Environmental Health Criteria 12

NOISE

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World Health Organization

INTERNATIONAL PROGRAMME ON CHEMICAL SAFETY

ENVIRONMENTAL HEALTH CRITERIA 12

NOISE

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CONTENTS

ENVIRONMENTAL HEALTH CRITERIA FOR NOISE

NOTE TO READERS OF THE CRITERIA DOCUMENTS

While every effort has been made to present information in the criteria documents as accurately as possible without unduly delaying their publication, mistakes might have occurred and are likely to occur in the future. In the interest of all users of the environmental health criteria documents, readers are kindly requested to communicate any errors found to the Division of Environmental Health, World Health Organization, Geneva, Switzerland, in order that they may be included in corrigenda which will appear in subsequent volumes.

In addition, experts in any particular field dealt with in the criteria documents are kindly requested to make available to the WHO Secretariat any important published information that may have inadvertently been omitted and which may change the evaluation of health risks from exposure to the environmental agent under examination, so that the information may be considered in the event of updating and re-evaluation of the conclusions contained in the criteria documents.

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List of abbreviations and symbols used in this document

AI	articulation index
c	speed of sound
CNEL	community noise equivalent level
CNR	composite noise rating
f	frequency
I	sound intensity
L_{dn}	day-night average-sound level
L_e	aircraft exposure level
L_{eq}	equivalent continuous sound pressure level
L_p or SPL	sound pressure level
$L_p(A)$	A-weighted sound pressure level
L_{PN}	mean peak perceived noise level
NEF	noise exposure forecast
NI	noiseness index

NIPTS	noise-induced permanent threshold shift
NITS	noise-induced threshold shift
NITTS	noise-induced temporary threshold shift
NNI	noise and number index
NPL	noise pollution level
p	root mean square pressure
p_2	mean square sound pressure
P	sound power
PNL	perceived noise level
SIL	speech interference level
SPL or L_p	sound pressure level
TNEL	total noise exposure level
TNI	traffic noise index
WECPNL	weighted equivalent continuous perceived noise level
lambda	wavelength

ENVIRONMENTAL HEALTH CRITERIA FOR NOISE

A WHO Task Group on Environmental Health Criteria for Noise met in Brussels from 31 January to 4 February 1977. Dr. H. W. de Koning, Scientist, Control of Environmental Pollution and Hazards, Division of Environmental Health, WHO, opened the meeting on behalf of the Director General and expressed the appreciation of the Organization to the Government of Belgium for having made available the necessary financial support for the meeting. On behalf of the Government, the Group was welcomed by Professor Lafontaine, Director of the Institute for Hygiene and Epidemiology, Brussels. The Task Group reviewed and revised the second draft criteria document and made an evaluation of the health risks from exposure to noise.

The first draft of the criteria document was prepared by a study group that met in Geneva from 5-9 November 1973. Participants of the Group included: Dr. T. L. Henderson and Professor G. Jansen (Federal Republic of Germany); Dr A. F. Meyer (USA); Professor J. B. Ollerhead (United Kingdom, Rapporteur); Professor P. Rey (Switzerland, Chairman); Professor R. Rylander (Sweden); Professor W. J. Sulkowski (Poland); Dr A. Annoni, Mr E. Hellen, and Mr B. Johansson (Consultant), International Labour Organisation (ILO); Dr A. Alexandre, Organisation for Economic Co-operation and Development (OECD); Dr A. Berlin, Commission of the European Communities (CEC); Professor L. A. Saenz, Scientific Committee on Problems of the Environment (SCOPE); Mr H. J. Gursahaney, International Civil Aviation Organization (ICAO); Dr M. Suess, World Health Organization Regional Office for Europe; and Dr G. Cleary and Dr G. E. Lambert, World Health Organization, Geneva. Certain sections of the first draft were later completed with the assistance of Dr A. Alexandre (OECD), Dr D. E. Broadbent (UK), Professor G. Jansen (FRG), and Professor W. D. Ward (USA).

The second draft was prepared by the Secretariat after comments had been received from the national focal points for the WHO Environmental Health Criteria Programme in Czechoslovakia, Federal Republic of Germany, Finland, Greece, Japan, New Zealand, Poland, Sweden, Thailand, United Kingdom, USSR, and USA, and from the International Labour Organisation, Commission of the European Communities, the Organisation for Economic Co-operation and Development, the International Civil Aviation Organization, and the International Organization for Standardization. Many comments were also received from individual experts and commercial concerns including E. I. Du Pont de Nemours & Company, Wilmington, Delaware, USA, whose contributions are gratefully acknowledged.

The Secretariat particularly wishes to thank Dr D. Hickish, Ford Motor Company Limited, Brentwood, Essex, England, Dr G. E. Lambert, Professor J. B. Ollerhead, Professor P. Rey, Professor R. Rylander, and Ms A. Suter for their most valued help in the final phases of the preparation of the document.

This document is based primarily on original publications listed in the reference section and every effort has been made to review all pertinent data and information available up to 1978. In addition, reference has often been made to the various publications on noise of the International Organization for Standardization that include the international standards for noise assessment (ISO, 1971; 1973a; 1975a). The following reviews and criteria documents have been referred to: Burns & Robinson (1970), Karagodina et al. (1972), Burns (1973), NIOSH (1973a), US Environmental Protection Agency (1973a), ILO (1976), Thiessen (1976), Rylander et al. (1978), and Health and Welfare, Canada (1979).

Details of the WHO Environmental Health Criteria Programme including some terms frequently used in the document may be found in the general introduction to the Environmental Health Criteria Programme published together with the environmental health criteria document on mercury (Environmental Health Criteria 1, Mercury, World Health Organization, Geneva, 1976) and now available as a reprint.

1. SUMMARY AND RECOMMENDATIONS FOR FURTHER STUDIES

1.1 Summary

1.1.1 Introduction

Noise can disturb man's work, rest, sleep, and communication; it can damage his hearing and evoke other psychological, physiological, and possibly pathological reactions. However, because of their complexity, their variability, and the interaction of noise with other environmental factors, the adverse health effects of noise do not lend themselves to a straightforward analysis.

Probably the most important issue is the industrial noise problem, and a need for noise control and hearing conservation programmes is widely recognized. Road traffic is the main source of community noise that may disturb large segments of the urban population. Also of worldwide concern is aircraft noise, which can significantly affect the mode of life of people living in the vicinity of airports.

1.1.2 Noise measurement

Sound is produced by the vibration of bodies or air molecules and is transmitted as a longitudinal wave motion. It is, therefore, a form of mechanical energy and is measured in energy-related units. The sound output of a source is measured in watts and the intensity of sound at a point in space is defined by the rate of energy flow per unit area, measured in watts per ms. Intensity is proportional to the mean square of the sound pressure and, as the range of this variable is so wide, it is usual to express its value in decibels (dB)[a]. Because the effects of noise depend strongly upon frequency of sound pressure oscillation, spectrum analysis is important in noise measurement.

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[a] decibel = a measure on a logarithmic scale of a quantity such as sound pressure, sound power, or intensity with respect to a standard reference value (0.0002 microbars for sound pressure, 10^{-12}W for sound power, and 10^{-12}W/m^2 for intensity). Thus,

for example, when the sound intensity increases by a factor of 1.26 (= $10^{0.1}$), it is said to have increased by 1 decibel (dB); 1 Bel equals 10 dB or a factor of 10 in intensity. The standard reference values are implied throughout this document unless otherwise stated.

The perceived magnitude of sound is defined as loudness and its decibel equivalent is known as the loudness level. The loudness is a function of both intensity and frequency, and various procedures exist by which it may be estimated from physical measurements. The simplest methods involve the measurement of the sound pressure level (SPL) through a filter or network of filters that represent the frequency response of the ear. Despite the existence of other slightly more accurate but more complex techniques, the A-weighted sound pressure level scale is gaining widespread acceptance and is revommended for general use.[b] Whatever procedure is used, such frequency-weighted measurements are referred to simply as sound (or noise) levels.

Measurements of sound level may be averaged over two distinctly different periods of time. Steady sound levels and instantaneous levels of variable sounds are measured on a very short time scale of 1 second or less. Variable sounds can be measured with a much longer average time, over periods of hours if necessary, and are expressed in terms of the equivalent continuous sound pressure level (L_{eq}). This convenient measure of average noise exposure using the A-weighting correlates reasonably well with many human responses to noise and is recommended for general use.

Many noise indices have been developed for predicting human reaction to various noise levels. Some of these incorporate non-acoustic factors that influence the reaction. Although the use of such indices is not to be discouraged, it is desirable to adopt a uniform approach to noise measurement, whenever possible.

1.1.3 Effects of noise

1.1.3.1 Interference with communication

Although there appears to be no firm evidence, it is believed that interference with speech in occupational situations may lead to accidents due to inability to hear warning shouts etc. In offices, schools, and homes, speech interference is a major source of annoyance. Many attempts have been made to develop a single index of such interference, based on the characteristics of the masking noise, that directly indicates the degree of interference with speech perception. Such indices involve a considerable degree of approximation. The following are the three most widely used:

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[b] To obtain a single number representing the sound level of a noise containing a wide range of frequencies in a manner representative of the ear's response, it is necessary to modify the effects of the low and high frequencies with respect to the medium frequencies. The A-filter is one particular frequency weighting and, when this is used, the resulting sound level is said to be A-weighted.

Articulation index (AI). This is the most complicated index, since it takes into account the fact that some frequencies are more effective in masking speech than others. The frequency range from 250 to 7000 Hz is divided into 20 bands. The difference between file average speech peak level in each of these bands is calculated and the resulting numbers combined to give a single index.

Speech interference level (SIL). SIL was designed as a simplified substitute for the AI. It was originally defined as the average of the now obsolete octave-band SPLs in the 600-1200, 1200-2400, and 2400-4800 Hz octaves. At the present time, SIL, based upon the octave band levels at the preferred frequencies of 500, 1000, 2000, and 4000 Hz, is considered to provide a better estimate of the masking ability of a noise. As SIL does not take the actual speech level into account, the associated masking effect depends upon vocal effort and speaker-to-listener distance.

A-weighted sound level. This is also a convenient and fairly accurate index of speech interference.

It is usually possible to express the relationship between noise levels and speech intelligibility in a single diagram, based on the assumptions and empirical observations that, for speaker-to-listener distances of about 1 m:

(a) speech spoken in relaxed conversation is 100% intelligible in background noise levels of about 45 dB(A), and can be understood fairly well in background levels of 55 dB(A); and

(b) speech spoken with slightly more vocal effort can be understood well, when the noise level is 65 dB(A).

For outdoor speech communication, the "inverse square law" controls speech transmission over moderate distances, i.e., when the distance between speaker and listener is doubled, the level of the speech drops by approximately 6 dB. This relationship is less likely to apply indoors, where speech communication is affected by the reverberation characteristics of the room.

In cases where the speech signals are of paramount importance, e.g., in classrooms or conference rooms, or where listeners with impaired hearing faculties are involved, e.g., in homes for aged people, lower levels of background noise are desirable.

1.1.3.2 Hearing loss

Hearing loss can be either temporary or permanent. Noise-induced temporary threshold shift (NITTS) is a temporary loss of hearing acuity experienced after a relatively short exposure to excessive noise. Pre-exposure hearing is recovered fairly rapidly after cessation of the noise. Noise-induced permanent threshold shift (NIPTS) is an irreversible (sensorineural) loss of hearing that is caused by prolonged noise exposure. Both kinds of loss together with presbyacusis, the permanent hearing impairment that is attributed to the natural aging process, can be experienced simultaneously.

In the quantification of hearing damage, it is necessary to differentiate between NIPTS, hearing level (the audiometric level of an individual or group in relation to an accepted audiometric standard), and hearing impairment.

NIPTS is the hearing loss (i.e., the reduction of hearing level) attributable to noise exposure alone, disregarding losses due to aging. NIPTS occurs typically at high frequencies, usually with a maximum loss at around 4000 Hz. Noise-induced hearing loss occurs gradually, usually over a period of years. Once there is considerable hearing loss at a particular frequency, the rate of loss usually diminishes. Audiometrically, noise-induced losses are similar to presbyacusis. Hearing loss due to prolonged excessive noise exposure is generally associated with destruction of the hair cells of the inner ear. The severity of hearing loss is correlated with both the location and the extent of damage in the organ of Corti.

"Hearing impairment" is usually defined as the hearing level at which individuals begin to experience difficulties in everyday life. It is assessed in terms of difficulty in understanding speech. The amount of loss at the speech frequencies has been used as a basis for compensation and varies from one country to another. The unweighted average of the losses, in dB, at 500, 1000, and 2000 Hz that is widely used for assessing noise-induced hearing impairment, is somewhat misleading since most hearing loss usually occurs at 2000 Hz and above. Consequently, there is an increased tendency to include the frequencies of 3000 and 4000 Hz in damage assessment formulae.

Attempts have been made to establish the levels of noise that are permanently damaging to the ear and to identify individual susceptibility to NIPTS on the basis of NITTS measurements. However, the validity of the connection between NITTS and NIPTS has not been agreed.

There is also some disagreement concerning the relationship between the relative ear-damaging capacity of the noise level and its duration. However, the hypothesis that the hearing damage associated with a particular noise exposure is related to the total energy of the sound (i.e., the integrated product of intensity and time) is rapidly gaining favour for practical purposes. Thus, noise should preferably be described in terms of equivalent continuous sound level, L_{eq}, measured in dB(A). For occupational noise, the level should be averaged over the entire 8-h shift (L_{eq} (8-h)).

Available data show that there is considerable variation in human sensitivity with respect to NIPTS. The hazardous nature of a noisy environment is therefore described in terms of "damage risk". This may be expressed as the percentage of people exposed to that environment

who are expected to suffer noise-induced hearing impairment after appropriate allowance has been made for hearing losses due to other causes. It is now accepted that this risk is negligible at noise exposure levels of less than 75 dB(A) L_{eq} (8=h) but increases with increasing levels. Based on national judgements concerning "acceptable risk", many countries have adopted industrial noise exposure limits of 85 dB(A) $\pm$ 5dB(A) in their regulations and recommended practices.

The exposure to ototoxic drugs such as certain aminoglycosidic antibiotics however, can lower the threshold below which noise can damage the ear.

It is not yet clear whether the damage risk rules already mentioned can be extended to the very short durations of impulsive noise. Available evidence indicates that a considerable risk exists, when impulsive sound levels reach 130-150 dB, depending upon the temporal characteristics of the impulse.

Although there is a fairly wide range of individual variability, especially for high frequency stimuli, the threshold of pain for normal ears is in the region of 135-140 dB sound pressure level. Aural pain should always be considered to be an early warning sign of excessive noise exposure.

Wherever possible, problems of noise control should be tackled at source, i.e., by reducing the amount of noise produced. An acceptable alternative is to isolate people from the noise by the use of noise insulation, including soundproof enclosures, partitions, and acoustic barriers. If this is not possible, the risk can also be minimized by limiting the duration of exposure. Only in cases where these control measures are impracticable should personal ear protection be considered. These devices can and do provide useful protection but inherent problems include those of proper fitting and use, and a degree of discomfort.

If there is any risk of hearing damage, pre-employment and follow-up audiometric examinations of workers should be carried out to detect changes in hearing acuity that might indicate possible development of NIPTS, in order to initiate preventive action.

1.1.3.3 Disturbance of sleep

Noise intrusion can cause difficulty in falling asleep and can awaken people who are asleep. Detailed laboratory studies of the problem have been made by monitoring electroencephalographic (EEG) responses and changes in neurovegetative reactions during sleep.

Studies have indicated that the disturbance of sleep becomes increasingly apparent as ambient noise levels exceed about 35 dB(A) L_{eq}. It has been found that the probability of subjects being awakened by a peak sound level of 40 dB(A) is 5%, increasing to 30% at 70 dB(A). Defining sleep disturbance in terms of EEG changes, the

probability of disturbance increases from 10% at 40 dB(A) to 60% at 70 dB(A). It has also been observed that subjects who sleep well (based on psychomotoric activity data) at 35 dB(A) L_{eq} complain about sleep disturbance and have difficulty in falling asleep at 50 dB(A) L_{eq} and even at 40 dB(A) L_{eq}. Weak stimuli that are unexpected can still interfere with sleep.

Within a population, differences in sensitivity to noise occur related, for example, to age and sex. Adaptation has been observed only when noise stimuli are of low intensity. Even though sleep is more disturbed by noise rich in information, habituation to such noise has been observed. Based on the limited data available, a level of less than 35 dB(A) L_{eq} is recommended to preserve the restorative process of sleep.

1.1.3.4 Stress

Noise produces different reactions along the hypothalamo-hypophyseal-adrenal axis including an increase in adenocorticotropic hormone (ACTH) release and an elevation of corticosteroid levels. Some of these reactions have been elicited in an acute form in laboratory experiments at rather moderate levels of noise.

Effects on the systemic circulation such as constriction of blood vessels have been produced under laboratory conditions and a high incidence of circulatory disturbances including hypertension has been found in noise-exposed workers. A tendency for blood pressure to be higher in populations living in noisy areas around airports has been suggested but no conclusive evidence of this has been presented.

Noise affects the sympathetic division of the autonomic nervous system. Eye dilation, bradycardia, and increased skin conductance are proportional to the intensity of noise above 70 dB SPL, without adaptation to the stimulus.

Other sympathetic disturbances, such as changes is gastrointestinal motility, can be produced by intense sound. Medical records of workers have shown that, in addition to a higher incidence of hearing loss, noise-exposed groups have a higher prevalence of peptic ulcer; however, a causal relationship has not been established.

More studies are required to determine the long-term health risks due to the action of noise on the autonomic nervous system.

1.1.3.5 Annoyance

Noise annoyance may be defined as a feeling of displeasure evoked by a noise. The annoyance-inducing capacity of a noise depends upon many of its physical characteristics including its intensity, spectral characteristics, and variations of these with time. However, annoyance reactions are sensitive to many nonacoustic factors of a social, psychological, or economic nature and there are considerable differences in individual reactions to the same noise.

Attempts to define criteria linking noise exposure and annoyance have led to the development of many methods for the measurement of both variables. In social surveys, questionaires are used to assess the annoyance felt by an individual in response to various types of noise. Much research has been aimed at the definition of suitable questions through which annoyance reactions could be quantified.

In the search for a suitable noise index, numerous noise and some nonacoustic variables were assembled in various ways to discover which combinations were most closely correlated with annoyance reactions. The resulting diverse indices were given such names as composite noise rating (CNR), community noise equivalent level (CNEL), noise and number index (NNI), and noise pollution level (NPL) among many others. In fact, many experts consider that, in terms of annoyance prediction ability, there is little practical difference between the various indices and that an appropriate index should be selected for the convenience with which it can be measured or calculated. For this reason, variants of the equivalent continuous A-weighted sound pressure level (L_{eq}) are being widely adopted for general use. These are conveniently applied to noise exposure patterns of all kinds, from multiple sources if necessary, and are reasonably well correlated both with annoyance and with other specific effects of noise.

Whatever noise scale is used to express noise exposure, it must be recognized that, at any level of noise annoyance, reactions will vary greatly because of psychosocial differences. A useful technique for accommodating the possible extent of individual variation is the use of a criterion curve showing the percentage of persons who will be annoyed as a function of noise level.

Such curves have been derived for a variety of noise conditions but mainly for those concerned with aircraft or road traffic noise. On the basis of these, it can be concluded that, in residential areas where the general daytime noise exposure is below 55 dB(A) L_{eq}, there will be few people seriously annoyed by noise. This is recommended as a desirable noise exposure limit for the general community, even though it will be difficult to achieve in many urban areas. Some residents may consider this level too high, especially as substantially lower levels currently prevail in many suburban and rural areas.

Criteria relating noise exposure and complaint potential have found widespread application for environmental control purposes in some countries. However, the scientific basis for such criteria is rather fragmentary and surveys have indicated that the correlation between noise exposure and individual complaint behaviour is low. This may be explained in terms of the strong influence of psychosocial factors.

1.1.3.6 Effects on performance

The effect of noise on the performance of tasks has mainly been studied in the laboratory and, to some extent, in work situations, but, there have been few, if any, detailed studies of the effects of noise on human productivity in real-life situations. It is evident that when a task involves auditory signals of any kind, noise at an intensity sufficient to mask or interfere with the perception of these signals will interfere with the performance of the task.

Noise can act as a distracting stimulus, depending on how meaningful the stimulus might be, and may also affect the psycho-physiological state of the individual. A novel event, such as the start of an unfamiliar noise will cause distraction and interfere with many kinds of tasks. Impulsive noise (such as sonic booms) may produce disruptive effects as the result of startle responses which are more resistant to habituation.

Noise can change the state of alertness of an individual and may increase or decrease efficiency.

Performance of tasks involving motor or monotonous activities is not always degraded by noise. At the other extreme, mental activities involving vigilance, information gathering, and analytical processes appear to be particularly sensitive to noise. It has been suggested that, in industry, the most likely indicator of the effects of noise on performance would be an increase in accidents attributable to reduced vigilance.

1.1.3.7 Miscellaneous effects

Certain noises, especially impulsive ones, may induce a startle reaction. This consists of contraction of the flexor muscles of the limbs and the spine, a contraction of the orbital which can be recorded as an eye blink, and a focusing of attention towards the location of the noise. The startle reflex to acoustic stimulation has been observed in the 27-28 week fetus in utero as a change in the pulse rate.

It has been suggested that observed noise-induced equilibrium effects are due to the noise stimulating the vestibular apparatus, the receptors of which are part of the inner ear structure.

Although there is no clear evidence of a direct relationship between noise and fatigue, noise can be considered as an environmental stress which, in conjunction with other environmental and host factors, may induce a chronic fatigue that could lead to non-specific health disorders.

1.1.4 Summary of recommended noise exposure limits

The equivalent continuous A-weighted sound pressure level L_{eq} is recommended for use as a common measure of noise exposure. The measurement period should be related to the problem under study, for example in the case of occupational noise, L_{eq} (8-h) would be measured for a complete 8-h shift.

For the working environment, there is no identifiable risk of hearing damage in noise levels of less than 75 dB(A) L_{eq} (8-h). For higher levels, there is an increasing predictable risk and this must be taken into account when setting occupational noise standards.

In other occupational and domestic environments, acceptable noise levels can be established on the basis of speech communication criteria. For good speech intelligibility indoors, background noise levels of less than 45 dB(A) L_{eq} are required.

At night, sleep disturbance is the main consideration and available data suggest a bedroom noise limit of 35 dB(A) L_{eq}.

Data from surveys of community noise annoyance lead to the recommendation that general daytime outdoor noise levels of less than 55 dB(A) L_{eq} are desirable to prevent any significant community annoyance. This is consistent with speech communication requirements. At night, a lower level is desirable to meet sleep criteria; depending upon local housing conditions and other factors this would be in the order of 45 dB(A) L_{eq}.

1.2 Recommendations for Further Studies

Considerable research aimed at improving the scientific basis and application of environmental health criteria for noise is in progress in many countries. However, there are certain areas where present national and international efforts do not appear adequate. Thus, further studies should include:

(a) The identification of long-term health effects due to high level industrial noise and lower level general environmental noise. The potential contribution of noise stress to the general morbidity of the population, the ability of people to adapt to environmental noise, and the possibilities of noise-induced disease must be established not only for the working population, but also for the more vulnerable population segments, including the elderly, pregnant women, people undergoing medication, particularly with ototoxic drugs such as salicylates, quinine, and certain antibiotics, and those generally under stress. The possibility that the disturbance of sleep by noise can result in definite health impairment should be examined as part of these investigations.

(b) Studies on young people over many years prior to, and during, occupational noise exposure to find out to what extent changes in hearing acuity during adolescence are attributable to normal growth or to environmental conditions, to learn about noise susceptibility in childhood, and to obtain data on the progressive effects of noise (including high-level music and other leisure-time sounds) on the "normal" hearing level of the population. Monitoring of the total noise exposure of these groups over the whole observation period would be part of these studies. Similar studies in nonindustrialized countries would be of particular value.

(c) Work on the development of sensitive hearing tests and on tests to evaluate the problem of individual susceptibility to noise, since pure tone audiometry is only a crude technique for measuring hearing acuity and for detecting pathological damage.

(d) Longitudinal studies of communities exposed to major changes in environmental noise to refine existing dose-response (noise-annoyance) relationships and to include the effects of adaptation and societal changes on public reaction to noise. Attention should be given to the study of the response of specially vulnerable segments of the population.

The methods of study should be internationally uniform, as far as is feasible, to allow pooling of data and broader interpretation of the results.

2. PROPERTIES AND MEASUREMENT OF NOISE

Noise is considered as any unwanted sound that may adversely affect the health and well-being of individuals or populations.

Physically, sound is a mechanical disturbance propagated as a wave motion in air and other elastic or mechanical media such as water or steel.

Physiologically, sound is an auditory sensation evoked by this physical phenomenon. However, not all sound waves evoke an auditory sensation: for example, ultrasound has a frequency too high to excite the sensation of hearing.

The physical properties and perception of sound or noise are expressed and measured in different concepts and units.

2.1 Physical Properties and Measurements

Sound waves involve a succession of compressions and rarefactions of an elastic medium such as air. These waves are characterized by the amplitude of pressure changes, their frequency, and the velocity of propagation. The speed of sound *(c)*, the frequency *(f)*, and the wavelength (lambda), are related by the equation

lambda = c/f

A mechanical energy flux accompanies a sound wave, and the rate at which sound energy arrives at, or passes through, a unit area normal to the direction of propagation is known as the sound intensity, *I.* In a free sound field, the sound intensity is related to the root mean square [a] sound pressure, *p,* and the density of the medium, *q,* by the expression

$$I = \frac{p^2}{q\,c}$$

Sound intensity is normally measured in watts per square metre (W/m^2). The total sound energy emitted by a source per unit time is known as the sound power, P, and is measured in watts.

Sound intensities of practical interest cover a very large range and are therefore measured on a logarithmic scale. The relative intensity level of one sound with respect to another is defined as 10 times the logarithm (to the base 10) of the ratio of their

[a] The square root of the mean value of the squares of the instantaneous values of a quantity. For a periodic variation, the mean is taken over one period.

intensifies. Levels defined in this way are expressed in decibels (dB). Any acoustic quantity that is related to sound energy, e.g., power, intensity, or mean square pressure, may be expressed as a decibel level. To establish an absolute level, a reference value must be agreed. Thus, the sound pressure level of a sound with a mean square sound pressure p^2 is:

Table 1. Table for combining intensity levels

Excess of stronger	Add to the stronger to get

component	combined level
d8	d8
0	3.0
1	2.5
2	2.0
3	1.8
4	1.5
5	1.2
6	1.0
7	0,8
8	0.7
9	0.6
10	0.5

$$L_p = 10 \log_{10} \left(\frac{p}{p_{ref}}\right)^2 \text{ dB}$$

where the reference pressure p^{ref} has an internationally agreed value of 20 micropascals (μPa) (ISO, 1959). The reference values for sound power level and sound intensity level are 10^{-12} watts and 10^{-12} W/m^2, respectively (ISO, 1963). Sound levels are expressed in decibels (dB) relative to the international standard reference quantities, unless otherwise stated (dB re: 20 μPa).

Whereas sound intensities or energies are additive,[b] sound pressure levels (SPL) (in decibels) have to be first expressed as mean square pressures, and then added. The summation of sound pressure levels can be easily performed by using the following equation:

$$L_p = 10 \log_{10} \left[\frac{L_{p1}}{1010} + \frac{L_{p2}}{1010} + \frac{L_{p3}}{1010} \ldots . \right] \text{ dB}$$

[b] Such combinations of decibel values may be simplified by using Table 1.

A simple example will illustrate the use of this equation. If two sound sources of 80 dB SPL each have to be combined, then

$$L = 10 \log_{10} [10^8 + 10^{8]}$$

$$= 10 \log_{10} 2 + 80 = 10 \text{ X } 0.301 + 8 = 83 \text{ dB}$$

It is only when two sources generate similar levels that there is a significant increase in level when the sources are combined. The example just quoted gave a 3 dB increase. If there is any difference in the original, independent levels, the combined level will exceed the higher of the two levels but by less than 3 dB. When the difference between the two original levels exceeds 10 dB, the contribution of the quieter source to the combined noise level is negligible.

Sound is measured with a microphone that generates a voltage proportional to the acoustic pressure acting upon it. This signal can be measured and analysed using conventional electronic instrumentation. A sound level meter is usually a portable, self-contained instrument incorporating a microphone, amplifiers, a voltmeter and attenuators, the whole of which carl be calibrated to read sound pressure levels directly. Intensity levels and power levels can be derived from sound pressure level measurements if required.

The sound at a given location can be completely described in terms of the history of the sound pressure fluctuation. If this fluctuation is periodic, its fundamental frequency is the number of repetitions per second, expressed in hertz (Hz). Most real periodic cycles are quite complex and consist of a component at the fundamental frequency and components at multiples of this basic frequency, known as harmonics.

The simplest kind of sound, known as a pure tone, has a sinusoidal pressure cycle that is completely defined in terms of a single frequency and pressure amplitude (a more precise definition would also include phase which effectively defines the starting point in time, but this is usually of little or no interest).

Pure tones are relatively rare -- perhaps the nearest approximation is the sound of a tuning fork. Most musical sounds are periodic but contain many harmonics. Analytically these may be expressed as a sum of harmonically related components. This assembly is known as the frequency spectrum of the sound, and it specifies how the energy in the periodic sound is concentrated at certain discrete frequencies. The frequency distribution of sound energy is measured by electronic filters.

Although some kinds of machinery produce sound that is largely periodic, most noise is nonperiodic, i.e., the sound pressure does not oscillate with time in any regular or predictable way. Such sound is said to be random. Examples of random sound include the roar of a jet engine, the rumble of distant traffic, and the hiss of escaping steam. The energy of random sound is distributed continuously over a range of frequencies instead of being concentrated at discrete values, so that its frequency spectrum may be depicted as a curve of energy density plotted against frequency.

Frequency is related, but not identical, to the subjective pitch. Any periodic sound has a tonal character that can be ascribed a particular musical note. The note is basically defined by the fundamental frequency of the sound. For example, the note A above middle C on the piano has a fundamental frequency of 440 Hz. On the other hand, random sound has no distinct pitch, being characterized as a nondescript rumbling, rushing, or hissing noise, or low and high frequency noises depending upon the range of frequencies present.

Human hearing is sensitive to frequencies in the range of about 16-20 000 Hz (the "audiofrequency range"). The audible frequency range is covered by 10 octave bands. An octave is the frequency interval the upper limit of which is twice the lower limit. The so-called "preferred frequencies" at the centres of the standardized octave bands are spaced at octave intervals from 16 to 16 000 Hz (ISO, 1975a). It should be noted that the limits of the octave bands are f/square root 2 and f square root 2, where *f* is the centre frequency. The octave band level at a particular centre frequency is the level of the sound measured when all acoustic energy outside this band is excluded. One-third octave band filters, widely used for noise assessment purposes, subdivide each octave interval into three parts and provide a more complete description of the sound spectrum.

In order to measure sound pressure level, the mean square pressure must be averaged over a certain period of time. For steady sounds, the choice of averaging time is immaterial providing that it is long compared with the time period of sound pressure fluctuations. Standard sound level meters normally incorporate "fast" and "slow" response settings corresponding to averaging times of approximately 0.1 and 1.0 second respectively (IEC, 1973a) (section 2.2.4).

Impulsive noise consists of one or more bursts of sound energy, each of a duration of less than about one second (ISO, 1973a). Sources of impulsive noise include impacts of all kinds, e.g., hammerblows, explosions, and sonic booms. These may be heard singly or, as in the case of a stamping press, repetitively. To characterize such sounds acoustically, it is necessary to estimate the peak sound pressures together with the duration, rise time, repetition rate, and the number of pulses. The mean square pressure of such sounds may change so rapidly that it cannot be measured with a conventional sound level meter, even using the "fast response" (0.1 sec) setting. For more accurate measurements, a 35-millisecond averaging time is specified for standard "impulse" sound level meters (IEC, 1973b). The averaging time of the inner ear is very short (about 30 microseconds) and some new impulse sound level meters have "peak hold" settings with an averaging time of 20 microseconds.

2.2 Sound Perception and its Measurement

2.2.1 Loudness and loudness level

The physical magnitude of a sound is given by its intensity and its subjective or perceived magnitude is called its loudness. Loudness depends on both intensity and frequency and the average quantitative relationship between these factors has been deduced by experiment (see for example Fletcher & Munson, 1933; Stevens, 1955).

The basic unit of loudness is the sone which is defined as the loudness of a 1000 Hz pure tone heard at an SPL of 40 dB re: 20 μPa under specified listening conditions (ISO, 1959). Two sones equal twice the loudness of one sone and so on. For sound at a particular frequency, at least over a significant fraction of the practical intensity range, loudness is proportional to some power of the sound intensity. This is the power law of loudness which is in general accordance with the Weber-Fechner law (Stevens, 1957b). In the mid audiofrequency range, the exponent in the power law is such that a twofold change in loudness corresponds to a tenfold change in intensity, i.e., a 10 dB change in level (Stevens, 1957a). At low frequencies, loudness changes more rapidly with changes in level. This is demonstrated in Fig. 1, which shows a standard set of equal loudness contours for pure tones (Robinson & Dadson, 1956; ISO, 1961), each line showing how the SPL of the tone must be varied to maintain a constant loudness. Each curve, in fact, corresponds to a particular loudness in phons. The loudness of a sound, in phons, is, by definition, equal to the SPL of that 1000 Hz tone which is equally loud -- again under specified listening conditions (ISO, 1959). For practical purposes, the relationship between the phon and sone scales may be expressed as:

$$\text{phon} = 40 + \log_2 (\text{sone})$$

2.2.2 Calculation and measurement of loudness level

Ideally, sound measurement meters should give a reading equal to loudness in phons bu it is difficult to achieve this objective, because the human perception processes are complex. Nevertheless, procedures have been developed and adopted as international standards (ISO, 1975b) but, as they are too complex to be incorporated into a simple measurement meter, they are rarely used in practice, except where the highest possible precision is required.

For most practical purposes, a much simpler approach is used. A filter is used to weight sound pressure level measurements as a function of frequency, approximately in accordance with the frequency response characteristics of the human ear, i.e., energy at low and high frequencies is de-emphasised in relation to energy in the mid-frequency range. Most precision sound level meters incorporate three selectable filters labelled A, B, and C (IEC, 1973a) and sometimes

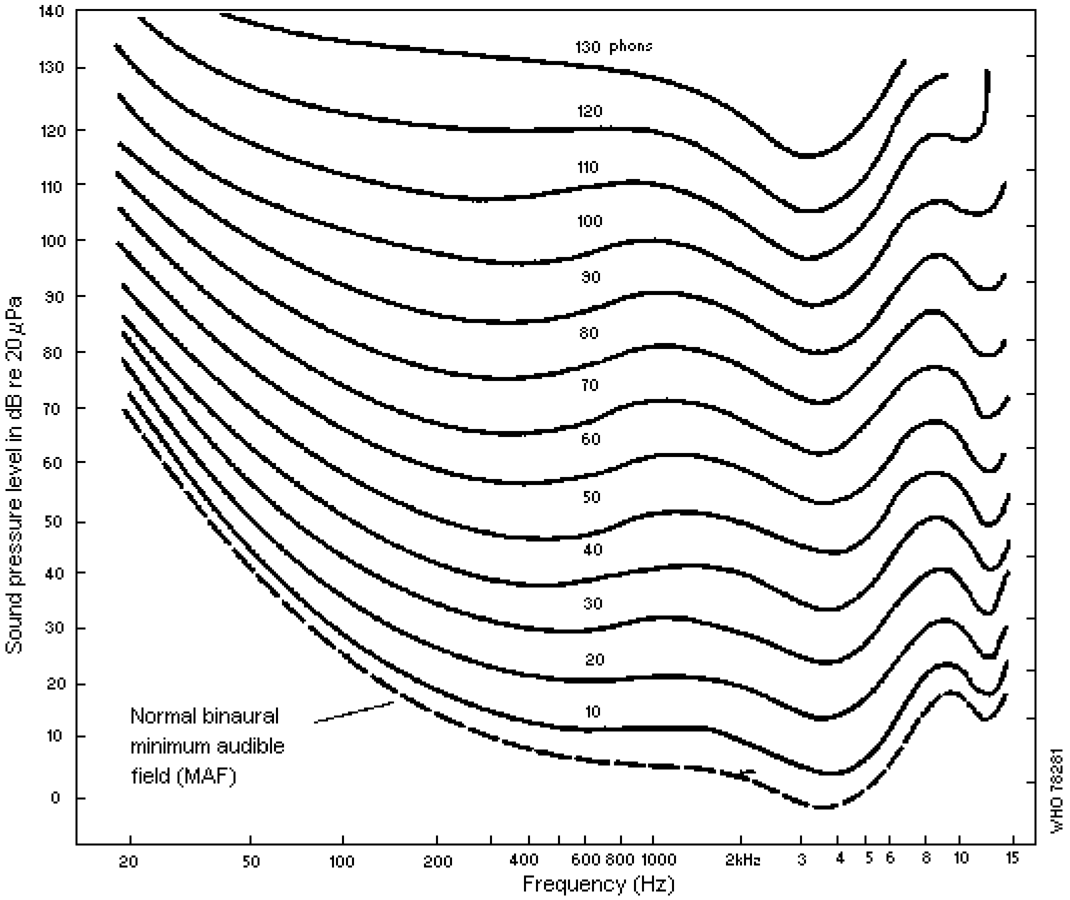

Fig. 1. Normal equal-loudness contours for pure tones (From: Robinson & Dadson, 1956).

D-filter (see section 3.7.2) (IEC, 1973b), the characteristics of which are illustrated in Fig. 2. The A, B and C filters are intended to match the ear-response curves at low, moderate, and high loudness respectively. However, extensive experience has shown that the A-filter usually provides the highest correlation between physical measurements and subjective evaluations of the loudness of noise. Levels on the A-scale are also measured in decibel units and are commonly expressed as dB(A), a convention that is used throughout this document.

The A-weighting is used for sound measurements in a variety of situations, as it is widely accepted that the A-weighted sound pressure level, Lp(A), is a reasonably reliable and readily measured estimate of loudness (Botsford, 1969; Young & Peterson, 1969). It must be emphasized that this in only true for broadband sounds with no spectral concentrations of energy, in which case Lp(A) is typically some 10 decibel units lower than loudness in phons. For narrow frequency range sounds, considerable care must be exercised in the interpretation of A-weighted sound pressure level readings, since they may not accurately reflect the loudness of the sound. It should be noted that the A-scale has been adopted so generally that sound levels frequently quoted in the literature simply in dB are in fact A-weighted levels. Furthermore, many general purpose sound level meters are restricted solely to A-weighted measurements (IEC, 1961).

2.2.3 Sound level and noise level

The phrase "noise level' is widely used by laymen to describe the severity of an environmental noise. In acoustics, the word "level" should be reserved for all quantities expressed on a decibel scale. In this document, as is now common practice in many countries, the phrases "sound level" and "noise level" refer to decibel scales that account for human hearing characteristics (the A-weighted SPL scale being the most widely used). Care should be exercised to distinguish between sound pressure level, sound power level, sound intensity level, and sound or noise level.

2.2.4 The time factor

Sounds can appear to be steady to the human ear because the auditory averaging time is inherently long, much longer than the acoustic cycle times. Similarly, sound level measurements can be made to appear steady by selecting a suitably long averaging time. On precision sound level meters the "slow" value is appreciably longer than the auditory averaging time and is used to obtain a steady reading, when the signal level audibly fluctuates at a rapid rate. The "fast" response time is of the same order as that of the ear.

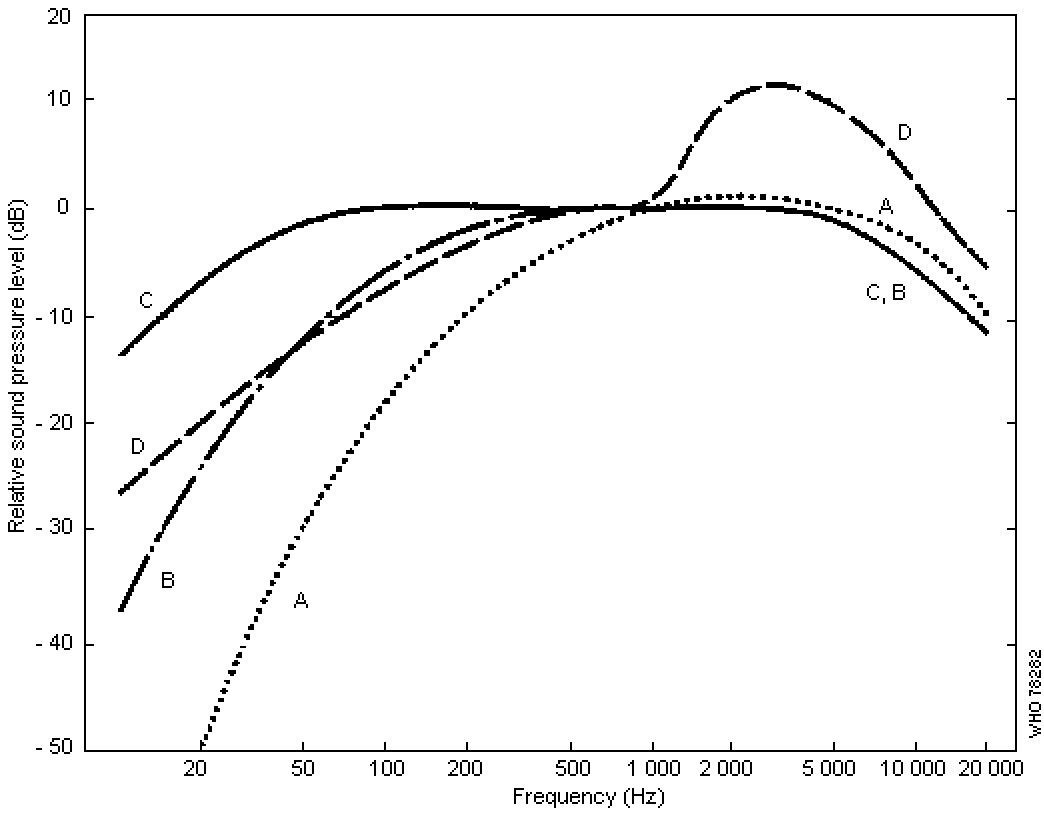

Fig. 2. Standard A, B, C, and D filter characteristics for sound level meters (IEC, 1973a, 1973b).

Sound level fluctuations, which can be smoothed out by the use of the slow response setting, are usually ignored for noise assessment purposes. However, difficulties arise when "slow response" readings vary significantly with time, as they do in many environments. Often, such level fluctuations are small but in some situations, for example, near to roads and airports, the fluctuations can be measured in tens of dB; the rate of fluctuation can also vary widely.

2.2.5 Noise exposure scales

In many noise indices that are well correlated with the subjective effects of interest, various underlying acoustic and nonacoustic factors have been combined in different ways. These composite indices are discussed in section 3.7 and the present section is restricted to the question of the physical measurement of noise.

The basic objective of measurement is to quantify overall noise exposure in the simplest possible terms. The physical characteristics of a noise which, on the basis of intuition and laboratory experiment, might be expected to influence its subjective effects include the following: loudness level (recognizing average and peak values together with impulsive characteristics where appropriate); total noise "dose"; level fluctuation amplitudes; and rates of fluctuation. Clearly, the acoustic variables alone have many dimensions; the following two procedures are commonly used to measure some of them.

2.2.6 Equivalent continuous sound pressure level

To measure an average sound level the meter averaging time is extended to equal the period of interest *T,* which may be an interval of seconds, minutes, or hours. This gives the equivalent continuous sound pressure level (L_{eq}) derived from the mathematical expression:

$$L_{eq} = 10 \log_{10} \frac{1}{T} \text{integral}_{o}^{T} \frac{L_p(A)(t)}{10^{10}dt} \text{ db(A)}$$

Because the integral is a measure of the total sound energy during the period *T,* this process is often called "energy averaging". For similar reasons, the integral term representing the total sound energy may be interpreted as a measure of the total noise dose. Thus, L_{eq} is the level of that steady sound which, over the same interval of time, contains the same total energy (or dose) as the fluctuating sound.

Equivalent continuous sound level is gaining widespread acceptance as a scale for the measurement of long-term noise exposure. For example, it has been adopted by the International Organization for Standardization for the measurement of both community noise exposure (ISO, 1971) and hearing damage risk (ISO, 1975c). It also provides a

basis for more elaborate composite noise indices discussed in subsequent sections including the day-night sound level (L_{dn}) (section 3.7.3.3).

Following the introduction of jet aircraft into commercial service, it was suggested that the then existing loudness scales were inadequate for aircraft noise rating purposes. An alternative scale of perceived noise level (PNL) was developed, with units dB(PN) (Kryter, 1959). This was derived from the loudness level procedure of Stevens (1956) on the grounds that the attribute of perceived noisiness defined as the "unwantedness" of the sound was different and more relevant to aircraft noise than loudness. In fact, the only difference between the calculations involved was the use of different frequency response curves. As research progressed towards legislation for aircraft noise emission control (US Federal Aviation Regulations, 1969; ICAO, 1971), the perceived noise level scale was modified to include special weightings for "discrete frequency components", i.e., irregularities in the spectrum caused by the noticeable periodic components of engine fan and compressor noise, and the duration of the sound (Kryter & Pearsons, 1963). This modified quantity, known as effective perceived noise level, is expressed in dB(EPN).

Because PNL could not be measured with a simple meter, a parallel development was the D-weighting filter, with characteristics based on an equal noisiness (rather than an equal loudness) frequency response curve (IEC, 1976). This filter is available on some sound level meters and is intended for aircraft noise monitoring purposes.

2.2.7 Level distribution

A widely used method of recording the variations in sound level is that of level distribution analysis, sometimes called statistical distribution analysis. This yields a graph of the percentage of the total time *(T)* for which any given sound level is exceeded; such information can be summarized by reading specific levels from this graph. For example L_{10}, L_{50}, and L_{90}, the levels exceeded for 10%, 50%, and 90% of the time, are frequently used as measures of typical peak, average, and background levels, respectively.

2.3 Sources of Noise

2.3.1 Industry

Mechanized industry creates the most serious of all large scale noise problems, subjecting a significant fraction of the working population to potentially hazardous noise levels. This noise is due to machinery of all kinds and often increases with the power of the machines. The characteristics of industrial noise vary considerably, depending on specific equipment. Rotating and reciprocating machines generate sound that is dominated by periodic components; air moving equipment tends to generate broad-band random sounds. The highest noise levels are usually caused by components or gas flows that move at high speed [e.g., fans, steam pressure relief valves) or by

operations involving impacts (e.g., stamping, riveting, road breaking). In industrial areas, the noise usually stems from a wide variety of sources, many of which are of a complex nature.

Machinery noise generation mechanisms are reasonably well understood and the technical requirements for low noise output in new machinery can usually be specified. The difficulty of reducing the noisiness of existing equipment is a serious obstacle to the improvement of working environments.

2.3.2 Road traffic

The noise of road vehicles is mainly generated from the engine and from frictional contact between the vehicle and the ground and air. In general, road contact noise exceeds engine noise at speeds higher than 60 km/h. The level of noise from traffic is correlated with the traffic flow rate, the speed of the vehicles, and the proportion of heavy vehicles, which, together with motorcycles, tend to be about twice as loud as motor cars.

Special problems arise in areas where the traffic movements involve a change in engine speed and power, such as at traffic lights, hills, and intersecting roads.

2.3.3 Rail traffic

Trains generate a relatively low frequency noise but variations are present depending upon the type of engine, wagons, and rails. Impact noises are generated in stations and marshalling yards because of shunting operations. The introduction of high speed trains has created special noise patterns, especially when such trains pass over bridges or other structures that cause amplification of the noise. At speeds of around 200 km/h, the proportion of high frequency sound energy increases and the sound is perceived to be similar to that of overflying jet aircraft. Furthermore, with increasing speed the onset of the noise is more sudden than with conventional trains. Thus, severe noise problems have been created in countries where high speed trains operate, notably in Japan.

2.3.4 Air traffic

Aircraft operations have caused severe community noise problems. Introduction of the early turbojet transport aircraft led to a surge of community reactions against commercial airports, and more research has been devoted to aircraft noise than to any other environmental noise. The noise generation is related to air velocity, which is an important feature for aircraft and aircraft engines. Fast moving bodies such as propellers and compressor blades, as well as jet exhaust gases are very efficient sources of noise.

Aircraft noise is characterized by a wide frequency range with the periodic components of rotating machinery noise (fans, propellers, and rotors) superimposed on a general broadband background noise. For jet aircraft, the periodic components tend to be more dominant on landing than on take-off when the broadband exhaust noise predominates. For aircraft with quiet engines, noise from the hull may become dominant when landing.

Aircraft noise control depends critically on the reduction of engine component and gas velocities. The high by-pass ratio turbo-fan engines of newer aircraft with components operating at significantly lower speeds have resulted in a reduction in aircraft noise levels, and offer considerable promise of less noisy airports, as they gradually replace older equipment.

2.3.5 Sonic booms

The sonic boom is a shock wave system generated by an aircraft, when it flies at a speed slightly greater than the local speed of sound. The shock wave extends from an aircraft throughout supersonic flight in a roughly conical shape. At a given point, the passage of the shock wave causes an initial sudden rise in atmospheric pressure followed by a gradual fall to below the normal pressure and then a sudden rise back to normal. These pressure fluctuations, when recorded, appear in their typical form as so-called N-waves. When they occur with a separation greater than about 100 milliseconds, the sonic boom has a characteristic double sound. Rise times from less than 0.1 to 15 milliseconds and durations up to 500 milliseconds have been recorded for typical sonic booms generated by military or civilian aircraft.

Low intensity sonic booms with longer rise times are perceived as a noise similar to distant thunder. As the rise time increases, the noise becomes progressively sharper and attains a "dry cracking" character. An aircraft in supersonic flight trails a sonic boom that can be heard over more than 50 km on either side of its ground track depending upon the flight altitude and the size of the aircraft (Warren, 1972).

2.3.6 Construction and public works

Building construction and earth works are activities that cause considerable noise emissions. A variety of sounds is present from cranes, cement mixers, welding, hammering, boring, and other work processes. Construction equipment is often poorly silenced and maintained, and building operations are frequently carried out without considering the environmental noise consequences.

2.3.7 Indoor sources

Indoor noise originates from a variety of sources such as air conditioners, waste disposal units, and furnaces. Noises from outdoor sources also penetrate through windows and weaknesses in building structures, although with some attenuation. Within a building, noise is transmitted from room to room through ventilation ducts and through the building structure itself. Of particular interest is the low frequency sound emitted by ventilation or air conditioning equipment. This noise, which often has discreet frequencies, can be generated by fans, vibrations in conducting ducts, or at air outlets.

2.3.8 Miscellaneous sources

Apart from the major categories of noise already identified, which affect a large number of people in the community, many other sources of noise can be important in individual cases. Firing ranges, sports fields, and pleasure grounds are examples of fixed sources, while noises from garbage collection and power-operated lawn-mowers are other examples of machine-produced noise that can interfere with man's comfort and rest. Neighbourhood noise also includes noise from domestic animals, farm equipment, boats, and the sirens of emergency vehicles.

3. EFFECTS OF NOISE

3.1 Noise-induced Hearing Loss

3.1.1 Hearing impairment

Normal hearing is regarded as the ability to detect sounds in the audiofrequency range (16-20 000 Hz) according to established standards. However, individual hearing ability in man varies. Some of these variations may be attributed to the effects of different environmental influences (Roberts & Bayliss, 1967); in industrialized countries, women generally have better hearing than men (Kylin, 1960; Dieroff, 1961; Gallo & Glorig, 1964).

As a rule, hearing sensitivity diminishes with age, a condition known as presbyacusis (Glorig & Nixon, 1962). Consequently, corrections for aging should be considered when examining data on hearing loss caused by noise exposure. However, the literature reflects controversy concerning the degree to which cumulative effects of noise exposure in everyday life may contribute to eventual hearing loss (socioacusis), thus obscuring the effect due to aging alone. Moreover, there is considerable variation between individuals in both the amount and rate of hearing loss due to aging. The general pattern of progression of presbyacusis has been quite well-established, and data are available in numerous reference sources (US National Institute for Occupational Safety and Health, 1972; US Environmental Protection Agency, 1973a, 1974). Loss of hearing sensitivity due to aging occurs mainly at the higher audiometric frequencies and is almost invariably bilateral (i.e., in both ears).

3.1.1.1 Hearing level, noise-induced threshold shift, and hearing impairment

In order to discuss the effects of noise on hearing, it is necessary to differentiate between hearing level, noise-induced threshold shift (NITS), and hearing impairment.

Hearing level refers to the audiometric threshold level of an individual or group in relation to an accepted audiometric standard (ISO, 1975d) and is sometimes termed "hearing loss". Noise-induced threshold shift is the quantity of hearing loss attributable to noise alone, after values for presbyacusis (including socioacusis) have been subtracted. These values may differ slightly according to where and how the presbyacusis data were collected (see for example Hinchcliffe, 1959; Gallo & Glorig, 1964; Spoor, 1967; US National Centre for Health Statistics, 1975).

Hearing impairment is generally referred to as the hearing level at which individuals begin to experience difficulty in leading a normal life, usually in relation to understanding speech. Hearing impairment has been defined in the USA as an arithmetic average of

26 dB or more hearing loss at the frequencies, 0.5, 1, and 2 kHz (the definition is currently being revised); in Poland, it is defined as 30 dB or more at 1, 2, and 4 kHz (after age correction), and in the United Kingdom, it is 30 dB or more at 1, 2, and 3 kHz. It should be noted that a damage risk criterion of 30 dB at 1, 2, and 4 kHz may be more protective than a criterion of 26 dB at 0.5, 1, and 2 kHz, because hearing loss at high frequencies is usually greater than the loss at 500 Hz.

3.1.1.2 Noise-induced temporary threshold shift[a]

A person entering a very noisy area may experience a measurable loss in hearing sensitivity but recover some time after returning to a quiet environment. This phenomenon can be measured as a shift in audiometric thresholds, and is called noise-induced temporary threshold shift (NITTS).

Recovery from NITTS depends on the severity of the hearing shift, individual susceptibility, and the type of exposure. If recovery is not complete before the next noise exposure, there is a possibility that some of the loss will become permanent. Information on NITTS has been used for two purposes: first, to predict noise levels that could be permanently damaging to the ear, and second, to attempt to predict individual susceptibility to hearing loss caused by excessive noise. Measurements of NITTS are made by comparing pre- and post-exposure audiograms. The extent of NITTS, for the same exposure, varies considerably between individuals. Recovery can take hours, days, or even weeks after exposure. It should be noted that NITTS can be experienced by individuals who already suffer from permanent noise-induced hearing losses. Thus, when assessing permanent damage, sufficient recovery time in the quiet should be allowed before audiometry.

It would appear from recent investigations that the relationship between NITTS and the noise-induced permanent threshold shift (NIPTS) is very uncertain and that damage-risk criteria should be based on epidemiological rather than on NITTS data.

3.1.1.3 Noise-induced permanent threshold shift

The typical pattern of NIPTS usually involves a maximum loss at around 4000 Hz. Because the loss is sensorineural, it is seen in both air and bone conduction audiograms. Noise-induced hearing loss is not an abrupt process but occurs gradually, usually over a period of years. The rate and extent of loss depends on the severity and duration of the noise exposure, but individual susceptibility also

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[a] Sometimes called auditory fatigue.

seems to have a considerable effect on the rate of progression. Noise-induced losses are rather similar to losses due to aging and the two types of losses are difficult, if not impossible, to distinguish. Fig. 3 shows the progression of noise-induced hearing loss observed in workers with increasing duration of exposure to high noise levels (Johansson, 1952).

The first stages of noise-induced hearing loss are often not recognized because they do not impair speech communication ability. As the loss becomes greater, difficulty may be encountered particularly in noisy locations.

Hearing of important sounds other than speech, such as door bells, telephones, or electronic signals, may also be impaired. With further loss in hearing, speech communication may be severely affected.

3.1.1.4 Incidence of noise-induced permanent hearing loss

The prevalence of hearing loss among workers in noisy industries has been recognized since ancient times, and excessively loud noises are popularly described as deafening. Clinical observations of noise-induced hearing loss have been reported for more than a century, but it is only recently that the problem has been studied intensively. It has been suggested that even though people exposed to intense noise frequently experience a substantial noise-induced temporary threshold shift, sometimes accompanied by tinnitus (ringing in the ears), the fact that very often such symptoms seem to disappear within a short time may lead them to believe that no permanent damage has occurred. However, neither the subjective 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.

As there is considerable variation among individuals, it is very difficult to identify a safe limit of noise exposure that can be applied for all ears.

Most current knowledge of hearing loss due to noise has been obtained from industrial surveys. There is also evidence that non-industrial exposure to noise can be harmful. Results of several studies have confirmed that high levels of "rock and roll" and similar music can produce considerable temporary threshold shift and even permanent threshold shift. Audiograms of "pop-musicians" typically show losses at 400 Hz in both ears (Kowalczuk, 1967). It has also been shown that men and women are equally at risk of hearing damage, when exposed to over-amplified music (Fletcher, 1972). Other non-occupational activities that can contribute to hearing loss include shooting and motorcycling.

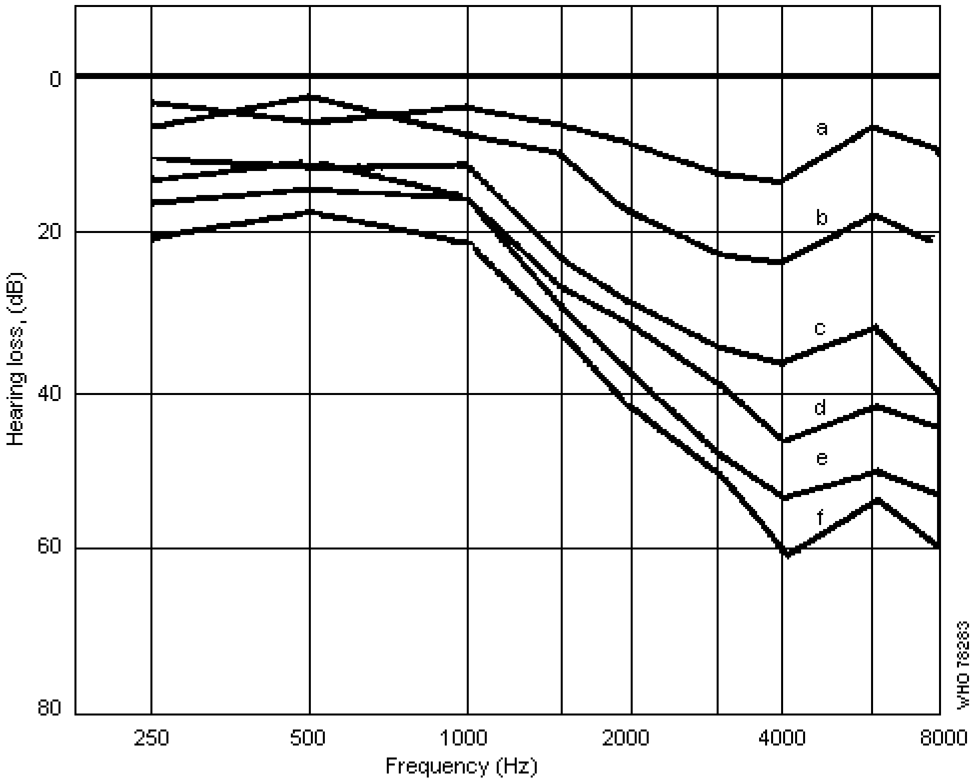

Fig. 3. Hearing loss as a function of number of years of noise exposure.
Mean audiograms for 203 miners, best ear tested.

a < 1 year
b 1 - 5 years
c 6 - 10 years
d 11 - 20 years
e 21 - 30 years
f > 30 years

(from: Johansson, 1952).

3.1.2 Relation between noise exposure and hearing loss

In the normal auditory process, sound vibrations in the air travel through the ear canal and cause the eardrum to vibrate. The vibrations are then transmitted by the bones of the middle ear to the sensory organ of the inner ear (cochlea). Here they are transduced by hair cells into nerve impulses and transmitted to the brain, where they are perceived as sound or noise.

Blasts and other intense or explosive sounds can rupture the eardrum or cause immediate damage to the structures of the middle and inner ear, while hearing loss due to prolonged noise exposure is generally associated with destruction of the hair cells of the inner ear. The severity of noise-induced hearing loss depends on both the location and the extent of damage in the organ of Corti, which, in turn, depend on the intensity and frequency of the sound stimulus. The higher the frequency, the nearer the point of maximum displacement of the basilar membrane is to the base of the cochlea where the basilar membrane is narrowest. This point is shifted towards the apex of the cochlea as the stimulus frequency decreases. The maximum stimulation of cells occurs at the point of maximum displacement. A large part of the upper cochlea is responsive to low frequency stimulation and loss of hair cells can be quite extensive without significant loss in low frequency sensitivity. On the other hand, much more localized portions of the basal region of the cochlea are responsible for high frequency sound sensation and loss of hair cells in these lower portions results in significant losses of high frequency sensitivity (Miller, 1971a).

The number of hair cells damaged or destroyed increases with increasing intensity and duration of noise and, in general, progressive loss of hair cells is accompanied by progressive loss of hearing.

Even though numerous experiments have been performed with animals, the mechanisms involved in the destruction of the Corti organ are not completely clear, although several explanations have been proposed. For example, mechanical stresses could destroy cells, repeated circulatory troubles through vascular contractions could deprive cells of an appropriate blood supply; an increase in local temperature could damage proteins, and repeated stimuli could exhaust the metabolic supply of cells. Various theories have been reviewed by Ward (1973).

An important fact is that noise-induced hearing loss is of a neural type involving irreversible injury to the inner ear. Furthermore, such losses are almost always bilateral.

3.1.2.1 Laboratory studies

Laboratory studies on temporary and permanent hearing loss and on the anatomy of the noise-damaged inner ear have been carried out on a number of animal species. Temporary hearing loss studies on human subjects have included a variety of noise exposure patterns, including

noises of different spectra, interrupted noise patterns, and short-duration noise exposures. In extrapolating the results of such studies to permanent hearing loss in man, it has always been necessary to consider: (a) temporary versus permanent threshold shift in man; (b) permanent threshold shift in man versus permanent threshold shift in animals; and (c) anatomical damage in animals versus permanent threshold shift in man. However, it should be noted that a thorough knowledge of such relationships has not been necessary. For example, in using animals to study the cumulative effects of noise, it has not been necessary to assume that the absolute sensitivity of animals and man to noise is the same, but merely that the relative sensitivity of animals to alternative noises of specified temporal patterns is similar to that of man.

Experimental studies have resulted in the following general observations:

(a) There is considerable variability among individuals in susceptibility to temporary hearing loss, the rate at which temporary hearing loss approaches its asymptotic level, and the rate of recovery.

(b) Temporary hearing losses in man are most pronounced at frequencies slightly above the predominant frequency of the noise stimulus.

(c) In most cases, the rate of increase of, and subsequent recovery from, temporary hearing loss is different for impact noises and for steady noise. NITTS from impulse noise increases more slowly than NITTS from steady noise (Ward et al., 1961) and recovery is slower (Cohen et al., 1966).

(d) In general, the equal energy rule (section 3.1.3) has been found to be compatible with experimental results for uninterrupted exposures to steady noise. However, it may not always be the best predictor of NITTS with regard to the audiometric frequency since it tends to overestimate NITTS below 2000 Hz and underestimate losses above 2000 Hz (Yamamoto et al., 1968). Although NITTS from interrupted noise may be overestimated (Ward, 1970), it is thought that the rule gives a good prediction of NIPTS from interrupted noise (Burns & Robinson, 1970).

(e) Audiograms of persons exhibiting temporary hearing loss in laboratory studies tend to be similar to those of persons exposed to comparable noise over a period of several years (Nixon & Glorig, 1961).

3.1.2.2 Occupational hearing loss

Several reports have been published on the subject of occupational hearing loss (Atherley et al., 1967; Burns & Robinson, 1970; King, 1971; Robinson, 1971; Stone et al., 1971; Baughn, 1973; Burns, 1973; Paschier-Vermeer, 1974; Sulkowski, 1974).

All these studies were cross-sectional audiometric studies and many incorporated surveys of noise exposure. Specific occupational groups were usually studied, including workers in heavy industry, shipyards, textiles, jet-cell test rooms, foundries, transportation, and forestry. Some definition of hearing impairment was generally applied in order to define a percentage of people with hearing loss. Audiograms were usually compared with so-called "normal" thresholds. In this respect, presbyacusis was often accounted for. In many cases, efforts were made to screen the data to exclude those persons who had previously held noisy jobs, possible nonoccupational noise exposures, and otological abnormalities. In some studies, such persons were purposely included in order to provide a realistic estimate of hearing levels in a typical noise-exposed population.

Virtually every study revealed that workers exposed to intense noise daily, for several years, showed noise-induced hearing loss fitting the classic pattern. Considerable hearing loss was rare at lower frequencies but frequent at higher frequencies.

In the studies for which noise exposure levels were known, a clear relationship was generally seen between increasing incidence of hearing loss and increasing noise level. In groups exhibiting considerable noise-induced hearing loss, the variation of audiometric thresholds was generally higher than in groups not exposed to noise. Cases of sudden deafness occurring after long-term exposure to noise, without previous impairment, have been reported in Japan (Kawata & Suga, 1967) and may indicate special susceptibility.

Taking into account duration of exposure and age as well as other pathological conditions, Rey (1974) found that the proportion of workers with noise-induced deafness (defined as 25 dB average loss at 0.5, 1, and 2 kHz) was as high as 60% in the metal industry (noise levels equal to and above 95 dB(A)). Cohen et al. (1970) compared the mean hearing levels of exposed workers with those of a control group for several noise intensities and several durations of exposure and found that noise levels between 85 and 88 dB(A) could be harmful to the ear, and that, even at 75 dB(A), there was some loss of hearing.

According to two other studies performed in industry, there is a definite risk of hearing damage associated with prolonged exposure to noise levels between 85 and 90 dB(A) (Roth, 1970; Martin et al., 1975).

Fig. 4 compares the percentages of workers with hearing impairment as a function of age for unexposed groups and for groups exposed to occupational noise levels of 85, 90, and 95 dB(A) (NIOSH, 1973b). In this case, hearing impairment is defined as an average hearing loss greater than 25 dB(A), at frequencies of 1, 2, and 3 kHz.

3.1.2.3 Factors that may influence the incidence of noise-induced permanent threshold shift

Certain people who live in remote and generally quiet areas of the world have been found to have unusually acute hearing in comparison with members of urban populations in corresponding age groups (Rosen et al., 1962). However, it is not clear whether such audiometric differences are due to the lack of noise exposure alone. Differences in the patterns of hearing found between communities that are widely separated geographically and culturally may result from cultural, dietary, and genetic factors and differences in general environment (Rosen et al., 1962; Rosen & Rosen, 1971).

Although it has been suggested that older people are more susceptible to NIPTS (Kryter, 1960), there is no clear experimental evidence that this is so (Kupp, 1966; Nowak & Dahl, 1971). Indeed, studies by Schneider et al. (1970) and Davis (1973) indicate that there is probably no causal relationship between age and susceptibility to NIPTS, at least in people of working age.

There is some controversy in the literature as to whether pathological changes in the middle ear protect the inner ear from noise-induced damage, or whether they may instead increase the chance of noise-induced hearing loss. Some authors have expressed the view that in cases of middle ear damage, bone conduction becomes more effective and that the defence action of the middle ear muscles is impaired (Mounier-Kuhn et al., 1960; Ward, 1962; Dieroff, 1964; Mills & Lilly, 1971). In contrast, others have reported cases where noise-induced hearing loss was less in damaged ears than in normal ears (Johansson, 1952).

Variation in individual susceptibility to noise-induced permanent hearing loss is illustrated by observations from surveys of occupational hearing loss, which indicate that workers from the same noisy environment display radically different audiograms, and that some workers, even after many years of exposure to noise, show little or no sign of noise-induced hearing loss.

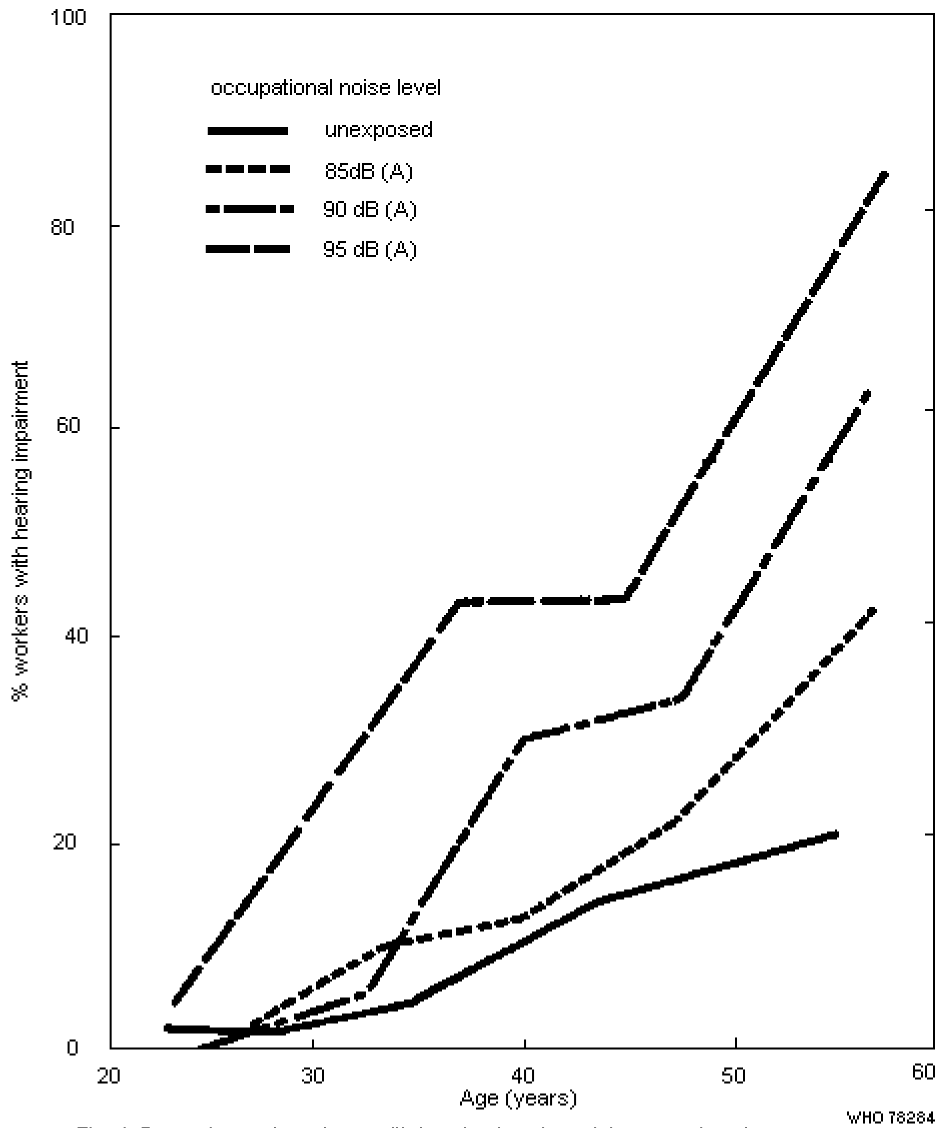

Fig. 4. Percentage of workers with hearing impairment (average hearing loss at 1, 2, and 3 kHz > 25 dB) (From: US National Institute for Occupational Safety and Health, 1972, 1973).

Factors causing such differences in individual susceptibility could include fatigue of the acoustic reflex, anatomical differences in the structure of the middle and inner ear, the functional status of the autonomic system, and latent vitamin B deficiency (Kawata, 1955).

To some extent, the ear is protected from damage by the middle ear reflex or stapedius reflex. The contraction of the stapedius muscle changes the movement of stapes which increases the impedance of the conductive mechanisms. The amount of sound energy delivered to the inner ear is reduced by about 15-20 dB at low and middle frequencies (Miller, 1961). The effectiveness of the middle ear reflex as a protective device varies with the intensity and the spectrum of the sound. In normal ears, the onset of the reflex occurs at sound levels of 75-90 dB. In man, the muscle contraction subsides very quickly after the onset of the sound for frequencies above 3000 Hz, while for lower frequencies, the contraction can last for a considerable time (Johansson et al., 1967). Impulsive sounds or sounds with a sudden onset can penetrate the ear without stimulating the protective mechanism, because of a time lag in the muscle contraction. Furthermore, the reflex action weakens with fatigue and thus provides little protection against prolonged steady sounds. The fact that its effectiveness also varies considerably among individuals may be related to variations in individual sensitivity to certain sounds.

Measurements of NITTS have been used to investigate the protection provided by the stapedius reflex. In patients with peripheral facial palsy including unilateral stapedius muscle paralysis, the NITTS after low frequency noise exposure was significantly greater in the affected ear than in the unaffected ear (Zakrisson, 1974). However, results of animal studies, in which the stapedius muscle was severed, contradict these findings (Steffen et al, 1963; Ferris, 1966).

3.1.2.4 Combined effects of intensity and duration of noise exposure

Most data concerning the long-term hazard of noise are related to occupational exposure. There is a shortage of information about short-term exposures, and very little information concerning exposures lasting longer than 8 h. In order to predict the effects of long-term noise exposure, investigators have been obliged to extrapolate the results of field observations and laboratory investigations of NITTS. It is difficult to establish limits for safe noise exposure, since predictions using different methods of extrapolation conflict with each other. The following is a brief review of the bases of some of the methods used to integrate the combined effects of intensity and duration.

The equal temporary effects rule is the hypothesis that the NIPTS due to long-term, daily, steady-state noise exposure is equal to the average NITTS produced by the same daily noise in healthy young ears (Ward et al, 1958, 1959). In a later study, Ward (1960) suggested that metabolic insufficiency induced in the hearing organ by noise might underlie both the temporary and permanent hearing defects caused by excessive noise. NITTS studies also tend to support the observation (reflected in industrial studies of NIPTS) that for a given length of exposure, frequently interrupted noise is less harmful than continuous steady-state noise of the same level (Ward et al, 1959; Miller et al., 1963).

An extension of this theory is that NIPTS is unlikely, if there is complete recovery from the NITTS before the beginning of the next day's exposure. An early occupational noise criterion was based on this assumption (Kryter et al., 1966).

The equal energy rule is the theory that the hazard to hearing is determined by the total sound energy (the integrated product of sound intensity and duration) entering the ear each day. This rule has natural appeal, since the exposure dose is quite simple to assess and, according to epidemiological data, is reasonably well correlated with the accumulated physical damage. The rule allows a 3-db increase in a steady sound level for each halving of the duration (Burns & Robinson, 1970; Ward & Nelson, 1971; US Environmental Protection Agency, 1973b; Martin, 1976). However, it should be noted that the range of sound duration covered by this rule might be limited by the need for protection against possible damage by high level, short duration, impulsive sounds (section 3.1.3).

Various other theories are based, to a certain extent, on the equal temporary effect hypothesis. Such criteria are usually identified by the change in sound level that is necessary for each doubling of the exposure duration, e.g., the "5-dB rule" means that the level must be 5 dB less for each doubling of the exposure duration. The rules most frequently quoted in the literature are:

(a) 3 dB rule: equal energy rule incorporated in ISO standard 1999 (ISO, 1975c);

(b) 5 dB rule: purported to partially compensate for typical interruptions and intermittency and used in the 1969 Walsh-Healey Public Contracts Act in the USA (Federal Register, 1969);

(c) 4 dB rule: purported to be more reliable for protection at higher frequencies than the 5 dB rule and used by the United States Air Force (US Air Force, 1973); and

(d) 6 dB equal pressure rule, a more conservative criterion suggested by some research workers (US Department of Health, Education and Welfare, 1972).

None of the rules (a) to (d), account for a reordering of the noise exposure pattern, i.e., the predicted risk is independent of the order in which a sequence of sounds is experienced, even if this sequence includes periods of quiet. Thus, there is some conflict between these rules and the equal temporary effect hypothesis.

To simplify different damage risk criteria, noise exposure histories are frequently expressed as equivalent 8-h continuous levels. For example, using the equal energy (3 dB) rule, an exposure of 88 dB for 4 h could be expressed as an equivalent level of 85 dB.

3.1.2.5 Estimation of hearing impairment risk

The hearing loss that may result from noise exposure, can be expressed in terms of probable NIPTS, or hearing impairment. For example, the percentage of people who will suffer an NIPTS of 5 dB (the smallest amount measurable) at the most sensitive frequency (4000 Hz) may be defined as a function of an equivalent 8-h level (Fig. 5). From this diagram, an 8-h equivalent level of 75 dB(A) can be identified as the limit for protection against significant NIPTS (ISO, 1975c). Since it is often impractical to reduce occupational 8-h equivalent noise levels to 75 dB(A), practical criteria for "safe" levels have been based upon less stringent definitions of hearing impairment or hearing handicap. For example, "damage-risk" has been defined as the percentage of a population with a given amount of hearing impairment after corrections have been made for those people who would "normally" incur losses from causes other than noise exposure. Table 2 shows the percentage risk and the total percentage with impaired hearing resulting from various levels of noise and years of exposure (ISO, 1975c).

3.1.2.6 The importance of high-frequency hearing

It is common practice to assess hearing handicap for compensation purposes, and even for prevention purposes, in terms of the ability to understand "everyday" speech. According to the ISO definition (ISO, 1975c), hearing handicap begins with a 25 dB loss averaged for the frequencies 500, 1000, and 2000 Hz. However, in most languages, speech includes energy at higher frequencies and therefore good high frequency hearing is important for speech intelligibility, especially when listening conditions are less than optimal (i.e., in background noise or when the speech is disorted in some way) (Kryter et al., 1962; Harris, 1965; Niemeyer, 1987; Acton, 1970; Kuzniarz, 1974; Antansson, 1975). Under good listening conditions, impaired hearing may not diminish speech intelligibility because of the redundancy (multiplicity of cues) of speech (section 3.2.1). This redundancy is reduced in noisy conditions or when the speech is muffled, the accent or the message is unfamiliar, or when these constraints occur in combination.

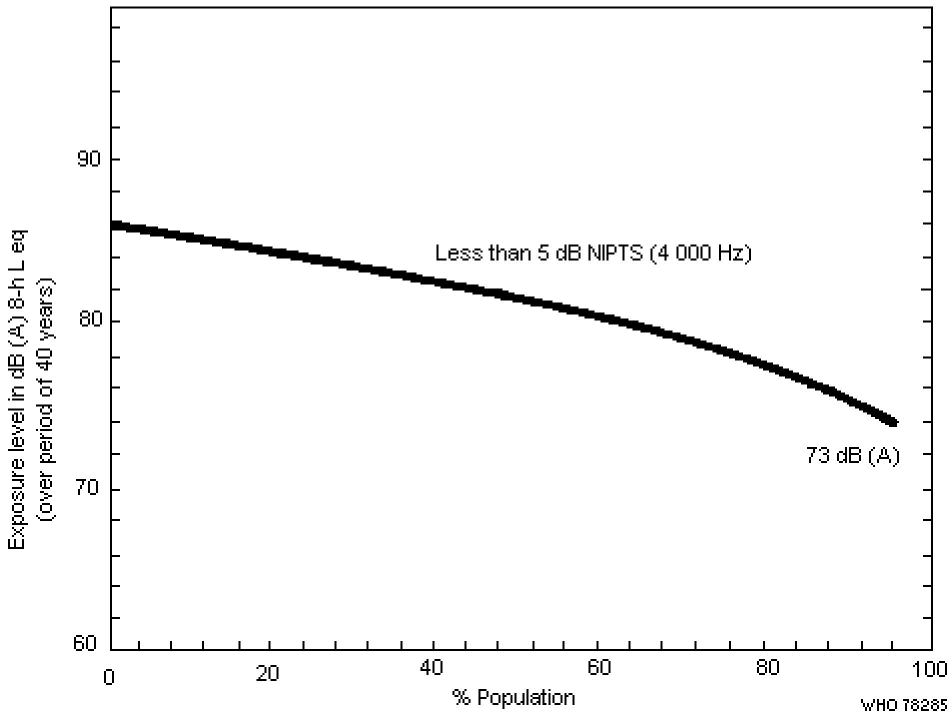

Fig. 5. Percentage of exposed population that will incur no more than 5 dB NIPTS shown as a function of exposure level. Population ranked by decreasing ability to hear at 4000 Hz. (US Environmental Protection Agency, 1974).

Table 2. Percentage of exposed people with impaired hearing as a functi noise level (L_{eq} (8-h) dB(A))^x after different periods of exposure

Occupational noise level L_{eq} 8-h dB(A)	Cause of impairment	Period of exposure (years) 0	5	10	15	20	25	30
<80	(a) All causes y	1	2	3	5	7	10	14
	(b) Occupational noise	0	0	0	0	0	0	0
85	(a) All causes	1	3	6	10	13	17	22
	(b) Occupational noise	0	1	3	5	6	7	8
90	(a) All causes	1	6	13	19	23	26	32
	(b) Occupational noise	0	4	10	14	16	16	18
95	(a) All causes	1	9	20	29	35	39	45
	(b) Occupational noise	0	7	17	24	28	29	31
100	(a) All causes	1	14	32	42	49	53	58
	(b) Occupational noise	0	12	29	37	42	43	44
105	(a) All causes	1	20	45	58	65	70	76
	(b) Occupational noise	0	18	42	53	58	60	62

Table 2 (contd)

Occupational noise level Leq 8-h dB(A)	Cause of impairment		Period of exposure (years)						
			0	5	10	15	20	25	30
110	(a)	All causes	1	28	58	76	85	88	91
	(b)	Occupational noise	0	26	55	71	78	78	77
115	(a)	All causes	1	38	74	88	94	94	95
	(b)	Occupational noise	0	36	71	83	87	84	81

[x] Based on: ISO (1975c).
[y] The values in row (a) for L_{eq} < 80 dB(A) are estimates of the percentage of hearing impairment caused by factors other than occupational noise exposur subtracted from row (a) in all cases to obtain row (b) the percentages of impairment attributable to occupational noise. Impairment is defined as a more averaged for the frequencies 500, 1000, and 2000 Hz.

Example: Out of a group of people exposed to an occupational noise level of for 25 years, 39% will exhibit hearing impairment. However, 10% (se impaired hearing without exposure to occupational noise. Thus the r damage is 29%.

The use of a simple, unweighted average at 500, 1000, and 2000 Hz for assessing noise-induced hearing handicap is restrictive because most hearing loss occurs at higher frequencies. Consequently, the frequencies 3000 Hz and 4000 Hz are included in damage-risk formulae by some countries.

3.1.3 Effects of impulsive noise

At present, most know]edge of hearing loss due to impulsive noise comes from studies of the effects of gunfire (see for example Coles et al., 1968) with some limited data from industrial situations (Dieroff, 1974; Ceypek & Kuzniarz, 1974). Important properties of impulsive noise exposure include the peak SPL, duration, rise and decay times, type of wave form, repetition rate, spectrum, and number of impulses.

The present state of knowledge is that a hazard exists and, accordingly, that ear protection should be worn when impulsive noises, measured with appropriate instrumentation, exceed an SPL of 140 dB for more than 5 milliseconds regardless of rise time, spectrum, or the presence of oscillatory transients. Higher peak levels may be tolerable for durations of less than 5 milliseconds. Levels in excess of 165 dB SPL, even for short durations, are likely to cause cochlear damage (Acton, 1967; Burns & Robinson, 1970). It should be noted that the response time of the acoustic reflex (section 3.1.2.3) is of the order of 100-300 milliseconds, which is too long to give any protection against such short duration sound (Coles et al., 1968; Coles & Rice, 1970).

Although it is not common practice to extend the equivalent 8-h sound level criteria down to impulsive durations, the recent studies of Rice & Martin (1973) and Martin (11976) suggest that the criteria based on the equal energy rule, may be applicable to high-intensity impulsive noise (Fig. 6).

3.1.4 Infrasound and ultrasound

Frequencies below 16 Hz are referred to as infrasonic frequencies. Perception of sound from 100 Hz down to about 2 Hz is a mixture of aural and tactile sensations. For example, frequencies around 10 Hz, can cause discomfort through a modulation of the vocal cords. Reactions caused by extremely high levels of infrasound can resemble those of mild stress reaction and may include bizarre auditory sensations, describable as pulsation and flutter. High levels of infrasound can cause resonance responses in various organs in the human body, although the long-term effects of such stimulation are not known (Johnson, 1973).

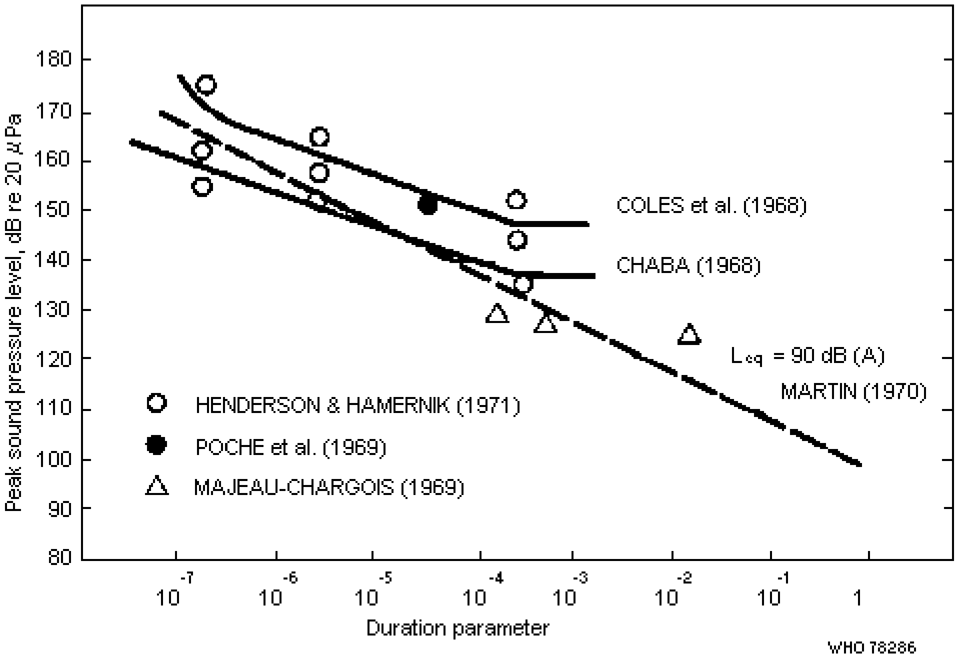

Fig. 6. Comparison of various damaga risk criteria for impulse noise with equal energy curves for L_{eq} = 90 dB (A) (From: Martin, 1976).

The effects of high intensity ultrasound (above 20 kHz and 105 dB SPL), which will be discussed in a separate document, are reported to be similar to those observed during stress. However, these effects may be partly due to associated high (but less than ultrasonic) frequency sound (Acton, 1967). Although it is usually accepted that levels below 105 dB SPL have no adverse effects, there is evidence from one experiment, that physiological changes can occur at lower levels (98-102 dB) (Lisickina, 1968).

3.2 Interference with Communication

3.2.1 Masking and intelligibility

The interference of noise with speech communication is a process in which one of two simultaneous sounds renders the other inaudible. The ratio of a given desired signal (speech, music) to that of the interfering noise will determine whether or not the signal can be perceived. The higher the level of the masking noise and the more energy it contains at speech frequencies, the greater will be the percentage of speech sounds that are inaudible to the listener.

An important aspect of communication interference in occupational situations is that the failure of workers to hear warning signals or shouts may lead to injury. Although cases do not appear to have been documented in the literature, there is anecdotal evidence of such occurences.

In the last half century, knowledge concerning the masking of simple signals such as pure tones, narrow bands of noise, and even isolated phonemes of speech has increased considerably. Empirical relationships are available that permit accurate prediction of the audibility for a normal-hearing listener of a particular speech sound in the presence of a specified noise (Webster, 1969, 1974; Kryter, 1970). However, communication is almost never carried on by means of single acoustic signals, but rather by a rapid sequence of different speech sounds, the overall intensity and spectral distribution of which are constantly shifting; in fact, the same word, when repeated, may be quite different acoustically. Furthermore, even when the masking noise is judged to be steady, the energy in different frequency regions fluctuates from moment to moment.

Most of the sentences of ordinary discourse can be understood fairly well, even when a large number of individual speech sounds are masked, because of the redundancy of speech. Even when a particular sound is masked or even omitted, the word or sentence in which it occurs may be correctly perceived because the remaining sounds are sufficient to convey the meaning. However, the interpretation required to compensate for the masking effect is an additional strain on the listener.

Other characteristics of the communication process may affect the effectiveness of communication, when additional sounds are present.

Examples of such factors are the familiarity of the listener with the dialect or accent of the speaker, the presence of reverberation, the importance and familiarity of the message, distance from speaker to listener, the motivation of the listener, and any hearing loss that may produce a degradation in the perceived sound. Thus, the relationship between the spectrum, level, and temporal characteristics of a masking noise and the "intelligibility" of ordinary speech, i.e., the proportion of speech correctly understood is very complex. Much research has involved the measurement of intelligibility of nonsense syllables and of isolated words in phonetically-balanced lists. Based upon work with real sentences, conversion charts have been constructed to transform scores involving only words to approximate expected scores for sentences of ordinary speech. For example, when 75% of the items on a list of isolated words are correctly perceived, about 95% of the key words in a sentence of ordinary discourse will be correctly heard (Kryter, 1970). Sentence intelligibility refers to the percentage of key words that are perceived correctly in a series of sentences.

3.2.2 Speech interference indices

Many attempts have been made to develop a single index based on the characteristics of the masking noise that directly indicates the degree of interference with speech perception. Naturally, such indices involve considerable degrees of approximation. The three most common indices are: the articulation index (AI), speech interference level (SIL), and the A-weighted sound pressure level ($L_p(A)$).

3.2.2.1 Articulation index

The AI (French & Steinberg, 1947; Kryter, 1962) is the most complicated of these indices, since it takes into account the fact that some frequencies are more effective than others in masking speech. Frequencies below 250 Hz and above 7000 Hz are not included, as they are not considered to contribute to the intelligibility of speech. The frequency range from 250 to 7000 Hz is divided into 20 bands, each of which contributes 5% to the total intelligibility. In order to determine the AI for a particular noise, the difference in dB between the average speech level and the average noise level in each of these 20 bands is calculated, and the resultant numbers are combined to give a single index. Essentially, this process predicts how much masking of individual speech sounds will occur and then integrates this information.

Although the AI is an accurate index for the prediction of the effects of noise on speech intelligibility, it is complicated to use and difficult for the layman to interpret. Thus, simplified procedures for estimating the AI from weighted measurements of octave-band levels have been developed (Kryter, 1962).

3.2.2.2 Speech interference level

The SIL was designed as a simplified substitute for the AI (Beranek 1947). Contributions to intelligibility by the lowest and highest frequencies have been omitted to a greater extent than for the AI. A modern version of the SIL is the arithmetic average of the sound pressure levels in the three octave bands centred at the preferred frequencies 500, 1000, and 2000 Hz (abbreviated SIL 0.5, 1, and 2). Many variations of SIL in terms of the specific octave bands to be averaged have been suggested. For example, SIL (0.25, 0.5, 1, 2) includes the 250 Hz band. At the present time, the US National Standards Institute recommends SIL (0.5, 1, 2, 4) as providing the best estimate of the masking ability of a noise.

3.2.2.3 A-weighted sound pressure level

The simple A-weighted SPL is also a useful index of speech interference. The A-weighting process emphasizes the middle frequencies, as do the AI and SIL, but does not omit the lowest and highest frequencies completely.

Experiments have shown that the AI is more accurate than any of the SILs or the A-weighted SPL in predicting the speech-masking ability of a large variety of noises. For noises of practical importance however, A-weighted SPL and SIL continue to be used, as the advantage of accuracy in the AI does not outweigh the ease of measurement of the first two indices. Comparisons of SILs and A-weighted SPLs show that, on average, the SIL is about 10 decibels lower than the A-weighted SPL for the same degree of interference (Klump & Webster, 1963; Kryter, 1970), although for unusual noises the average difference could vary substantially.

3.2.3 Perception of speech out-of-doors

Measurements indicate that, during relaxed conversation in the home, the speech level is approximately 55 dB(A) (Kryter, 1970; Pearsons et al., 1976), and that as the noise levels increase, people tend to raise their voices to overcome the masking effect. The so-called "normal effort" voice resembles a "stage" voice, and is used when people are given a prepared text to read (Korn, 1954), or when they wish to project their voices. Since everyday speech is spoken at a reasonably predictable level, it is possible to express many of the empirical relationships between background noise level and speech intelligibility in a single graph, as in Fig. 7 (US Environmental Protection Agency, 1974).

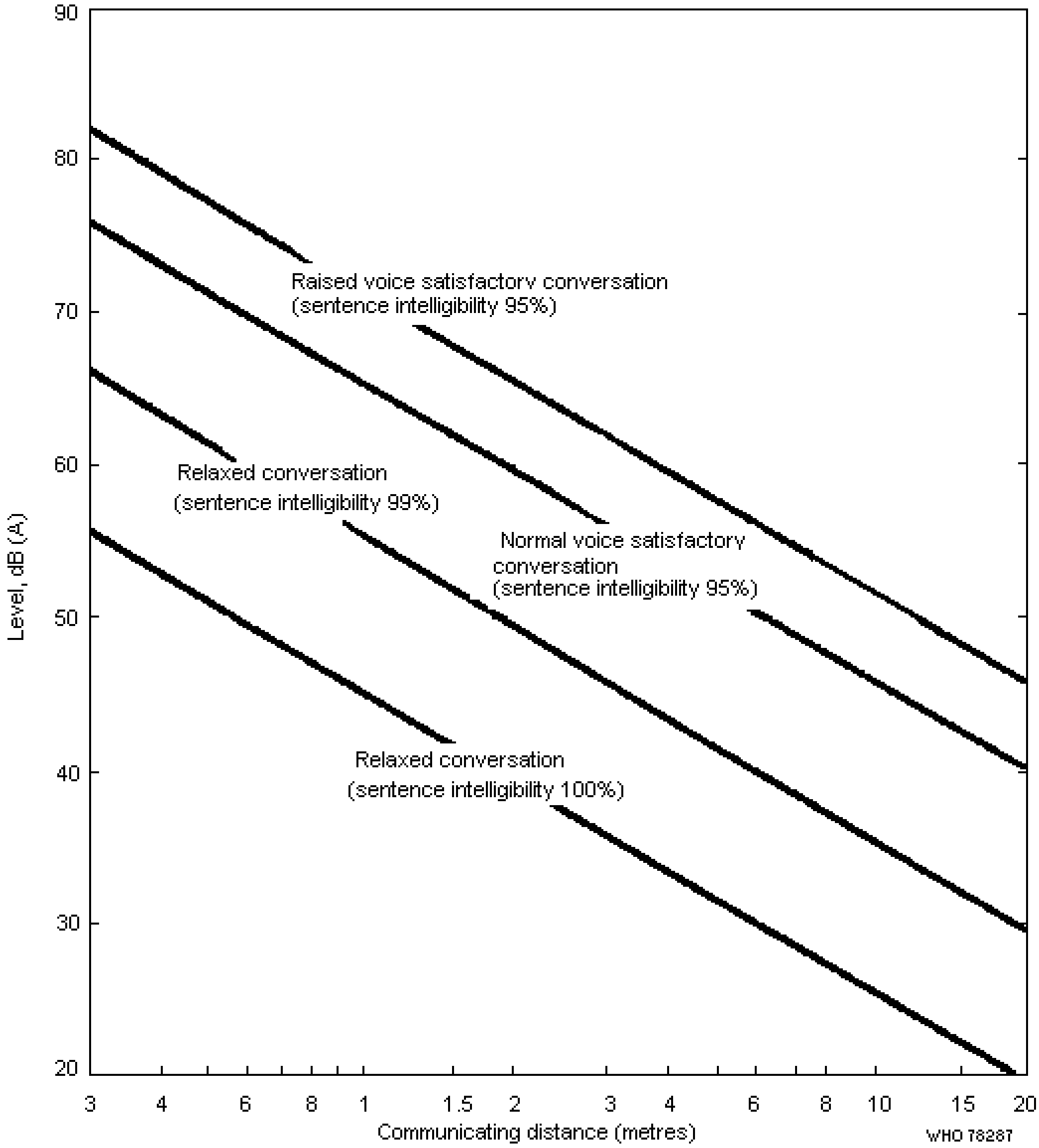

Fig. 7. Maximum distance outdoors over which conversation is considered to be satisfactorily intelligible in steady noise (US Environmental Protection Agency, 1974).

This figure, which is applicable to outdoor conditions, is based on the assumptions and empirical observations that:

(a) at a distance of 1 m from the speaker, relaxed conversation occurs at a voice level of approximately 56 dB(A) and normal and raised voices at levels of approximately 66 dB(A) and 72 dB(A), respectively; and

(b) for 100% sentence intelligibility the speech level should exceed the noise level by 10 dB(A). When the speech level is 10 dB(A) lower than the noise level, intelligibility falls to 95%. Because of the redundancy of speech, 95% intelligibility usually permits reliable although not necessarily comfortable conversation. The location of the curves in Fig. 7 may shift in certain circumstances, although it is difficult to predict to what extent spatial factors may facilitate or impair speech communication in noise. Lower noise levels may be required, if the speaker does not enunciate clearly or if the speaker and the listener use different dialects. People with hearing impairment may need more favourable speech-to-noise ratios depending on the variation of speech-to-noise ratio with frequency.

Adequate communication in higher noise levels than those indicated in Fig. 7 can occur, if the messages are restricted, e.g., when only numbers are being transmitted. Lipreading or observing facial or manual gestures may also improve communication. If the noise source is clearly localized at a position different from that of the speaker, speech communication may be possible in higher noise levels than those indicated in Fig. 7.

Intermittent and impulsive noises as well as noises fluctuating in level will provide various degrees of masking. Again, the redundancy of speech means that an isolated short burst of noise is unlikely to produce much disruption in the communication process; however, the likelihood of disruption increases with increasing duration and frequency of occurrence of the noise bursts.

The detailed characteristics of noises are also important. While the A-weighted SPL is an adequate index of the speech-interfering quality of many noises, others may require a more detailed analysis. This is true of noises that are dominated by either low or high frequencies, e.g., the rumble of distant traffic or the hiss of compressed air. For unusual noises, the AI should be calculated for a reliable prediction of speech intelligibility.

3.2.4 Indoor speech communication

The relationships shown in Fig. 7 apply only to outdoor (free field) communications, as they depend on the applicability of the inverse square law. Relationships indoors are different because of reverberations caused by reflections from the walls, floor, ceiling, and objects in a room. Instead of decreasing 6 dB for each doubling of distance, the sound level of the speech or the noise may drop by only 1 or 2 dB. There is no simple formula that will predict speech interference indoors. Instead, it is usual to set standards on the basis of the average noise levels that have been judged in the past to be acceptable in similar settings.

For example, Fig. 8 (US Environmental Protection Agency, 1974) shows the estimated sentence intelligibility, at speaker-listener distances greater than 1 m, as a function of A-weighted SPL in the reverberant conditions found in a typical living room. This shows that for 100% intelligibility, which is considered desirable for indoor listening conditions, a background noise level of less than 45 dB(A) is required.

3.3 Pain

Aural pain is induced, when the tympanic membrane tissue is stretched by large amplitude sound pressures. Under extreme conditions, the membrane can rupture (Hirsch, 1968).

Although there is a fairly wide range of individual variability especially for high frequency stimuli (von Gierke et al., 1953), the threshold of pain for normal ears is in the region of 110-130 dB. The threshold for physical discomfort is in the region of 80 dB (Spreng, 1975).

In abnormal ears, for example in cases of inflammation, pain may be caused in the eardrum or middle ear by sound levels of about 80-90 dB SPL. By comparison, people without eardrums may feel no sensation of pain at sound levels of up to 170 dB SPL.

A second type of aural symptom occurs as a result of abnormal function in the cochlea. Certain sensorineural disorders, and most frequently noise-induced hearing losses, are accompanied by a condition called auditory recruitment. Recruitment is defined as an abnormal increase in loudness perception. The phenomenon of recruitment is commonly used for the diagnosis of noise-induced hearing loss (audiometric suprathreshold tests). In some cases of sensorineural hearing disorders, such as Ménière's disease, another symptom appears in addition to recruitment called syscusis, which is a lowering of the threshold of aural discomfort and pain.

An important consideration with regard to aural pain is the effect of noise on hearing-aid users. Discomfort associated with exposure to sudden loud noises, loud music, and even raised voices is a common complaint of people who wear hearing aids. Hearing aids that automatically limit output to 100-120 dB SPL or less, provide protection for sensitive ears, provided they are properly selected and fitted (Gabrielsson et al., 1974).

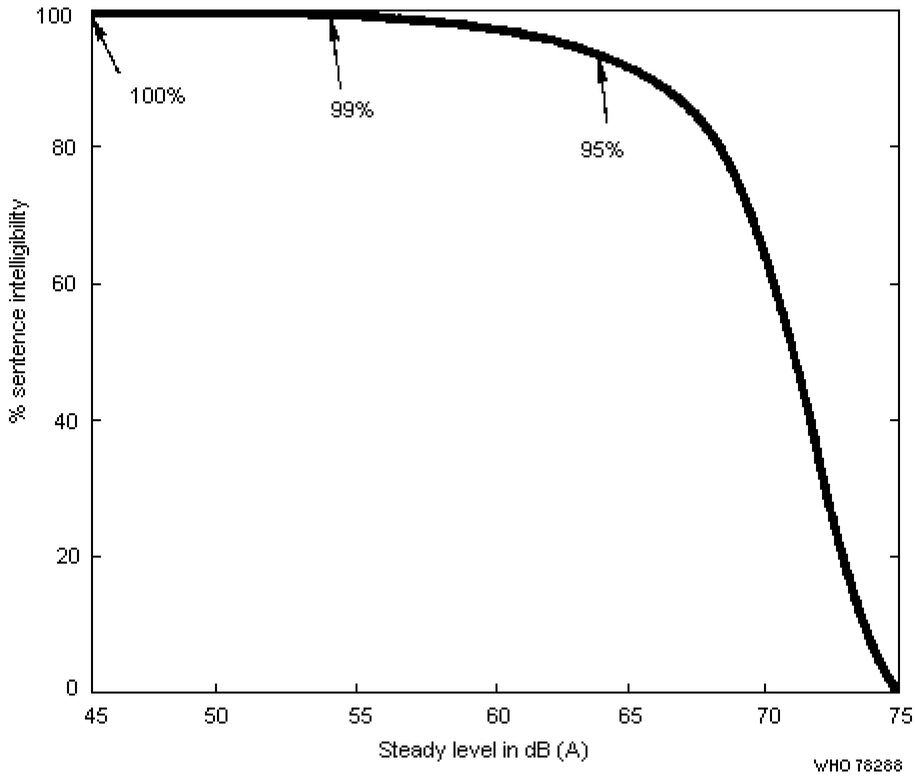

Fig. 8. Normal voice intelligibility as a function of the steady background sound level in a typical living room US Environmental Protection Agency, 1974).

3.4 Sleep

3.4.1 Nature of sleep disturbance

Many people experience sleep disturbance due to noise and the problem has been reviewed by several authors (see for example, Griefahn et al., 1976). Social survey data indicate that sleep disturbance is considered to be a major environmental noise effect (Alexandre, 1974). However, in what proportion noise contributes to regularly occurring sleep disturbances or awakenings in the general population is not clear. Noise exposure can cause difficulty in falling asleep, disrupt sleep patterns, and awaken people who are asleep.

Detailed laboratory studies of the problem have been made by monitoring electroencephalograph (EEG) responses and changes in neurovegatative reactions during sleep. Many of these experiments have only involved small numbers of test subjects over limited time periods and under laboratory conditions. Care must therefore be exercised in extrapolating conclusions to the population at large.

Several stages of sleep can be identified from EEG responses. On relaxing, prior to sleep, the EEG pattern changes from rapid, irregular waves to a regular pattern; the alpha rhythm. This is followed by sleep stage 1, characterized by prolonged reductions in wave amplitude and frequency. Later, in sleep stage 2, the pattern changes to one of bursts of waves (spindle waves) mixed with single, slow waves of relatively large amplitude (K-complexes). About 30-45 minutes later, periods of slow, high amplitude waves (delta waves) appear in the EEG (stage 3). When the delta waves occur for about 50% of the recording period, the deepest sleep, stage 4, is reached. About an hour and a half later, the EEG pattern resembles that found in stage 1, but electrodes placed near the eye reveal rapid eye movement (REM); this is the stage during which most dreaming occurs. Some research workers have been able to elicit relatively complex motor responses to verbal instructions in the REM stage of sleep (Evans et al., 1966).

During normal sleep, a person progresses through sleep stages 1-4 with occasional reversals, the time spent in deep sleep and in the lighter stages of sleep depending upon age. With increasing age, a greater proportion of time is spent in the lighter sleep stages; from the age of 60 years onwards, sleep stage 4 is almost totally absent. It is considered that all stages of sleep are necessary for good physiological and mental health.

Stimulation by noise causes changes in the EEG pattern lasting for a few seconds or more. These may appear as K-complexes (increases of wave frequency) that are only detectable by close inspection of the EEG recording, or changes of sleep stage. It has been reported that the effects of noise are related to the stage of sleep. Results from some studies suggest that thresholds for awakening are lower in the REM sleep stage, for nonimpulsive as well as impulsive noises (Berry & Thiessen, 1970). EEG pattern changes are least likely to occur in the REM stage (Thiessen, 1972).

The effects of noise upon sleep depend upon the characteristics of the noise stimulus, the age and sex of the sleeper, the history of previous sleep, adaptation, and motivation.

3.4.2 Influence of noise characteristics

In studies of the effects of noise upon sleep, a variety of stimuli have been used including synthetic sounds as well as the sounds of aircraft (flyover noise and sonic booms) and road traffic.

The effects of noise on sleep appear to increase as the ambient noise levels exceed about 35 dB(A) L_{eq} (Beland et al., 1972). In one study, the probability of subjects being awakened by a peak sound level of 40 dB(A) was 5%, increasing to 30% at 70 dB(A). When changes in sleep stage were taken as an indication of disturbance, the proportion of subjects affected was 10% at 40 dB(A) and 60% at 70 dB(A) (Thiessen, 1969). It was also observed that subjects who slept well (based on psychomotor activity data) at a noise level (L_{eq}) of 35 dB(A) complained about sleep disturbance and had difficulty in falling asleep at an L_{eq} of 40 dB(A). At the higher level of noise, subjects took over an hour to fall asleep initially, and awakened frequently during the sleep period (Karagodina et al., 1972).

Exposure to noise levels of 48-62 dB(A) resulted in changes in sleep EEG patterns, manifested especially as an initial depression or interruption of alpha rhythm (Wilson & Zung, 1966). For sound stimuli of 70 dB(A), the most likely reaction was to awaken, followed by shifts in sleep stages (Thiessen, 1970). At 50 dB(A), 50% of subjects showed one of the following reactions: (a) slight changes in EEG pattern lasting for a few seconds; (b) pattern changes lasting up to a minute; (c) change of sleep stage; (d) awakening.

It has been reported that brief acoustic stimuli are the most effective in eliciting EEG-K-complex in stage 2 of sleep (Vetter & Horvath, 1962). When the sleep disturbance effects of impulsive tone bursts, simulated sonic booms, and truck noise ranging from 85-105 dB were compared, it was observed that the frequency of awakening was lower for the impulsive noise and independent of the noise level. Increases in the level of truck noise and aircraft flyover noise increased the frequency of awakenings and shifts in sleep stages (Berry & Thiessen, 1970).

The rate of occurrence of stimuli and/or fluctuation in the sound level were also found to influence sleep. The noise of low density traffic disrupted sleep more than that of high density traffic (Mery et al., 1971). Similarly, steady white noise of 40 dB(A) was not found to affect sleep, although fluctuating road traffic or factory noise with the same median level caused sleep disturbance (Osada et al., 1968). Short duration sounds of passing aircraft and trains with peak levels up to 60 dB(A) caused a similar degree of disturbance as steady noise at 40 dB(A), even though their total duration was less than 30 minutes per night (Osada et al., 1969, 1972b, 1974). Hord et al. (1966) reported that a 3-second, 30 dB, 1000 Hz signal during sleep caused an increase in the heart rate of 5 subjects over a short period and that the response was most marked during REM sleep.

The increase in eosinophils and basophils normally occurring during sleep was inhibited by continuous noise, such as traffic or factory noise, at levels of 40 dB(A) or more and by intermittent noise, such as aircraft or train noise (Osada et al., 1968, 1969, 1972a, 1974).

The number of field studies on sleep disturbance after noise exposure is very limited. In a study made during a 3-month period (Rylander et al., 1972a), civilian and military subjects were exposed during the night to sonic booms with peak over-pressures in the range of 6-64 Pa. It was observed that at about 60 Pa, 15% of military personnel had an increased rate of awakening and 56% of civilians reported sleep interference and difficulties in getting back to sleep.

3.4.3 Influence of age and sex

A number of studies have indicated that the sleep of children and young persons is less affected by noise than that of middle-aged or older persons (Dobbs, 1972; Nixon & von Gierke, 1972).

On the other hand, children of 4-6 years of age seem to be particularly disturbed by sudden arousal from sleep stage 4 (Miller, 1971b). It has also been reported that babies, who have had gestational difficulties or have suffered brain injury, are particularly sensitive to noise (Murphy, 1969).

Certain data indicate that women are more sensitive to noise during sleep than men (Steinicke, 1957; Wilson & Zung, 1966; Lukas, 1972b) and that middle-aged women are particularly sensitive to subsonic jet aircraft flyovers and simulated sonic booms (Lukas & Dobbs, 1972).

Ando & Hattori (1970) found that about 50% of the women who had moved to Itami City, near Osaka Airport in Japan, during the first 5 months of pregnancy said that, after birth, their infants slept soundly through the aircraft noise. However, this was true for less than 15% of the infants whose mothers had moved in during the last 5 months of pregnancy. Because of limitations in the methods used in this study, these results should be considered with caution.

3.4.4 Influence of previous sleep deprivation, adaptation, and motivation

The amount of accumulated sleep time affects the probability of awakening. Arousal is more likely to occur after long periods of sleep, irrespective of the stage of sleep (Dement & Kleitman, 1957; Lukas & Kryter, 1970). Adaptation to noise during sleep is present if repeated exposure to sound stimuli during sleep results in progressively less interference with normal sleep.

LeVere et al., (1972) studied the EEG response and task performance of six 20-24-year-old males. The experiment lasted 14 nights, 7 of which involved exposure to 80 dB(A) jet aircraft noise for 20 seconds, 9 times each night. No adaptation in EEG noise response was observed. In studies on the effects of simulated sonic booms on sleep, Lukas & Dobbs (1972) concluded that some adaptation occurred. Thiessen (1972) reported that although the awakening response seemed to diminish with time, there was no adaptation of the EEG response to aircraft and traffic noise.

Results of studies of simulated sonic booms with indoor intensity levels of 80-89 dB(A), applied alternatively 2 and 4 times each night for 2 months, did not reveal any adaptation in EEG pattern and vegetative function during, and shortly after stimulation. In the first quarter of the night, there was a significant reduction of the total time spent in the deepest stage of sleep but during the remainder of the night (with 4 booms) the duration of deep sleep was comparable with the nightly total before and after the noise test series (Jansen & Grifahn, 1974).

Motivation and instructions given to subjects before sleep may influence the effects of noise on sleep. An ability of sleeping subjects to discriminate among various types of stimuli has been observed in experiments where the discrimination was learned when the subject was awake (Wilson & Zung, 1966). Research workers employing simulated sonic booms to investigate the effects on sleep behaviour, moods, and performance instructed their subjects to "ignore disturbances and attempt to get the best night's sleep possible". They found that the number of responses to booms were lower than those in similar studies where instructions had not been given (Collins & Iampiatro, 1974).

It has been observed that effects of motivation on sleep disturbance depend to a certain extent upon the stage of sleep (Miller, 1971b). Instructions and financial incentives produced an increase in the frequency of stage shifts and awakening following exposure to moderate sound stimuli of different kinds (Wilson & Zung, 1966).

3.4.5 Long-term effects of sleep disturbance by noise

The long-term physiological and psychological effects of noise-induced sleep disturbance are practically unknown (Lukas, 1972b). Some insight into possible consequences may be obtained from experiments studying behaviour and performance after noise-induced sleep deprivation. A review of the influence of noise exposure on task performance is given in section 3.8.

Some experiments have demonstrated that intense noise may improve performance in persons who have been without sleep and are tired, even when they are performing a task that would be highly affected by noise, if sleep had been normal (Corcoran, 1962; Wilkinson, 1963). On the other hand, LeVere et al. (1972) found decreased performance in a task involving a memory component after nightly exposure to 80 dB(A) aircraft noise.

Tasks involving monitoring, mental arithmetic, and pattern discrimination were not influenced following nightly exposure of 24 male subjects to 8 simulated sonic booms (100 Pa at 1-h intervals for 12 nights) (Chiles & West, 1972). Cantrell (1974) exposed 20 men to 80, 85, and 90 dB(A) tonal pulses with a 22-second interval throughout 24 h for 10 days. EEG recordings showed evoked response activity during sleep but clearcut effects on various task performance tests were not observed. Exposure of 6 male subjects to a 15-second, 80 dB(A) noise, 24 times per night resulted in a significant deterioration in the performance of a choice reaction/memory time test (LeVere et al., 1975).

The results of studies reported so far suggest that the type of noise occurring during sleep as well as the type of performance test applied determine whether effects can be found or not. No observations have been reported concerning possible effects after repeated disturbance over a prolonged period of time or on the effects on populations exposed under real-life conditions.

3.5 Nonspecific Effects

3.5.1 The stress response

Exposure to noise may evoke several kinds of reflex responses, particularly when the noises are of an unknown character or unexpected. These reflex responses are mediated through the vegetative nervous system and represent a part of the reaction pattern that has commonly been named the stress reaction. This response generally reflects primitive defence responses of the body and may also develop after exposure to other stimuli.

If the exposure is temporary, the system usually returns to a normal or pre-exposure state within minutes. If the noise stimulation is sustained or consistently repeated, it has been postulated that persistent changes may develop in the neurosensory, circulatory, endocrine, sensory, and digestive systems. However, most available information on such effects has been obtained from animal experiments in which high levels of noise were used.

Neurophysiologically, noise is a potent stimulus for the establishment of a reflex are incorporated in the syndrome of general adaptation to chronically maintained stress (Selye, 1955, 1956). The reticular and hypothalamic portions of the brain represent the centre of the reflex arc, the acoustic pathways represent the afferent branches and the ascending/descending nervous projections represent the efferent branches. Target organs include the visceral organs (heart, blood vessels, intestines, endocrine glands etc.) which are innervated by the autonomic nervous system and the hypothalamo-diencephalic centres that regulate the alternating rhythms of sleep-arousal, endocrine secretion, and other functions (Bergamini et al., 1976). The action of noise on the reticular formation depends not only upon its level and duration, but also upon its temporal characteristics. While impulse noise produced a stable and prolonged excitation of the reticular formation of the midbrain and of the temporal cortex in rabbits, results of one study showed that similar effects due to continuous noise exposure became insignificant after one hour (Suvorov, 1971).

The reflex reactions also include changes in the functioning of the adrenal glands. In studies by Henkin & Knigge (1963), exposure of rats to continuous, high intensity sound (130 dB, 220 Hz) resulted in an initial high rate of hormone secretion followed by a depression of corticosterone output and a return to normal or high levels. In another experiment, an increased urinary excretion of epinephrine was found in 9 normal rats as an after-response to repeated 2-second exposures to high frequency sound (20 kHz) at 100 dB (Ogle & Lockett, 1968). Temporary eosinopenia and temporary changes in the adrenal gland occurred in mice exposed daily to a single, 15 or 45-min period or intermittant periods (alternating 100-min periods) of noise at a level of 110 dB, 10-20 kHz (Anthony & Ackermann, 1955). However, in studies by Osintseva (1969), pathological changes could not be demonstrated in the adrenal glands of rats, one month after exposure to a noise level of 80 dB for periods ranging from 18 to 26 days. Horio et al. (1972) suggested that discrepancies in the reported results might be due to differences in the intensity and duration of noise exposure. As an example, they reported a study on 4 groups of rats (number pre group not stated) that were exposed for 8 h to noise of 60, 80, and 100 phons. Compared with control animals, the blood concentration of adrenal 11-hydroxy corticosteroid rose rapidly at the beginning of exposure reaching a maximum level within 15 min that was directly proportional to the intensity of the noise. Levels fell to those of the control group within 1-4 h. The results of a study by Anthony et al. (1959) showed that exposure to white noise (150-4800 Hz, 140 dB SPL) produced different acute effects in the mouse, rat, and guineapig. The authors concluded that the noise exposure was not harmful to the animal except in terms of hearing. Exposure was for 15 min per day over a 4-week period. There was a reduction in activity

(exploratory), which was most obvious in the guineapig. Some of the mice and rats exhibited a freezing reaction. There were no apparent changes in the weight of the adrenals, but the width of the fosciculate zone in rats and mice was greater in exposed animals. This is a sign of increased adrenocortical activity. No changes were seen in serum ions or blood sugar. Thus, the authors concluded that short-term noise exposure did not give rise to excessive adrenocortical activity.

In a study by Rosecrans et al. (1966), groups of 12 rats were exposed to variable stress (sound, flashing lights, and cage oscillation) for 3, 5, or 7, four-hour periods per week, for 16 weeks. The noises were 100 dB compressed air blasts, bells, buzzers, and tuning fork impulses for periods of 30 seconds at 5 min intervals. All the stress programmes produced significant increases in plasma corticosterone levels compared with unexposed controls. Furthermore, levels were significantly higher in isolated rats than in animals housed in pairs, indicating that isolation should also be considered as a stress.

In human studies, increased urinary excretion of epinephrine and norepinephrine after exposure to 90 dB (2000 Hz) for 30 min was a constant finding in 5 healthy subjects and in 3 groups of 12 patients who, (a) had high blood pressure without known cause; (b) were recovering from a heart attack; or (c) were psychotic (Arguelles et al., 1970). Exposure of 5 healthy male students, twice a day for 30 min to noise levels of 55, 70, or 85 phons resulted in changes in the levels of leukocytes, eosinophils, and basophils, as well as in urinary 17-hydroxycorticosteroid, compared with controls exposed to levels of 30-45 phons (Tatai et al., 1965, 1967). In another study, 6 subjects were exposed for 2 or 6 h for several days to noise levels of 40, 50, and 60 dB(A). Urinary excretions of 17-hydroxycorticosteroids and noradrenaline increased significantly during the period of exposure (Osada et al., 1973).

3.5.2 Circulatory system responses

Vasoconstriction or vasodilation of blood vessels can be induced by high levels of noise during acute exposures. Several studies in animals have demonstrated that prolonged exposure to high levels of noise can cause a persistent increase in blood pressure. In the study by Rosecrans et al. (1966), the stress increased the average blood pressure of rats by approximately 3.9 kPa (30 mmHg) compared with that of control animals. It has also been reported that the absence of sound can cause hypertension in rats (Lockett & Marwood, 1973).

Other animal studies have shown that the cerebral blood supply can be influenced by high levels of noise. Alternating spasms and dilation of the arterial blood vessels were observed in rats exposed to a continuous noise level of 100 dB (Alekseev et al., 1972). At levels up to 100 dB, the constriction was proportional to the amount by which the overall SPL exceeded 70 dB, reaching values as much as

40% higher than resting values. As well as creating a condition of generalized vasoconstriction, continuous exposure of rats to a noise level of 110 dB SPL, for 48 h, resulted in an inadequate supply of blood to the cochlear cells (Lawrence, 1966; Lipscomb & Roettger, 1973). These reports suggest that damage to the cochlear tissue may result from an insufficient supply of oxygen and other nutrients (section 3.1.2).

As a result of observations made in animal experiments, the relationship between noise exposure and chronic circulatory disease has been investigated in man. Ten subjects were exposed to 90 dB white noise for 29 min. No effects were observed on cardiac output, cardiac rate, cardiac stroke volume, or pulmonary artery pressure (Etholm & Egenberg, 1964). Klein & Grübl (1969) found an approximately equal distribution of increases and decreases in the pulse rate of the internal carotid artery among 40 persons exposed to 92-96 dB noise for 10 seconds.

Differences between the sexes have been demonstrated in an experiment involving exposure to jet aircraft and to railway and pile-driver noise of 70-85 dB(A) (Osada et al., 1972b). Pulse rate fluctuations, vascular constriction, and increase in urinary noradrenaline levels were greater in female subjects than in males. From studies by Jansen (1970) and Lehmann & Tamm (1956), it can be concluded that meaningless noise causes an ergotropic reaction in the circulatory system with peripheral vasoconstriction and reduction of heart stroke value without change of pulse rate and blood pressure.

Certain authors have found evidence in man of an association between continuous noise exposure and constriction of blood vessels that is primarily manifested in the peripheral regions of the body such as fingers, toes, and earlobes (Lehmann & Tamm, 1956; Grandjean, 1960).

Some workers have reported that vasoconstriction does not completely adapt with time, either on a short-time or long-term basis, and that effects often persist for a considerable time after cessation of the noise. Peripheral vessel constriction has been found to occur equally in noise-sensitive and noise-insensitive subjects (Valcic, 1974). It has been suggested that vasoconstriction, with its concomitant effect on the circulatory system in general, will eventually lead to heart disease (Jansen, 1969). A higher incidence of circulatory problems, peripheral blood flow disturbances, and irregularities of heart rate have been reported among steel workers exposed to a noise level of 95 dB (Jansen, 1961).

Significantly increased blood pressure levels compared with those of control groups have been reported from studies on machine-shop operators (Andriukin, 1961) and weavers (Parvizpoor, 1976). According to Jonsson & Hansson (1977), differences in blood pressure levels were also found in a noisy factory, between a group of workers with hearing losses and another group with no loss of hearing.

In view of some epidemiological shortcomings in the previous studies, particularly with reference to the selection of population segments, further studies in the industrial environment are required to elucidate the association between exposure to noise and increased blood pressure. Community studies are scarce and should be extended, since tendencies similar to those found in industrial populations have been observed. In a survey involving residents around an airport, psychophysiological and medical tests showed that experimental exposure to aircraft noise caused constriction of blood vessels, and increases in heart rate and electrical muscular activity. However, a tendancy for blood pressure to be higher among persons living in the noisier areas was not statistically significant (Deutsche Forschungsgemeinschaft, 1974).

3.5.3 The startle reflex and orienting response

Certain noises, especially those of an impulsive nature, may cause a startle reflex, even at low levels. The startle (Molinie, 1916) occurs primarily in order to prepare for action appropriate to a possible dangerous situation signalled by the sound. It consists of contraction of the flexor muscles of the limbs and the spine and a contraction of the orbital muscles that can be recorded as an eye blink. It may be followed by an orienting reflex that causes the head and eyes to turn towords the source of a sudden sound in order to identify its origin (Thackray, 1972). The startle reflex can sometimes be followed by a fright reaction, in which case the effects on the circulatory system become more pronounced. Skin conductance is also influenced due to alterations in perspiration. A dose-related depression of the galvanic skin response was found after exposure to a 15-second white noise (Klosterkötter, 1974).

The presence of these reflexes is detected either by noting behavioural reactions or by the electrophysiological study of muscle tension and activity (Galambos et al., 1953; Davis et al., 1955). Although low level sound stimulation may be sufficient in abruptness and information to induce a startle reflex, the fact that a person has experienced some degree of startle, may often only be recorded electrically.

For meaningless noise of various types, it has been observed that orienting reflexes are elicited at the very beginning of a series of stimuli; but that habituation occurs. At higher noise levels, habituation is less marked.

Experiments involving sonic booms (outdoor levels ranging from 60 to 640 Pa and corresponding indoor levels ranging from 20 to 130 Pa) demonstrated that startle reactions in 56 female volunteers increased with the intensity of the boom. The reactions of the subjects were evaluated using two different steadiness tests and a tracking test (Rylander et al., 1974b). A tendency to habituation and a masking

effect of background noise was also found. The possible long-term effects on human subjects of sustained repetition of acute startle reactions are not known.

3.5.4 Effects on equilibrium

A high level of noise may influence equilibrium because of the stimulation of the vestibular sense organ. However, available data concerning this subject are both inconclusive and inadequate. Complaints of nystagmus (rapid involuntary side-to-side eye movements), vertigo (dizziness), and balance problems have been reported after noise exposure in the laboratory, as well as in field situations. However, the levels needed to cause such effects in personnel working on jet engines were quite high, typically, 130 dB SPL or more (Dickson & Chadwick, 1951). Less intense noise levels ranging from 95 to 120 dB SPL also disturb the sense of balance, if there is unequal stimulation of the two ears. This was demonstrated in laboratory studies in which subjects wearing various combinations of ear protectors and balancing on rails of different widths were exposed to various noise levels (Nixon et al., 1966; Harris, 1974).

3.5.5 Fatigue

Additional strain on the body, induced by noise, may cause the development of fatigue either directly, or indirectly through interference with sleep. A variety of environmental agents as well as conditions within the individual may cause symptoms of fatigue - thus the role of noise as a causal factor is difficult to establish.

In one study, symptoms of extreme fatigue were reported by subjects exposed to high levels of infrasound; this was interpreted as evidence of a direct link between fatigue and high intensity noise (Mohr et al., 1965). In another study, workers from workshops with 5 different levels of noise intensity ranging from 50 to 125 dB were investigated. In this case, no simple relationship was found between noise levels and feelings of fatigue. The authors suggested that social as well as cultural factors should be taken into account to obtain a better understanding of the way exposed persons feel about noise (Matsui & Sakamoto, 1971).

The influence of noise on fatigue can also be related to performance. As will be discussed in section 3.8, noise may interfere with performance as well as leave it unchanged or even improved. Since many studies on performance have not taken fatigue into consideration, the question arises as to whether the strain of overcoming noise disturbance in order to maintain performance might not lead to fatigue.

Questions concerning fatigue are usually included in social survey studies on annoyance (section 3.7) but, so far, no extensive evaluation of these data in relation to noise exposure levels has been presented.

3.6 Clinical Health Effects

3.6.1 Background

Earlier in the document, it has been shown that exposure to noise may result in a variety of biological reflexes and responses. Most of the information has been derived from short-term studies on animals and human subjects, but it has been postulated that, if provoked continuously, such responses would ultimately lead to the development of clinically recognizable physical or mental disease in man.

Numerous clinical symptoms and signs have been attributed to noise exposure including nausea, headache, irritability, instability, argumentativeness, reduction in sexual drive, anxiety, nervousness, insomnia, abnormal somnolence, and loss of appetite (Jirkova & Kromarova, 1965).

From a theoretical point of view, an assessment of the causal relationship between noise exposure and such nonspecific health effects presents difficulties. Increases in blood pressure level, heart disease, gastric ulcers, and other stress-related syndromes have a multifactorial origin. It is difficult to exercise sufficient control over all relevant risk factors in epidemiological studies, particularly as several of the risk factors such as social class, personal habits, and personality characteristics are difficult to define.

The study of selected population segments exposed to high levels of noise in industry has been suggested as an epidemiological model to overcome some of these difficulties.

3.6.2 General health

In one study, medical records of 969 workers exposed to noise levels of 85-115 dB were compared with those of workers in areas where levels were 70 dB or less (Jirkova & Kromarova, 1965). In addition to a higher incidence of hearing loss, the noise-exposed group was found to have a higher prevalence of peptic ulcers and hypertension. In a previously cited study (Jansen, 1962) on workers exposed to high intensity noise, there was evidence of a higher frequency of circulatory problems and a higher incidence of fatique and irritability in the exposed group compared with the controls. Cohen (1973) studied the medical records of 500 workers working in noisy areas (95 dB(A) or more) and those of a group matched for age and length of plant experience, working in quieter areas (80 dB(A) or less). The noise-exposed workers tended to have more symptomatic complaints and more diagnosed medical problems. It is difficult, however, to relate these findings to noise only, since noisy work places are, presumably, also work places with other health hazards. Benko (1959, 1962) examined workers exposed to noise levels of

110-124 dB and found a persistent narrowing of the visual field as well as a decrease in colour-perception. The second finding could not be varified in studies reported by Kitte & Kieroff (1971).

Methods of studying industrial populations have shortcomings that make it difficult to draw conclusions concerning the different populations. The group is always selected, i.e., those not able to tolerate the exposure and those developing medical symptoms may have left. The group usually consists of males in good physical condition and older age groups are under-represented.

Only a few studies of the relationships between general health in the population and noise exposure are available. In a study by Karazodina et al., (1969), 140 000 patients registered at the outpatient departments of different hospitals were divided into those living 6-10 km from large airports and those living in quiet areas. A 2-4 fold increase in hypertension, nervous disorders, gastritis, gastric ulcers, and auditory disease was found in the noise-exposed group. As an increase was also found in respiratory disease, factors other than noise pollution may have been responsible for the differences between the two groups.

In a study on aircraft noise around Munich, Federal Republic of Germany, no signs of disease were found in a thoroughly examined sample of the population exposed to 82-100 dB(A) aircraft noise (Deutsche Forschungsgemeinschaft, 1974).

3.6.3 Mental health

An association between exposure to high levels of occupational noise and the development of neurosis and irritability and also between environmental noise and mental health has been proposed by several workers. Herridge (1972) suggested that noise was not a direct cause of mental illness but that it might accelerate and intensify the development of a latent neurosis.

Studies of the records of some, 124 000 persons living in a noisy area around London Heathrow airport and in a quieter area nearby revealed a higher rate of admittance to mental hospitals in the noisy area (Abey-Wickrama et al., 1969). However, the design of the epidemiological study was questioned by other workers (Chowns, 1970) and the finding could not be verified in a later investigation (Gattoni & Tarnopolsky, 1973). The relationship between noise exposure, the presence of mental disorders, and annoyance was studied in a field investigation on 200 persons, half of whom lived near London Heathrow airport. No association was found between noise exposure and mental morbidity, but symptoms of mental disorders were more common among those who reported that they were very annoyed by the noise (Tarnopolsky et al., 1978).

The consumption of tranquilizers and sleeping pills has been proposed as an indication of latent disease or mental disturbance in noise-exposed communities. Grandjean (1974) reported an increase in the consumption of such drugs among persons exposed to aircraft noise. Findings to the contrary were reported from a study of subjects living in the neighbourhood of Munich airport (Deutsche Forschungsgemeinschaft, 1974). A possible explanation for the discrepancy between the two studies is the manner in which the questions concerning drug consumption were posed and related to aircraft noise exposure.

3.7 Annoyance

3.7.1 Definition and measurement

Annoyance may be defined as a feeling of displeasure associated with any agent or condition known or believed by an individual or a group to be adversely affecting them. While it is often useful or necessary from a practical point of view to focus attention on a single agent, in this case noise, it should be recognized that, in real life, it is only one of a combination of environmental stresses.

Annoyance is generally related to, the direct effects of noise on various activities, such as interference with conversation, mental concentration, rest, or recreation. The degree of physical exposure as well as intervening psychosocial variables determine the occurrence and extent of the annoyance response. All these variables must be measured in experimental or epidemiological studies, in order to arrive at an appropriate judgement concerning annoyance effects (Borsky, 1972).

Numerous techniques have been devised to measure annoyance (section 3.7.4). A subject can classify the degree of annoyance verbally (from "not annoyed" to "very annoyed") or with the aid of a number scale (e.g., 1-7 or 1-10). The annoyance can then be assessed using these responses, or by different scaling techniques based on several other questions relating to disturbance and activity interference (Kryter, 1970).

Studies on annoyance have been made in both laboratory and field experiments. Different degrees of annoyance can be described with relatively high precision, and the results seem to be reproducible between different studies, although it has been questioned whether there is a consistent relationship between annoyance measurements (Berglund et al., 1974).

Laboratory studies on annoyance involve judgements of individual noise events in controlled environments. Such studies have isolated some of the acoustic and sociopsychological factors contributing to annoyance. Examples of such factors are the level of noise, its

spectral, temporal, and impulsive characteristics, information conveyed by the noise, the sex, age, and occupation of the respondent, and attitudes towards the source of the noise.

A number of surveys have been performed to determine how annoyance reactions are affected by, and related to noise (McKennell, 1961; Cedarlöf et al., 1963, 1967; Auzou & Lamure, 1966; Bruckmayer & Lang, 1967; Coblenz et al., 1967; Lamure & Bacelon, 1967; Griffiths & Langdon, 1968; TRACOR, 1971; Deutsche Forschungsgemeinschaft, 1974; Grandjean, 1974; Rylander et al, 1974a; Nishinomiya, 1976). Methods that allow the prediction of annoyance from measurements of the physical characteristics of the noise have been suggested. These studies have also served as a basis for the development of noise criteria and standards. Few studies have included an analysis of the incidence of annoyance in relation to the specific health effects described previously.

The following sections describe present knowledge concerning the relationships between annoyance and different kinds of noises.

3.7.2 Instantaneous noise dose

It is generally assumed that the annoyance effects of short-term exposure to noise are a function of loudness, i.e., the louder of two sounds will cause the more annoyance. There are many data in the literature on the measurement of loudness, defined as the perceived magnitude of sound, and numerous techniques exist for estimating loudness from the spectral analysis of the sound. The most complex (Stevens, 1956; Zwicker, 1959; Kryter & Pearsons, 1963) are based upon accepted auditory function theory and give loudness estimations in phons. More practical alternatives to these are available based on standard sound level meters in the form of A, B, and C frequency weighting filters that simply weight the sound energy in accordance with various auditory frequency response functions (section 2.2). The A-weighted SPL has gained widespread acceptance as a suitable noise level scale for general use. Other units have been developed for particular noises e.g., the perceived noise level (PNL) for aircraft noise (section 2.2.6).

3.7.3 Long-term noise dose

Characteristics related to the disturbance and annoyance-inducing potential of long-term noise exposure include the manner in which the loudness level (instantaneous noise dose) varies with time (e.g., the distribution of noise events over a 24-h period). Considerable effort has been devoted to the search for an acoustic index of chronic noise exposure. The major requirements of such an index are that it should be well correlated with human reactions and that it should be convenient to measure. Thus, for airport noise, which is characterized by infrequent but very intense aircraft sounds superimposed on relatively low background levels, indices have emerged that are based upon measurements or estimates of the individual aircraft sound

levels. For road traffic noise, usually involving much greater vehicle movement frequencies, it would be quite impractical to record or estimate the level of each individual vehicle. In this case, noise variables are based on automatically integrated noise analysis. For certain industrial noise environments, indices are calculated from sound level meter readings of a set of relatively steady levels. Most indices include a summation process that accounts for the repetitive or continuous nature of the sound.

3.7.3.1 Aircraft noise

An early general noise exposure index was the composite noise rating (CNR) devised by Rosenblith & Stevens (1953) for assessing environmental noise nuisance. Initially, this index was quite elaborate, accounting in a semiquantitative way for average noise level, discrete frequencies, impulsiveness, repetitiveness, and background noise. Some psychosocial factors were also taken into account by considering time of day (on the assumption that people are more noise-sensitive at night) and the history of the previous noise exposure of the community. It was later modified in the light of new experience (Stevens et al., 1955) and a special version was developed for application to airport noise (Stevens & Pietrasanta, 1957). The aircraft noise model was modified to its currently existing form (Galloway & Pietrasanta, 1967) largely to simplify it and to incorporate the PNL. Essentially, CNR has the form:

$$CNR = L_{PN} + 10 \log_{10} N + C$$

where N is the number of aircraft sounds during a particular time interval, L_{PN} is their mean peak PNL and C is the sum of a collection of weighting factors that account for time of day, season of the year, and ground engine test runs, to which the community is particularly sensitive. The procedure provides guidance on the community reaction to be expected as a function of noise level.

Later developments of the CNR were the noise exposure forecast (NEF), (Bishop & Horonjeff, 1967) and the total noise exposure level (TNEL) recommended by the International Civil Aviation Organization (ICAO, 1971).

On the basis of a social survey at London Heathrow Airport by McKennell, (1961), it was deduced that airport noise exposure should be expressed as a noise and number index (NNI) (Wilson, 1973).

$$NNI = L_{PN} + 12 \log_{10} N - 80$$

The main difference between CNR and NNI is the use of a "number" coefficient of 15 rather than 10. Robinson (1969) later remarked that this difference really represented an "intermittency" correction in the case of NNI, implying that community annoyance grows with the frequency of event more rapidly than is indicated by the equal energy concept inherent in the CNR formula. Doubts arose concerning the

validity of the factor 15 following a later survey around London Heathrow (MIL Research Limited, 1971) and a Swiss study by Grandjean (1974).

The relative influence of the noise and number terms is still a basic issue and a number of subsequent studies (Connor & Patterson, 1972; Deutsche Forschungsgemeinschaft, 1974; TRACOR, 1971; 1976) have not provided any clear answer to the problem.

A number of variations of the basic formula:

Noise Index = $L + K \log_{10} N + C$

have been adopted for use in various countries, and the effective values of K are given for some of these in Table 3. Other suggested values of K range up to 24 (McKennell, 1961; Deutsche Forschungsgemeinschaft, 1974). It is evident from the table that, for K, the value 10 is commonly in use, probably because of its compatibility with the equal energy principle.

All indices have a great deal in common with each other as well as other similar indices not included in the table. All involve measurements of average aircraft noise levels expressed in dB(A), dB(PN), or dB(EPN). Some take into account the duration of the sound, others do not. In most cases, the influence of some psycho-social factors is accounted for, directly or indirectly. Basically, the differences in various indices for the estimation of mean perceived magnitude are small (Botsford, 1969; Young & Peterson, 1969; Ollerhead, 1973).

Other concepts concerning the relationship between aircraft noise exposure and consequent annoyance reactions have been suggested which contrast with the rather uniform approach to aircraft noise assessment just discussed.

In studies in Scandinavia (Rylander et al., 1972a) and in an analysis of earlier studies (Rylander et al., 1974b), the extent of annoyance was found to be related to the A-weighted SPL of the noisiest type of aircraft. An increasing number of overflights increased the extent of annoyance at the same dB(A) level up to a certain threshold, beyond which a further increase in the number of events did not influence the annoyance. The second finding was also present in the second London Heathrow study (MIL Research Limited, 1971),and a reanalysis of aircraft noise survey data from the USA (TRACOR, 1976).

Table 3. Examples of aircraft noise exposure Indices

Country/Organization	Index	K	References
France	Isopsophic Index	10	French Government
Germany, Federal Republic of	Störindex Q (and L_{eq})[a]	13.3	Koppe et el. (1693
Japan	WECPNL[a]	10	Japanese Environme
Netherlands	"Total Noise Load" B	15	Kosten et at. (19
South Africa	Noisiness Index NI	10	South African Bur Standards (1973)
United Kingdom	NNI	15	Wilson (1973)
United States of America	CNR/NEF, L_{dn}	10	Galloway & Pietras

			Bishop & Horonjef Von Gierke (1975)
California	Community Noise Equivalent Level (CNEL)	10	State of Californ
ICAO	TNEL	10	ICAO (1971)
ISO	Aircraft Exposure Level L_E	10	ISO (1970)

[a] A special version for aircraft noise.

3.7.3.2 Road traffic noise

The traffic noise index (TNI) was developed from the results of a social survey in London (Griffiths & Langdon, 1968). It was based on the weighted combination of the sound levels (in dB(A)) exceeded for 10%, 50%, and 90% of the time according to the formula:

$$TNI = L_{50} + 4 (L_{10} - L_{90}).$$

This index reflects the conclusion that traffic noise annoyance depends not only upon the average or typical noise level (L_{50}) but also upon the magnitude of the fluctuation (L_{10}-L_{90}). However, further investigation revealed that, because of the practical difficulties of predicting L_{90} with an adequate degree of confidence, the value of TNI was susceptible to large errors. Thus, TNI was subsequently rejected in favour of L_{10} for traffic noise compensation regulations (UK Statutory Instrument, 1975), even though its correlation with annoyance was shown to be inferior to that of TNI in the original survey.

Because of a very high correlation between different indices that are sensitive to peak levels in the noise-time history, it may safely be assumed that any such index will predict traffic noise annoyance reactions with equal reliability. Evidence of the importance of peak noise levels comes from investigations in England (Langdon, 1976) and Sweden (Rylander et al., 1976) in which the extent of annoyance was found to be well-correlated with noise levels generated by heavy vehicles. The correlation between L_{eq} and annoyance was relatively low in the second of these studies.

A high correlation was found between L_{eq} for urban traffic noise and the extent of annoyance in the exposed population in studies by Lang (1965).

A detailed re-evaluation of available data on traffic-noise exposure and annoyance has recently been carried out by a working group of the International Organization for Standardization. Several existing and newly-proposed indices, mostly derived from L_{eq}, were correlated with subjective response and though it was recognized that insufficient data were available to draw a firm conclusion, it was recommended, that, at present, L_{eq} (as described in ISO, 1971) should be used for the assessment of road traffic noise.

3.7.3.3 General environmental noise

On several occasions, single noise exposure indices that could be used to predict the annoyance caused by all kinds of environmental noise have been proposed, recognizing that different psychosocial influences might alter the dose-response function for different kinds of noise.

In a search for such a general noise index, Robinson (1969) modified the traffic noise index to form the noise pollution level (NPL) given by

$$NPL = L_{eq} + 2.56\ \text{delta}$$

where L_{eq} is the equivalent continuous sound level and delta is the standard deviation of the temporal fluctuations of the level. The noise pollution level concept has been given considerable attention by research workers in various countries. It was rejected by the British Noise Advisory Council as a recommended "unified" noise index (Noise Advisory Council, 1975), in favour of L_{eq} on the grounds that further research into the utility and validity of NPL was desirable. Meanwhile, Robinson (1972) and others have considered refinements of NPL, effectively making the coefficient of delta a function of level fluctuation rate.

!!

In the USA, after an exhaustive review of available noise impact research, an interagency task force concluded that a modified equivalent continuous sound level, taken over a 24-h period, with a 10-dB penalty applied to night-time sound levels, was the noise index that combined ease of measurement and high correlation with annoyance, complaint behaviour, and overt community reaction caused by noise of all kinds (US Environmental Protection Agency, 1973a). This index, which was named the day-night average sound level (L_{dn}), was based upon the use of the A-weighted SPL scale (yon Gierke, 1975).

Over the past few years, there has been a widespread tendency to use L_{eq} for general noise assessment purposes because of its simplicity. L_{eq} is normally computed for specific portions of the 24-h day or, alternatively, a weighted average, such as L_{dn}, is computed after emphasizing noise that occurs during noise-sensitive periods.

3.7.4 Correlation between noise exposure and annoyance

The direct correlation between long-term noise exposure and annoyance has been studied for various kinds of noise exposure. The numerous composite noise indices that have emerged from these studies have been attempts to improve this correlation, by taking into account various factors including: time of day (day, evening, night), noise source (e.g., aircraft, road traffic, industrial source) and type of neighbourhood (e.g., rural, suburban, commercial). The choice of appropriate noise index (L_{eq}, NEF, etc.) normally depended on the source whereas the type of neighbourhood was usually considered in the interpretation of scale values concerning the likely response (e.g., for land use planning purposes).

Regardless of how the dose scale was derived, the main technique for evaluating its validity was through use of the social survey and the annoyance measuring techniques already mentioned. Such surveys (e.g., McKennell, 1961; TRACOR, 1971) have shown that the correlation

coefficient between noise exposure and average response (e.g., the average response of all respondents exposed to a given noise) is relatively high (> 0.8) implying that the noise scales are useful predictors of average reaction. However intersubject variability is high, and the correlation coefficient between noise exposure and individual annoyance is low (< 0.5). That individuals vary in their susceptibility to a particular level of exposure is a biological phenomenon common to all environmental influences. For all kinds of agents including chemical substances and physical factors, an increasing dose will gradually lead to an increasing number of persons being affected in any type of population. Thus, for the setting of standards, the relationship between the exposure to an environmental agent and the reaction has to be based upon the average reaction among a group of individuals. This group may be defined as a representative sample of the population or a particularly sensitive group. The variation between individuals can be attributed to sociopsychological factors. In one study of aircraft noise (TRACOR, 1971), the most important of the factors were fear of crashes, general noise susceptibility, ability to adapt to noise, opinions about the importance of the aircraft operations, and belief that the noise could be better controlled. The interrelationship between these factors is very complex. Even the direction of the causality is not clear: does fear of crashes increase noise annoyance or vice versa? The multivariate statistical analyses performed in some studies are not adequate to resolve such questions and further investigations are needed.

By comparing results of noise annoyance surveys around major airports, it has been found that variation between the reactions of individuals is very similar from place to place and from time to time (Alexandre, 1970; Ollerhead, 1973; Rylander & Sörensen, 1974). Regardless of how the reaction is measured, people express similar degrees of annoyance in relation to similar ranges of noise exposure. However the total range is considerable. Fig. 9 shows the cumulative distribution of annoyed people at London Heathrow airport as a function of noise exposure measured in NNI (Ollerhead, 1973). The different curves represent different annoyance levels, and each is a cumulative normal (Gaussian) distribution with a standard deviation of 20 NNI. Comparison of these curves with similar data from other surveys suggests that they would be valid for any major international airport with about 20% of its aircraft movements occurring at night.

Attempts have been made to combine survey data from various sources. Fig. 10 shows two typical results (US Environmental Protection Agency, 1973a; Schultz et al., 1976). The differences between these two curves reflect different interpretations of the type of reaction that constitutes "high" annoyance. The noise exposure scale in Fig. 10 is L_{eq} (day time) or L_{dn} (expressed in dB(A)), since these variables tend to be roughly equal for typical 24-h work exposure. Interpretation of Fig. 10 for non-typical night-time noise exposure would depend upon the night-time weighting selected on the basis of local circumstances. In the USA, this is taken to be + 10 dB

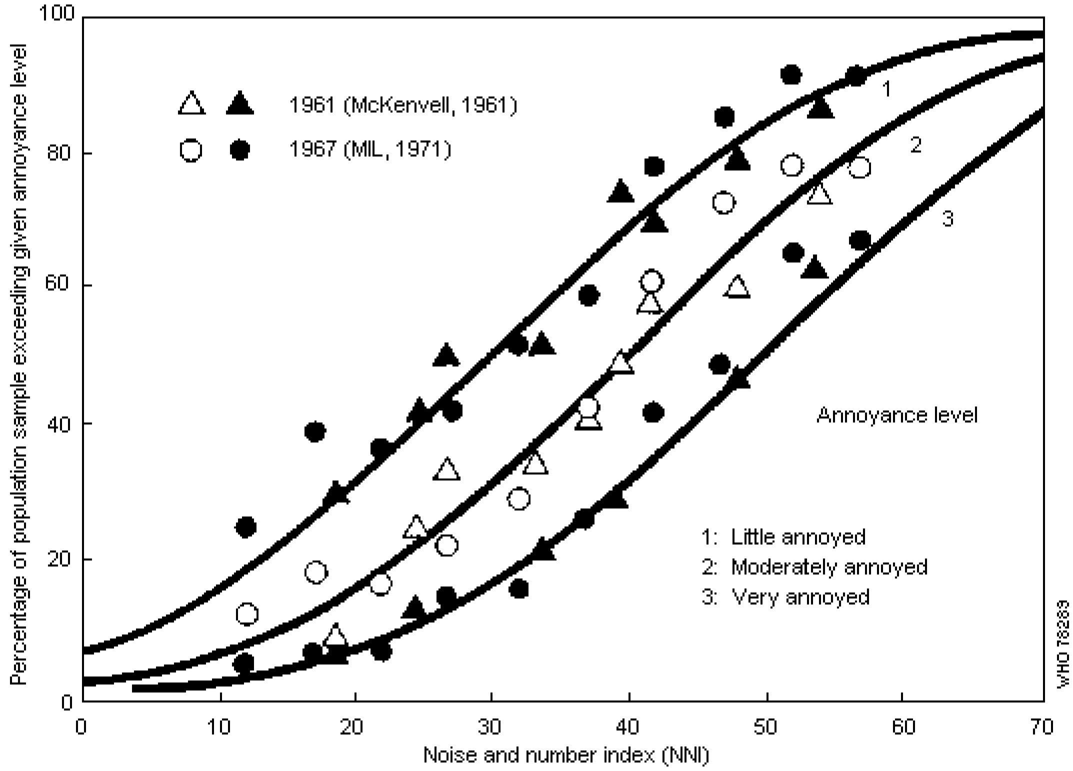

Fig. 9. Normal distribution of annoyance scores (Ollerhead, 1973).

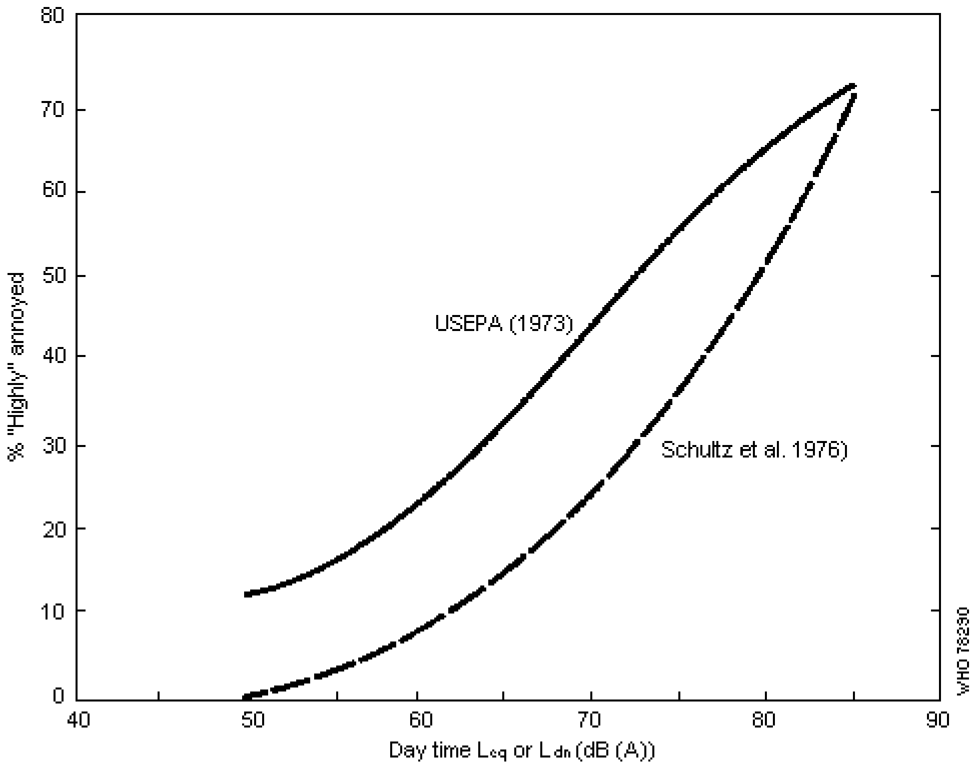

Fig. 10. Percentage of people "highly" annoyed as a function of outdoor noise level. Curves fitted to results from several social surveys in different countries (Schultz et al., 1976; US Environmental Protection Agency, 1973a).

(incorporated in L_{dn}). Despite the disparity associated with the meaning of "highly" annoyed, Fig. 10 indicates that a level of L_{eq} (day-time) or $L_{dn} < 55$ dB(A) will cause relatively little annoyance and may be considered as an ultimate goal for general environmental noise exposure.

3.7.5 Overt reaction

Complaints and other forms of community overt reaction to noise provide important indicators of the existence of a noise problem. On the other hand, because of the greater influence of psychosocial factors, the number of complaints is very poorly correlated with the noise exposure level (McKennell, 1961; TRACOR, 1971).

Several procedures have been suggested for predicting the likelihood of overt reaction to noise exposure taking into account some sociopsychological factors. These include the CNR method already referred to (Stevens et al., 1955) and the British (BSI, 1967) and ISO (ISO, 1971) recommendations. However, in some ways the British and ISO practices may be considered as developments of CNR. In the ISO procedure, the expected community response is divided into five categories ranging from "none" to "very strong" with the descriptions; no observed reaction; sporadic complaints; widespread complaints; threats of community action; and vigorous community action. The likely reaction is specified as a function of the amount by which the rating level exceeds: the criterion value.

Caution must be exercised in the use of such standards, since the evidence upon which they are based is fragmentary; indeed the ISO recommendation admits to only a "rough connexion" between public reaction and noise.

3.8 Effects on Task Performance

The effect of noise on the performance of tasks has mainly been studied in the laboratory but also to some extent, in work situations. Comprehensive reviews of these studies are available (Broadbent, 1957, 1971; Cohen, 1968; Kryter, 1970; Glass & Singer, 1972; Burns, 1973). There have been few detailed studies of noise effects on human productivity under normal living conditions.

In general, when a task involves auditory signals, whether speech or nonspeech, noise at any intensity sufficient to mask or interfere with the perception of these signals may interfere with the performance of the task. When the task does not involve auditory signals, the effects of noise on performance are more difficult to assess. The literature shows that noise can interfere with or enhance performance but that often it does not cause any significant change. A possible explanation of this seems to be the different uses of the term performance. As already mentioned, the most varied forms of reaction (e.g., control activity, rapidity of reaction, learning performance, memory training, intelligence tests) are all defined as performance.

Basically, all performance, whether mental or motor can be adversely affected by noise. This effect is likely to be more severe as the task becomes more difficult and complex and as the duration of the noise exposure increases.

3.8.1 Noise as a distracting stimulus

Noise can act as a distracting stimulus, depending on the meaningfulness of the stimulus and file psychophysiological state of the individual. According to a widely accepted theory in psychology, the human sensory system receives more information than can be analysed by the higher centres. In order to screen out useless information such as noise, the concept of a mental "filter" has been developed (Broadbent 1972). This "filter", however, has the following limitations:

(a) it tends to reject or ignore unchanging signals over a period of time, even though they may be important, as in vigilance tasks;

(b) an individual's state of arousal, stress, or fatigue may hinder the mental filter's ability to discriminate; and

(c) the filter can be overridden by irrelevant stimuli that demand attention because of novelty, intensity, unpredictability, or learned importance.

Thus a novel event, such as the start of an unfamiliar noise, will cause distraction and interfere with many kinds of task. This will be equally true, however, of the sudden stopping of a familiar noise; and, in each case, the effect will disappear once the novelty has worn off. These reaction patterns are well established experimentally (Kryter, 1970; Glass & Singer, 1972).

In 1955, Hebb suggested that changes in stimulation not only initiate appropriate cortical responses but also activate or arouse areas of the cerebral cortex other than those involved in the response. This wider arousal activity originates in the reticular formation, a portion of the central nervous system, and affects the person's psychological state as well as physiological systems.

Too low a level of arousal can mean complete absence of activity and therefore poor performance. On the other hand, too high a level may cause inefficiency through over-reaction to distraction, leading to incorrect responses. Thus, loud noise might increase or decrease task performance depending on the previous state of arousal.

3.8.2 Effects on tasks involving motor or monotonous activities

It appears that steady noise has little, if any, effect upon many tasks, once it has become familiar. Such tasks include tracking or controlling tasks where noise levels are fairly continuous and where average, rather than instantaneous, levels of performance are important (Broadbent, 1957; Kryter, 1970). Many mechanical or repetitive tasks found in factory work would fall into this category. Generally it can be concluded that noise is likely to reduce the accuracy rather than the total quantity of work (Broadbent, 1971).

However, it appears that moderate levels of noise increase arousal during monotonous tasks. McGrath (1963) found that various auditory stimuli at 72 dB improved visual vigilance performance.

3.8.3 Effects on tasks involving mental activities

Studies have occasionally been reported where noise exposure produces a mixture of positive and negative effects on task performance. Woodhead (1964) showed that noise adversely affected tasks involving a combination of memorizing and problem solving. However, when noise was introduced into the calculation phase only, performance was improved. Other studies by Hockey (1970) showed that, sometimes, performance on high-priority aspects of a task could be enhanced while performance on low-priority aspects was diminished by noise. The author found that by introducing a noise stimulus to a visual perception task, centrally-located visual signals were more effectively perceived, whereas peripherally-located signals tended to be ignored. The theory derived from these studies is that noise can increase the tendency to be selectively perceptive. If distraction occurs, this may be particularly harmful, but if attention is concentrated on the task, it may be helpful.

Experiments involving complex mental tasks have shown that there is an increase in mistakes in the presence of intermittent noise stimuli (Glass et al., 1971; Glass & Singer, 1972).

The effects of noise on performance have been reported to depend upon intelligence (Bryan & Colyer, 1973). Under noisy conditions, people with high intelligence showed a decrease in the quality of test performance whereas people with average intelligence showed constant or slightly better performance.

Tasks that have been described in the literature as being particularly affected by noise, even when it has become familiar, include tasks of vigilance, information gathering, and analytical processes. Vigilance activities are not repetitive, do not allow for self-pacing, and demand rapid and accurate decisions. Thus, they are more adversely affected by distraction than many other activities.

There is also some evidence that an individual performing the same task becomes less sensitive to noise, if the rate of arrival of the signals is low, if motivation is reduced, if the individual tested has a low level of anxiety, or if the noise is felt to be under the person's own control rather than imposed upon him. Basically these are "unarousing" conditions (Broadbent, 1971).

Because of the effects on vigilance tasks, and on the accuracy of continuous serial reaction, it has been suggested that accidents would be the most likely indicators of noise effects in industry. Data on this subject are scarce; one study showed a higher accident rate in noisy places (Raytheon Service Co., 1972), and an earlier study showed an increase in errors (Broadbent & Little, 1960).

Various experiments have demonstrated a disruptive effect of noise on learning or information gathering. Wakely (1970) pointed out that noise may interfere by competing for the limited number of channels available for information input. If the system is already overloaded, an individual must take more time to evaluate the usefulness of the intruding stimulus or run the risk of making errors. When tasks are not self-paced, increased errors will result.

It has also been found that high levels of noise interfere with short-term memory tasks (Jerison, 1954). Noise from sonic booms at 120 Pa could interfere with the learning of an eye/hand coordination skill without impairing the accuracy of the task (Lukas, et al., 1970).

These findings are important in relation to the specification of noise limits for classrooms or offices, where mental work predominates. It is important to differentiate between communication masking effects on the one hand, and the disturbance of concentration caused by noise on the other. In general, students in classrooms designed to meet the speech criteria discussed earlier would not have problems with interference in learning and other mental work. Although it may be tentatively concluded that complex tasks involving mental activity such as concentration, perception, or the intake of important information are more likely to be affected than those that only require predictable motor actions, additional experimental and field data are required.

Noise of short or variable duration and impulsive noise tend to produce short residual effects on noise-sensitive tasks. Woodhead (1959) found that a one-second noise burst could have residual effects on performance of from 15 to 30 seconds. She also found that simulated sonic booms of 80-250 Pa produced residual disruptive effects (Woodhead 1969). Similar results were reported from an experiment with real sonic booms ranging from 40-260 Pa (Rylander et al., 1972b). The disruptive, effects seen in these experiments could be the result of a startle response (as opposed to the orienting response). These startle effects differ from the distraction effect mentioned earlier, by being more resistant to habituation.

4. EVALUATION OF HEALTH RISKS TO MAN FROM EXPOSURE TO NOISE

4.1 Environmental Noise

People are exposed to many kinds of environmental noise that can be distinguished according to the source of the noise or to its physical characteristics such as intensity, frequency spectrum, and variations in time. There is wide agreement on both the instrumentation requirements and the procedures for the physical measurement and description of such noise. International organizations have provided standards for measurement, which continue to be revised and supplemented as knowledge improves. These standards and up to date technical publications can be used as a basis for reliable predictions of likely environmental noise in various circumstances.

Description of noise sources, characterization of noise emissions, and understanding of basic noise generation mechanisms are also relatively satisfactory.

Difficulties arise in describing the human noise dose. There are two major problems associated with the description of a person's cumulative noise exposure over a period of time. During each day, a person is exposed to a variety of environmental noises at home, in the general environment, and at work. This pattern might change from day to day or year to year. The noise exposure pattern and dose change with age, lifestyle, occupation, and many other factors. Thus, estimates of total noise exposure are always very crude approximations.

From a practical point of view, even if the noise exposure history of an individual could be recorded, the data would have to be reduced to a few exposure variables that could be correlated with the subjective effects caused by that exposure.

Much noise-related research is focused upon the establishment of valid dose description. Because of the importance of correlating the various biological effects of noise with the appropriate physical characteristics of the environmental noise, many attempts to condense the exposure history into single numerical descriptors have been made and alternative techniques will continue to be explored. The increasing use of personal noise dosimeters in industry might provide valuable information on the integrated noise dose experienced by people over long periods. However, the problem remains as to which variables of the environmental noise are important and can be suitably reduced to a single number.

It is important to keep these basic concepts in mind, when the dose-response relationships required for the specification of practical exposure guidelines or noise limits are constructed. These relationships are complex and in some instances can only be deduced from data gathered over a number of decades. Thus, characterizations of the exposure variables as well as of the responses, are frequently

rough approximations. Although it is possible and necessary for the solution of specific problems to refine these relationships, the consequent complications might hinder the development of a noise abatement programme or the achievement of environmental health goals. For this reason, the relatively simple and convenient equivalent continuous sound level, L_{eq} in dB(A), can be used as a basic, common measure of environmental noise, and health criteria should be related to this index, whenever possible.

The period over which L_{eq} is averaged will depend upon specific applications. For describing the 24-h general noise environment, a weighted average such as the day-night average sound level (L_{dn}) may be used to take account of sensitive periods of the day or night.

The convenience of combining different acoustic characteristics of various noises into a single index is evident. This principle has, however, been questioned both for industrial and environmental noises, particularly when the number of events is low and there are large differences between peak and background noise levels. The individual, identifiable influences of different acoustic components in the cause-and-effect chain should be recognized, particularly in research, and the limitations of the equal energy principle should be borne in mind when guidelines are established.

4.2 Population Affected

High noise levels are a feature of several work environments and extensive efforts are necessary to reduce the incidence of occupational deafness. Noise-induced hearing loss occupies a leading place among occupational diseases, and, in all nations, industrial noise abatement and hearing protection programmes should be a matter of priority for bodies that are responsible for the health of the working population.

People who work in less noisy places may run a negligible risk of hearing impairment but could suffer from other noise-induced ailments derived from stress or chronic fatigue. Noise causes difficulties in communication and in work conditions in a wide variety of occupations.

People are exposed to nonoccupational noise during leisure and rest hours. Environmental noise may interfere with, and affect the performance of leisure-time activities, causing general annoyance. Leisure activities may also introduce a hearing hazard, e.g., rifle shooting, loud music in discotheques etc. Nonoccupational noise may prevent normal performance at work and may, over a period of time, lead to health impairment. For the same reason, people with reduced adaptability or reserve capacity such as the sick, the aged, people with impaired sleeping functions, or those who are subject to other environmental strains may be particularly vulnerable and in need of special protection against excessive noise.

4.3 Specific Health Criteria

4.3.1 Physical injury

Exposure to SPLs exceeding 140 dB, even for short periods, involves a risk of morphological damage to the ear, usually consisting of rupture of the tympanic membrane.

Aural discomfort is experienced at SPLs above 100-110 dB and acute pain begins at SPLs above approximately 130 dB. This must be considered as a warning signal of incipient damage and an urgent requirement for preventive or protective measures. Painful sound intensities are far above those that cause hearing loss, when regularly experienced for several hours per day, and even brief exposure to such levels should be avoided.

4.3.2 Hearing loss

Long-term occupational exposure to high level noise can result in a gradual loss of hearing. The time scale of this process varies considerably depending on individual susceptibility, noise intensity, spectrum, and exposure pattern, and many other factors not yet fully understood. In some people, severe damage may be caused in the first few months; in others, hearing loss can develop gradually over the whole period of a working life. Combined with presbyacusis, it can lead to severe handicap and disability that is not amenable to treatment.

In spite of considerable research, no method has yet been found to identify individuals who may be particularly susceptible to noise-induced hearing loss. For this reason, it is extremely important to avoid exposure of workers to noise levels that are known to involve a risk of permanent hearing loss. This should be achieved by effective noise-control measures. If this is not possible, then workers should be protected by a hearing conservation programme following recognized occupational health standards. Early detection of incipient hearing impairment is most important in the prevention of progressive deafness. Since the earliest loss of auditory acuity usually occurs at frequencies in the region of 4000 Hz, loss at this frequency is the most sensitive indicator of incipient damage. Losses at lower frequencies usually indicate progressive damage. NITTS is occasionally used to predict NIPTS, but there is little agreement on the validity of this practice.

Recent research and analysis of most of the available data has provided a statistical basis for predicting the degree of hearing loss likely to be experienced by people exposed to steady noise during an 8-h working day, for periods up to 40 years. The risk is negligible for L_{eq} (8 h) $\leq$ 75 dB(A). Above this limit, the risk of noise-induced permanent hearing loss increases with increase in noise level. If the significant noise exposures are concentrated over shorter periods during the day, this basic criterion implies that the risk

would also be negligible with a 4-h exposure to 78 dB(A), a 2-h exposure to 81 dB(A), or a 1-h exposure to 84 dB(A). Conversely, if additional exposure occurs outside the 8 working hours, for example as a result of commuting to work or leisure activities, the limit of safe exposure would be more adequately expressed as an L_{eq} of 70 dB(A) averaged over a 24-h day.

Any comparison of noise exposures with recommended exposure limits should be based on measurements taken at the worker's ear under actual working conditions. Noise levels should be monitored at periodic intervals. For fluctuating exposures, the L_{eq} for the total workday should be determined. If the noise contains impulsive components, the peak pressure, duration, and repetition rate of the impulses must be compared with separate limits, in addition to those just stated, in order to assure a safe level of noise in an environment.

Based on available risk tables, legislative provisions or recommended practices adopted by several countries specify occupational exposure limits in the range of L_{eq} (8-h) = 85 dB(A) $\pm$ 5 dB(A), with an increasing tendency to aim at lower limits. L_{eq} (8 h) = 75 dB(A) can probably be considered as the limit below which there is little or no risk of permanent hearing damage and no necessity for protective measures. Hearing conservation programmes should be adopted in the case of routine occupational exposure to higher levels.

4.3.3 Nonspecific health effects

The nonauditory health effects of noise are complex and not yet fully understood. Laboratory and field studies have revealed a variety of physiological reactions such as changes in heart rate, blood pressure and peripheral resistance, and vestibular reactions. Many of these noise-induced reactions are nonspecific and are usually referred to as stress reactions.

Much of the information is based upon animal experiments, many of which have been performed on rodents. These animals differ considerably from man in their reactions to noise. Thus, it is very difficult to assess the significance of such experiments for human health and wellbeing.

The possibility cannot be ignored that short-term, and long-term, noise-induced stress, particularly with insufficient time for recovery between periods of work, could increase susceptibility to other work-related diseases, degenerative diseases, and nonspecific diseases that are regarded as consequences of chronic general stress. People normally exposed to hazardous stress during work and sensitive groups such as the sick, the elderly, pregnant women, and children may be particularly at risk. However, although the reported observations are considered by many to be indications of potential danger to health and have been suspected as predecessors of pathological changes, research

on this subject has not yielded any positive evidence, so far, that disease is caused or aggravated by noise exposure, insufficient to cause hearing impairment. More epidemiological and animal studies are required to clarify the nature of nonauditory health risks associated with noise.

4.3.4 Interference effects

Frequent or severe interruption of various human activities by noise must affect human health and well-being to various degrees. The main interference effects studied have been those associated with sleep, communication, and with task performance.

The probability that sleep will be disturbed by a particular noise depends on a number of factors including the interference criterion used (e.g., awakening or EEG changes), the stage of sleep, the time of night, the noise stimulus, and adaptation to the noise. Individual differences in sensitivity are marked. Although systematically collected field data on sleep disturbance are limited, there is some consensus of opinion that night-time noise levels of 35 dB(A) L_{eq} or less will not interfere with the restorative process of sleep.

The masking effect of noise on speech communication is well understood and methods are available to calculate word, message, and sentence intelligibility as a function of the characteristics of the masking noise. These methods are widely used in the design of rooms and the specification of background noise from external and internal noise sources to satisfy communication requirements. Various acoustic engineering reference works give background noise limits for various types of rooms such as offices, conference rooms, classrooms, and auditoria. However, it has been noted that communication requirements in industrial situations frequently do not receive adequate attention, particularly with reference to the accident risk. To guarantee satisfactory (100%) speech intelligibility in private homes, indoor noise levels of less than 45 dB(A) L_{eq}, are generally required.

Task performance interference is complex and depends to a large extent on the nature of the task. It is primarily an occupational problem and there is little evidence that it is significant in situations where noise does not interfere with communication or does not pose a risk of hearing impairment.

Concentration and mental work of all kinds are often assumed to require a quiet environment. However, there are no reliable field data to confirm this and it seems likely that the disruptiveness of noise depends more upon the information it conveys than upon its level. No generalized criteria relating task efficiency and noise level or duration can be stated.

4.4 General Health, Welfare, and Annoyance Criteria

The health criteria and exposure limits described in section 4.3 provide guidance for the reduction or avoidance of noise-induced effects under specific circumstances. However, they are of limited use for decisions concerning the environment of the general population.

The results of social surveys on the extent of annoyance can be used as guidance concerning the relation between different types of outdoor noise and the extent of dissatisfaction or annoyance in the community. Available data indicate that daytime noise levels of less than 50 dB(A) L_{eq} cause little or no serious annoyance in the community. With noise at this level, other factors such as transport needs, road safety, and the availability of schools are likely to cause more concern than occasional noise disturbances. Based on this likelihood, daytime noise limits in the region of 55 dB(A) L_{eq} might be considered as a general environmental health goal for outdoor noise levels in residential areas. However, technological and economic limitations may make this goal impracticable, at present, for many existing urban areas.

5. NOISE CONTROL AND HEALTH PROTECTION

Noise levels in the environment can be reduced or limited by emission control, which should be aimed at noise sources contributing most to the effects experienced by man. The relevant sources are not always those that contribute most to the total dose from an acoustic point of view. Environmental noise control can be implemented by the use of environmental noise standards. These standards can be met by control at the source, by limiting the number of sources, by the physical separation of noise sources and people, and by changes in work methods. The technological background and information on dose-response relationships for both environmental and industrial noise are sufficient to allow appropriate action to be taken and to predict the effectiveness of noise abatement programmes.

The control of environmental noise requires the participation of local health authorities and interested organisations. As problems caused by environmental noise, such as aircraft and traffic noise, are mostly due to mistakes in planning policies, it may be difficult to put a sufficiently stringent noise abatement programme into action in built-up areas. Care should therefore be taken that planning programmes include all long-term noise control measures which may be necessary.

Action concerning specific sources of noise such as cars or aircraft, often has to be taken at an international level using long-term planning strategy as a background.

5.1 Noise Control at Source

The most efficient action against excessive noise is the reduction of the noise at source. In industry, noise control technology is available for solving many typical noise problems arising from the use of machinery. Usually the most effective approach is to redesign or replace noisy equipment. If this is not possible, significant reductions in noise levels can be achieved by structural and mechanical modifications, or the use of mufflers, vibration isolators, and noise protection enclosures (Beranek, 1971; Mags, 1978).

5.2 Control of Sound Transmission

A further reduction in noise can be obtained by increasing the distance between people and the noise source. For example, this can be achieved in the community by planning the location of transport facilities and, in industry, by the careful selection of work sites. Sound transmission can also be controlled by the use of partitions or barriers, e.g., for traffic noise along streets or, in industry, around particularly noisy or disturbing machinery. Reverberent noise levels can be reduced by sound-absorbing materials. The techniques for the control of sound propagation and transmission are well developed (Beranek 1971).

5.3 Reduction in Length of Exposure

A reduction in the length of exposure can be used in industry to supplement the previous measures, if necessary. This may be accomplished by job rotation or by restricting the operation of the noise source.

5.4 Education of Workers

It is vitally important that persons who face a risk of exposure to potentially hazardous noise levels should be educated in: (a) the possible consequences of excessive noise exposure; (b) the means of protection; and (c) the limitations of these means (e.g. improper use of ear-muffs).

5.5 Ear Protection

If it is absolutely impossible to reduce noise to a harmless level then some form of ear protection, i.e., ear-plugs, ear-muffs, and/or helmets, should be used. They should also be used during infrequent exposures that may not be part of a worker's normal routine. When the use of personal ear protection is necessary, attention must be given to: the effectiveness of specific types and models of protectors; instruction in their proper use; hygiene, discomfort, allergic reactions, and other medical problems that may arise through their use; and the means for ensuring proper, diligent, and effective use. In this connexion, it is important to provide quiet facilities and the opportunity for the temporary removal of ear protectors by those working in high noise levels. It should be noted that the commonly held view that ear protectors interfere with communication is incorrect, at least in continuous, high level noise -- indeed, the reverse is often found to be the case.

5.6 Audiometry

Pre-employment and follow-up audiometric examinations should be included in a hearing conservation programme. They provide opportunities for the detection of persons threatened by the development of NIPTS in order to take preventive action. Audiometric tests are also helpful in monitoring the effectiveness of ear protection and of noise abatement programmes. The examinations should be performed by qualified technicians under the supervision of physicians or health officials. It is usually accepted that the measurement of pure-tone air conduction thresholds is sufficient for this purpose. However, it should be stressed that periodical checks on equipment calibration, background noise levels in testing rooms, and audiometric procedures are necessary to minimize measurement errors. The frequency of follow-up audiometric tests is, in principle, dictated by the type and level of noise exposure. A general rule for audiometric testing is to wait at least 16 h after the last noise exposure to allow recovery from NITTS.

Whenever noise exposures are such that an unavoidable risk of permanent hearing loss exists, occupational health services should provide for a hearing conservation programme. Such programmes, for which detailed guidelines exist, contain 3 elements: education concerning the hazards of noise; education in the proper use and supervision of the wearing of ear protection; and monitoring audiometry including periodical medical examination, when necessary. Monitoring audiometry, if properly planned and executed, will identify workers at risk from incipient hearing impairment, so that they can be removed from the noisy workplace before irreversible damage is caused.

Since present occupational noise standards in most countries allow a certain risk of permanent hearing loss, a hearing conservation programme is usually highly advisable in addition to the specification of maximum exposure levels. Hearing conservation programmes are considered desirable when 8-h daily exposures exceed 75 dB(A). Present concepts of acceptable risk and economic constraints limit their practical application in most countries to levels around 85 dB(A).

There are data which suggest that exposure to noise during leisure time in certain cases may constitute a risk to hearing in some segments of the general population. Noise from electronic music, discotheques, home power tools, guns, and certain other sports equipment might cause hearing impairment. These hearing losses occur primarily in young people, frequently prior to their occupational exposure. Hazardous noise exposures during leisure time should be controlled through consumer product control, noise labelling of products, environmental noise limits, and public education. Ear protection should be recommended in conjunction with equipment producing hazardous noise levels.

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See Also:
Toxicological Abbreviations