FINAL REPORT

TECHNICAL ASSESSMENT OF UPPER LIMITS ON NOISE IN THE WORKPLACE

APPROVED BY THE
INTERNATIONAL INSTITUTE OF NOISE CONTROL ENGINEERING

Executive Summary

In the 1990s it has become widely recognized that the economic and social costs of high levels of noise in the workplace require significant action to reduce the exposure of workers to noise. Such costs include not only the financial compensation or damages that must be paid, and the reduced enjoyment of everyday life for those with a hearing loss, but also less quantifiable factors such as reduced productivity, increased stress, disturbed speech communication and risk of accidents for a large number of workers.

This International INCE Technical Assessment is presented in the form of a report that briefly reviews the extensive scientific and epidemiological evidence relating exposure to noise, including impulsive noise, and risk of hearing damage, and discusses the factors that are relevant to legislation. The basic features of existing legislation from many jurisdictions are tabulated. The setting of specific limits on exposure to noise is a political decision, with results that vary between jurisdictions depending on economic and sociological factors. It is however also important that regulations be harmonized internationally. The report therefore makes specific recommendations for legislation in the areas of daily exposure levels normalized to 8 hours, limitation of peak sound pressure levels for short-duration (impulsive) noises, acceptable sound pressure level changes for longer or shorter daily exposure periods, sound absorption in working areas, the inclusion of sound output requirements in purchase specifications for new machinery, the use of personal hearing protection, and audiometric testing.

Specific recommendations are:

1. It is desirable for jurisdictions without regulations, or with currently higher limits, to set a limit on the level of exposure over a workshift, A-weighted and normalized to 8 hours, of 85 dB as soon as may be possible given the particular economic and sociological factors that are pertinent;
2. This exposure level should include the contribution from all sounds that are present including short-term, high-intensity sounds. If such sounds are further limited in regulations to a maximum sound pressure level, then regulations should set a limit of 140 dB for C-weighted peak sound pressure level;
3. An exchange rate of 3 dB per doubling or halving of exposure time should be used. This exchange rate is implicit when the exposure level is stated in terms of 8-hour-average sound pressure level;
4. Efforts should be made to reduce levels of noise in the workplace to the lowest economically and technologically reasonable values, even when there may be no risk of long-term damage to hearing.

Such action can reduce other negative effects of noise such as reduced productivity, stress and disturbed speech communication;

5. At the design stage of any new installation, consideration should be given to sound and vibration isolation between noisier and quieter areas of activity. Rooms normally occupied by people should have a significant amount of acoustical absorption in order to reduce the spatial distribution of sound;
6. The purchase specifications for all new and replacement machinery should contain clauses specifying the maximum emission sound power level and emission sound pressure level at the operator's position when the machinery is operating;
7. A long-term noise control program should be established and implemented at each workplace where the level of the daily exposure, normalized to 8 hours, exceeds 85 dB. This program should be reassessed periodically in order to exploit advances in noise-control technology;
8. The use of personal hearing protection, either earplugs or other hearing protection devices, should be encouraged when engineering and other noise control measures are unable to reduce the daily, normalized-to-8-hours, A-weighted exposure level of workers to 85 dB. The use of hearing protection devices should be mandatory when the exposure level is over 90 dB; and
9. All employers should conduct audiometric testing of workers exposed to more than 85 dB at least every three years, or at shorter intervals depending on current exposure levels and past history of the individual worker. Records of the results of the audiometric tests should be preserved in the employee's permanent file.

Foreword

The International Institute of Noise Control Engineering (I-INCE) General Assembly on 1992 July 22 approved formation of a Working Party to review current knowledge and practice concerning *Upper Noise Levels in the Workplace*. At that time, all Member Societies of I-INCE were invited to nominate a representative to serve as a member of the Working Party and to contribute information.

Nine Member Societies volunteered to participate. Their position papers covered existing legislation, compensation practices, typical levels of industrial noise, programs to enforce regulations and their effectiveness, and future plans and expectations in the countries of the participants. This information was compiled into an initial draft report that was reviewed during a meeting of the Working Party in Leuven, Belgium, 1993 August 23, and reported during INTER-NOISE 93. After several further drafts, a major revision was presented during INTER-NOISE 94 in Yokohama, Japan, and with minor changes was published in the 1994 December issue of *Noise/News International* for wider discussion and vote by Member Societies. This report embodies a number of the suggestions that accompanied the votes of nineteen Member Societies of International INCE.

This report is not an International or National Standard. It is a brief review of the scientific, engineering and legislative aspects of noise limits in the workplace, coupled with recommendations to assist managers or officials in their policy decisions.

The charge to the I-INCE Working Party was to examine the technical factors that influence the selection of upper noise limits in the workplace as follows:

1. Identify the development of regulations specifying upper limits on noise in the workplace since 1950;
2. Concentrate on the two most widely specified limits of 85 dB and 90 dB for eight-hour-average A-weighted sound pressure levels, as the quantity and numerical limits with the greatest degree of acceptance in the noise control engineering community;
3. Examine the scientific basis for the two trading relationships (time-average A-weighted sound pressure level versus duration of exposure) most commonly used, 3 dB and 5 dB per doubling or halving of the duration, and recommend the one that is appropriate for regulatory purposes;

4. Make recommendations for the content of regulations which include an upper limit on exposure level, a trading relationship between sound pressure level and duration of exposure, and a noise measurement methodology; and
5. Make recommendations for measures to be implemented if noise limits are exceeded; for example, noise measurements and noise emission declaration for new machinery, sound attenuation in workplaces, implementation of a noise control program, or the wearing of hearing protection.

Each member of the Working Party that prepared this report represents a different Member Society that supports the International Institute of Noise Control Engineering; in addition there was a Special Adviser and a Convener. Countries and members of the Working Party were as follows:

Convener: Tony F. W. Embleton

Australia: Bruce Gibson-Wilde
Brazil: Jules G. Slama
Canada: Edgar A. G. Shaw
France: René Gamba
Germany: Hans Lazarus
Hungary: Peregrin Lazlo Timar
New Zealand: George Bellhouse
USA (ASA): W. Dixon Ward
USA (INCE/USA): Stephen I. Roth
Special Advisor: Alice H. Suter

Background

This 1992 July 22 initiative of the International Institute of Noise Control Engineering (I-INCE) deals with the effects of upper noise limits for individuals in their working environments. It concerns the potential of prolonged exposure to high levels of noise to induce hearing loss in those exposed to the noise. This initiative is not primarily concerned with sound levels in the workplace that are so low that the chances of causing noise-induced temporary or permanent hearing threshold shift are insignificant. However it should be noted that countries of the European Union and some other jurisdictions set lower limits than discussed in this report for work involving mental concentration or frequent spoken communication.

Since workplace noise regulations were first introduced in the 1950s, there have been many proposals that the upper limits should be significantly lowered. But this increased stringency has generally not happened because the progressive reduction of noise limits has low legislative priority and budget in most jurisdictions once regulations are in place. Furthermore, there is usually a widespread lack of effective enforcement with small economic penalties on employers who ignore the regulations.

This report has been approved for publication by a substantial consensus of the Member Societies of International INCE. Only one negative vote, that of INCE/USA, remains outstanding. The reasons that INCE/USA gives for its negative vote are to be found in the Annex to the report on page 216.

Report by the International Institute of Noise Control Engineering Working Party on "Upper Limits of Noise in the Workplace"

Tony F.W. Embleton
Convenor of the Working Party
P.O. Box 786, Nobleton, Ontario,
Canada L0G 1N0

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84, 62.1,67.1, 67.4

Introduction

The primary goal of this report is to contribute to reducing the risk and magnitude of long-term hearing damage to a practical minimum for those people habitually exposed to noise in the workplace. A secondary result of reducing noise in the workplace is likely to be some increase in worker safety due to enhanced ability to hear warning signals, and reduced stress on the job. The regulations, and terms of financial compensation for loss of hearing in several industrialized countries are summarized as examples of current practice, to show their overall similarities but also their sometimes considerable differences in detail. It is hoped that this summary and resulting recommendations may eventually promote international uniformity, and encourage jurisdictions that currently do not control noise in the workplace to enact regulations, by showing what is generally considered by legislators to be socially desirable and economically reasonable in other countries.

Many countries have introduced regulations that set upper limits on noise in the workplace. The European Union has taken steps to coordinate the setting of upper noise limits, and most countries in Europe have already adopted these uniform limits. There is general agreement in Europe, in some non-European countries, and in most scientific communities, that the methods defined in International Standard ISO 1999:1990, "Acoustics — Determination of occupational noise exposure and estimation of noise-induced hearing impairment," are valid[1] and should be used by regulatory bodies for guidance in setting upper limits. That International Standard contains a disclaimer that states: "The selection of maximum tolerable or maximum permissible noise exposures ... requires consideration of ethical, social, economic and political factors not amenable to international standardization. Individual countries differ in their interpretation of these factors and these factors are therefore considered outside the scope of this International Standard."

In most industrially advanced countries, there are few people who question the need for workplace noise limits, but the commercial and financial costs to comply are often cited as reasons for non-compliance. The administrative difficulties and costs of effective and uniform enforcement of regulations are also a deterrent to those who might otherwise wish to reduce the level of noise. These are valid concerns, and it is important to present the technical basis for the establishment of upper noise limits in a manner as independent as possible of non-technical factors that influence the selection. This I-INCE review of current regulations does however illustrate what legislators have considered to be suitable national goals, given each country's particular mix of "ethical, social, economic and political factors."

There are overall similarities in factors that are regulated in each country, but differences in the noise limits set (see Table 1). For example, most countries have an exposure limit of 85 dB (A-weighted, 8-hour average sound pressure level), though Argentina, India, Japan, and Uruguay have a limit of 90 dB. The US has a time-weighted average of 90 dB. The allowed change in sound pressure level for a doubling or halving of exposure time, often called the exchange rate, is generally 3 dB, though Brazil, Chile, Israel and USA allow a 5-dB exchange rate.

Exposure to impulsive sounds is treated separately from equivalent continuous exposure for eight hours in most jurisdictions, with a separate limit set for the peak sound pressure level of individual events. The maximum level permitted regardless of duration is expressed in different ways in different countries but is generally in the range of 115 dB (A-weighted, Fast) to 140 dB (C-weighted, peak). In some regulations, C-weighted, and in others flat-weighted or unweighted peak sound levels are specified for the same purpose, namely as the limit for impulsive events. Some experts argue that C weighting is preferable because it is precisely defined in Standards and hence leads to more repeatable measurements, while others consider that flat or unweighted peak levels are more protective of a worker because a wider range of sound frequencies may be included even though there is no standardization of the Flat frequency response or the tolerances around the manufacturer's design goal.

Most countries require certain engineering and administrative controls to be implemented when average sound pressure levels during a work period exceed a certain limit. These controls take several forms but include such requirements as specifications for the acoustical performance of new machinery, mandatory audiometric testing programs, adjustment of work schedules to reduce the duration of exposure, or the use of hearing protection.

Table 1. Some features of legislation in various countries.*					
Country (Jurisdiction)	8-hour average A-weighted sound pressure level (dB)	Exchange rate (dB)	8h-average A-wtd limit for engineering or administrative controls (dB)	8-h-average A-wtd limit for monitoring hearing (dB)	Upper limit for peak sound pressure level (dB)
Argentina	90	3			110 A Slow
Australia (varies by State)	85	3	85	85	140 unwgted peak
Austria (a), (c)	85		90		
Brazil	85	5	90, no exposure > 115 if no protection, no time limit	85	130 unwgted peak or 115 A Slow
Canada (Federal) (ON, PQ, NB) (Alta, NS, NF) (BC)	87 90 85 90	3 5 5 3	87 90 85 90	84 85 (b)	140 C peak
Chile	85	5			140 unwgted peak or 115 A Slow
China	70-90	3			115 A slow
Finland (c)	85	3	90		
France (c)	85	3	90	85	135 C peak
Germany (c), (d)	85	3	90	85	140 C peak
Hungary	85	3	90		140 C peak or 125 A Slow
India	90				140 A peak
Israel	85	5			140 C peak or 115 A Slow
Italy (c)	85	3	90	85	140 C peak
Japan	90		85 hearing protection mandatory at 90	85	
Netherlands (c)	85	3	90	80	140 C peak
New Zealand	85	3	85	85	140 unwgted peak
Norway	85	3		80	110 A Slow
Poland	85	3			135 C peak or 115 A Slow
Spain (c)	85	3	90	80	140 C peak
Sweden (c)	85	3	90	80	140 C peak or 115 A Fast
Switzerland	85 or 87	3	85	85	140 C peak or 125 ASEL
United Kingdom	85	3	90	85	140 C peak
USA (e) USA (Army and Air Force)	90 (TWA) 85	5 3	90	85 85	140 C peak or 115 A Slow 140 C peak
Uruguay	90	3			110 A Slow
This Report Recommends	85 for 8-hour normalized exposure level limit	3	85, see also text under recommended engineering controls	on hiring, and at intervals thereafter, see text under audiometric programs	140 C peak

See the notes to the table on the following page.

*	Information for Austria, Japan, Poland, and Switzerland was provided directly by these Member Societies of I-INCE. For other countries not represented by Member Societies participating in the Working Party the information is taken with permission from Ref. 15.
(a)	Austria also proposes 85 dB (AU-weighted according to IEC 1012) as a limit for high frequency noise, and a separate limit for low frequency noise varying inversely as the logarithm of frequency.
(b)	A more complex situation is simplified to fit this tabulation.
(c)	All countries of the European Union require the declaration of emission sound power levels of machinery, the use of the quietest machinery where reasonably possible, and reduced reflection of noise in the building, regardless of sound pressure or exposure levels. In column 4, the limit for other engineering or administrative controls is 90 dB or 140 dB C-weighted peak. In column 6, the upper limit for sound pressure level is 140dB C-weighted peak (or lower) or 130 dB A-weighted impulse.
(d)	The rating level consists of time-average, A-weighted sound pressure level plus adjustments for tonal character and impulsiveness.
(e)	TWA is Time Weighted Average. The regulations in the USA are unusually complicated. Only A-weighted sound pressure levels of 80 dB or greater are included in the computation of TWA to determine whether or not audiometric testing and noise exposure monitoring are required. A-weighted sound pressure levels less than 90 dB are not included in the computation of TWA when determining the need for engineering controls.

There are major differences in the financial aspects of compensation for hearing damage (see Table 2); in some countries there is a lump-sum payment, in others the payment is related to some fraction of the minimum salary and paid as a supplement, or as a pension paid upon retirement. In most jurisdictions the practice is to allow partial compensation for partial loss of hearing, although in some cases compensation is paid only if there is an actual loss of earning power as a result of the hearing loss that has been suffered.

A factor complicating the effectiveness of regulations in the control of noise-induced hearing loss, and the correlations between exposure to noise and resulting hearing damage, is the choice of instrumentation used for measurement. Workplace sound pressure levels are sometimes monitored using conventional exponential-time-weighting sound level meters but should be measured using integrating sound level meters. (Reference 1, Section 4.1 states that "the average A-weighted sound exposure and/or the noise exposure level normalized to a nominal 8-hour work day shall be either measured directly by sound exposure meters or integrating sound level meters or calculated from sound pressure measurements and exposure time." There is no mention of conventional sound level meters or the use of either F (fast) or S (slow) exponential time weighting.) If instruments with an exponential time weighting are used to determine a time-average or equivalent continuous sound pressure level, then the result is likely to differ from the sound pressure level determined from the time integral of instantaneous squared sound pressures.

Scientific Basis

Two reviews, both with extensive bibliographies, of great relevance to this report were "Occupational Noise Exposure and Noise-Induced Hearing Loss: Scientific Issues, Technical Arguments and Practical Recommendations," by Edgar A. G. Shaw[2], and "The relationship of the exchange rate to noise-induced hearing loss" by Alice H. Suter[3]. The review by Suter has been reprinted, and for many may be more accessible, in *Noise/News International*[4].

The body of scientific knowledge on noise-induced hearing loss is extensive, and has been built up since the early 1950s through the contributions of many researchers worldwide. The amount of hearing loss produced by exposure to noise is a function of many factors that interact in a complicated way that precludes any simple set of rules relating such exposure to hearing loss. These factors include the nature of the sound itself (its sound pressure level and spectral content), and whether it is steady or variable, impulsive, continuous, or intermittent. In this latter situation it is important how long the quiet periods last, and how much quieter they are compared with the noise, in determining the extent to which they may help to reduce the hearing loss caused by exposure to the noise.

The permanent loss of hearing caused by habitual exposure to excessive noise, as occurs on a daily basis over many months or years in the workplace is known as Noise-Induced Permanent Threshold Shift (NIPTS). Although protection against NIPTS is the goal of regulation, it is the form of hearing loss least amenable to direct and controlled scientific investigation, because of the risk of permanent damage to the subjects. The most relevant alternative is to conduct epidemiological studies of NIPTS, but these studies are more difficult to design and evaluate because the use of hearing protection, administrative controls, or quieter machines leads to small sample sizes and subjects having exposure to noise that has changed with time. In some studies from

Table 2. Some features of compensation for loss of hearing in several countries. The values of compensation listed are from information provided in 1994.

Country	Compensation basis
Australia	Generally lump-sum compensation; provisions vary between States and Territories
Brazil	20% of minimum salary (extra pay as compensation for higher level of exposure).
Canada	Varies by province; permanent major loss of hearing in both ears is defined as 20 to 25% of total physical disability. Full or partial payment is made only when earning power is reduced because of hearing loss.
France	Averages 600 000 FF per admitted claim, paid by company (amount depends on wage and degree of disability).
Germany	Paid if loss of earning ability greater than 20%. In 1987 - 88, average pension was DM 6150 per year.
Hungary	Damages are paid as a supplement to earnings. Supplement increases progressively from 8% when degree of hearing impairment is between 16% and 25%, to 30% for impairment of 50% or greater. Paid for only two years if impairment is less than 26%, otherwise continuously.
Japan	Paid on retirement. Amount depends on extent of hearing loss; there must have been exposure to 8-h normalized workplace sound levels greater than 85 dB over a long period of time.
New Zealand	Fine on employer. Maximum compensation is 80% of pay if unable to work plus allowance of up to NZ$40 per week depending on the amount of injury.
USA	Varies by State. For major loss of hearing in both ears payment ranges from USD 12 000 (Colorado and North Dakota) to USD 125 000 (Iowa) and 132 500 (Pennsylvania). Some states pay only for loss due to trauma, not for NIPTS.

earlier years, before the time of widespread preventative measures, the sample sizes may have been adequately large, but the measurement of sound to which the subjects were exposed may have been made with instruments lacking the ability to measure properly short-duration impulsive sounds and lacking the wider range of linear operation of modern instruments.

For these reasons many investigations have employed secondary measures, such as Temporary Threshold Shift Two (TTS_2), or Asymptotic Threshold Shift (ATS). The use of either TTS_2 or ATS rests on the assumption that there is a close relationship between these temporary effects and permanent hearing loss, NIPTS. Evidence to date indicates that the relationship between temporary threshold shift and permanent hearing loss varies considerably between individuals. Suter concluded that temporary threshold shift (TTS) should not be relied upon for predicting the long-term adverse effects of exposure to noise.

Another experimental approach that avoids assumptions about the relationship between temporary and permanent threshold shifts is the use of animal subjects. Much valuable information has been obtained from animal studies concerning damage to hair cells in the inner ear and its relationship to NIPTS. But there are again major assumptions: that the ears of such animals respond in the same way as the human ear to all types of noises, and that the laboratory conditions under which these measurements are made are analogous to real-world human exposures.

Hence the relevance of much of the existing scientific knowledge to long-term exposure of humans to noise in the workplace, and the consequent permanent threshold shift that they may suffer, rests on various assumptions that were not adequately validated as of 1995. The ability to obtain a clear understanding of the relationships involved is made more difficult by the fact that some evidence comes from epidemiological studies of NIPTS, reviewed in References. 2 and 3, and some from controlled studies of TTS. The International Standard ISO 1999:1990[1] is based on evidence from epidemiological studies, hence its relationships between exposure to noise and NIPTS are reliable but apply statistically to groups of people, not to individuals.

A central issue in both scientific work and in legislation is the relation between two or more sounds that produce the same amount of NIPTS when the sounds differ in sound pressure level, duration, and temporal pattern. This relationship has come to be known as the "exchange rate." It is expressed as the number of decibels by which the sound pressure level may be decreased or increased for a doubling or halving of the duration of exposure.

Suter's review suggested: (a) that laboratory studies on both humans and animals generally support a value for the exchange rate of 3 dB rather than 5 dB; (b) that data from a number of field studies also generally support the 3-dB "equal-energy" rule; (c) that some field data from outdoor occupations having intermittent exposures, such as forestry and mining, show less hearing loss than expected when compared with continuous exposure to noise; and (d) that the ameliorative effect of intermittence does not support the use of a 5-dB exchange rate although it might allow an upward adjustment to the maximum exposure limit for certain occupations.

Shaw [Ref. 2, p. 32] analysed many of the same scientific and epidemiological studies and reached conclusions similar to those of Suter. In his words: "It is concluded (a) that for steady, intermittent and varying noise, there is adequate scientific support for the acceptance of the equivalent continuous A-weighted sound pressure level or, in the terminology of ISO/R1999-1984, the 'time integral of the squared, A-weighted sound pressure,' with an appropriate integration period, as the best available measure of sound exposure, (b) that there is at present no scientifically acceptable means of refining this approximate measure, and (c) that there is at present no scientifically acceptable alternative measure of sound exposure. In other words, the 3 dB exchange rate should be accepted and the 5 dB exchange rate firmly rejected."

Individuals almost certainly differ in their susceptibility to noise-induced hearing loss. No single descriptor of the exposure can closely predict the likely NIPTS for an individual, even if all the known complexities associated with the varying nature of the noise, such as its spectral content, sound pressure level and time variations, could be correctly taken into account. Thus a factor that may lead to some confusion, and which should be recognized explicitly in legislation, understood during the process of developing regulations, and in the interpretation of scientific studies, is whether one is dealing with a level of exposure that presents no risk to anyone (or no more than a certain small degree of hearing loss in everyone), or a level of exposure that produces a zero or negligible loss of hearing (or a small degree of noise-induced hearing loss) for the average, or median individual. Obviously a level of exposure that protects everyone is lower than the level that protects the average person.

The International Standard ISO 1999:1990[1] tabulates values of hearing threshold levels for the median individual at six audiometric frequencies, viz. 500, 1000, 2000, 3000, 4000 and 6000 Hz, but does not specify any preferred frequency combinations or weighted combinations to be used for the evaluation of hearing handicap, nor does it specify a hearing threshold level that must be exceeded for a hearing handicap to exist. Selection of these parameters is explicitly left to the user. The use of higher frequencies or lower threshold levels makes the risk appear to be higher, and conversely the use of lower frequencies or higher threshold levels makes the risk appear to be lower.

The status of an individual's hearing is the result of the combination of occupational exposure to noise, exposure to the noises of everyday life, the aging process, and disease processes. This report is primarily concerned with occupational exposures to noise. Reliable separation of the contributions of occupational and non-occupational exposure to any measured hearing loss is difficult. Non-occupational exposure to noise occurs in all human populations as a consequence of such factors as transportation, communications, mechanical or powered tools, and many other sound sources, and is probably increasing with time in all societies. Thus any meaningful screening of subjects for non-occupational exposure, whether to determine the effects of aging alone or to determine the effects of occupational NIPTS, is likely to leave a population that is too small, possibly even zero, for reliable study in most industrial societies.

In Sweden it was recommended that exposure levels should not exceed 75 dB (A-weighted, 8-hour average sound pressure level) [Ref. 5, p. 22 and Ref. 6, p. 203] in the workplace if all risk of NIPTS is to be avoided for all persons. To quote from Ref. 6, page 203: "The Commission of the European Community has established $L_{eq} = 75$ dB as the noise level at which the risks of sustaining hearing damage can be considered negligible (Proposal for a Council Directive, Com/92/560). This level is based on the findings of a number of medical studies. In the proposal, 75 dB is defined as a threshold level. The proposal gives some room for flexibility by defining action levels in the range between 75 and 90 dB and by declaring 90 dB the upper limit." It must be pointed out that there is no general agreement that an 8-hour-average sound level as low as 75 dB is necessary to avoid all risk of long-term hearing loss. Ward [Ref.7, p. 97, Fig. 4.5] showed that the estimated industrial noise-induced permanent threshold shift at 4 kHz, for the average person, decreases to zero at a sound level of about 80 dB.

Published knowledge of the effects of impulsive noises, as may be encountered in industry, is not as extensive as for the other factors mentioned above. However, based on the available information, Shaw reached the conclusion [Ref. 2, page 36]: "... that, in the measurement and specification of sound exposure, no distinction should be made between impulsive noise and other types of noise. Steady, intermittent, varying and impulsive noise should all be included in a comprehensive measurement of 'the time integral of the squared A-weighted sound pressure,' in accordance with ISO/1999-1984."

The published text of the International Standard ISO 1999:1990 makes it clear that the definition of exposure to noise is comprehensive in that it "applies to audio frequency (less than 10 kHz) noise" including "noise which is impulsive in character." While no explicit peak sound pressure level is given, it is stated that the "Use of this International Standard for instantaneous sound pressures exceeding 200 Pa (140 dB relative to 20 μPa) and for higher sound pressures should be recognized as extrapolation." This statement does not set 140 dB as a limit for the maximum sound level to which a person should be exposed, but does suggest that the principle of energy equivalence may not be valid at higher sound pressures.

Factors Relevant to Regulation

A recent survey by the public health authorities in Hungary[8] is typical and concluded that "In the middle of the 1980s we have estimated that the number of workers working in higher noise immission than [8-hour L_{Aeq} = 85 dB] is about 500,000. This is about 30% of the industrial workers, 10% of the wage earners and 5% of the whole population." Authorities in Germany[9] estimated that 15% of the wage earners or working population were exposed to more than 85 dB. In the Netherlands it was estimated that about 18% of industrial workers are exposed to 8-hour-average sound levels between 80 and 85 dB; 22% between 85 and 90 dB; 7% between 90 and 95 dB; and about 2% to more than 95 dB. Hence the fraction of industrial workers exposed to sound pressure levels greater than 85 dB in Hungary and the Netherlands are similar, even though the definition of "industrial" may not be the same in the two countries. If it is decided that the workplace should be without risk of noise-induced hearing loss for anyone due to long-term exposure then "noise levels around L_{eq} = 85 dB are not satisfactory for the working environment... exposure levels of L_{eq} 70 to 75 dB should be the goal for production facilities." [Ref. 6, page 203]. Assuming that this statement in Ref. 6 is correct, then it is clear from existing legislation, see Table 1, that governments have so far set limits on the levels of exposure to noise that allow some chance of hearing damage for a small fraction of the population, but which reduce the amount of damage to a low value, deemed acceptable, for most of the noise-exposed population.

Normalized 8-hour Exposure Level Limit

Most legislation sets a limit of 85 or 90 dB (time-averaged A-weighted sound level, normalized to 8 hours) for the permissible level of exposure to noise in the workplace. Such a limit implicitly accepts that some small fraction of workers will suffer a hearing handicap sufficient to affect adversely some of the communication activities of daily life, as the result of habitual exposure. A level of 85 dB if enforced, compared with a limit of 90 dB, reduces the fraction suffering NIPTS as well as the magnitude of the hearing loss in those that are affected. These greater social benefits are often associated, sometimes erroneously, with greater financial costs to achieve lower average sound pressure levels, at least in terms of initial capital investment. The choice between 85 and 90 dB as the upper limit for daily exposure level is therefore based, for each jurisdiction, on its particular choice of "ethical, social, economic and political factors not amenable to standardization" — the proviso in ISO 1999:1990. The balance between these non-technical, sociological factors often changes over a period of time, and hence there is adequate justification to change the limit for noise exposure level and other requirements in legislation as society's expectations evolve. Several European countries base their national legislation on the EC Directives (the statutory regulations of the European Union). For example in Germany[10], Workshop Ordinance (ArbStättV) Section 15 states that the rating level (A-weighted 8-hour average sound pressure level plus adjustments for impulses and tones) should not exceed 55 dB for mental activities, recreation or sanitary rooms; 70 dB for simple or mainly mechanized office work; or 85 dB for all other activities.

Exchange Rate

No exchange rate between sound pressure level and exposure duration is applicable in all possible situations. Even if all scientific details of this complicated matter were better established than they currently are, simplification is needed for purposes of legislation. This simplification has been achieved by setting a single number, either 3 or 5 dB in most jurisdictions. However, there are several possible choices:

1. The simplest, and almost certainly the best choice, is to leave the exchange rate undefined, at least in explicit terms. This can only be done provided that the legislation very clearly defines a specific limit for the exposure level of a worker, and not the sound pressure level which exists in a workplace. The allowed value then limits the total exposure during a workshift for the individual worker, regardless of whether this exposure is acquired at a lower sound pressure level over a longer period or at a higher sound pressure level for a shorter period. The technical definition of equivalent A-weighted sound pressure level is based on the time-average of the squared instantaneous A-weighted sound pressure over some specified time interval and hence implicitly defines the use of a 3-dB exchange rate. As noted above, Ref. 2 concluded that there is adequate scientific support for the use of the 3-dB exchange rate and, at present, no scientifically acceptable means of refining it even though in some cases it is an approximate measure.
2. Many jurisdictions have regulations that set limits on allowable sound pressure levels in the workplace, and hence these regulations must also set the exchange rate in order to control the duration of exposure for an individual worker. The exchange rate used by most jurisdictions is 3 dB, see Table 1. This value is equivalent to the choice noted in (1) above. An increase in sound pressure level of 3 dB represents a doubling of the sound energy. Thus a 3-dB exchange rate has the simple connotation of an "equal energy rule" wherein exposure to equal amounts of A-weighted sound energy is assumed to produce equal amounts of NIPTS regardless of the time pattern of the exposure. The consensus of the scientific evidence is that 3 dB is the most reasonable exchange rate for daily exposure to noise. Statistically it is also a good approximation for the results of many epidemiological studies relating to intermittent and time-varying exposures[2], even though these studies show considerable spread about any mean curve. If the total exposure is broken by quieter periods spread throughout a workshift that happen to be beneficial, any deviation of the correct exchange rate for the specific situation, from the legislated 3-dB rate, affords extra protection to the worker.
3. The exchange rate used in Brazil, Chile, several Canadian provinces, Israel and the United States (civilian) is 5 dB. This rate assumes that the average level of sound may be allowed to increase by more than 3 dB per halving of exposure time because of the beneficial effects of intermittence. Even if this supposition is valid, the 5-dB exchange rate is not limited to appropriate situations by regulation, and so it is often applied to many situations where it is clearly not appropriate. For example, in many industrial situations the only lengthy "intermittence" involved is the lunch break. Where this happens there is a chance that the worker may be exposed to more risk of hearing damage during the workshift than assumed by the regulations, even when regulations based on the 5-dB exchange rate are being properly followed.
4. In some industrial situations, notably in forestry and mining operations, the duration of each period of exposure to intense sound may be brief and be followed by long periods of low-level sound. In these cases the noise-induced TTS may recover completely and an increase in allowed exposure to noise could be justified. It has been suggested in Ref. 4 that in these few industrial situations an exchange rate of 3 dB should still be used, but that there should be a special allowance of several decibels to account for the long quiet periods that allow recovery of the ear. The amount of the special allowance should be set at a value that depends on the limit set for the maximum allowable daily exposure level or time-averaged sound pressure level; a larger allowance could be justified provided the limit on daily exposure level is lower.

Maximum Upper Limit

For a fraction of the most susceptible individuals even a single burst of intense sound can produce a permanent loss of hearing. Most legislation, see Table 1, limits the peak sound pressure level of impulsive sound, independently of its contribution to the daily 8-hour noise exposure, to a C-weighted peak level of about 140 dB. This upper limit is often stated in different terms such as 130 dB A-weighted impulse or 115 dB A-weighted S (slow exponential time-weighting). These stated limits vary by about 10 dB between different jurisdictions, and also may provide varying degrees of protection for a worker depending on the spectral content of the sound.

Recommendations

The variability in the data from different epidemiological studies results partly from different measurement methods and partly from non-acoustical factors that are not controlled, and are not statistically separable in small sets of data. From a scientific and practical point of view the best course of action would be to provide and adhere to a set of internationally recognized procedures, so that all future data would contribute to a single large epidemiological study known to have been made according to the guidelines.

The primary goal of this report, and its recommendations, is to provide information to minimize the risk of long-term hearing damage for exposed people. This report makes the following recommendations based on current practice in different jurisdictions. Each feature recommended has been considered to be practicable by at least one national jurisdiction and there may be some experience of its usefulness. Much current legislation was enacted several years ago, before the more recent scientific evidence was available, and before it was integrated into current understanding of this complex topic. Even some of the recent standards and technical reviews, including Refs. 1 to 4, rely heavily on epidemiological studies that were conducted some years ago. With more recent knowledge, better instruments, and because socio-economic factors have changed with time in many jurisdictions there is adequate technical and social justification to modify existing regulations if there is the political will to do so.

This report deals only with exposure to noise in the workplace. However, for its recommendations to be valid it is important that exposures outside the workplace, i.e., caused by noisy leisure time activities, should not contribute significantly to hearing loss and should remain low. International Standard ISO 1999:1990[1] states "Only if this non-occupational exposure is negligible compared with the occupational exposure does this International Standard allow prediction of the occurrence of hearing impairment due to occupational noise exposure. Otherwise, it should be used to calculate the hearing impairment to be expected from the combined (occupational plus non-occupational) total daily noise exposure."

Normalized 8-hour Exposure Level Limit

Allowed normalized 8-hour exposure levels in most jurisdictions are either 85 or 90 dB. Such values accept that some small fraction of the exposed population will suffer some degree of permanent hearing loss over a period of many years that is in excess of that resulting from aging. The economic costs, and resulting disruptive social consequences, are probably too great for an 8-hour exposure level less than 85 dB to be achieved in the near future in all situations or in most jurisdictions. Recognizing these non-technical factors, it is therefore recommended that all jurisdictions with a limit for normalized 8-hour average sound pressure level or exposure level in the workplace greater than 85 dB, and those jurisdictions without regulations, should set a limit of 85 dB for normalized 8-hour sound pressure level as soon as may be possible given the particular technical, economic, and sociological factors that are pertinent for that jurisdiction.

Exposure to Impulsive Sounds

The normalized 8-hour exposure level of the previous recommendation should include any contribution from short-term, high-intensity sounds. Such sounds are traditionally also limited in legislation to a maximum sound pressure level. Instruments having adequate capability for accurate measurement should be used, and it is recommended that regulations should set a limit of 140 dB for the C-weighted peak sound pressure level of impulsive sounds. Frequency weightings or time weightings other than C-weighted peak are either less precisely defined in standards or allow measurements to be made that are subject to variability depending on the band-width of the microphone and instruments used, and the spectral content of the sound.

Exchange Rate

Stating the normalized 8-hour exposure level in terms of an 8-hour average sound pressure level implies an exchange rate of 3 dB per halving or doubling of exposure time. This exchange rate is the recommendation of this report for all exposures regardless of the degree of intermittence or time-varying characteristics of the noise. An exchange rate of 3 dB may not always be correct, but when it deviates from the correct value it is likely to afford some extra protection for the hearing of a worker. Furthermore, a 3-dB exchange rate is the easiest to understand and the easiest to implement in the design of a measuring instrument.

Engineering Controls

Efforts should be made to reduce levels of sound in the workplace to the lowest technically and economically reasonable values, even when there is no risk of long-term damage to hearing, see Refs. 10, 12 and 14. It is essential that workers be able to hear alarm signals clearly and to understand spoken warnings. To prevent noise-induced health hazards and performance decreases, different noise limits for different activities are recommended in Refs. 10 and 13.

Two administrative approaches should be required at the design stage of any new installation, or as a retrofit when existing installations are being upgraded or new machinery purchased. These are able to provide long-term reduction of sound pressure levels, see Refs. 12 and 13, and when introduced at the design stage can often be done at significantly reduced cost. Later changes to bring a noisy installation into conformity with relevant regulations are usually more costly and sometimes impractical.

1. Purchase specifications for all new and replacement machinery should contain clauses specifying the maximum emission sound power level and maximum emission sound pressure level allowable at an operator's position when the machinery is operating. The specifications should consider what is said in Ref. 13: "A-weighted immission sound pressure levels at the work stations of a machine can be about 5 to 15 dB higher than the noise emission values declared, due to noise from similar neighboring machines, workroom reverberation and operating conditions different from those for which the noise declaration was made." When the manufacturer cannot fulfill these specifications there should be a noise declaration as specified in regulations or standards[11, 17] so that the purchaser can consider additional noise control measures. Even if the manufacturer is able to meet these specifications, sound levels generated by the machinery should be provided to the purchaser when available.
2. The acoustical design of a building should provide for sound and vibration isolation between noisier and quieter areas of activity. Machinery and equipment that is relatively noisy, especially if it does not require the presence of an operator but only infrequent maintenance, should be separated from the main production areas and offices. Rooms normally occupied by people should have a significant amount of attenuation of the spatial distribution of sound, which can be achieved by acoustical absorption located on walls and ceilings (even in busy areas) and using screens, see Ref. 13.

A Noise Control Program

A long-term noise control program should be established and implemented. This program should include the measurement and assessment of sound pressure levels in the workplace, measurement of the exposure levels of individual workers (or a statistically valid sample if the number of similarly exposed workers is large), and the identification of all significant sound sources. Noise reduction measures should be selected when appropriate, carried out, and verified for effectiveness.

Hearing Protection

Efforts to reduce levels of noise in the workplace, by the use of engineering controls of the kind described above, are sometimes unable to reduce normalized 8-hour-average exposure levels to 85 dB or less. Some further reduction in the risk of hearing damage can usually be achieved by the use of personal hearing protection devices, such as ear covers (ear muffs) or ear plugs. Their effectiveness depends on careful fitting to avoid air leaks. Other factors to be considered are the need for training in the timely use, proper fitting, and hygienic care of these devices, and in some cases the reduced audibility of warning signals. It is recommended that personal hearing protection devices be provided when the normalized 8-hour-average A-weighted exposure level exceeds 85 dB. Use of these devices should be required when the daily exposure level exceeds 90 dB or when C-weighted peak sound pressure levels exceed 130 dB. This recommendation is already included in a Directive of the European Community and is followed in Japan and certain other countries.

Audiometric Testing Programs

In many countries, prudent employers already require pre-placement audiometric testing at the time of hiring a new worker. This action serves at least two purposes: (a) it provides a baseline record for the new workplace of hearing levels against which future audiograms can be compared, and provides an employer and new employee with the earliest possible warning of existing hearing damage; and (b) it is likely to provide some legal protection for an employer against later claims of hearing loss, possibly incurred before hiring, when the current workplace is in fact safe. All employers should conduct audiometric testing at intervals that depend on current exposure levels and the past history of the individual worker.

European Directives on noise control in the workplace[14] require certain actions to be taken when limits on exposure to noise are exceeded. These include audiometric testing and the wearing of hearing protection. For example in Germany[10], testing is conducted 12 months after an initial test on hiring, and then every 60 months if the normalized 8-hour average exposure level is about 85 to 90 dB, and every 30 months at exposure levels of 90 dB or greater. In Hungary [Ref. 8], testing is conducted every 48 months for exposure levels of 85 to 95 dB, every 24 months for exposure levels of 95 to 105 dB, every 12 months for exposure levels of 105 to 115 dB, and every 6 months for exposure levels above 115 dB. In Japan[16], audiometric testing is conducted at the time of employment, at times of relocation, periodically during employment (at least once every three years), and when employment ceases.

It is recommended that the hearing level of workers should be measured at least every three years, and at shorter intervals when normalized eight-hour average exposure levels exceed 85 dB or for workers with prior histories of hearing problems. Records of the results of each audiometric test should be preserved in the employee's permanent employment file.

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Appendix

For clarity, some measures of sound used in this report are defined as follows (see for example ANSI S1.1—1994 "American National Standard Acoustical Terminology"):

1. **peak sound pressure.** Greatest absolute instantaneous sound pressure within a specified time interval. Unit, pascal (Pa). Note — peak sound pressure may be measured with a standardized frequency weighting.
2. **peak sound pressure level, peak frequency-weighted sound pressure level.** Level of peak sound pressure with stated frequency weighting within a stated time interval.
3. **sound (noise) exposure level.** Ten times the logarithm to the base ten of the ratio of the time integral of squared instantaneous A-weighted sound pressure, over a stated time interval or event, to the product of the squared reference sound pressure of 20 micropascals and reference duration of one second. The frequency weighting and reference duration may be otherwise if stated explicitly.
4. **time-average sound level, equivalent continuous sound pressure level.** Ten times the logarithm to the base ten of the ratio of the mean square of the instantaneous A-weighted sound pressure, during a stated time interval, to the square of the standard reference sound pressure.
5. **8-hour-average sound level.** Time-average sound level when the time interval is explicitly stated to be 8 hours, viz. the nominal duration of a work shift.
6. **normalized 8-hour-average exposure level.** For durations of exposure to noise that are either longer or shorter than 8 hours, the level of the same exposure stated as if it had been acquired during 8 hours.

Annex

Position Statement of the Institute of Noise Control Engineering of the USA (INCE/USA) on the April 15, 1996, (Final) Version of the I-INCE "Technical Assessment of Upper Noise Limits in the Workplace."

The April 15, 1996, (Final) Version is much improved and incorporates many recommendations from INCE/USA. The Convener is commended for developing a thorough and informative document. Even so, INCE/USA did not cast an affirmative vote on this document for the following two basic and overriding reasons:

It is inappropriate to recommend a specific upper-limit value of an eight-hour average sound level. Data should be provided to allow each jurisdiction to determine the most appropriate eight-hour average sound level for its specific conditions. INCE/USA has been consistent throughout all Drafts in stating this objection and recommendation.

All discussions to the desirability of an eight-hour averaged, A-weighted sound level of 75 dB are inappropriate and should be removed. There is no definitive and unambiguous scientific evidence to support an upper limit of 75 dB(A) for an eight-hour average sound level for exposure to noise in industrial workplaces. INCE/USA has been consistent throughout all Drafts in stating this objection and recommendation.