section IIIB, and A5.2 below).

Various weighting networks (also now standardized) may be switched into the measuring circuit in order to discriminate against certain frequencies in a manner resembling the human hearing function. When no such network is interposed, the meter may be used to measure the Sound Pressure Level (SPL) in decibels (dB), either overall or in octave bands (band pressure level). When a frequency-weighting network (filter) is inserted, the meter yields a measurement of weighted Sound Level. At least 4 networks have been devised, of which 3

("A", "B" and "C") have been standardized internationally and are customerily provided in commercial equipment. A fourth, "D", with variations (not yet standardized) is sometimes included and an "E-weighting" may be introduced for certain applications in the future. The present consensus is that the most appropriate weighting to use in the evaluation of noise hazardous to the hearing is "A-weighting". The measurement of sound level is then expressed in A-weighted decibels (dBA), which may be related to sound pressure level in decibels (dB) by the use of tables or computational procedures (see Appendix 8). For some purposes (Botsford, 1970), the C-weighting may also be used to evaluate hearing hazard: the noise is then measured in dBC.

It is important to remember that the decibel is not an absolute unit: it is a unit of level or ratio and its use implies a reference level (zero decibels) to which the actual measurement relates. In acoustical sound pressure level measurements, the international standard reference zero is 0.00002 newtons per metre squared (N/m^2). It is independent of frequency. In audiology, the same unit, the decibel, is also used to specify the amount of hearing change or loss with reference to other agreed reference levels, such as a standard reference zero for audiometry, which is a function of frequency; or with reference to an arbitrary otological "fence".

A5.1.2 A-weighted sound level (Unit: dBA). This is generally the most convenient and useful measurement to make in field surveys or on-the-spot investigations of noise. With certain exceptions, A-weighted sound level is a fairly reliable predictor of noise hazard in most practical situations. It can incidentally provide a direct, if approximate, estimate of loudness level in phons (the original purpose of the weighting) in the case of tonal or narrow-band random noise, provided that the noise is not too widely distributed in frequency or accompanied by significant levels of noise in other regions of the spectrum. It is useful for making comparative evaluations of the noise from different sources, or from the same source before and after noise control measures have been taken, provided that the noises compared are broadly similar in spectral composition and that the source or sources are essentially omnidirectional. The measurement is made using a sound level meter switched to the A-weighting network. The conditions of measurement (including distance from the source) should be reported along with the level readings.

The A-weighted sound level in dBA* loses power as a predictor of hazard to hearing, subjective response, or other frequency-dependent human reactions to noise, particularly when comparisons are attempted between narrow-band or discrete tonal noise on the one hand and broad-band noise on the other; or when evaluating noise in bounded spaces whose acoustical characteristics are strongly frequency-dependent. For such evaluations, octave band or narrower-band SPL measurements are appropriate, from which other predictive indices of the human response may be calculated as required. Many authorities now use dBA values in planning for community noise control. A-weighted sound level is recommended for general use as a hearing damage risk predictor in the appraisement of noisy environments. Caution sould be exercised if the noise contains strong tonal components, however, for dBA measurements may underestimate the hazard.

A5.1.3 <u>Equivalent continuous sound level, L_{eq} (Unit: dBA)</u>. This is a notional daily average level of noise (normalized to a continuous 8-hour exposure) calculated from partial (less than 24-hour) exposures. It is used to predict hearing hazard in the event of the daily noise being intermittent, of varying duration, or fluctuating level. The quantity, L_{eq}, is yielded by the formula:

$$L_{eq} = \frac{\text{Log } F}{0.1} + 90, \text{ where}$$

$$F = \frac{t}{8} \text{ antilog } \left[0.1(L - 90)\right], \text{ in which}$$

t is the exposure time in hours and L is the sound level of the exposure in dBA. A procedure for calculating L_{eq} is given in Appendix 8.

A5.1.4 <u>Noise immission level, E_A (Unit: numerical, related to dBA)</u>. This A-weighted index of industrial noise hazard, devised by Robinson (1971) is given by:

$$E_A = L_A + 10 \log(T/T_o),$$

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* Some authorities maintain that the unit of measurement should properly be designated dB(A), which is the usage in some international standards (ISO, 1971), but dBA is a commonly used convenience, adopted here.

where:

E_A = A-weighted noise immission level;

L_A = A-weighted sound level (daily average) in dBA;

T = the duration of working exposure in years; and

T_o = the reference duration of 1 year.

Further details of the use of this index are given in Appendix 7.

A5.1.5 Noise pollution level, NPL (Unit: dBA, dBD or PNdB). This concept, recently introduced by Robinson (1969), is an attempt to formulate a unifying criterion embracing all manner of environmental noise, including ambient noise in urban communities and intruding noise from traffic, industry and aircraft operations. The NPL is obtained from weighted sound level or perceived noise level (PNL) values. It is defined by the formula:

$$L_{NP} = L_{eq} + 2.56\sigma,$$

where L_{eq} is "energy-mean" or equivalent continuous noise level and σ is the standard deviation of the instantaneous levels recorded over a specified period of time. It remains to be seen whether this concept, which is a promising approach to the unification of noise evaluation procedures according to the criterion of preserving the peace of communities, will achieve wide acceptance.

A5.1.6 Noise rating (NR) contours (Unit: none. NR contours are based numerically on SPL in dB at 1000 Hz). In 1962 Kosten and van Os refined a series of idealized noise spectra which, with minor modifications, have been accepted by the ISO for consideration as an international standard. These curves are a weighted frequency function which attempts to specify the general decline in the human tolerance of noise with rising frequency at any given SPL. The NR contours are essentially similar to the Noise Criterion (NC) contours of Beranek (1960) but include a modification of the frequency scale which takes account of the ISO preferred frequencies for acoustical measurement (1962). The change to ISO preferred frequencies introduced small changes in level.

NR contours are intended as general guidelines according to a wide range of criteria, including hearing conservation, speech intelligibility, and the protection of communities from noise nuisance. There is some doubt as to whether such a simple figure of merit as an NR number can have such universal applicability. Nevertheless, NR estimations appear to provide useful guidance to required acoustical treatments in offices and other rooms in buildings exposed to interior or intrusive noise. Kosten and van Os (1962) provided numerous examples of acceptable NR for a variety of situations (eg, conference rooms, general and private offices, workshops, hospitals, domestic accommodation and so on), with correction factors (ranging from +25 to -5 dB) according to the nature of the noise - for example, whether it is steady or intermittent; tonal or distributed - and such factors as the location of the area in question (eg, in a suburban residential or industrial area). Passchier-Vermeer (1968) used NR values calculated for the speech frequency range to specify averaged occupational noise levels hazardous to the hearing. An approximation acceptable over a fairly wide range of measurement in practice (and used in the present report) is given by the relationship:

(NR) = (dBA) - 5 (eg, 80 dBA is equivalent to NR 75).

The NR contours are probably most useful for the evaluation of interior noises in buildings, where interference with verbal communication forms an important part of the basis of judgment. They are of less certain value, and have not won universal acceptance, where hearing conservation is the criterion.

A5.1.7 <u>Sound pressure level, SPL (Unit: dB)</u>. For the overall appraisement of a noisy environment it is often sufficient to measure simply the sound pressure level (SPL) of the noise contained within the instrumental frequency range. This can be obtained as a single reading on a sound level meter using the "linear" setting. When the instrument is properly calibrated and used correctly, the reading may be accepted as the instantaneous value of the SPL at the particular point of measurement. It is expressed in decibels above the standard reference pressure (0.00002 N/m^2).

Sound level meter circuits, as commonly designed, incorporate relatively long time constants (of the order 0.1 to 0.25 sec) which are intended to simulate the integration time of human audition. These values permit reasonably stable readings from the meter when, as is often the case, the instantaneous sound pressure fluctuates. The reading obtained is thus an estimate (time-average) of the hypothetical "true" SPL at the instant of measurement. For this and other reasons, conventional sound level meters intended for general noise measurements, even when adjusted for a "fast" response, are not suitable for the measurement of transient or impulsive noises of rapidly changing level and frequency content. Filter sets may be used to measure the octave or third-octave SPL (band pressure level) in decibels when it is desired to evaluate the spectrum of the noise (see below).

Many commercially manufactured sound level meters are of the linear rectifier type (these yield a mean rectified value of the sound pressure) or have hybrid rectifying characteristics. The reading given is a sufficient approximation to the true root mean square (rms) value of sound pressure to render the instrument adequate for most noise measurements in the field. For more fundamental determinations it may be appropriate only to use true rms meters but these are apt to be more complicated and expensive. The type of meter used, its settings, the conditions in which readings were taken and other relevant information should be specified when noise measurements are reported.

As mentioned above, sound level meters customarily incorporate at least three frequency-weighting networks which can be switched in selectively when it is desired to appraise hearing hazard, estimate loudness, or to make an assessment of the frequency composition of the noise in question. These weightings are intended to discriminate against very high and low frequency noise picked up by the microphone, in a manner simulating the frequency selectiveness of the human ear. As originally conceived, the three principal weightings, designated A, B and C, were intended to give the meter a frequency-response corresponding with the 40-phon equal loudenss contour for low intensities of noise (A scale), the 70-phon contour for moderate intensities (B scale) and an almost flat response up to about 8000 Hz (but with a slight attenuation at the extremes of the audio-frequency range) for high-intensity noise (C scale). In recent years these scales have received national and international standardization, as have the specifications for sound level meters (IEC, 1965, 1966).

When readings are taken from a sound level meter using one of the weighting networks, they are properly called not SPL but sound level readings and are expressed in decibel units with a suffix designating the scale used. Thus, a reading of 60 decibels taken with the instrument set to the A scale is reported as 60 dBA. As rough rules of thumb it may be useful to note that, if, for a given noise broadly distributed in frequency, the readings taken wilh all three scales in turn differ by less than 3 dB the noise is mainly composed of relatively high frequencies (above 500 Hz); but if the readings taken using the C weighting exceed those using the A and B scales by more than some 6 dB the noise contains mainly low-frequency components (below 500 Hz).

A5.1.8 Subjective noise meters. Some instruments, called subjective noise meters (Anderson, 1960), have been developed which, using various frequency-weighting or limiting networks, purport to measure directly the subjective noisiness, loudness or speech interference level of noise. Caution should be exercised when using such instruments or interpreting readings obtained with them; for the network characteristics may not have been standardized or even have been generally accepted by acousticians. Subjective noise meters are inappropriate to the evaluation of hearing hazard.

A5.1.9 Noise exposure meters (noise cumulators and dosimeters). Integrating noise meters (dosimeters) can be constructed which total acoustic irradiation of a measuring point taking place in a selected period of time. Some instruments can be adjusted so as to integrate only the exposure above a selected level (Cox, 1959; Benson, 1964; Strong & Neely, 1968). The measuring may be done at a fixed point such as a workplace; or the meter can be carried on the person so as to total the individual's noise exposure.

A5.1.10 Surveying noise. It is important to appreciate that an isolated reading taken with a sound level meter, yielding a single weighted level or an octave band spectrum, is very rarely adequate to define a noisy environment; for the sounds encountered in most instances change substantially from time to time and from place to place. A familiar example is the noise from aircraft flying over a city, disturbing people to an extent which depends not only upon the maximum sound levels reached at given points on the ground during fly-overs but also upon the time, frequency and regularity of operations and upon many other factors affecting the propagation of noise from moving sources.

A5.1.11 Broad-band frequency analysis. A coarse frequency analysis is adequate for many purposes, for instance, the appraisal of the sound fields of aircraft or vehicles in order to define what is required by way of noise control. When the noise is broadly distributed in frequency, and when the spectrum may be presumed to be continuous, as in the cases of jet aircraft noise and much industrial noise, octave-band analysis is precise enough for many purposes. Using this technique, band-pass filters covering contiguous frequency bands, nominally one octave wide and based upon a logarithmic series of center-frequencies, are inserted sequentially into the measuring equipment. An octave spans frequencies having a ratio of 2:1. For example, the octave centered on 1000 Hz extends nominally from 707 to 1414 Hz. The energy in each filter pass-band is recorded and may be plotted graphically as a spectrum of band pressure level against frequency. After many years of debate amongst acousticians, a preferred series of octave-band center-frequencies based on the series 1000, 2000, ... Hz has now been generally accepted and has received standardization (ISO, 1962). However, some acoustical instruments and test codes are still in widespread service using non-standard filter sets such as those covering the octave bands 37.5-75 Hz, 75-150 Hz and so on, which have different center-frequencies. In audiometry (see Appendix 6), audiograms are customarily plotted on a preferred frequency scale running in octaves from 125 to 8000 Hz, with the interpolation of the audiometrically significant frequencies 3000 and 6000 Hz.

When the noise level varies substantially with frequency, perhaps having steep slopes and sharp peaks in its spectrum, an approach to narrow-band analysis may be necessary. A practical compromise between imprecision and complexity of analysis is achieved by the use of one-third (1/3) octave band analysis (some equipment, not now in common use, divides the spectrum into half-octaves). Conveniently, ten 1/3-octave bands span a decade of frequency (eg, 1000 Hz to 10 kHz). Moreover, the frequency ratio $10^{0.1}$ is sufficiently close an approximation to the ratio $2^{1/3}$ (actually the ratios are 1.2589 and 1.2599 respectively) for the spacing of the standardized bands to be based upon the former value. A typical 1/3-octave band filter set, available commercially, covers the acoustical range 25 Hz to 22 kHz in 30 steps, centered at the ISO preferred frequencies for acoustical measurements already cited.

The type of frequency analysis used must be specified when sound spectra are interpreted and compared. For identical noises yield spectra which differ according to the degree of resolution of the analysis. The shape and overall level of the spectrum depend upon the attenuating characteristics (ie, the sharpness and linearity of cut-off outside the pass-band) of the filter or filters used in the analyzer and, to a lesser extent, upon the type of microphone and amplifiers used to pick up and process the noise signal. Ideally, an analytical filter should let through all the energy falling within its nominal pass-band and discriminate totally against energy at frequencies outside it. Unfortunately, like most ideals, such a filter cannot exist. Electronic filters possess finite powers of discrimination against frequencies outside the pass-band and, theoretically, they pass some energy at all frequencies. An insertion loss of up to 4 dB at the center frequency occurs when octave-band filters are used, depending upon the type of filter. Moreover, the insertion loss in the pass-band is greater for narrower-band filters than for broad-band filters of similar characteristics (for example, the loss can be up to 6 dB in the case of a 1/3-octave band filter of conventional design), which is one of the reasons why the overall level of the spectrum of a given distributed noise appears higher on broad-band than upon narrow-band analysis. Insertion loss is corrected for by calibration or computation. National and international standards (IEC, 1966) have been laid down defining the characteristics and precision of band-pass filters for use in acoustical work.

A5.1.12 Spectrum level. This is sometimes defined as the band pressure level of noise that would be measured using an ideal analyzer with flat frequency-response and a bandwidth of only 1 Hz. Readings taken from analyzers having differing characteristics and using different analytical bandwidths can be compared upon conversion to spectrum levels. Computational data for carrying out this conversion may be found in acoustical handbooks or in the information provided by the manufacturers of sound analyzing instrumentation. The band pressure level of distributed noise recorded in bands of different widths differs by a factor related to the logarithm of the ratio of the bandwidths and it decreases with decreasing bandwidth.

A5.2 Impulsive (transient) noise

A5.2.1 Varieties of impulsive noise. These were defined (according to Coles and Rice, 1971) in Section III. The two main varieties (see Figure A5-1) are Type A (Friedländer wave) and Type B (oscillatory decay). Neither of these types can be measured adequately with a conventional time-averaging sound level meter: use of such an instrument may grossly underestimate the hazard to hearing associated with the high peak level of an impulsive noise. The error rises with decreasing duration of the peak (eg, in the noise of gunshots or metallic impacts in industry). Coles and Rice have, however, distinguished a third variety of noise, Type C, which although impulsive in origin, may be treated as essentially continuous in nature, and hence amenable to measurement using a sound level meter. Further details are given below.

A5.2.2 Type A noises. The important features to be measured are the peak level (AB in Figure A5-1) and the duration of the positive phase of the wave, AC; and of course the number of impulses and their frequency of occurrence. The waveform can only be measured with precision by oscillographic analysis of the discrete pressure signal at grazing incidence upon the microphone (Coles & Rice, 1971). The peak sound pressure level may be expressed in decibels (dB) with respect to the standard reference zero for SPL measurements. In certain application (eg, sonic boom work), it is customarily expressed dimensionally as an absolute pressure measurement.

A5.2.3 Type B noises. Here again the notional peak value (BD in Figure A5-1) and the duration of the wave envelope (AD) must be measured oscillographically when precise determinations are called for. It may also be appropriate to extend the oscillographic analysis to yield spectral information (ie, to identify the oscillatory composition of the impulse at the point of measurement).

A5.2.4 Type C noises. It is debatable at what point a series of closely-spaced Type A or B noises becomes, for practical purposes, a Type C noise, and so amenable to treatment as continuous noise (ie, quantifiable in dBA). Coles and Rice (1971) have suggested that merged impulses having a repetition rate exceeding 10 per second may be so treated and their averaged level specified in dBA provided that the repeated decay from peak to minimum level in the wave-envelope (see Figure A5-1) does not exceed 6 dB.

A5.3 Bibliography on noise measurement*

A5.3.1 General references.

Coles, R R A & Rice, C G. Assessment of risk or hearing loss due to impulse noise. In: Occupational hearing loss, ed. Robinson, D W, London and New York: Academic press. 1971. 71-77.

Environmental Protection Agency. Fundamentals of noise: measurement, rating schemes, and standards. US Environmental Protection Agency, Office of Noise Abatement, Washington, DC: NTID.300 15. Washington: US Government Printing Office. 1971.

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Peterson, A P G & Gross, E E. Handbook of noise measurement. Concord: General Radio Company. 7th edn. 1972.

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Robinson, D W. Estimating the risk of hearing loss due to exposure to continuous noise. In: Occupational hearing loss, ed. Robinson, D W. London and New York: Academic Press, 1971. 43-62.

A5.3.2 Relevant standards.

International Electrotechnical Commission. Precision sound level meters. IEC Publication 179. Geneva: IEC 1965.

International Electrotechnical Commission. Octave, half-octave and third-octave band filters intended for the analysis of sound and vibration. IEC Publication 225. Geneva: IEC. 1966.

International Organization for Standardization. Expression of the physical and subjective magnitudes of sound or noise. ISO Recommendation ISO/R131. Geneva: ISO. 1959.

International Organization for Standardization. Preferred frequencies for acoustical measurements. ISO/R266. Geneva: ISO. 1962.

International Organization for Standardization. Power and intensity levels of sound or noise. ISO/R357. Geneva: ISO. 1963.

International Organization for Standardization. Standard reference zero for the calibration of pure-tone audiometers. ISO/R389. Geneva: ISO. 1964 (with addendum 1 to ISO/R389-1964: Additional data in conjunction with the 9A coupler. 1970).

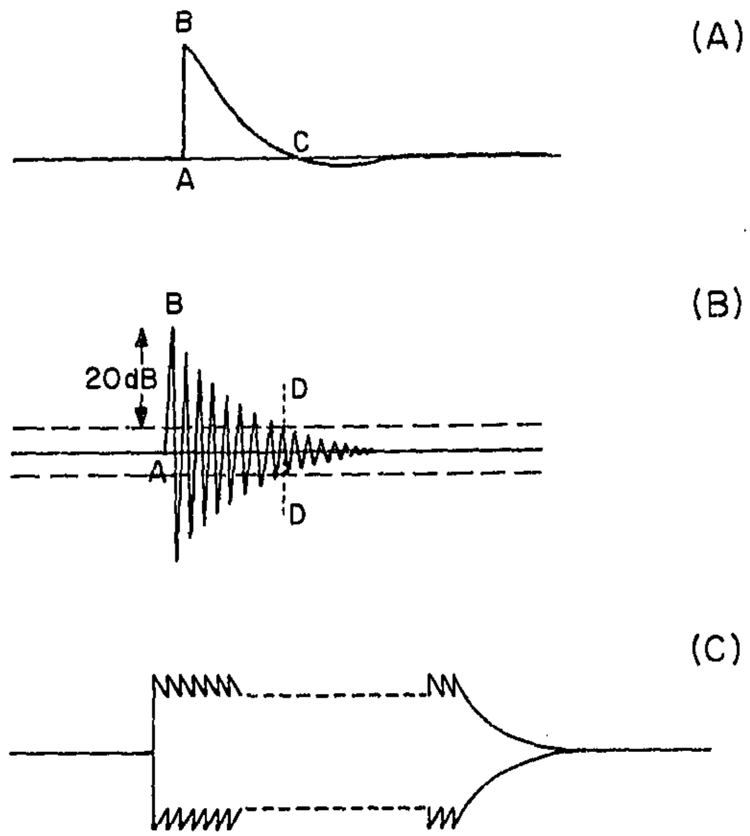


Figure A5-1. Types of impulse noise (diagrammatic). (A) Simple diphasic wave. AB = peak pressure; AC = effective duration. (B) Oscillatory wave. AB = peak pressure; BD = effective duration. (C) Wave envelope of quasi-steady-state series of closely-spaced impulses. (After Coles & Rice, 1971.)

Appendix 6

AUDIOMETRY

A6.1 Pure-tone audiometry

The hearing may be tested clinically in several ways, ranging from simple tests of the subject's ability to detect or distinguish tones, spoken words or other sounds, to pure-tone and speech audiometry. Pure-tone audiometry is most widely used, with recourse to speech audiometry for certain diagnostic purposes. In pure-tone air conduction audiometry, the subject is presented with a succession of sounds at discrete frequencies (pure tones). The sounds generated by the audiometer are heard through earphones, by means of which the two ears are customarily tested separately in a regular sequence. The level of each tone is varied progressively, the purpose being to find the lowest level at which the subject can just detect the tone in prescribed conditions of listening. The subject's hearing threshold level is defined with respect to a standard reference level.

The selection of tones and the variation of level may be accomplished manually or, in some techniques, by a semi-automatic program (Békésy audiometry). The subject's threshold response for each ear is plotted on a chart as a function of frequency (the audiogram). As to the frequencies tested, most commercially available audiometers cover the range 250 to 8000 Hz in octave or, in some instruments (more rarely used) half-octave steps. The interpolated frequencies 3000 and 6000 Hz are often included in the test series. The range 250 to 8000 Hz (some would say 500 to 6000) is generally deemed to be sufficient for purposes of screening audiometry such as in industrial hearing conservation programs. For many purposes in clinical audiology, concerned particularly with the assessment of disability due to occupational noise-induced hearing loss, the hearing changes at 500, 1000 and 2000 are used as indices of impairment or handicap. For particular applications in research or diagnostic audiometry a wider audiometric range of frequency may be investigated including 125 Hz at the lower end of the scale and frequencies up to 12 kHz or even higher at the upper end. Testing above 8 kHz is more difficult to perform accurately and usually requires special testing facilities. It is a sine qua non of audiometry that the instrument be properly calibrated and used in accordance with prevailing standards. National and international standards have been laid sown, defining the characteristics and the condition and method of operation of audiometers, as well as the reference zero to be used in pure-tone audiometry (ISO, 1964).

A6.2 Speech audiometry

Spondaic words (in standard lists) are used instead of pure tones to test the subject's speech reception threshold (SRT). At suprathreshold levels, speech audiometry using spondees may also be used to determine the optimum loudness for speech reception. Phonetically balanced (PB) word lists are also used in speech audiometry, mainly to determine the subject's ability to discriminate speech at suprathreshold levels. These functions are of particular value in appraising the efficiency of hearing data. An important purpose of speech audiometry is to test the patient's ability to discriminate speech in noise.

A6.3 Pulsed-tone Békésy audiometry

Comparing the use of continuous with pulsed tones in Békésy audiometry, McCommons and Hodge (1969) maintain the latter to be preferable, having shown the pulsed tone technique to be superior in both the accuracy and repeatability of threshold determinations. For optimum sensitivity and freedom from intratest variability, these authors have recommended the use of tones having the following characteristics: a period of 500 ms; a duty cycle in the range 50 to 60%; and an attenuation rate in the range 4 to 5 dB/s. The advantage of pulsed over continuous tone audiometry has been ascribed by McCommons and Hodge to the greater amount of perceptual "feedback" making the subject's task of decision-making easier in the pulsed tone technique.

Jokinen (1969) has pointed out that presbyacusis data may be influenced, inter alia, by the method used to test hearing in the elderly: in old age, pulsed tone tracing indicated better hearing than the steady tone threshold. Manual audiometry gave poorer results than automatic testing in inexperienced subjects. Jokinen has claimed that advancing age does not decrease the performance of Békésy audiometry and that the best thresholds are obtained using an automatic pulsed technique.

A6.4 Sources of variance in audiometry

A6.4.1 Audiometry: calibration variance. An important source of confusion in comparisons between data on hearing levels in different populations has hitherto been the lack of universal standardization of audiometric reference thresholds. For example, differences between different national standard reference zeros for audiometers (eg, ASA Z24.5: 1951 in the USA and BS 2497: 1954 in the United Kingdom) can average more than 10 dB and have at certain frequencies exceeded 20 dB.

For this reason, it is imperative to be clear as to which reference zero the data in question refer to. In 1964 the International Organization for Standardization issued a Recommendation (ISO/R389) attempting to unify the conflicting threshold values into an international standard reference equivalent threshold sound pressure level, specified for various reference types of earphones, couplers and artificial ears. A detailed account of the complex process of reconciliation attempted by the ISO has been published by Weissler (1968). It would appear that inter-instrumental variance of several decibels is implicit in the Recommendation.

Individual physical factors can introduce an element of uncertainty into the actual level of test sounds delivered to the eardrum. For example, outer-ear configuration and canal size vary with age, sex and race. This variation may therefore be a factor underlying differences observed between groups in audiometric surveys. Such differences can affect the interpretation of standardized reference zeros (Erber, 1968). Delany (1970) has commented critically upon the use of circumaural earphones in clinical audiometry because of their inherent difficulty of calibration. With regard to instrumental variance in general, however, Jackson _et al_ (1962), describing audiometric practice at an industrial plant, have maintained that this problem can be kept to an acceptable minimum when sufficient care is taken in calibration and audiometric technique.

A6.4.2 _Audiometry: subject variance._ It would seem to be axiomatic that, irrespective of any changes due to age, noise or otological disorder, there will be some long-term instability of an individual's audiometric threshold. Substantial replication variances (eg, $20dB^2$ at 3000 Hz) were reported in non-noise-exposed industrial control subjects by Burns and Robinson (1970) but, in properly controlled conditions of testing, this source of variation can be kept small, about half of it being attributable to an inherent long-term fluctuation (Delany, 1970).

Moreover, replicate testing is apt to show changes (usually "improvements" in hearing sensitivity) associated with familiarization or re-familiarization with the audiometric procedure, even in non-naive subjects. Practice or experience may account for a change in threshold of the order of 1 to 3 dB. A similar order of difference can be seen in measurements taken using pulse-tone self-recording as against manual techniques (Delany, _et al_, 1966, 1970). Learning effects can add to audiometric variance (Jackson _et al_, 1962); moreover the practice effect can be enhanced (leading to lowered measured thresholds) by reward and feedback (Zwislocki _et al_, 1958). The latter factor can account for the increased sensitivity seen when using pulsed-tone techniques.

A6.4.3 Audiometry: variance due to personality. Measurements may be subject to minor variance arising from the personality of the audiometrician (largely eliminated in Békésy audiometry) and from observer differences in the reading of audiograms (Stephens, 1970). Observer influences upon the subject may even affect the response in average evoked response audiometry (an ostensibly objective technique), in which the response can alter with the level of arousal of the subject (Stephens, loc cit).

Although it is of uncertain practical significance, subject personality can also be a variable: threshold detection variance is dependent to some extent on the subject's degree of extroversion/introversion; moreover, differences in the pattern of excursion in Békésy audiometry have been said to relate to various scores on personality inventories (Stephens, 1970). Hinchcliffe (1965, cited by Stephens: unpublished thesis to London University, "A psychological investigation into vertigo") has found patients with certain otological conditions to be more neurotic than normal. This could be a minor factor influencing the range of variability of their audiograms.

Regarding the audiological assessment of individuals in whom NIHL is suspected, and particularly those for whom the question of compensation arises, Hinchcliffe (1970) has reminded us that a non-organic component in the loss must always be excluded. He has remarked that "where compensation is involved, it is not a question of whether or not there is a functional component, but to what extent there is a functional component". He has also pointed out that, even when such a component has been excluded, and due allowance made for presbyacusis, one is still not justified in attributing any remaining fraction of hearing loss entirely to noise: the possibility of loss due to a variety of clinical conditions, irrelevant noise exposure (in occupationally-related assessments), or to noise-equivalent trauma (eg, head injury) must be borne in mind. Such conditions may of course operate to impair hearing even in the interval between pre-and post-noise exposure audiograms, such as may be recorded in an occupational setting. Attribution of hearing loss to noise exposure in the individual is thus a difficult matter of balancing probabilities.

A6.5 Audiometric zero - a critique and comparison

Riley et al (1965) have published a cogent critique of both the concept and practical specification of audiometric reference zero, drawing attention to the substantial discrepencies standing between various standards and reference data in current use (Table A6-I).

Table A6-I. Comparison of ASA (1951) and ISO (1964) audiometric zeros with hearing threshold level of selected young (16 - 25 year old) industrial employees. In dB SPL re 0.00002 N/m^2 (data from Riley *et al*, 1965). Note employees' hearing "better" than ASA reference zero in the Eastman-Kodak series.

Data	Parameter	250	500	1000	2000	3000	4000	6000
ASA: 1951	Mode	39.5	25.0	16.5	17.0	16.0	15.0	17.5
Selected males (Eastman-Kodak)	Mean	35.3	21.5	12.6	15.1	14.2	19.9	22.5
	Median	31.0	18.0	9.4	11.2	9.4	15.0	17.8
Selected females (Eastman-Kodak)	Mean	34.5	20.2	11.3	13.8	10.7	14.7	16.4
	Median	29.3	16.6	7.8	10.2	6.5	10.7	12.3
ISO 1964 recommended	Median	24.5	11.0	6.8	8.5	7.5	9.0	8.0

A6.6 Audiometric pattern of noise-induced hearing loss

Both AC and BC audiometry are necessary to distinguish a mixed hearing loss. In typical cases, the loss begins at 4000 or 6000 Hz, characteristic "notch" deepening and widening with continued noise exposure so as to involve higher and lower frequencies. In contrast to the typical patterns for conductive and sensorineural hearing loss from other causes, the audiogram of the noise damaged ear is recognizable from a progressive depression of hearing from 1000 to 6000 Hz, accompanied in some cases by a relative upswing of the curve at 8000 Hz and higher frequencies. As noted elsewhere in this document a similar pattern is seen in presbyacusis; and distinguishing diagnostic evidence, gleaned from the patient's otological history, may be at best circumstantial.

Sometimes an audiogram is found to show an absolute or relative depression of the hearing at low frequencies. In rare cases, small amounts of threshold shift at frequencies below 1000 Hz may be attributable to noise damage, where the causative noise (or bone-conducted vibration) has itself been of very low frequency (see Appendix 10 on infrasound).

But commonly, the accuracy of such an audiogram is suspect, because of the possibilities of a distorting artifact affecting the measurement. Some causes of a false audiometric pattern include excessive ambient noise in the test room; loose or poorly fitted earphones; lack of adequate practice when the patient is using an automatic audiometer; and malfunction or erroneous calibration of the audiometer.

Progressive losses above 4000 Hz are warning signs that the patient is at immediate risk of impairment if he or she continues to be exposed to intense noise. Progressive loss at 3000 Hz indicates an immediate need for maximum protection of the hearing--if necessary, by removal from hazardous noise exposure.

A6.7 Audiometric and clinical pointers to susceptibility

Within the context of industrial hearing conservation using noise monitoring and routine serial audiometry, Summar (1965) has suggested some pointers to undue individual sensitivity to noise which should be looked for. An employee may be regarded as unduly susceptible to occupational NIHL if he:

1) Works in relatively low levels of noise (less than 85 dBA) but reveals progressive hearing loss of noise-induced type;

2) Works in high levels without protection and shows abnormally rapid shifts; or

3) Works in high levels with protection but shows undue continuing threshold shifts.

Other warning symptoms can be undue difficulty with speech discrimination in noise; loudness recruitment; and tinnitus persisting unduly after removal from the noise.

Appendix 7

NOISE-INDUCED HEARING LOSS: INDUSTRIAL EXPERIENCE AND PREDICTIVE METHODS

A7.1 Effects of continuous noise on hearing: industrial experience

Gallo and Glorig (1964) examined audiometric data from 400 men (aged 18-65) and 90 women (18-35) exposed regularly to high-level industrial plant noise (102 dB SPL overall; 89, 90, 92, 90, 90 and 88 dB respectively in the octave bands spanning 150 to 9600 Hz). These subjects were selected from larger groups of 1526 male and 650 female employees, using a screening process designed to exclude otological abnormalities and irrelevant noise exposure (eg, to military noise), and to maintain in the men a high correlation between age and time on the job. The purpose of the study was specifically to investigate age and duration of steady-state noise exposure as factors in PTS. It showed that hearing level tends to rise relatively rapidly over the first 15 years of exposure but then to level off at the higher audiometric frequencies, 3, 4 and 6 kHz. By contrast, hearing level at 500 Hz, 1 and 2 kHz rose more slowly but continued to rise in an essentially linear manner over exposures up to some 40 years.

A comparison of data for 4 kHz in the men with equivalent data from non-noise-exposed males showed that the effects of the age and noise were not simply additive. Examination of individual differences showed that the spread of hearing level within groups tends to increase with both increasing exposure time and with audiometric frequency (a similar effect was reported by Taylor et al in 1965); and also, in the men studied, that the time and frequency dependence of noise-induced hearing level change is similar for most subjects. Gallo and Glorig concluded from this study that early evidence of PTS at 4000 Hz is the best indicator of susceptibility to noise-induced PTS on either a group or individual basis. A cognate study by Taylor et al (1965) in female jute weavers supported the finding of Gallo and Glorig that noise-induced deterioration in hearing takes place rapidly and mainly in the first 10 to 15 years of exposure, with, however, further deterioration at the speech frequencies continuing in later years.

Taylor et al (1965) carried out retrospective audiometric studies of groups of women working in or retired from the jute weaving industry in Scotland. The contributions to their group hearing levels attributable to the regular noise

(99-102 dB SPL overall with higher peaks) to which they had been exposed were evaluated by comparison with non-noise exposed control subjects and by corrections for presbyacusis using Hinchcliffe's (1959) median data. In the main, this study reported the conclusions of Gallo and Glorig (1964), namely, that the effect of noise on hearing levels is greatest, earliest and most rapid at the higher audiometric frequencies (4 and 6 kHz), where it mostly takes place in the first 10 or 15 years of occupational exposure; but that further deterioration involving frequencies in the range 1 to 3 kHz (being most marked at 2 kHz) becomes manifest during the third decade of noise exposure. After as few as 10 years on the job in high-level (90 dB SPL or higher) industrial plant noise, men as young as 30 years old may have hearing levels worse than non-noise-exposed men twice their age and may in some cases already suffer impaired speech perception (Gallo & Glorig, 1964).

PTS produced by noise exposure and PTS produced by aging (presbyacusis) may not be distinguishable on either a group or individual basis (Gallo & Glorig, 1964). Noise induced PTS is found primarily among industrial workers who have been exposed repeatedly and over a long period to high-intensity noise: provided that the ears affected are otologically normal, the PTS found in noise-exposed people may be attributed to the combined effects of aging and habitual noise exposure. Moreover, the component attributable to noise exposure may be viewed as the result of repeated noise-induced TTS exceeding a certain critical level (about 20 dB).

Gallo and Glorig (1964) have summarized some general characteristics of noise-induced PTS, as seen in occupational contexts, namely, (1) the magnitude of the resulting PTS is related to the noise levels to which the ear has habitually been exposed; (2) the magnitude of the resulting PTS is related to the length of time for which the ear has been exposed; (3) the growth of occupationally related PTS at 4000 Hz is most rapid during the first 10 to 15 years of exposure, after which it tends to slow down (see also Passchier-Vermeer, 1968); and (4) there are large individual differences in susceptibility to noise-induced PTS. The data of Summar and Fletcher (1965) imply that age at the time of exposure is probably not a significant factor in industrial NIPTS.

A7.1.1 Differences between the sexes. In Gallo and Glorig's study (1964) of hearing level changes in men and women exposed regularly ro high-level industrial plant noise, the men in the age range 18 to 35 years were found to show larger changes and greater variability in hearing level than the equivalent group of working women. It might be inferred from this that men are more susceptible to noise than women. The authors pointed out, however, that the data were likely to have been influenced by the facts that the women's noise exposure was more intermittent (due to mandatory work-breaks), probably allowing some recovery from TTS; and that (the screening procedure notwithstanding) some of the men may already have suffered significant noise exposure in the armed forces (see Appendix 2).

A7.1.2 Social significance of hearing loss at retirement. Kell et al (1971) have reported that more than two thirds of a surveyed group of elderly (mean age 64.7 years) women who had worked as weavers (with steady daily noise exposures of approximately 100 dBA) for up to 50 years had difficulty with such social intercourse as understanding conversation, using the telephone, and attending to public meetings or church services. By contrast, fewer than one in six age-matched women who had not been in a noisy occupation was similarly handicapped.

A7.1.3 The reliability of the data from industrial studies. Unfortunately, many hearing loss data from industry are heavily contaminated by what Glorig and others (see Cohen, Anticaglia & Jones, 1970; and Ward, 1970) have called "sociacusic" factors (ie, undeterminable losses due to non-occupational noise exposure in military, recreational or other pursuits; or to disease affecting the ear); by the effect of presbyacusis, which is inextricably bound up with the time-dependent effect of noise exposure (and which is presumed largely on a priori rather than evidential reasoning to be simply additive); and even within the setting of industrial noise exposure, by lack of continuity (eg, due to personnel changing jobs) affecting both retrospective and prospective studies.

Ward (1970) has drawn attention to the particular weakness of the evidence in relation to intermittent exposure, pointing out that the "equal-energy" rule (probably a reasonably satisfactory hypothesis over a wide range of durations of continuous noise) makes no allowance for different patterns of recovery from TTS in different patterns of intermittency. For example, the rule cannot distinguish the effect of a single 2-hour exposure from two 1-hour exposures to the same noise with variable amounts of intervening quiet. It was in an attempt to meet this shortcoming that CHABA evolved a criterion based on the observation, of debatable validity, that two noises producing equal temporary loss (conventionally measured as TTS_2) will produce equal ultimate PTS (see Appendix 1).

A7.1.4 Interrupted noise exposure. A noise interruption has been defined (Federal Register, 35 (238), 9 December 1970, pp 18671-18672) as a period of time "equal to at least 20% of the duration of the preceding noise burst when the noise level falls below 80 dBA". A lower figure, say 70 dBA, may however be more appropriate where hearing protection is the criterion. The significance of noise interruption resides in the belief that the interruption allows the ear to recover to some extent from depression of the hearing caused by the noise. It follows that intermittency of noise exposure allows higher noise levels to be tolerated than when the noise is not interrupted. Several factors may affect the auditory tolerance of intermittent noise exposure. These include the number and duration of interruptions (Schmidek et al, 1972; Ward, Glorig & Selters, 1960); the relationships between continuous and intermittent noise exposures (Ward, 1970; Ward, Glorig and Sklar, 1959; Cohen & Jackson, 1968); and possibly the level of noise below 80 dBA during the interruption (Schmidek et al, 1972). In the present document interrupted noise exposure is treated as a special case of fluctuating level (see Section IIIA).

A7.2 TTS and PTS: Prediction in the individual

A7.2.1 Burns' approach. The search for a reliable prognostic test for individual susceptibility to PTS based on tests of TTS continues (Burns & Robinson, 1970); and some promising findings have recently been published by Burns (1970). He has developed a relative index (based on the regression of TTS on hearing level) of susceptibility to TTS (D_T) and, using the predictive method of Robinson (1968), an index (D_p) of PTS, being the deviation (dB) of the individual's age-corrected HTL from the predicted median value of HTL for his peers in age and noise-exposure. This index again has the advantage of being a relative one, permitting subjects of various HTL's, ages and noise-exposures to be grouped for purposes of correlation with the TTS index, D_T. Having determined values of D_T for 3 groups of subjects distinguished by sound level (L_{A2} in the range 93 to 104 dB) causing TTS, Burns has performed regressions of D_T upon D_p for numerous combinations of audiometric test frequencies and found a positive if rather low (not greater than 0.34) correlation coefficient for several such combinations. Somewhat unexpectedly, the most promising result was found when D_T was based on low audiometric frequencies (1 and 2 kHz) and D_p on high (3, 4 and 6 kHz), for reasons which the author admitted to remain obscure. Burns considers this test to have potentialities and has suggested possible ways of strengthening it: its present weakness rests largely in the large residual variance of D_T in the regression of D_T upon D_p.

A7.2.2 The question of TTS_2 as a predictor of hazardous noise exposure. Luz and Hodge (1971) have recently presented complementary evidence, from studies of recovery from impulse-noise induced TTS in monkeys and men, to show that the recovery is not a simple process and that, accordingly, a single measure such as TTS_2 may not be a particularly reliable predictor in the construction of damage risk criteria for hazardous noise exposure. Luz and Hodge have described multiple TTS recovery patterns (cf. Ward's (1963) logarithmic rule) and have postulated the existence of two types of threshold shift, due to "metabolic" and "structural" auditory fatique respectively. They adduce the "rebound" recovery phenomenon as strong evidence for a delayed component in recovery from TTS (evident from other work also) and hypothesize with some conviction that this is related to permanent damage.

A7.2.3 "Equal-energy" hypothesis. Some recent work by Ward and Nelson (1970) on noise-induced threshold changes in chinchillas appears to confirm the observations of Eldredge and Covell (1958) in guinea pigs that there is an equivalence of time and energy (at least within certain ranges of parameters) for continuous, uninterrupted noise exposure. In other words, there is probably a limiting constant product of intensity and time (analogous to Robinson's "immission") for single unbroken exposures. Ward and Nelson (loc cit) urge caution however, in extrapolation to repeated or to interrupted exposures. They cite the findings of Miller, Watson and Covell (1963) that frequent interruptions of noise exposure by noise-free periods reduces both the TTS and the PTS produced by the noise.

A7.2.4 Growth of TTS in constant noise. Miller, Rothenberg and Eldredge (1971) have shown in the chinchilla exposed to constant octave-band (300-600 Hz) noise at 100 dB SPL that TTS grows in magnitude and in audiometric range with duration of exposure over the first 1 - 2 days, then remains essentially constant (asymptotic) with continuing exposures up to 7 days. After cessation of exposures of that duration, the TTS decays approximately exponentially over some 5 days (decay took about 2 days after identical exposures leasting only 193 minutes). These noise exposures produced demonstrable cochlear damage, although this was associated with only a small PTS measured 3 months after the noise exposure.

A7.2.5 TTS from prolonged noise exposure. Recent work in the chinchilla (Carder & Miller, 1969) and in man (Mills, Gengel et al, 1970) has confirmed that TTS due to a maintained steady-state octave-band noise exposure reaches an asymptotic level after some (up to 12) hours; and that recovery from asymptotic TTS is slow (3 to 6 days for complete recovery in man) and exponential in form.

A7.2.6 Asymptotic TTS as a function of noise level. Using behavioral audiometry in monaural chinchillas, Mills (in the press) has further demonstrated asymptotic threshold shift following 4 kHz octave-band exposures of up to 9 days (see also Carder and Miller, 1972). The magnitude of threshold shift at asymptotic ($TS_{4\infty}$) was found empirically to be predicted by the equation:

$$TS_{4\infty} = 1.7\ (SPL - 47),$$

where SPL is the sound pressure level in decibels relative at 0.00002 N/m^2. The frequency distribution, temporal pattern and degree of persistence of the TTS were also found to depend on the noise exposure level. TTS caused by 80 dB noise was purely temporary, decaying from the asymptotic value to zero in 3 to 6 days. Noise in the range 86 to 98 dB, however, caused a "permanent" component to persist in the threshold shift, which had not decayed to zero after 90 days. The magnitude of this residual ("permanent") threshold shift was related to noise level, being of the order of 10 dB at the higher audiometric frequencies following 86 dB expsoure, about 20 dB following 92 dB exposure and up to 40 dB (at 5.7 kHz) following 98 dB exposure. It cannot of course be inferred that similar values or temporal patterns of TTS and PTS would be caused by the same exposures in man, but this work would appear to support a correlation between threshold shifts measured within 20 minutes of exposure and persistent threshold shifts measured 90 days after exposure. The threshold shift measured 90 days following exposure may reasonably be presumed to be a permanent threshold shift. This work is considered in more detail in Appendix 12.

A7.2.7 Pitfalls of generalizing from animal studies to man. Price (1968) has shown that, although the cat is regarded as being more susceptible than man to behaviorally measurable NIHL (see Miller, Watson & Covell, 1963), as is the chinchilla (Peters, 1965), the cochlear microphonic in the cat appears to be much more resistant to alteration by noise stress (at 5 kHz) than is the auditory threshold measured (TTS) in man (although both changes follow a rate law which is linear with the logarithm of time). Price has urged caution in drawing parallels between cochlear microphonic and TTS data, although he has suggested that mechanical factors in the peripheral auditory mechanism may explain certain paradoxes in the growth of TTS resulting from high intensity sustained versus impulse noise exposure (see Ward, Selters & Glorig, 1961). Price (1972) has recently published similar findings at 500 Hz.

Poche et al (1969) have shown that impulsive (cap gun) noise and pure tones (2 kHz at 125-130 dB SPL for 4 hours) produce similar patterns of hair cell damage in the guinea pig. They have pointed out, however, that no firm correlation has yet been established between hair cell damage and hearing loss either in animals (see Miller et al, 1971) or in man.

A7.2.8 Asymptotic TTS in man. In tentative observations upon his own ear, Mills (1970) has found evidence that TTS in prolonged (24-48 hour) octave-band noise reaches an asymptote in man, as in the chinchilla. The time to reach it appears to be in the range 4 to 12 hours for man; and the time required for complete recovery some 3 to 6 days.

A7.2.9 Miscellaneous factors considered in TTS. In 1958, in a widely cited paper, Trittipoe maintained that pre-exposure non-TTS-producing noise levels as low as 48 dB SPL could enhance subsequent TTS due to a high (118 dB) brief noise exposure. This has been taken as evidence that there is no threshold of noxiousness for noise hazardous to the ear. This observation and its interpretations have, however, been disputed by Ward (1960).

Durrant and Shallop (1969) have recently reviewed evidence for central factors in TTS; and have contended that the state of attention can affect the acoustic reflex and hence its protective function, in turn affecting the pattern of TTS. It would appear very doubtful, however, whether such an effect would be of any practical significance in regard to the risk of PTS in noise exposures.

A7.3 Theories underlying continuous noise damage risk criteria

Because most of our data concerning the long term hazard of noise come from 8-hour industrial-type noise exposures, there is a relative lack of information about shorter term intermittent or incomplete daily exposures; and virtually no data about continuous human exposure to noise going on longer than 8 hours, or around the clock. One is accordingly driven to make interpolations and extrapolations on the basis of theories of noise trauma. Two main theories have been supported by substantial amounts of field observation and experimental work. A continuing difficulty in setting guidelines for safe noise exposure is that equivalent predictions using these two thoeries conflict. Because the conflict is not resolvable in many circumstances, an empirical decision has to be faced as to which theory to follow in evaluating a particular noise hazard.

A7.3.1 <u>The "equal-energy" hypothesis</u>. Simply expressed, this argues that the hazard to the hearing is determined by the total energy (a product of sound level and duration) entering the ear on a daily basis. This rule is basic to the damage risk criteria embodied in certain important and widely used regulatory or guiding documents, notably the United States Air Force (1956) Regulation AFR160-3 (the first formal implementation of the rule). The "equal-energy" rule allows a 3 dB increase in sound pressure level for each halving of the duration (below 8 hours) of continuous daily steady-state noise exposure. Extrapolation to prolonged durations of continuous noise exceeding 8 hours daily exposure, and extension to extremely brief exposures and impulses, has only recently been proposed (Johnson, 1973; Robinson, 1971). In practice, a cut-off is introduced by the widely recognized mandatory absolute limit of 135 dB (BENOX, 1953) for unprotected exposure, irrespective of duration. Botsford (1970) has remarked that there is still a lack of experimental or empirical verification for the "equal-energy" hypothesis, except perhaps for overall durations of everyday exposure extending over years (the only application for which the rule was originally proposed). However, the theory possesses the attractions of simplicity and a certain <u>a priori</u> reasonableness (Eldred, Gannon & von Gierke, 1955).

A7.3.2 <u>The "equal temporary effect" hypothesis</u>. This theory, originally based largely on the work of Ward, Glorig and Sklar (1958; 1959) argues that the long-term hazard (of PTS) due to steady-state noise exposure is predicted by the average TTS produced by the same daily noise in the healthy young ear. As Botsford (1970) has noted in a recent review, this hypothesis is plausible because (unlike the "equal-energy" rule) it relates to an observable physiological function of the ear. Moreover, recent work suggests that a unifying (but as yet unproven) hypothesis of metabolic insufficiency induced in the hearing organ by noise my underlie both the temporary and permanent hearing defects caused by excessive noise (Hawkins, 1971). The essence of the supporting data is that noise intense enough to cause PTS in the long run is intense enough to produce TTS in the normal ear; while noise which does not produce measurable TTS is not associated with NIPTS (Ward, 1960). TTS studies also tend to support the observation (reflected in industrial studies of PTS) that intermittent noise is less harmful than constant exposure to steady-state noise at the same level (Sataloff, 1969; Cohen & Jackson, 1968). Adoption of this theory has led to a number of current criteria, including that of CHABA (1965), considered below.

A7.3.3 <u>CHABA criterion for steady-state noise exposure</u>. CHABA's criterion is based essentially upon the hypothesis of "equal temporary effect" already alluded to. In essence it states that a noise exposure is unsafe if, upon testing the normal ear two minutes after the cessation of the exposure, an average TTS_2 of 10 dB is exceeded at audiometric frequencies up to 1000 Hz; 15 dB at 2000 Hz; or 20 dB at 3000 Hz and above (Kryter, 1963; CHABA, 1965). According to Ward (1970) this criterion reflects the empirical observation that in most normal-hearing people, a TTS_2 of 20 dB or less recovers completely within 16 hours (when the worker would be due to renew a typical 8-hour industrial exposure). The corollary to that is that it is deemed unlikely that any PTS is building up when the TTS recovers completely before the commencement of the next working day. (A fraction of "sensitive" ears, of course, will not recover completely.) This makes no allowance, however, for non-occupational exposure outside working hours.

A7.4 "Industrial" methods of predicting long-term hazard from daily continuous noise exposure

Predictive methods were alluded to in Section IIIA and are considered in detail in Supplement 2. These methods permit predictions of the amount of noise-induced change in hearing level to be predicted for designated fractions of otologically normal working adult populations notionally exposed day by day to steady-state industrial type noise, as a function of average noise level (or equivalent continuous sound level - see Appendix 8).

A7.4.1 Method and data of Passchier-Vermeer (1968). In order to determine the influence of steady-state broadband noise on the hearing levels of people exposed to noise for 8 hours a day, at least 5 days a week, literature data were analyzed from 20 groups of employees (about 4600 people) by Passchier-Vermeer (1968). Noise-induced shifts of hearing levels were considered for exposure times between 10 and 40 years and for noise with Noise Ratings (NR) for 500 to 2000 Hz between 75 and 98, or sound levels between 79 and 102 dBA.

The median noise-induced hearing losses ($D_{50\%}$) at 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz were first examined as a function of exposure time. The increase of $D_{50\%}$ with exposure time varied with frequency. The findings were:

(1) $D_{50\%}$ at 4000 Hz remained constant at exposure times of at least 10 years. The only exception was the female group, for which $D_{50\%}$ increased slightly after 10 years of exposure.

(2) $D_{50\%}$ at 2000 Hz was a linearly increasing function of exposure time from the very beginning of exposure.

(3) $D_{50\%}$ at 500, 1000 and 3000 Hz increased, for exposure times of at least 10 years, year by year with respectively 2%, 2.5% and 1% of the median hearing loss caused by an exposure to noise for 10 years. If $D_{50\%}$ after 10 years is zero, then $D_{50\%}$ remains zero for longer exposure times.

(4) $D_{50\%}$ at 6000 and 8000 Hz did not increase after 10 years of exposure, provided that the NR for 500 to 2000 Hz was at most 92. At higher NR's for 500 to 2000 Hz, $D_{50\%}$ at 6000 and 8000 Hz increased year by year with about 0.3(X-92)% of the median noise-induced hearing loss occurring after 10 years of exposure (where X is equal to the NR for 500 to 2000 Hz).

The analysis showed that the relation between noise and median noise-induced hearing losses is most accurate, when the NR for 500 to 2000 Hz is taken as a parameter of the noise. Passchier-Vermeer (1968) has stated that the sound level in dBA may also be used to estimate the median noise-induced hearing losses, if the octave band spectrum contains sound pressure levels in the two highest octave bands (mid-frequencies 4000 and 8000 Hz) that are relatively low compared with the sound pressure levels in the other octave bands; if the sound pressure levels in those two octave bands are about as high as the other sound pressure levels, then the median noise-induced hearing losses will be overestimated.

The only difference found between the median noise-induced hearing losses of men and those of women, was a slight increase of $D_{50\%}$ at 4000 Hz for the female group for longer exposure times. At the other frequencies there was no difference between the $D_{50\%}$-values of men and women. However, the data from only one female group could be considered.

Because mean hearing levels of four groups were given in the literature studied by Passchier-Vermeer (1968), the mean noise-induced hearing losses of those four groups were calculated. It appeared that there was no difference between those four mean values and the median values of the noise-induced hearing losses, if all these values were related to the NR for 500 to 2000 Hz. However, it was not possible to exclude the possibility that curves based on mean values only have a shape different from curves based on median values only.

Considering the median hearing losses caused by an exposure to noise for 10 years as a function of frequency, Passchier-Vermeer's analysis showed that these hearing losses are maximal at 4000 Hz and decrease with increasing and decreasing frequency. After 10 years of exposure, differences between the hearing losses at 3000 Hz and 4000 Hz are slight. With increasing exposure time the median noise-induced hearing loss moves from 4000 Hz towards lower frequencies at higher NR's for 500 to 2000 Hz. (At NR 98 the median hearing loss caused by an exposure to noise for 40 years was maximal at 2000 Hz.) If the NR for 500 to 2000 Hz is at most 80, the median noise-induced hearing losses are generated during the first 10 years of exposure. At NR 85, $D_{50\%}$ increases for longer exposure times - mainly at 2000 Hz. At higher NR's for 500 to 2000 Hz the increase of $D_{50\%}$ at all frequencies, except 4000 Hz, is considerable after 10 years of exposure time, at least for the values limited by the hearing levels not exceeded in 75% and 25% of the people exposed to noise. The spread of the hearing levels depends simply upon the NR for 500 to 2000 Hz; it is an increasing function of the NR for 500 to 2000 Hz, at each frequency, except at 4000 Hz. At 4000 Hz the spread is a decreasing function of the NR for 500 to 2000 Hz. A consequence is that, at NR's of at most 80 at all frequencies, except 4000 Hz, the spread of the hearing levels of people exposed is just as large as that of people not exposed. The reverse occurs at high NR's (at least 96) where the spread of the hearing levels at 4000 Hz is the same for people exposed and people not exposed, but at the other frequencies the spread of the hearing levels of the people exposed is larger. If the spread of the hearing levels of people exposed to noise is larger than that of people not exposed to noise, this increase in spread must be caused by noise. Passchier-Vermeer's analysis showed that, in addition to an increase in median hearing level, it is possible that the spread of the hearing levels also increases as a result of exposure to noise.

"Approximations" of the noise-induced hearing losses not exceeded in 75% and 25% of the people, were also calculated by Passchier-Vermeer (1968). The median hearing level of those people not exposed to noise who had the same mean age as the people exposed was subtracted from the hearing levels not exceeded in 75% and 25% of the people exposed. This implies an approximation, because the spread in the hearing levels of people not exposed to noise was not taken into account. Calculation of the exact values of the noise-induced hearing losses not exceeded in 75% and 25% of the people is impossible, because it is not known exactly what would have been the hearing level of a person, when he had not been exposed to noise. However, it is possible to calculate the noise-induced increase in the hearing levels not exceeded in 75% and 25% of the people. Designating these shifts as $D_{75\%}$ and $D_{25\%}$, then $D_{75\%}$, $D_{50\%}$ and $D_{25\%}$ are equal when the spread in the hearing levels does not increase as a result of exposure to noise, and they are different when the spread does increase. The differences between $D_{75\%}$ and $D_{50\%}$ and between $D_{50\%}$ and $D_{25\%}$ were found to be independent of exposure time, at exposure times of at least 10 years. These differences increased with the NR for 500 to 2000 Hz at all frequencies except at 4000 Hz, where they were decreasing functions of the NR for 500 to 2000 Hz.

An appendix to the report of Passchier-Vermeer (1968) contains the data necessary to estimate from industrial type noise measurements:

(1) the median noise-induced hearing loss;

(2) the approximations of the noise-induced hearing losses, not exceeded in 75% and 25% of the people;

(3) the noise-induced shifts of the hearing levels not exceeded in 75% and 25% of the people;

(4) The distribution of the hearing levels of a group exposed to noise, with an arbitrary mean age.

All these extimations can be made for exposure times between 10 and 40 years and NR for 500 to 2000 Hz between 75 and 98.

Using that Appendix, estimates of median, quartile, 10% and 90% values of that part of HL attributable to noise have been derived from Passchier-Vermeer (1968), with certain modifications of her method. These data are given in Table A7-III. The end-decile values mark off extremely sensitive ears (10%) and extremely resistant ears (90%) respectively. The values apply equally to otologically normal men and women. Presbyacusis corrections should be added to predict actual hearing threshold levels.

Note. The values in Table A7-III were obtained using Passchier-Vermeer's method of approximation to yield values of $D'_{25\%}$ and $D'_{75\%}$ for T = 10 years. The nature of the data justified rounding up the resulting decibel values to the nearest integral value. Observations by Robinson (1970) and further reports by Passchier-Vermeer (1969, 1971) were considered to justify the use of double the values in Table C in order to calculate $D'_{10\%}$ and $D'_{90\%}$ from $D'_{50\%}$. Negative values obtained by subtraction from low values of $D'_{50\%}$ were entered as zero in the tables which follow. Table A7-III presents the 10th, 25th, 50th, 75th and 90th percentile values as a function of audiometric frequency (500 through

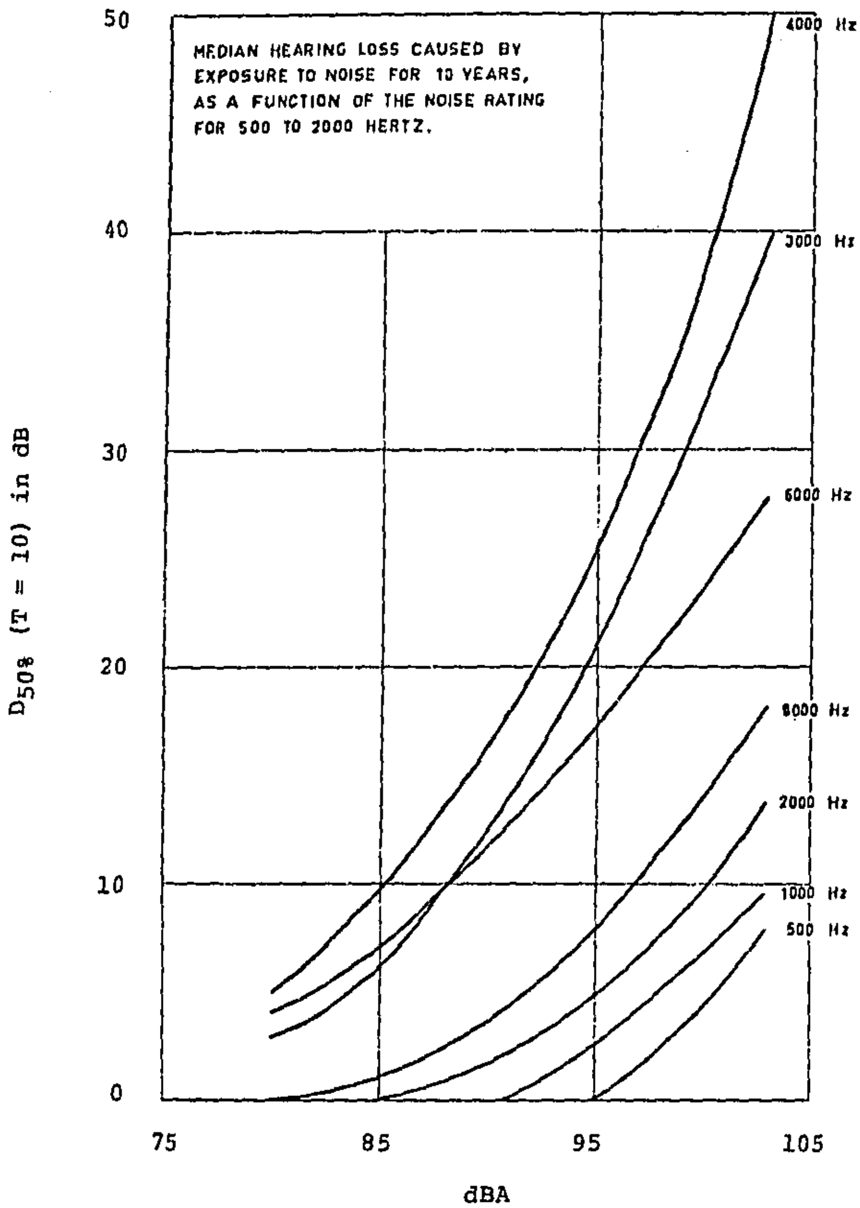


Figure A7-1. Median NIHL at 10 years as a function of level of noise exposure (Passchier-Vermeer, 1968).

8000 Hz), noise exposure level in dBA (80 through 100 in 5dBA steps) and years of exposure (10, 20, 30, 40)*. Linearly increasing median values may be assumed to take place for years from 0 to 10. The values of dBA have been assumed to equate with Passchier-Vermeer's values of "$NR_{.512}$" when 5 is added to the latter (eg, 75 NR = 80 dBA: see Appendix 5). For comparison, corresponding tables are appended in which the values were derived using Passchier-Vermeer's Table B (ie, the method yielding $D_{25\%}$ and $D_{75\%}$). The methods of Passchier-Vermeer are considered further by Johnson (1973).

Table A7-I. Passchier-Vermeer's (1968) Tables A and B for predicting median, 25% and 75%-ile noise-induced hearing level changes from the data illustrated in Figure A7-1.

Table A

Frequency	Increase of $D_{50\%}$ in relation to $D_{50\%}(T=10)$ for exposure times of at least 10 years			
500 Hz	2	% per year		
1000 "	2,5	"		
2000 "	10	"		
3000 "	1	"		
4000 "	0	"		
6000 "	0	"	NR	92
	0.28 (NR-92)	"	NR	92
8000 "	0	"	NR	92
	0.37 (NR-93)	"	NR	92

Table B

NR for 500 to 2000 Hz	Addition (dB) to be made to $D_{50\%}$ to obtain $D_{75\%}$ 500	1000	2000	3000	4000	6000	8000 Hz
75	0	0	0	0	4	0	0
80	0	0	1	0	3.5	1	1
85	0	0	2	2.5	3	2.5	2
90	0	0	3	4.5	2	3.5	3
94	0	0	4.5	4.5	0.5	4	3
98	0	0.5	7	4.5	0	5	3

NR for 500 to 2000 Hz	Subtraction (dB) to be made from $D_{50\%}$ to obtain $D_{25\%}$ 500	1000	2000	3000	4000	6000	8000 Hz
75	0	0	0	1	5	1	0
80	0	0	0	1	5	3.5	0
85	0	0	0.5	2.5	5	6	0
90	0	0	3	3.5	4	7	0
94	0.5	0.5	4	3.5	2	7.5	0
98	1.5	1.5	5	3.5	1	8	0

* 10 to 40 years of exposure typically occurring for 8 h/day, 5 days/week.

Table A7-II. Passchier-Vermeer's Table C, for use with the "approximate" method of predicting noise-induced hearing level changes (1968).

Table C

NR for 500 to 2000 Hz	Addition (dB) to be made to $D_{50\%}$ to obtain $D'_{75\%}$ 500	1000	2000	3000	4000	6000	8000 Hz
75	4	5	5.5	6	13	8	8
80	5	5	7	8	12.5	10	10
85	5	5	8	11.5	12	11.5	11
90	5	5	9	13.5	11	12.5	12
94	5	5	10.5	13.5	9.5	13	12
98	5	5.5	13	13.5	7.5	14	12

NR for 500 to 2000 Hz	Subtraction (dB) to be made from $D_{50\%}$ to obtain $D'_{25\%}$ 500	1000	2000	3000	4000	6000	8000 Hz
75	4	4	3	9	13	9	6
80	4	4	3	9	13	11.5	7
85	4	4	5.5	10.5	13	14	7.5
90	4	4	8	11.5	12	15	7.5
94	4.5	4.5	9	11.5	10	15.5	8
98	5.5	5.5	10	11.5	9	16	8.5

Table A7-III. Composite table of median, 10%, 25%, 75% and 90%-ile values of noise-induced hearing level change predicted as a function of length of exposure, using the direct (first series) and "approximate" (second series) methods of Passchier-Vermeer (1968) with the modifications alluded to in this appendix. The predictions are given as a function of average noise level in dBA for a given audiometric test frequency on each of the following pages. (Pages A7-16 through A7-29.)

First series (500 to 8000 Hz): direct method

500 Hz

Exposure Level	%ile	Exposure (Years) 10	20	30	40
80 dBA) 85 ") 90 ")- 95 ")	All	0	0	0	0
100 dBA	50- 75 90	5 4 3	5 4 3	5 4 3	5 4 3

1000 Hz

Exposure Level	%ile	Exposure (Years) 10	20	30	40
80 dBA	All	C	0	0	0
85 dBA	All	0	0	0	0
90 dBA	All	0	0	0	0
95 dBA	All	5	6	8	9
100 dBA	50-	8	10	12	14
	75	7	9	11	13
	90	6	8	10	12

2000 Hz

Exposure Level	%ile	Exposure (Years)			
		10	20	30	40
80 dBA	All	0	0	0	0
85 dBA	10	2	4	6	8
	25	1	2	3	4
	50+	0	0	0	0
90 dBA	10	6	8	10	12
	25	4	6	8	10
	50	2	4	6	8
	75	1	3	5	7
	90	0	2	4	6
95 dBA	10	11	16	21	26
	25	8	13	18	23
	50	5	10	15	20
	75	2	7	12	17
	90	0	4	9	14
100 dBA	10	20	30	40	50
	25	15	25	35	45
	50	10	20	30	40
	75	6	16	26	36
	90	2	12	22	32

3000 Hz

Exposure Level	%ile	Exposure (Years) 10	20	30	40
80 dBA	10	3	3	4	4
	25	3	3	4	4
	50	3	3	4	4
	75	2	2	3	3
	90	1	1	2	2
85 dBA	10	6	7	7	8
	25	6	7	7	8
	50	6	7	7	8
	75	5	6	6	7
	90	4	5	5	6
90 dBA	10	18	19	20	22
	25	15	16	17	19
	50	12	13	14	15
	75	9	10	11	12
	90	6	7	8	9
95 dBA	10	31	33	35	37
	25	26	28	30	32
	50	21	23	25	27
	75	17	19	21	23
	90	13	15	17	19
100 dBA	10	42	45	48	51
	25	37	40	43	46
	50	32	35	36	42
	75	28	31	34	38
	90	24	27	30	34

4000 Hz

Exposure Level	%ile	Exposure (Years) 10	20	30	40
80 dBA	10	13	13	13	13
	25	9	9	9	9
	50	5	5	5	5
	75+	0	0	0	0
85 dBA	10	18	18	18	18
	25	14	14	14	14
	50	10	10	10	10
	75	5	5	5	5
	90	0	0	0	0
90 dBA	10	22	22	22	22
	25	19	19	19	19
	50	16	16	16	16
	75	11	11	11	11
	90	6	6	6	6
95 dBA	10	30	30	30	30
	25	28	28	28	28
	50	26	26	26	26
	75	22	22	22	22
	90	18	18	18	18
100 dBA	10	40	40	40	40
	25	39	39	39	39
	50	38	38	38	38
	75	36	36	36	36
	90	34	34	34	34

6000 Hz

Exposure Level	%ile	Exposure (Years) 10	20	30	40
80 dBA	10	4	4	4	4
	25	4	4	4	4
	50	4	4	4	4
	75	3	3	3	3
	90	2	2	2	2
85 dBA	10	9	9	9	9
	25	8	8	8	8
	50	7	7	7	7
	75	3	3	3	3
	90	0	0	0	0
90 dBA	10	18	18	18	18
	25	15	15	15	15
	50	12	12	12	12
	75	6	6	6	6
	90	0	0	0	0
95 dBA	10	26	26	26	26
	25	22	22	22	22
	50	18	18	18	18
	75	11	11	11	11
	90	4	4	4	4
100 dBA	10	32	33	33	34
	25	28	29	29	30
	50	24	25	25	26
	75	16	17	17	18
	90	8	9	9	10

8000 Hz

Exposure Level	%ile	Exposure (Years) 10	20	30	40
80 dBA	All	0	0	0	0
85 dBA	10	3	3	3	3
	25	2	2	2	2
	50+	1	1	1	1
90 dBA	10	8	8	8	8
	25	6	6	6	6
	50+	4	4	4	4
95 dBA	10	14	14	14	14
	25	11	11	11	11
	50+	8	8	8	8
100 dBA	10	20	21	21	22
	25	17	18	18	19
	50+	14	15	15	16

Second series (500 to 8000 Hz): approximate method

500 Hz

Exposure Level	%ile	Exposure (Years) 10	20	30	40
80 dBA	10	8	8	8	8
	25	4	4	4	4
	50+	0	0	0	0
90 dBA	10	10	10	10	10
	25	5	5	5	5
	50+	0	0	0	0
100 dBA	10	15	15	15	15
	25	10	10	10	10
	50	5	5	5	5
	75+	0	0	0	0

1000 Hz

Exposure Level	%ile	Exposure (Years) 10	20	30	40
80 dBA)					
85 dBA)-	10	10	10	10	10
90 dBA)	25	5	5	5	5
	50+	0	0	0	0
95 dBA	10	15	16	18	19
	25	10	11	13	14
	50	5	6	8	9
	75	1	2	4	5
	90	0	0	0	1
100 dBA	10	18	20	22	24
	25	13	15	17	19
	50	8	10	12	14
	75	3	5	7	9
	90	0	1	3	5

2000 Hz

Exposure Level	%ile	Exposure (Years) 10	20	30	40
80 dBA	10	11	11	11	11
	25	6	6	6	6
	50+	0	0	0	0
85 dBA	10	14	14	14	14
	25	7	7	7	7
	50+	0	0	0	0
90 dBA	10	18	20	22	24
	25	10	12	14	16
	50	2	4	6	8
	75	0	0	0	2
	90	0	0	0	0
95 dBA	10	23	28	33	38
	25	14	19	24	29
	50	5	10	15	20
	75	0	2	7	12
	90	0	0	0	4
100 dBA	10	31	41	51	61
	25	21	31	41	51
	50	10	20	30	40
	75	1	11	21	31
	90	0	2	12	22

3000 Hz

Exposure Level	%ile	Exposure (Years) 10	20	30	40
80 dBA	10	15	15	16	16
	25	9	9	10	10
	50	3	3	4	4
	75+	0	0	0	0
85 dBA	10	22	23	23	24
	25	14	15	15	16
	50	6	7	7	8
	75+	0	0	0	0
90 dBA	10	35	36	37	39
	25	24	25	26	28
	50	12	13	14	16
	75	1	2	3	5
	90	0	0	0	0
95 dBA	10	48	50	52	54
	25	35	37	39	41
	50	21	23	25	27
	75	9	11	13	15
	90	0	0	2	4
100 dBA	10	59	62	65	68
	25	46	47	50	53
	50	32	35	38	42
	75	20	23	26	30
	90	9	12	15	19

4000 Hz

Exposure Level	%ile	Exposure (Years) 10	20	30	40
80 dBA	10	31	31	31	31
	25	18	18	18	18
	50	5	5	5	5
	75+	0	0	0	0
85 dBA	10	35	35	35	35
	25	23	23	23	23
	50	10	10	10	10
	75+	0	0	0	0
90 dBA	10	40	40	40	40
	25	28	28	28	28
	50	16	16	16	16
	75	3	3	3	3
	90	0	0	0	0
95 dBA	10	48	48	48	48
	25	37	37	37	37
	50	26	26	26	26
	75	14	14	14	14
	90	2	2	2	2
100 dBA	10	57	57	57	57
	25	48	48	48	48
	50	38	38	38	38
	75	28	28	28	28
	90	18	18	18	18

6000 Hz

Exposure Level	%ile	Exposure (Years) 10	20	30	40
80 dBA	10	20	20	20	20
	25	12	12	12	12
	50	4	4	4	4
	75+	0	0	0	0
85 dBA	10	27	27	27	27
	25	17	17	17	17
	50	7	7	7	7
	75+	0	0	0	0
90 dBA	10	35	35	35	35
	25	24	24	24	24
	50	12	12	12	12
	75+	0	0	0	0
95 dBA	10	43	43	43	43
	25	31	31	31	31
	50	18	18	18	18
	75	4	4	4	4
	90	0	0	0	0
100 dBA	10	50	51	51	52
	25	37	38	38	39
	50	24	25	25	26
	75	8	9	9	10
	90	0	0	0	0

8000 Hz

Exposure Level	%ile	Exposure (Years) 10	20	30	40
80 dBA	10	16	16	16	16
	25	8	8	8	8
	50+	0	0	0	0
85 dBA	10	21	21	21	21
	25	11	11	11	11
	50	1	1	1	1
	75+	0	0	0	0
90 dBA	10	26	26	26	26
	25	15	15	15	15
	50	4	4	4	4
	75+	0	0	0	0
95 dBA	10	32	32	32	32
	25	20	20	20	20
	50	8	8	8	8
	75+	0	0	0	0
100 dBA	10	38	39	39	40
	25	26	27	27	28
	50	14	15	15	16
	75	6	7	7	8
	90	0	0	0	0

A7.4.2 Robinson's method for evaluating long-term risk from continuous industrial-type noise. Based on recent British data relating hearing levels to continuous industrial-type noise exposure, Robinson (Robinson & Cook, 1968; Robinson, 1971) has devised a method for estimating the magnitude of NIPTS due to a known or predicted noise exposure to be expected in designated fractions of an otologically normal population. Assuming that the noise is of the same general type as is found in manufacturing industries, where the worker's ear is exposed throughout every shift to a fairly constant (steady-state) assault, Robinson's formula may be used to determine the A-weighted noise immission level, E_A, as a measure of the total equivalent exposure*. Noise immission level has been defined by Robinson according to the formula:

$$E_A = L_A + 10 \log (T/T_o),$$

where L_A is the average A-weighted sound level of the noise in dBA, T is the duration of exposure in calendar years (up to 50) and T_o is the reference duration of 1 year. The principal assumptions underlying Robinson's method, and his formula for predicting the distribution of hearing levels, were shown in Appendix 1.

A7.4.3 Baughn's estimations of hazard due to occupational exposure. In 1966, Baughn published averaged data showing the incidence (percentage of a male working population as a function of age above 20 years) of hearing impairment associated with typical day-by-day occupational exposures to continuous industrial type noise at average levels of 78, 86 and 92 dBA. The percentages were estimated for average hearing levels (AHL) (tested conventionally at 500, 1000 and 2000 Hz in the right ear) exceeding 15 and 20 dB above the ASA 1951 reference zero (Figures A7-3 and A7-4). For comparison, Baughn (1966) plotted his 15 dB AHL data against Glorig's (1960) incidence of hearing impairment exceeding the same fence in a supposedly comparable non-noise exposed population; and he concluded that 78 dBA was an essentially innocuous level of daily occupational noise exposure, ie, a level not materially raising the incidence of noise-induced hearing loss in an industrial population. This interpretation has, however, been questioned critically by Kryter (1973). A critique and a more detailed account of Baughn's (1966,1973) method of estimating risk (incidence of significantly elevated hearing level at the conventional speech frequencies, as a function of age and average daily continuous noise level) are given by Johnson (1973).

* cf L_{eq}, the equivalent continuous sound level (Appendix 8).

Appendix 8

EQUIVALENT CONTINUOUS SOUND LEVEL

A8.1 Calculation of equivalent continuous sound level, L_{eq}

The equivalent continuous sound level is a notional sound level which, in an 8-hour period, would cause the same total A-weighted sound energy to be received as that received from the actual noise during the day (24 hours). This quantity, L_{eq}, is yielded by the formula:

$$L_{eq} = \frac{\text{Log } F}{0.1} + 90\text{, where}$$

$$F = \frac{t}{8} \text{ antilog } \left[0.1(L - 90)\right]\text{, in which}$$

t is exposure time in hours and L is the sound level of the exposure in dBA.

The value of L_{eq} for a daily exposure to on-going noise may be obtained from the nomogram at the end of this Appendix, using the following procedure:

(1) For each component of the total exposure, determine the fractional exposure value, F, from the central scale by connecting the values of L (level in dBA) and t (duration of exposure component) in the nomogram.

(2) Sum the values of F for all the exposure components received in the day.

(3) Read off the value of L_{eq} corresponding to the total value of F on the central scale of the nomogram.

A8.1.1 Continuous exposure to constant (steady-state) noise for 8 hours. In this case the equivalent continuous sound level is numerically equal to the measured or predicted sound level in dBA.

A8.1.2 Single continuous exposure to constant (steady-state) noise for other durations. Using the nomogram, a single value of F is found for the duration in question (up to 24 hours). The corresponding value of L_{eq} is then found from the central scale. Example: a 90 dBA noise lasting for just one hour in a day has an equivalent continuous sound level, L_{eq}, of 81 (to the nearest decibel).

A8.1.3 Noise of fluctuating level (including "intermittent" noise). In this case the value of L_{eq} is found from the sum of the values of F for each component of the exposure. Example: Suppose that the day's exposure comprises the following components (with corresponding values of F).

Duration of Component Exposure	Sound Level, L (in dBA)	F (from nomogram
5 hours	85	0.2
1 hour	95	0.4
10 minutes	115	6.5

The total value of F is 7.1 in this case, giving a value for L_{eq} of 99 (to the nearest decibel).

Appendix 8a

SUPPLEMENTARY METHOD OF CALCULATION

A8a.1 Calculation of equivalent continuous sound level, L_{eq}

Step 1: Add to (or subtract from) each measured sound level the adjustment value found from Table A8a-I.

Table A8a-I. Adjustments to measured sound level for cumulative noise exposure.

Additions		Subtractions	
Total Exposure per day (h)	Adjustment (dB)	Total Exposure per day (h)	Adjustment (dB)
24	+4.8	7	-0.6
16	+3.0	6	-1.2
12	+1.8	5	-2.0
11	+1.4	4	-3.0
10	+0.9	3	-4.3
9	+0.5	2	-6.0
8	0	1	-9.0
		0.5	-12.0

Step 2: Convert adjustment levels to values of F, using Table A8a-II.

Step 3: Add up the values to obtain total value of F.

Step 4: Reconvert total value of F to L_{eq}, using Table A8a-II in reverse.

Table A8a-II. Values of F for adjusted sound level (fractional exposure) or equivalent continuous sound level.

Level (dBA)	Fractional Exposure (F)	Level (dBA)	Fractional Exposure (F)
120	1000	99	7.9
119	794	98	6.3
118	630	97	5.0
117	501	96	4.0
116	398	95	3.2
115	316	94	2.5
114	251	93	2.0
113	200	92	1.6
112	158	91	1.3
111	126	90	1.0
110	100	89	0.8
109	79.4	88	0.6
108	63.1	87	0.5
107	50.0	86	0.4
106	39.8	85	0.3
105	31.6	84	0.3
104	25.1	83	0.2
103	19.9	82	0.2
102	15.9	81	0.1
101	12.5	80	0.1
100	10.0		

A8a.2 Conversion of octave-band sound pressure levels in dB to sound level in dBA

Sound level in dBA may be calculated from octave-band pressure level measurements in decibels using the following method and tables (pages A8-6 and A8-7).

CONVERSION OF OCTAVE BAND SPL (dB) TO A-WEIGHTED SOUND LEVEL (dBA)

(1) Subtract or add the appropriate A-weighting correction given in Table I for each octave band SPL.

Table I. Relative response for sound level meters (IEC, 1965)

Frequency (Hz):	16	31.5	63	125	250	500	1000	2000	3150	4000	8000	16000
Correction (dB):	-56.7	-39.4	-26.2	-16.1	-8.6	-3.2	0	+1.2	+1.2	+1.0	-1.1	-6.6
Approximation (dB):	-57	-39	-26	-16	-9	-3	0	+1	+1	+1	-1	-7

(2) Convert the A-weighted band levels to arbitrary intensity units, I_{band}, using Table II:

Table II. Values of I_{band} corresponding to octave band SPL from 50 dB to 129 dB

dB	0	1	2	3	4	5	6	7	8	9
50	0.00010	0.00013	0.00016	0.00020	0.00025	0.00032	0.00040	0.00050	0.00063	0.00079
60	0.0010	0.0013	0.0016	0.0020	0.0025	0.0032	0.0040	0.0050	0.0063	0.0079
70	0.010	0.013	0.016	0.020	0.025	0.032	0.040	0.050	0.063	0.079
80	0.100	0.126	0.158	0.200	0.251	0.316	0.398	0.501	0.631	0.794
90	1.00	1.26	1.58	2.00	2.51	3.16	3.98	5.01	6.31	7.94
100	10.0	12.6	15.8	20.0	25.1	31.6	39.8	50.1	63.1	79.4
110	100	126	158	200	251	316	398	501	631	794
120	1000	1260	1580	2000	2510	3160	3980	5010	3160	7940

(3) Add up the values of I_{band} (ΣI_{band}).

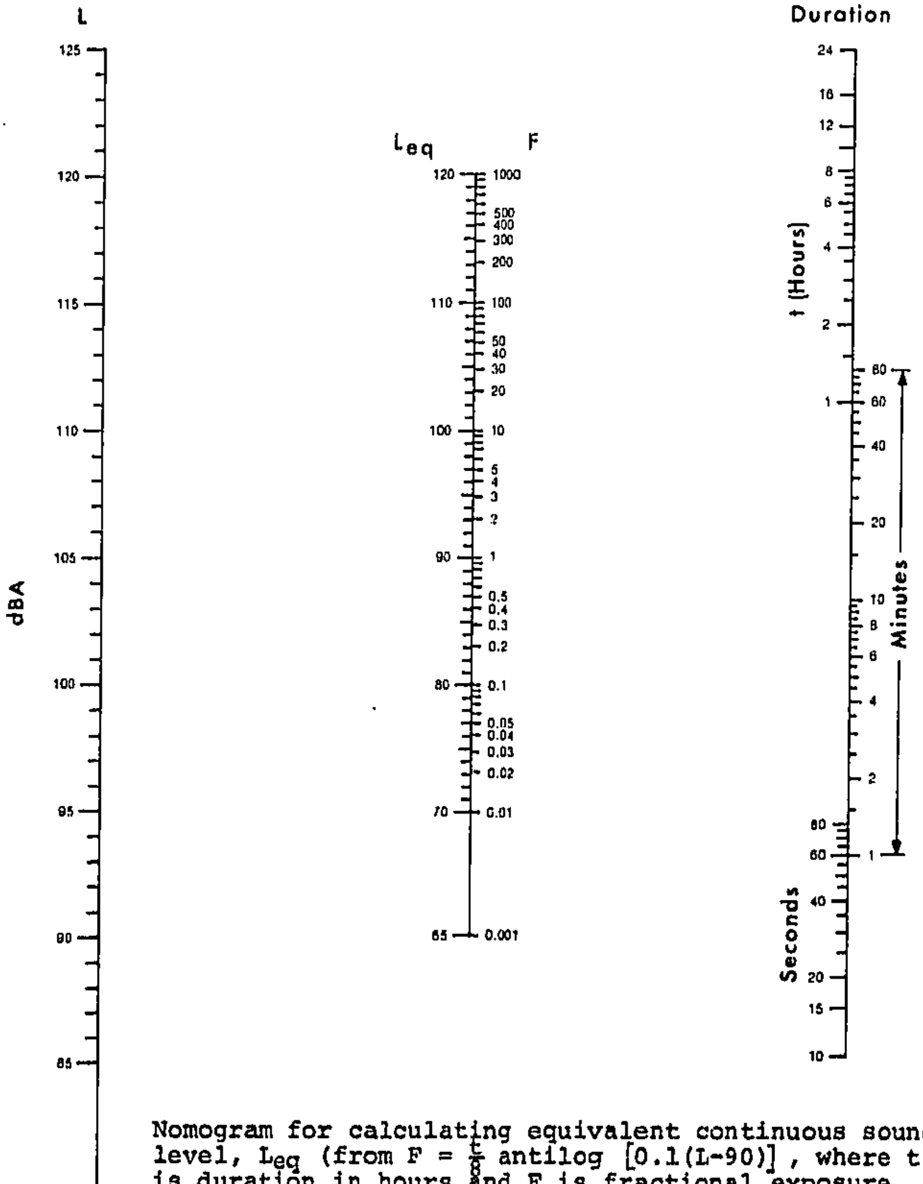
(4) Re-entering Table II, reconvert the total value ΣI_{band} into the A-weighted sound level in dBA (if the ΣI_{band} falls between two values in Table II, take the higher value).

<u>Example</u>: The first two columns of the Table below give the octave band sound pressure <u>levels</u> of a typical industrial noise (riveting machine). Column 3 shows the A-weighting corrections taken from Table 1 which are added to the levels in column 2 to obtain the A-corrected octave band levels in column 4. These are converted in to values of I_{band} using Table 2, added together, then converted into A-weighted sound level using Table 2.

1 Octave band centre frequency Hz	2 Octave band sound pressure level dB	3 A-weighting correction (from Table 1) dB	4 A-corrected octave band level dB	5 (from Table 2)
125	88	-16	72	.016
250	85	-9	76	.040
500	77	-3	74	.025
1000	78	0	78	.063
2000	80	+1	81	.126
4000	70	+1	71	.013
8000	69	-1	68	.006

Total value of I_{band}= 0.289

From Table 2, A-Weighted sound level 85 dBA (to the nearest decibel)



Nomogram for calculating equivalent continuous sound level, L_{eq} (from $F = \frac{t}{8}$ antilog $[0.1(L-90)]$, where t is duration in hours and F is fractional exposure value). For each noise exposure, connect sound level, L, in dBA with exposure duration, t, and determine fractional exposure, F, from the scale at center, right. Determine total F by summing all values received in day. Read off value of L_{eq} from scale at center, right.

Appendix 9

PHYSIOLOGICAL FACTORS AFFECTING THE NOISE SUSCEPTIBILITY OF THE EAR

A9.1 State of health and the general physiological state

It is possible that debilitatory diseases and certain acute systematic diseases that reduce the body's general resistance to noxious agents might increase a person's susceptibility to NIHL. It may further be postulated that this is particularly likely to be so when the effect of the disease (eg, anemia from any cause) is to reduce the level of oxygen circulating in the bloodstream; for there is an association between local hypoxia and haircell damage in the inner ear (Misrahy et al, 1958; Hawkins, 1971). In the absence of reported studies of noise-susceptibility in relation to the general state of health, however, such a relationship remains speculative. Evidence for a link between "stress" disorders, particularly high blood pressure (Rosen et al, 1962, 1971; Bergman, 1966; Sataloff et al, 1969), and hearing loss (although not necessarily noise-susceptibility) has been reported but is similarly inconclusive. It is mostly based on studies comparing the hearing of noise-exposed populations living and working in urban or industrial settings with that of other groups living in quiet rural conditions. It is clearly debatable whether audiometric differences between such groups are due to differences in the prevailing stress or noise exposure alone, for many factors, including genetic, cultural, dietary and nonacoustical environmental differences, may underlie differences in the patterns of hearing found in dissimilar populations or communities who are widely separated geographically or culturally.

A9.1.1 Cochlear hypoxia and NIHL. Hawkins (1971) has recently reviewed metabolic theories to explain the temporary and permanent effects of intense noise upon the hearing organ; and has reported new micropathological observations in guinea-pigs exposed to noise at 118 to 120 dB SPL for 8 to 110 hours. He describes noise-induced capillary vasoconstrictions which which would appear to be a plausible basis for attributing TTS to a regional relative hypoxia occurring in the organ of Corti during excessive acoustic stimulation. Hawkins theorizes that the local vascular response may have the physiological functions of moderating the distribution of blood supply in the organ of Corti to meet the metabolic demands imposed by "natural" levels and patterns of noise; but that excessive and prolonged noises (mostly generated by mechanized human activity) render the response pathological, leading to irreversible vasospastic damage in susceptible regions of the cochlea (including both the hair cells themselves and the capillaries carrying their essential blood supply). Hawkins' hypothesis is still speculative, however, and the way in which repeated vasoconstrictive reactions causing TTS may accumulate to establish permanent damage remains an open question.

A9.2 Otological health

Abnormalities of the middle ear affect the flow of acoustic energy to the inner ear and hence might be expected to affect the development of NIHL. However, there is no unequivocal evidence to show an enhancement of intrinsic susceptibility to PTS in cases of middle ear disease or abnormality. Specific studies have shown that stapedectomized ears are no more susceptible than normal ears, at least with respect to TTS (Steffen et al, 1963; Fletcher & King, 1963). Indeed, some middle ear conditions may, in effect, protect the hearing organ from NIHL by cutting down the acoustic input. Dieroff (1964) has reported such an effect in the "protected" ear in cases of unilateral otosclerosis; related data have been published by Gerth (1966). Chronic perforation of the tympanic membrane may have a similar protective effect in some workers exposed to industrial noise (Dohi, 1953).

It is possible (but unproven) that inner ear infection (which can be the sequel to acute otitis media) might lead to an enhanced susceptibility of the hair cells to noise damage. It remains likewise an open question whether ototoxic drugs can render the inner ear significantly more prone to damage by noise (Dayal *et al*, 1971).

A9.2.1 Noise susceptibility of already diseased ears. As a general rule (Hinchcliffe, 1967) the diseased ear (with the possible exception of endolymphatic hydrops) is probably less susceptible to NIHL, or no more so, than is the normal ear. This is likely to be so particularly in cases of conductive defects, provided there is no sensorineural complication; for middle ear obstructions are apt to act as an ear protector. However, there can be exceptions, making an individual with conductive deafness abnormally susceptible to NIHL. One is loss of the acoustic reflex (as in otosclerosis); another condition is a reduction of pneumatization of the mastoid bone (leading to a loss of air-damping of tympanic membrane movement) associated with chronic middle ear infections (Link, Handl and others cited by Hinchcliffe, 1967). It appears that stapedectomized patients are not unusually susceptible to NITTS (Ferris, 1965) although there may again be exceptions to this rule (Bull, 1966).

A9.2.2 Non-acoustic causes of sensorineural hearing loss resembling NIHL. It has been known since ancient times (Hinchcliffe, 1967; King, 1972) that blows to the head, falls with head injury and direct injury to the ear can cause partial or total hearing loss. Hearing loss associated with head injury is audiometrically identical with noise-induced hearing loss, characterized typically by the 4000 Hz notch in the audiogram; and, accordingly, may be difficult to exclude, except inferentially, in clinical assessments of disability attributed to noise exposure. The hearing organ (apart from the middle ear mechanism) can also be damaged by abrupt and severe changes in atmospheric or extra-tympanic pressure, as in aviation, diving, or exposure to blast waves from explosions (Coles, 1965; King, 1972). In this connection, Hinchcliffe has distinguished five classes of "insult" to the hearing organ, namely:

1) Noise-induced hearing loss
2) Acoustic trauma (see Glossary)
3) Otitic blast injury (Commonly damaging the middle ear as well as the organ of Corti)
4) Acoustic accident (see Glossary)
5) Head injury

(Of these, 1, 2 and 4 are generically linked.)

A9.3 Physiological defensive mechanisms

A9.3.1 The acoustic (middle-ear) reflex. The middle ear contains two small muscles, stapedius and tensor tympani, which act upon the ossicular chain. Both muscles have been shown to contract in response to acoustical stimuli. They also respond to mechanical irritation of the external auditory canal or of the skin of the face or neck around the ear. Functionally, these miniature skeletal muscles have opposing actions: stapedius acts to withdraw the foot of the stapes from the oval window, while tensor tympani tends to pull the handle of the malleus (attached to the tympanic membrane) inwards. The resulting combined action is to increase the stiffness, and probably also the damping, of the ossicular chain, thereby changing the impedance of the middle ear in a way which principally discriminates against the conduction of intense low-frequency sound to the hearing organ. The action of the acoustic reflex (which is also called the intra-aural or middle-ear reflex) can be observed in man by measuring the acoustical impedance of the ear (tympanomanometry) and the change in impedance can be used diagnostically for audiometric and otological purposes.

Because the acoustic reflex is a physiological response with a latency of at least 10 ms, it is of little value in protecting the ear against unanticipated noises which are impulsive or of extremely rapid onset (eg, gunfire). Some protection against such noises may be obtainable by alerting the reflex with a moderate premonitory noise (Fletcher & Riopelle, 1960).

It is evident that the acoustic reflex protects against PTS in the same way that it can be shown to protect against TTS, but the threshold and the protective efficiency of the reflex vary substantially between individuals (Ward, 1962). Coles and Knight (1965) showed that, in 40 newly trained Marines tested with a Madsen acoustic impedance meter, those with poorer high-tone hearing exhibited a higher reflex threshold than the men with "good" hearing for a 4000 Hz test zone. It appears, however, that the variability of the reflex and its innate fatiguability (ie, its tendency to decay in the presence of maintained or repetitive stimulation) make it doubtful whether, except in certain circumstances (eg, intense short-term noise exposure), it is a significant factor in practice.

Loeb _et al_ (1965) have adduced some slightly atypical evidence that the acoustic reflex may in fact have some power of protection against high frequency (above 600 Hz) TTS produced by impulse noise from an arc-generator. (The TTS observed after this type of noise was not linearly related to number of impulses but somewhat less than logarithmically. Moreover, reflex-activating sounds were not reliable in diminishing the TTS produced by the impulses.)

A9.3.1.1 _Acoustic reflex and critical bandwidth._ Searching for (and finding) confirmatory evidence for a peripheral auditory mechanism underlying the critical bandwidth in loudness summation, Flottorp _et al_ (1971) have shown that the acoustic reflex threshold (expressed in dB re 0.00002 N/m^2) is approximately constant as the bandwidth of an exciting noise is increased up to a critical bandwidth, beyond which the threshold falls with widening bandwidth at a rate of about 3 to 6 dB/octave. This finding would appear to lend support to the idea that the reflex is more readily excited or sustained by (and is hence of greater protective value in) broadband than narrow band or tonal noise (see Cohen & Baumann, 1964).

A9.3.1.2 Acoustic reflex and tonal noise. Cohen and Baumann (1964) systematically varied the relative strengths of tonal components (in the range 500 to 4000 Hz) with respect to a background of broadband noise (overall SPL = 105 dB in all 20-minute exposures) and measured TTS in men exposed to these combinations. They found that tonal components (some exceeding the AF160-3 criterion) were most "noxious" (ie, they caused greatest TTS) when they were of low frequency (below 2 kHz) and contained most of the energy of the combined noise (when the tone was most intense, the background broadband noise was made least intense, to yield the same overall level). This finding supports the hypothesis that prominent low-frequency tonal components may be unduly noxious because of failure of the relatively moderate background random noise to sustain the acoustic reflex (which rapidly adapts to a tonal stimulus).

Mills and Lilly (1971), using TTS measurements at 1000 Hz, have recently shown that the acoustic reflex has a differentially protective effect against low frequency (710 Hz) tones compared with narrow-band noise with the same upper cutoff frequency (both noises lasted 10 minutes at 110 dB SPL). Comparing normal subjects with six others who lacked an acoustic reflex (having been stapedectomized), they found that the normals had 10 dB more TTS_2 following tonal than equivalent 1/8-octave band noise, which latter noise presumably caused a stronger or more maintained reflex contraction. In the stapedectomized subjects this differential effect was not seen: the TTS_2 in those subjects was about the same following both types of noise.

A9.3.1.3 Noninteraction of TTS's; and the acoustic reflex. Ward (1961) showed that distinct TTS's produced at well separated audiometric frequencies by correponding high (2400-4800 Hz) and low frequency (600-1200 Hz) noises do not interact. That is to say, the presence of one TTS has no effect upon the growth or recovery of the other. Ward attributed this finding to the relative independence of fatigue processes (presumably associated with regional vasoconstriction leading to a relative hypoxia of each part of the organ of Corti--see Hawkins, 1971) at different locations in the basilar membrane. He pointed out that the protection afforded by the acoustic reflex against one such noise is not affected by prior exposure to the other.

A9.3.1.4 Acoustic reflex protection against impulse noise. Fletcher (Fletcher & Riopelle, 1960) and Ward (1962; 1970) have suggested the use of a provocative tone, preceding the noise, to induce the acoustic reflex to contract as a defense against impulsive sounds of known time of onset (eg, when shooting). Ward has shown (1962) that at least 150 ms is required for the reflex to take full effect; but that some protection begins substantially earlier (eg, 1 dB at 25 ms; 5 dB at 62 ms; 13 dB at 100 ms). Individual and temporal differences in the protective value of the reflex are large: Ward (1962) found this to vary from zero to some 15 dB. He expressed doubt, moreover, as to whether specific (ie, standardizable) values of the protective effect of the reflex could be arrived at, because of the great variability of the response with both intrinsic (physiological) and extrinsic (acoustic) factors.

Cognate studies by Cohen et al (Cohen, Kylin & LaBenz, 1966) had earlier implicated the acoustic reflex as a variable factor influencing the patterns of TTS and contralateral remote masking (CRM), an indirect measure of acoustic reflex response, in various combinations of impulsive and steady-state noise. They showed that, while the addition of moderately strong (90 to 100 dB SPL) broadband steady-state noise reduced the effect of impulses (order of 124 to 127 dB peak SPL), the addition of impulses also, somewhat paradoxically, reduced the temporary noxious (TTS-producing) effect of a higher level (110 dB SPL) of the same steady-state noise.

A9.3.2 Generalized aversive response. Intense noise (above about 100 dB SPL), especially if it is of rapid onset and of high frequency, can evoke a generalized, initially involuntary, response of tensing, grimacing and covering the head and ears with the arms and hands. Animals with movable pinnae (eg, cats) characteristically flatten their ears and crouch or run during sustained intense noise (but erect the ears in the startle response). Some people feel a compelling urge to hide or run away from noise of extreme intensity. This response can be enhanced by conditioning, for example, in those who have been exposed to the sounds of battle in highly stressful circumstances: the provocative noise in these cases does not necessarily have to resemble closely the sound of the sufferer's combat experience. Abnormal sensitivity or responsiveness to loud noise is sometimes associated clinically with certain acute or chronic systemic disorders (eg, febrile states and idiopathic hypertension).

A9.4 Ear protectors and NIHL

Several authors have recently reviewed the principles practical use and protective value of insert and circumaural ear defenders (Michael, 1965; King, 1972; Rice & Coles, 1966). Now that the use of these devices is becoming customary, if not mandatory in many occupational and some non-occupational noise exposure situations, it is to be expected that ear protection will have some effect upon the NIPTS measurable or predictable in groups. Summar and Fletcher (1965; and Summar, 1965) reported that almost complete protection against industrial noise can be achieved. As a rule, however, such an overall protective effect is inherently difficult to estimate; it is more likely than not to be overestimated, because in practice ear defenders are not universally worn, even where their use is mandatory (Kopra, 1957), and they are frequently misused or worn with an imperfect fit which reduces their theoretical effectiveness. In the present state of knowledge, therefore, it is difficult to allow for the use of ear defenders when predicting the effect of noise exposures upon the hearing of groups or individuals.

Appendix 10

INFRASOUND, VIBRATION AND ULTRASOUND

A10.1 Infrasound and mechanical vibration

Various transient physiological reactions have been observed during human exposure to airborne infrasound in the range 0.5 to 16 Hz. These responses generally resemble those seen during whole-body vibration (Alford et al, 1966; Cole et al, 1966; Guignard, 1972; Mohr et al, 1965; Nixon & Johnson, 1973) and are mostly of a non-specific nature, resembling reactions to mild stress or alarm. However, a variety of bizarre sensations can be experienced during exposure to airborne infrasonic waves, including fluttering or pulsatile sensations in the ear. It is debatable whether true auditory sensations are elicited in the 1 to 15 Hz range (Yeowart et al, 1967). There is evidence (Parker et al, 1968) that intense infrasound can stimulate the vestibular system, as can low-frequency vibration, leading to disequilibrium if the stimulation is severe enough, but little evidence that the hearing organ is affected at intensities likely to be encountered in practical situations (Mohr et al, 1965; Nixon & Johnson, 1973). Low-frequency mechanical vibration of the whole body at severe intensities. however, can be shown to produce a small TTS in man involving the lower audiometric frequencies (Guignard & Coles, 1965) and it may be inferred from this that airborne infrasound at equivalent intensities could do likewise, constituting a potential hazard to the hearing.

Few data exist, at present, to serve as the basis of a hearing damage risk criterion for infrasound. It may be argued by extrapolation from data pertaining to the low audible range, however, that no unprotected ear should be exposed to infrasound exceeding 135 dB SPL, irrespective of either the subjective magnitude or the duration of the disturbance; nor should unprotected whole-body exposures to levels exceeding 150 dB SPL at frequencies above 0.5 Hz be permitted, whether or not ear protectors are worn (Nixon and Johnson, 1973).

In the event of prolonged exposure (eg, daily occupational or constant exposure) to infrasound (0.5 to 16 Hz) at levels exceeding 130 dB SPL (approximately 80 dBA at 20 Hz), specific measurement and narrowband analysis of the infrasound should be carried out to appraise the hazard, which may be treated conventionally as a noise hazard if its frequency or spectral maximum lies within the 8 to 16 Hz octave band.

A10.2 Ultrasound

A substantial review by Parrack (1966) and some recommendations by the same author and co-workers (1968, 1969) contain essentially all the available data pertaining to hearing hazard from airborne ultrasonics in man. Notwithstanding the fact that some people may perceive and claim to be disturbed by various sensations when in the vicinity of ultrasonic equipment, we agree with Parrack's conclusion that airborne ultrasound is not a practical threat to the ear except perhaps in very unusual circumstances (Skillern, 1965; Acton & Carson, 1967).

Nevertheless, it is important to recognize that a hazard may exist due to subharmonic or adventitious noise generated at audio-frequencies (below 20 kHz) when ultrasonic equipment is running. The hazard in that case is the same as that associated with audible noise at the same level from any other source. Parrack (1969) has made some recommendations concerning human exposure to the acoustic and ultrasonic output from ultrasonic devices. A summary of those recommendations is given in Table A10-I below.

Table A10-I. Recommended maximum acceptable levels of occupational exposure to airborne ultrasound (Parrack, 1968, 1969). Note: the figures pertain to third-octave band pressure levels measured at the subject's ear in the normal operating position with respect to an ultrasonic generator. For general adventitious exposures of people working within 15 feet (5 meters) of the operator's position, a reduction of 10 dB is recommended.

1. Frequency range 18,000 to 45,000 Hz.

Center-frequency of 1/3 octave band	1/3 octave band sound level in dB
20,000 Hz	105 dB
25,000 Hz	110 dB
31,500 Hz	115 dB
40,000 Hz	115 dB

2. Frequencies above 45,000 Hz.

No limit specified. Note:Parrack (1968) has stated that to set a limit for this range is scarcely practicable, because of measurement limitations and the fact that the rapid attenuation of ultrasound in air at such high frequencies renders the hazard from practical generators negligible.

Appendix 11

NON-OCCUPATIONAL NOISE EXPOSURE: PARTICULAR SITUATIONS

A11.1 Aircraft noise and hazard to the community

This hazard has been investigated by Parnell, Nagel and Cohen (1972) with equivocal results. Hearing in a community living near a major airport was compared with that in a demographically equivalent group living in a relatively quiet rural setting. The airport neighbors were subjected to flyover noise of which the maximum levels ranged from 76 to 101 dBA with a median value of 88 dBA. The noise levels in the quiet area rarely exceeded 60 dBA and were commonly below 50 dBA. The people exposed to jet noise showed marginally poorer (and more variable) hearing when tested at 3000, 4000 and 6000 Hz. Interestingly, in relation to the importance attached by many otologists to the measurements at the speech frequencies, the differences between the two communities' hearing at 500 Hz, 1 and 2 kHz were insignificant. (Probably because of the areas studied, both groups in this particular study yielded average hearing levels as good as or, at some frequencies, slightly better than the levels predicted (Glorig & Roberts, 1965) from the 1960-62 Public Health Survey). The authors were unable to say with certainty that the jet noise was damaging the hearing of the noise-exposed residents but did conclude from the evidence obtained that the possibility of such risk should not be neglected.

A11.1.1 Auditory hazard from sonic booms. In 1966 von Gierke reviewed the available information on the effects of actual and simulated sonic booms on people, citing a tabular summary of effects upon the ear (Nixon, 1965). This summary is reproduced in Table A11.I.

According to Rice and Coles (1968) the maximum sonic boom overpressures likely to occur in civil aviation are of the order of 10 lb/sq ft (equivalent SPL: 148 dB); and in practice booms are only rarely to be expected which exceed 2 lb/sq ft (134 dB). Testing young men with normal hearing (within 20 dB of British Standard 2497 zero) Rice and Coles concluded, on the evidence of minor amounts of transient TTS following simulated booms, that sonic booms up to 17 lb/sq ft (152 dB) could be disregarded as a potential auditory hazard. The criterion used was that of Garinther et al (1966). A threshold of hazard (PTS) due to sonic boom-type impulses was however deemed to lie somewhere above 44 lb/sq ft (160 dB). This is a somewhat more conservative estimate of the safe exposure limit than that (144 lb/sq ft ≐ 171 dB) published by von Gierke (1966).

Table A11-I. Observed and predicted auditory responses to sonic booms. (Summary of all observations reported.)

NATURE OF AUDITORY RESPONSE	SONIC-BOOM EXPERIENCE OR PREDICTION
Rupture of the tympanic membrane	None expected below 720 lb/sq ft None observed up to 144 lb/sq ft
Aural pain	None observed up to 144 lb/sq ft
Short temporary fullness, tinnitus	Reported above 95 lb/sq ft
Hearing loss: permanent	None expected from frequency and intensity of occurrence
Hearing loss: temporary	None measured (1) 3-4 h after exposure up to 120 lb/sq ft (2) immediately after boom up to 30 lb/sq ft
Stapedectomy	No ill effects reported after booms up to 3.5 lb/sq ft
Hearing aids	No ill effects reported after booms up to 3.5 lb/sq ft

Sonic booms may, if exposure to substantial overpressures is frequently repeated, cause hair-cell loss which is not necessarily observable behaviorally, at least in animals. Majeau-Chargois et al (1970) showed that hair-cell loss and scarring in the apical turn of the cochlea was an immediate consequence of exposing guinea-pigs to a long series of rapidly repeated simulated booms. The animals were subjected to a 1000 booms in the form of N-waves having an amplitude of ±130 dB applied once per second. The duration of the pressure signature (ranging from 2 to 125 ms) did not appear to influence the pattern of injury. Although all the 24 animals tested showed similar injury to autopsy, their behavioral response to test tones in the range 250 to 16,000 Hz (Preyer reflex) was not altered by the booming.

A11.2 Hearing hazard from pop music

Several recent studies have confirmed that the overall sound levels of very loud rock and roll and similar pop music frequently exceed current hearing damage risk criteria and can produce large amounts of TTS in both musicians and listeners (Dey, 1970; Fletcher, 1972; Lebo & Oliphant, 1968; Lipscomb, 1969; Rintelmann & Borns, 1968). Typical rock music can be regarded, from the point of view of the hair cells, if not of their owners, as a steady-state noise with interruptions. Typically, the maximum acoustic output from the bands' amplifiers lies in the region of 2000 Hz. Dey (1970) found that typical exposures averaging 100 to 110 dBA for up to 2 hours could produce TTS_2 exceeding 40 dB in 16% of young adults tested. Rintelmann and Borns (1968) measured representative levels of 105 dBA and found that some 5% of musicians (mostly quite young) showed evidence of NIPTS presumably attributable to their music. Clearly, the hazard is an occupational one for the performer and usually a recreational one for the listener.

Lipscomb (1969) has demonstrated cochlear damage in guinea-pigs exposed to 88 hours of recorded rock and roll music played at 122 dBA, a somewhat exceptional level which can however be exceeded at the ears of musicians and nearby listeners in some instances where excessive amplification of the music is used in reverberent rooms or dance-halls. Dangerous levels can also be reached near domestic stereos (Lipscomb, 1969). In a comparative study of the noise hazard to young people in various recreations, Fletcher (1972) found playing in rock-bands to be exceeded in degree of hearing hazard only by motorcycle and drag racing and by intensive sport shooting with inadequate ear protection. Fletcher observed incidentally that young men and women are equally at risk of hearing damage when exposed to over-amplified rock music. A similar conclusion was reached by Smitley and Rintelmann (1971).

A11.3 Impulsive noise from childrens' toys

Gjaevenes (1967) has cited Scandinavian data showing that between about 1 and 4% of teenaged children may show hearing injuries resulting from the impulsive noise from crackers or other noisy toys, and has argued that this degree of risk accords with a DRC of 155 dB peak pressure for impulsive toy-noise. He points out that there is no evidence that childrens' ears are more easily damaged by impulsive noise than are those of adults: all the data upon which existing impulse noise damage risk criteria are based (see Section IIIB) have come of course from adults (mostly exposed to gun noise).

Appendix 12

FURTHER DATA (PREPARED BY J. H. MILLS) ON THE PATTERN OF THRESHOLD SHIFT PRODUCED BY PROLONGED NOISE IN ANIMALS AND MAN

A12.1 Exposures longer than 8 hours and continuous exposures

Considerable attention has been given to hearing losses produced in human subjects by noise exposures of 8 hours or less. Hearing losses produced in human subjects by longer noise exposures have received very little attention. Thus, in attempting to deal with the problems created by long exposures to noise it is necessary to turn to studies completed with sub-human subjects, and to make comparisons with human subjects when possible.

A12.1.1 Studies with sub-human subjects. Available data have been obtained from monaural chinchillas trained in behavioral audiometry (see Carder and Miller, 1972). After pre-exposure audiograms are obtained the animals are exposed to noise in a diffuse-sound field for durations of 2 to 24 days. At regular intervals throughout the exposure the animals are removed from the noise, placed in a quiet room where auditory thresholds are measured, and then returned to the noise. The decay of threshold shift is measured after cessation of the exposure. At a post-exposure time of 2-3 months audiograms are obtained and compared with pre-exposure audiograms to reveal the presence of any permanent threshold shifts. Then, electrophysiological measurements are made, the animal is sacrificed, and the inner ear is processed for later anatomical study. The results of such experiments are summarized below.

Threshold shifts measured at a post-exposure time of 4-11 minutes increase for the first 24 hours of exposure and then reach an asymptote (Miller, Rothenberg and Eldredge, 1971; Carder and Miller, 1972; Mills and Talo, 1972; Mills, 1973). Threshold shifts at asymptote (TS_∞), in the frequency region of maximum effect, can be described by the equation

$$TS_\infty = 1.6\ (SPL - C) \qquad \text{(Eq 1)*}$$

where the subtractive constant C depends upon the particular band of noise. For an octave-band centered at 4.0 kHz the value of C is 47.0 and for an octave-band centered at 0.5 kHz the value of C is 65.0. The 18 dB difference between the subtractive constants can be attributed to the acoustic properties of the external and inner ears (Mills and Talo, 1972).

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* In Mills (1973) a slope of 1.7 is used.

The durations and levels of noise for which the asymptote can be maintained are not known. It has been established that the asymptote can be maintained for up to 9 days for threshold shifts as great as 80 dB (Mills, 1973) and for up to 21 days for threshold shifts as great as 30 dB (Carder and Miller, 1972).

In the frequency regions of maximal effects, exposure to high- or low-frequency noise produces highly similar growth and decay curves (Carder and Miller, 1972), providing the levels of the noises are adjusted for the acoustic properties of the external and inner ears (Mills and Talo, 1972). However, the spread of threshold shifts along the frequency dimension is substantially different. Whereas the threshold shifts produced by a high-frequency noise have a distinct maximum in the frequency region within and just above the band of noise, threshold shifts produced by a low-frequency noise are more widespread.

Recovery from asymptotic threshold shifts is slow, and it depends upon characteristics of the exposure. It may be possible, however, to place the various recovery patterns into one of three categories. First, for exposures that produce threshold shifts at asymptote of less than 55 dB and are shorter in duration than 22 days, recovery to zero requires between 3 and 6 days (Carder and Miller, 1972; Mills, 1973). Second, for complex exposures of 24 days where the threshold shift at asymptote is about 55 dB for the last six days of the 24-day exposure, recovery to zero or near-zero values requires about 7-15 days. Third, when the threshold shift at asymptote exceeds about 55 dB, recovery to zero does not occur. That is, a permanent threshold shift is produced (Mills, 1973). In this case, recovery to the final threshold value takes about 15-30 days. Thus, decay of asymptotic threshold shifts requires 3-6 days, 7-15 days, or 15-30 days depending upon characteristics of the exposure.

Recovery from an asymptotic threshold shift in the quiet (<30 dBA) is somewhat faster than the recovery from an asymptotic threshold shift in the presence of a low-level noise (57 dB SPL). This difference, however, is small both in terms of time (1-4 days) and magnitude (3-7 dB) (Mills, Talo and Gordon, 1973).

Anatomical and electrophysiological data have been reported for chinchillas who participated in some of the behavioral experiments. A major result is the presence of anatomical and physiological injuries in the ears of animals with normal auditory thresholds (Eldredge, Mills and Bohne, 1972). Specifically, 10 to 250 outer hair cells may be missing, input-output functions of the cochlear microphonic are decreased, and whole-nerve action potentials range from normal to as much as two standard deviations below normal. Thus, normal auditory thresholds measured after exposure to noise are no assurance that the exposure did not permanently injure the inner ear. As yet, the characteristics of exposure to noise that will produce cochlear injuries that are not detectable by audiometry are not known.

Pathologic physiology associated with asymptotic threshold shifts is most likely to be found at a peripheral level of the auditory system, specifically at the level of the hair-cell modulating mechanism (Benitez, Eldredge and Templer, 1972).

A12.1.2 Studies with human subjects. For human subjects, threshold shifts, measured a few minutes post-exposure, increase for the first 8-16 hours of exposure and then reach an asymptote (Mills et al, 1970; Mosko et al, 1970; Melnick, 1972). Threshold shifts at asymptote, in the frequency of maximum effect, increase about 1.6 dB for every 1-dB increase in the level of noise above about 75 to 80 dB. This result is for an octave-band noise centered at 0.5 kHz (Mills et al, 1970; Melnick, 1972). Recovery from asymptotic threshold shift is slow, requiring from 1 to 6 days.

A12.1.3 Comparison of human and sub-human data. For man or chinchilla and for continuous exposures to noise, it may be possible to describe the growth of TTS to asymptote and its subsequent decay after cessation of exposure by growth and decay functions with one or two exponential terms (Carder and Miller, 1972). The major differences between the species appear to be in the value of the time constants and in the minimum levels of noise that produce TTS (i.e., the subtractive constants). These differences have been summarized by Carder and Miller (1972), page 621:

> " TTS grows faster for man than for chinchilla (time constant is 2 - 5 hr for man and 6 - 12 hr for chinchilla); the decay of TTS may be faster for man than for chinchilla (time constant is 4 - 24 hr for man and about 29 hr for chinchilla); TTS at asymptote increases with the level of the noise at about the same rate for man and chinchilla; and it appears that the subtractive constants, that is the minimum noise levels that produce TTS, are higher for man than chinchilla (10 - 25 dB)."

A12.2 Continuous exposure to noise: estimated growth and decay of threshold shifts in human subjects

Based upon available data Miller (1971) has provided an impression of the quantitative facts of the growth and decay of threshold shifts caused by long exposures to noise (Figures A12-1 and A12-2). Many of the exposure conditions shown in

Figures A12-1 and A12-2 can not be used with human subjects for ethical reasons. Other conditions can be used with human subjects but as yet the necessary data are not available. Figures A12-1 and A12-2 are probably the best estimates currently available of the auditory effects of continuous exposure to noise in human subjects (see Miller, 1971, pages, 19-23).

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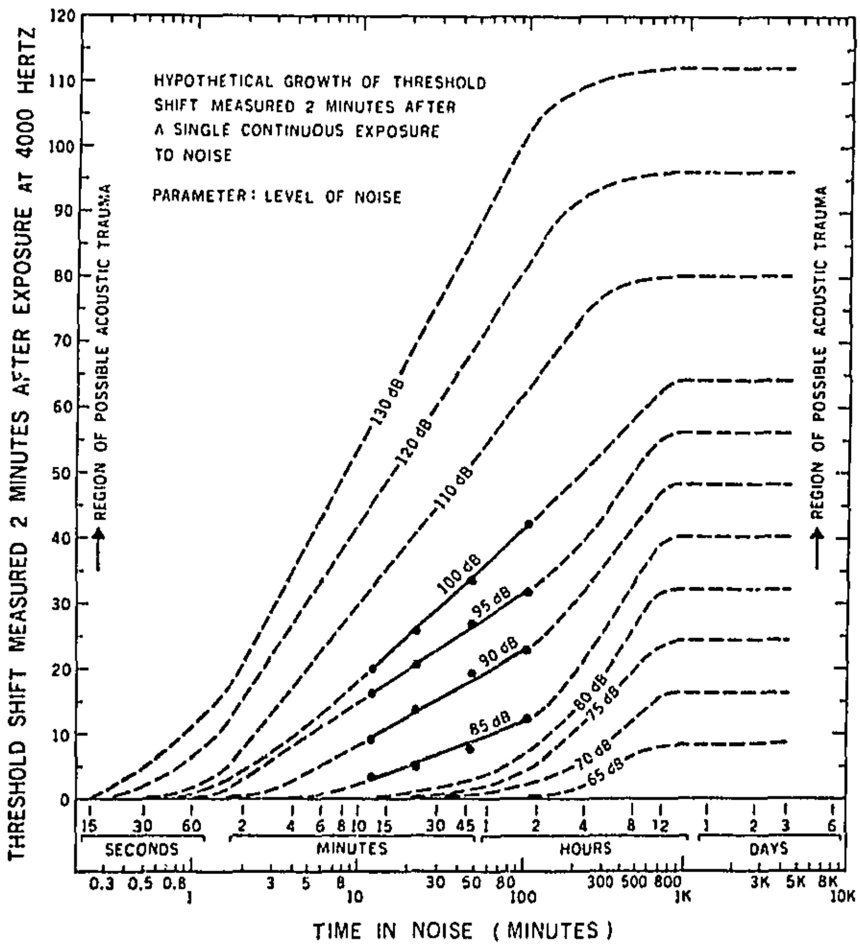
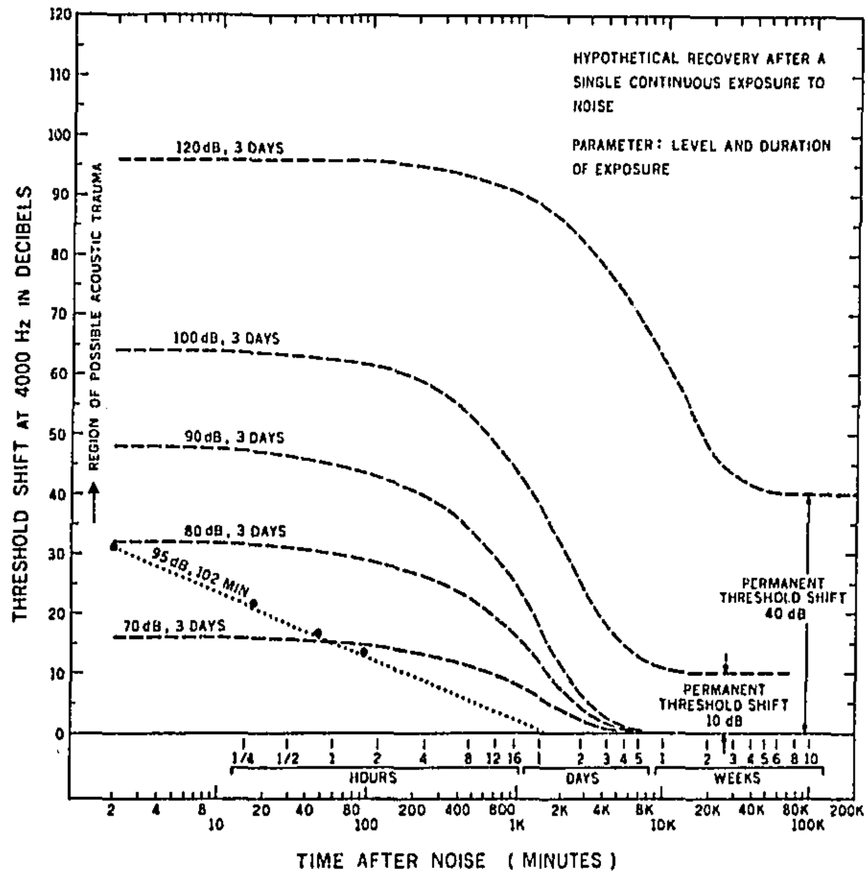


Figure A12-1. Hypothetical growth of threshold shift after various single and continuous exposures to noise. These curves represent predictions for an average, normally-hearing young adult exposed to a band of noise or pure tone centered near 4000 hertz. These are "worst-case" conditions as the ear is most susceptible to noise in this region. These hypothetical curves were drawn to be consistent with current facts and theory. They are for an average ear; wide differences among individuals can be expected. In many cases extrapolations had to be made from appropriately corrected data from animals (cats and chinchillas). The data points are from Ward, Glorig, and Sklar (1959a). Other relevant data can be found in papers by Botsford (1971), Carder and Miller (In press), Davis et al. (1950), Miller et al. (1963), Miller et al. (1971), Mills et al. (1970), Mosko et al. (1970), and Ward (1960, 1970b).



<u>Figure A12-2.</u> Hypothetical decay of threshold shift (see legend for Figure A12-1).

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B.1 Arrangement of Bibliography

The following references include citations in the main report (Sections I to V) and in Appendices 1 to 11, as well as other published material considered during the compilation. A list of relevant international and national standards, including those cited in the main report and in several of the appendices, is provided (B.3) below the main bibliography. Appendices 5 and 12 to the main report contain separate bibliographies covering citations made therein.

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B.3 Relevant standards

B.3.1 American National Standards Institute (ANSI*).

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B.3.2 International Electrotechnical Commission (IEC)**.

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B.3.3 International Organization for Standardization (ISO)*.

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B.4 Additional references

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