TECHNICAL ASSESSMENT OF UPPER NOISE LIMITS IN THE WORKPLACE

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Abstract

It is becoming widely recognized that the economic and social costs of high noise levels in the workplace require significant action to reduce the noise exposure of workers. 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 and risk of accidents for a much larger number of workers. This technical assessment is presented in the form of a report which briefly reviews the extensive scientific and epidemiological evidence relating noise exposure to 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 report makes specific recommendations for legislation in the areas of 8-hour daily noise exposure level, acceptable level changes for longer or shorter daily exposure periods, limitation of peak sound levels for short-duration (impulsive) noises, audiometric testing on schedules that depend on exposure level, sound absorption treatment in working areas, and the inclusion of noise performance in purchase specifications for new production machinery.

Sommaire

Il est de plus en plus reconnu que les coûts économiques et sociaux associés aux niveaux de bruit élevés dans les milieux de travail rendent nécessaires des actions significatives pour réduire l'exposition au bruit des travailleurs. Ces coûts incluent non seulement les compensations financières ou les dommages qui doivent être payés ainsi que la perte de jouissance de la vie pour les individus atteints de surdité, mais aussi des facteurs moins faciles à quantifier tels la baisse de productivité, l'augmentation du stress et les risques d'accident touchant un plus grand nombre de travailleurs. Cette évaluation technique est présentée sous la forme d'un rapport qui fait une brève revue des nombreuses évidences scientifiques et épidémiologiques concernant le lien entre l'exposition au bruit et le risque d'atteinte à l'audition, et discute des facteurs de nature législative. Les éléments de base de la législation en vigueur, émanant de plusieurs juridictions, sont présentés. Le rapport fait des recommandations spécifiques à l'égard de la législation dans le domaine du niveau d'exposition au bruit pour une période de 8 heures, des changements acceptables de niveaux pour des expositions de plus longue ou de plus courte durées quotidiennes, de l'échéancier des tests audiométriques qui dépendent du niveau d'exposition, du traitement acoustique des locaux de travail, et de l'ajout de spécifications d'achat concernant les performances acoustiques de nouvelles machines.

Preface

The International INCE General Assembly on 1992-07-22 approved an initiative to review current knowledge and practice concerning *Upper Noise Limits in the Workplace.* The background and concept for this initiative are described beginning on the facing page. 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 Advisor and a Convenor. Countries and members of the Working Party were as follows:

Convenor: 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 initiative of International INCE deals with the effects of upper noise limits on individuals in their working environments. It concerns the potential of prolonged exposure to high noise levels to induce hearing loss in those exposed to the noise. This initiative is not concerned with sound levels at the workplace which are so low that the chances of causing noise-induced temporary or permanent hearing threshold shift are insignificant.

Many countries have introduced regulations which set upper limits on noise levels at the workplace. There is little, if any, coordination internationally in the setting of the upper noise limits. Regionally, the European Community (EC) has taken steps to coordinate the setting of upper limits, and several Member States have already adopted these uniform limits. There is general agreement in Europe, as well as within scientific communities elsewhere, 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 and should be used by regulatory bodies for guidance in setting upper limits. Nonetheless, this International Standard contains a disclaimer which states: "The selection of maximum tolerable or maximum permissible noise exposures... require(s) consideration of ethical, social, economic and political factors not amenable to standardization. Individual countries differ in their interpretation of these factors and these factors are therefore considered outside the scope of this International Standard."

Since workplace noise regulations were first introduced more than 30 years ago, there have been many proposals that the upper limits should be significantly lowered. But this has generally not happened as the factors mentioned in the ISO disclaimer above have come into play.

Few people question the need for workplace noise limits, but the cost to comply is frequently cited as the reason for non-compliance. For this and other reasons, it is important to present the technical basis for the establishment of upper noise limits in a manner as independent as possible of the non-technical factors that influence the selection. In this area, I-INCE has identified a lack of objective evidence to support the selection of upper limits.

Concept

I-INCE has decided to undertake a study of the technical basis for the selection of upper noise limits at the workplace by regulatory authorities. This study will disregard the non-technical factors that influence the selection of upper noise limits and will be undertaken as follows:

1. Identify the development of regulations specifying upper limits on noise at the workplace during the past four decades.

2. Concentrate on the two most widely specified limits (L_{eq} = 85 dB and L_{eq} = 90 dB for eight-hour exposures) and the "fence" with the greatest degree of acceptance in the scientific community, and answer the question: what percentage of workers would suffer noise-induced threshold shifts due to long-time exposure at these levels?

3. Examine the scientific basis for the two trading relationships (equivalent continuous A-weighted sound pressure level versus time) most commonly used, 3 dB and 5 dB, and recommend the one that is more appropriate for regulatory purposes.

4. Develop a model regulation which includes an upper limit, a "fence" (hearing threshold level above which degrees of hearing disability exist), a trading relationship, and a noise measurement methodology.

The International INCE General Assembly approved the formation of a Working Party on Upper Noise Limits in the Workplace to carry out this work. Nine Member Societies volunteered to participate and contribute information. Their position papers covered existing legislation, compensation practices, typical industrial noise levels, 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, 1993-08-23, and reported during INTER-NOISE 93. After several further drafts, a major revision was presented during INTER-NOISE 94 in Yokohama, and with minor changes is now being published in *Noise/News International* for wider discussion and vote by Member Societies.

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

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1. Introduction

The primary goal of this report is to contribute to the reduction of risk and magnitude of long-term hearing damage, towards 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. It is hoped that this summary and resulting recommendations may eventually promote international uniformity, and encourage jurisdictions currently without control of noise levels in the workplace to enact regulations, by showing what is considered by legislators to be socially desirable and economically feasible in other countries.

Over the past 30 years, many countries have introduced regulations that set upper limits on noise levels in the workplace. In the past there has been little coordination internationally in the setting of such upper noise limits. Regionally, the European Community has taken steps to coordinate the setting of upper noise limits, and several Member States 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. This 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 noise levels. These are valid concerns, and so it has become 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. Review of the regulations does however illustrate what legislators consider 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, and in the methods of compensation for hearing damage (see Table 1). For example, most countries have an exposure limit of 85 dB (A-weighted, equivalent sound level for 8 hours), though the Netherlands has a limit of 80 dB, and the USA has a time-weighted-average limit of 90 dB, A-weighted. The allowed increase in sound level for a halving of exposure time, often called the exchange rate, is generally 3 dB, though Brazil, Israel and USA allow a 5-dB increase. The maximum sound level permitted for exposure, 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 (linear, peak). Exposure to impulsive noise or blast is treated separately from 8-hour exposure levels in most jurisdictions, with limits being set for the peak sound level of a single event. Most countries require certain engineering and administrative controls to be implemented when exposure levels exceed a certain limit. These controls take several forms but include such requirements as specifications for the noise performance of new machinery, mandatory audiometric testing programs, adjustment of work schedules to reduce exposure time, or the use of ear protection. 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. In most jurisdictions the practice is to allow partial compensation for partial loss of hearing, although in some cases compensation is only paid if there is an actual loss of earning power as a result of the hearing loss that has been suffered.

2. Scientific Basis

Two reviews, both with extensive bibliographies, of great relevance to this report are "Occupational Noise Exposure and Noise-Induced Hearing Loss: Scientific Issues,

Table 1. Some features of legislation tabulated for different countries*

Country (Juristiction)	L_{Aeq} 8-hour exposure rate	Exchange rate	Limit for engineering or administrative controls	Limit for monitoring hearing	Upper limit for sound level
Australia (varies by state)	85 dB	3 dB	85 dBA	85 dBA	140 dB lin, peak
Brazil	85 dB	5 dB	90 dBA. No exposure >115 dBA if no protection	85 dBA	130 dB peak
Canada (Federal) (ON, PQ, NB) (Alta, NS, NF) (BC)	87 dB 90 dB 85 dB 90 dB	3 dB 5 dB 5 dB 3 dB	87 dB 90 dBA 85 dBA 90 dBA	84 dBA 85 dBA (a)	140 dB peak
China	70–90 dB	3 dB			115 dBA
Finland	85 dB	3 dB	85 dB		
France (b)	85 dB	3 dB	90 dBA or 140 dB peak	85 dBA	135 dB peak
Germany (b) (c)	85 dB	3 dB	90 dBA	85 dBA	140 dB peak
Hungary	85 dB	3 dB	90 dBA		125 dBA or 140 dB peak
Israel	85 dB	5 dB			115 dBA or 140 dB peak
Italy	85 dB	3 dB	90 dB	85 dB	140 dB peak
Netherlands	80 dB	3 dB	85 dB		140 dB peak
New Zealand	85 dB	3 dB	85 dBA + 3 dB exchange rate		115 dBA slow or 140 dB peak
Norway	85 dB	3 dB		80 dBA	110 dBA
Spain	85 dB	3 dB	90 dbA	80 dBA	140 dB peak
Sweden	85 dB	3 dB	90 dBA	80 dBA	115 dBA, 140 dBC
United Kingdom	85 dB	3 dB	90 dBA	85 dBA	140 dB peak
USA (d) USA (Army and Air Force)	90 dB (TWA) 84 dB	5 dB 3 dB	90 dBA but no exposure >115 dBA	85 dBA 85 dBA	140 dB peak or 115 dBA 140 dB peak
This Report Recommends	**85 dB**	**3 dB**	**use quietest machines and room absorption in workplaces**	**on hiring and at intervals thereafter**	**140 dB peak**

* Information for countries not represented by Member Societies participating in the Working Party is taken from Ref. 15.

(a) A more complex situation is simplified to fit this tabulation.

(b) These countries require the noise declaration of machinery, the use of the quietest machinery where reasonably possible, and reduced reflection of noise in the building, regardless of sound or exposure levels.

(c) The noise exposure consists of L_{Aeq} and adjustments for tonal character and impulsiveness.

(d) TWA is Time Weighted Average. The regulations in the US are unusually complex because different thresholds are used to compute levels to initiate hearing programs (85 dBA), noise exposure monitoring (80 dBA), and noise reduction measures (90 dB), each using a 5–dB exchange rate.

Table 2. Some features of compensation tabulated by participating countries

Country	Compensation basis
Australia	Generally lump-sum compensation; provisions vary between States and Territories.
Brazil	10% to 40% minimum salary (extra pay as compensation for higher level of exposure).
Canada	Varies by Province; total loss of both ears is in the range of 20% to 25% of total disability. Paid only when earning power lost.
France	Averages FFR 600 000 per admitted claim paid by company (amount depends on wage and degree of disability).
Germany	Paid if loss of earning capacity greater than 20%. In 1987/1988, average pension was DM 6150 (whole term about DM 130 000).
Hungary	Damages are paid as a supplement of 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 2 years if impairment is less than 26%, otherwise continuously.
New Zealand	Fine on employer. Maximum compensation is 80% of pay if unable to work plus allowance of up to NZD 40 per week depending on the amount of injury.
USA	Varies by State. Total loss in both ears: from USD 125 000 (Iowa), USD 132 500 (Pennsylvania), to USD 12 000 (Colorado and North Dakota). Some states pay only for loss due to trauma, not for NIPTS.

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 over a period of at least 40 years 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 noise exposure to hearing loss. These factors include the nature of the sound itself (its sound 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 the exposure.

The goal of regulation is to reduce the permanent loss of hearing due to habitual exposure to excessive noise, as occurs on a daily basis over many months or years in the workplace. This is commonly known as Noise-Induced Permanent Threshold Shift (NIPTS). Whilst 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 are becoming more difficult to design and evaluate because the increased use of hearing protection, administrative controls, or quieter machines in recent years leads to small sample sizes and subjects having exposure to noise that has changed with time. In some studies from earlier years, before the time of widespread preventative measures, the sample sizes may have been adequately large, but the measurement of sound levels to which the subjects were exposed may have been made with instruments lacking the impulse and dynamic-range capabilities of modern instruments.

For these reasons many investigations have employed secondary measures, such as Temporary Threshold Shift Two (TTS2), or Asymptotic Threshold Shift (ATS). The use of either TTS2 or ATS rests on the assumption that there is a close relationship between these temporary effects and permanent hearing loss, NIPTS. In neither case has this assumption been adequately validated, and evidence indicates that the relationship varies considerably between individuals. Suter concludes that temporary threshold shift (TTS) should not be relied upon for predicting the long-term adverse effects of noise exposure. 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 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 noise exposure of humans in the workplace, and the consequent permanent threshold shift that they may suffer, rests on various assumptions that have not been adequately validated. One's ability to obtain a clear understanding of the relationships involved is also made more difficult by the fact that some evidence comes from epidemiological studies of NIPTS and some from controlled studies of TTS. The ISO Standard 1999:1990[1] is based on evidence from epidemiological studies, hence its relationships between noise exposure and NIPTS are clearly reliable but apply statistically to groups of people and do not apply to individuals.

A central issue in both scientific work and in legislation is the relation between two or more noises that produce the same amount of NIPTS when these noises differ in intensity, in duration, and in temporal pattern. This has come to be known as the "exchange rate." It is expressed as the number of decibels by which the sound level may be increased for a halving of the exposure time. Suter's review suggests (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, i.e. equal energy, rule, (c) some field data from outdoor occupations having intermittent noise exposures, such as forestry and mining, show less hearing loss than expected when compared with continuous noise exposure, and (d) the ameliorative effect of intermittence does not support the use of a 5-dB exchange rate although it might allow the use of an upward adjustment to the maximum permissible exposure limit (8-hour equivalent sound exposure) for certain occupations.

Shaw[2, p. 32] has analyzed many of the same scientific and epidemiological studies and reaches 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. Thus no single descriptor of the sound 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 level and time variations, can 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 sound level that presents no risk to anybody (or no more than a given degree of hearing loss in everybody), or a median sound level that produces a zero or negligible loss of hearing (or a given degree of hearing loss) in the average, or median individual. Obviously the exposure level to protect everybody is lower than the level to protect the average person.

Another factor that may lead to some confusion arises from the use of terms such as the percent risk of incurring a noise-induced hearing loss. This means the excess risk of exceeding a certain "fence" or threshold value of loss of hearing due to noise exposure, after subtracting the percentage of people that would exceed the fence due to the effects of aging alone (presbycusis). The actual percent risk from a given noise exposure is highly dependent upon a number of factors apart from the level and duration of the exposure itself: these include the audiometric frequencies used to define and measure the hearing loss; the hearing threshold level ("fence") beyond which a hearing loss is defined to have occurred; the hearing threshold levels of the non-noise exposed population used to estimate the effects of presbycusis, and especially the degree to which this population has been screened for occupational and even non-occupational noise exposure[1, Annex A and Annex B]. Initially, in the United States, audiometric frequencies of 500, 1000 and 2000 Hz were used and a fence of 25 dB. Later, NIOSH (U.S. National Institute of Occupational Safety and Health) started to use frequencies of 1000, 2000 and 3000 Hz with a fence of 25 dB, whilst the EPA (U.S. Environmental Protection Agency) used audiometric frequencies of 1000, 2000 and 4000 Hz. The Standard ISO 1999:1990[1] tabulates values of hearing threshold levels 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 ("fence") which 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 fences makes the risk appear to be higher, and conversely the use of lower frequencies or higher fences makes the risk appear to be lower.

The status of an individual's hearing is the result of the combination of occupational noise exposure, exposure to the noises of everyday life, the aging process, and disease processes - occupational NIPTS, sociacusis, presbycusis and nosoacusis respectively. The report is primarily concerned with occupational noise exposure. However, reliable separation of the contributions of occupational and non-occupational noise exposure to any measured hearing loss is difficult. Non-occupational noise exposure occurs in all human populations due to such factors as transportation, communications, mechanical or powered tools, and many other sources, and is probably increasing with time in all societies. Thus any meaningful screening of subjects for non-occupational exposure (sociacusis), whether to determine the effects of aging alone (presbycusis) 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 mechanized societies.

It has been recommended in Sweden that exposure levels should not exceed 75 dB (A-weighted, 8-hour equivalent sound level)[5, p. 22 and 6, p. 203] in the workplace if all risk of NIPTS is to be avoided **for all persons**. If such exposure is associated with 16 hours spent in much quieter surroundings, then this is equivalent to a 24-hour exposure level of 70 dB. To quote from Reference 6, page 203: "The Commission of the European Community has established L_{eq} = 75 dBA 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 dBA is defined as a threshold level. The proposal gives some room for flexibility by defining action levels in the range between 75 and 90 dBA and by declaring 90 dBA the upper limit." It must be pointed out that there is not general agreement that levels as low as L_{Aeq} = 75 dB are necessary to avoid all risk of long-term hearing loss; Ward[7, p. 97, Fig. 4.5] shows 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 dBA.

Published knowledge of the effects of impulsive noise, as generally encountered in industry, is not as extensive as for the other factors mentioned above. However, based on the available information, Shaw reaches the conclusion[2, p. 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 ISO 1999:1990 makes it clear that the definition of noise exposure given in the standard is comprehensive in that it "applies to all types of audio frequency (less than 10 kHz) noise including "noise which is impulsive in character." While no explicit peak 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 mPa) and for higher sound pressures should be recognized as extrapolation." This does not set 140 dB as a noise limit, but does suggest that the principle of energy equivalence may not be valid at higher sound pressures.

Exposure even for very brief periods to very intense noise, or to single impulses such as blast or gunshots, can cause permanent damage to hearing for the most susceptible individuals. This type of traumatic damage risk exists also with noise containing intense impulses, and may be higher than that caused by continuous noise.

3. Factors Relevant to Regulation

A recent survey by the public health authorities in Hungary[8] is typical and concludes 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 earners and 5% of the whole population." Authorities in Germany[9] estimate that 15% of the earners or working population is exposed to more than 85 dBA. If it is decided that the workplace should be without risk of noise-induced hearing loss for anybody due to long-term exposure then "noise levels around L_{eq} = 85 dBA are not satisfactory for the working environment .... exposure levels of L_{eq} < 70 - 75 dBA should be the goal for production facilities."[6, p. 203] It is clear from existing legislation that governments have so far set levels of noise in their regulations that allow some chance of hearing damage for some fraction of the population, but which reduce the amount of damage to a low value, deemed acceptable, for most of the noise-exposed population.

3.1 Basic Level of Exposure

Most legislation sets a limit of 85 or 90 dB (L_{Aeq} for 8 hours) for permissible noise exposure in the workplace. Such a limit implicitly accepts that some 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. Obviously a level of 85 dB, 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 sound levels, at least in terms of initial capital investment. The choice between 85 and 90 dB 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. It is clear that the balance between these non-technical, sociological factors can often change over a period of time, and hence that there is adequate justification to change the noise exposures 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 Community). For example, in Germany[10] Workshop Ordinance (A. bStättV), Section 15 states that the rating level (L_{Aeq} plus adjustments for impulses and tones) should not exceed 55 dB for mental activities, recreation or sanitary rooms etc; 70 dB for simple or mainly mechanized office work; or 85 dB for all other activities.

3.2 Exchange Rate

Scientifically, no exchange rate is applicable in all possible situations. Even if all scientific details of this complicated matter were better established than they currently are, much simplification is needed for purposes of legislation. This 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 the value set for L_{Aeq}, as the *exposure level* for the worker, and not as the sound level which exists at the workplace. The allowed value then limits the total 8-hour exposure for the individual worker, regardless of whether this is acquired at a lower sound level over 8 hours or at a higher sound level for a shorter period. The technical definition of equivalent A-weighted sound level, L_{Aeq}, is based on the time-averaging of sound energy and hence implicitly defines the use of a 3-dB exchange rate. As noted above, Ref. 2 concludes 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. Most jurisdictions have regulations that set limits on allowable *sound levels* in the workplace, and hence these regulations must also set a value for the exchange rate in order to control the period of exposure for the 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 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 of the ear to equal amounts of energy is assumed to produce equal amounts of NIPTS regardless of the time pattern of the exposure. The scientific evidence is that 3 dB is probably the most reasonable exchange rate for daily noise exposure. Statistically it is also a good approximation for the results of many epidemiological studies relating to intermittent exposures[2], even though these show considerable spread about any mean curve. If the exposure is broken by quieter periods spread throughout the day that happen to be beneficial, any deviation of the "true" exchange rate for any specific situation, from the legislated 3-dB rate, affords extra protection to the worker;

3. The exchange rate used in the United States (civilian), Israel and Brazil is 5 dB. This assumes that the sound level 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 "intermittence" involved is the lunch break. Where this happens there is a risk of over-exposure of the worker, 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 periods of exposure to intense sound may be brief and be followed by many minutes of very little sound. In these cases, the noise-induced TTS may recover completely and an increase in allowed noise exposure could be justified. It has been suggested in Ref. 4 that in these very 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 value set for the maximum allowable daily exposure, $L_{Aeq(8\ hours)}$; a larger allowance could be justified provided L_{Aeq} is lower.

3.3 Maximum Upper Limit

For a very small fraction of the most susceptible individuals, even a single burst of intense noise can produce a permanent loss of hearing. Most legislation, see Table 1, explicitly limits the peak sound level of a single burst of intense noise, or an impulse, independently of its contribution to the daily 8-hour noise exposure, to a value of about 140 dB (linear, peak). This upper limit is often stated in different terms such as 125 dB (linear, fast) or 115 dB (A-weighted, slow). These stated limits vary by about 10 dB between different jurisdictions, and also vary depending on the spectral content of the noise. The use of specifications involving A-weighting with fast or slow response time allows the sound to be monitored, albeit less precisely, using simpler instruments.

4. Recommendations

It is likely that the spread of data obtained from different epidemiological studies results 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 in effect 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 reduce the risk of long-term hearing damage in exposed people to a practical minimum. This report therefore makes the following recommendations based on current practice, drawn from various 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 scientific topic. Even some of the recent standards and technical reviews, including Refs. 1 to 4, rely heavily on studies that were conducted some years ago. Socio-economic factors in a society often change with time, so 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 noise exposure in the workplace. However, for its recommendations to be valid it is important that noise exposures outside the workplace, i.e. due to leisure time activities, should not contribute significantly to hearing loss and should remain low. The 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."

4.1 Exposure Levels

Allowed exposure levels in most jurisdictions are in the range of L_{Aeq} for 8 hours equal to 85 to 90 dB. This accepts 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 due to aging. A level no greater than about L_{Aeq} = 75 dB is desirable if work-related risk of hearing loss is clearly to be avoided for all exposed individuals, and this should be considered to be the ideal goal. However, the economic costs, and resulting disruptive social consequences, are probably too great for 75 dB, or even 80 dB, to be achieved in the near future. **It is therefore recommended that all jurisdictions with currently higher levels should set a basic exposure level of 8-hour L_{Aeq} = 85 dB as soon as possible.** For those working longer shifts, or in unusual environments, there is no evidence that the principle of equal energy does not apply; but it may be preferable to state the same exposure limit in equivalent but different terms, such as L_{Aeq} for 12 hours = 83 dB or L_{Aeq} for 24 hours = 80 dB.

4.2 Exposure to Impulsive Noises

The basic exposure level of the previous paragraph should include any contribution from short-term, high-intensity noises or blasts. Such noises are traditionally also limited in legislation to a maximum sound level - this additional limitation may not be strictly necessary given the present state of scientific evidence, but is certainly prudent.

Instruments having "impulse" or "peak sound level" capability should be used for measurement, and it is recommended that regulations should set a limit for impulses of 140 dB linear, peak.

4.3 Exchange Rate

Stating the exposure level in terms of equivalent sound level, L_{Aeq}, already implies that **an exchange rate of 3 dB per halving or doubling of exposure time** is to be used. This is indeed the recommendation for all exposures **regardless of the degree of intermittence or time-varying characteristics of the noise.** A value of 3 dB may not always be correct, but in those situations where it deviates from the "true" value it is likely to afford extra protection for the worker. Furthermore it is conceptually the easiest to understand, and is the easiest to implement simply in the design of a measuring instrument.

4.4 Engineering Controls

Efforts should be made to reduce sound levels in the workplace to the lowest reasonable values, even when there is no risk of long-term damage to hearing.

It is essential that workers be able to hear alarm signals clearly and verbal warnings intelligibly. To prevent noise-induced health hazards and performance decreases, target values differentiated 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 required retrofit when existing installations are being upgraded or new machinery purchased. Both are able to provide long-term reduction of sound levels, and in many cases can be done at little or no cost.

1. **The acoustical design of the 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 acoustic absorption; even in production areas this can usually be located on the upper surfaces of walls and on baffles suspended from the ceiling. **A minimum average absorption coefficient of 0.3 should be required for each occupied room.** (These matters are discussed further in Refs. 6 and 11 and the procedure has been used in Ref. 12.);

2. The purchase specifications for all new and replacement production machinery should contain clauses specifying the maximum emission sound power level or emission sound pressure levels allowable 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 fulfil these specifications, there should be a noise declaration as specified in regulations or standards[11] so that the purchaser can consider additional noise control measures.

4.5 Audiometric Programs

EEC Directives on noise control in the workplace[14] require certain actions to be taken when noise exposure limits of 85 or 90 dB are exceeded. These include audiometric testing and the wearing of ear protection.

Some prudent employers, for their own protection, require pre-placement audiometric testing at the time of hiring a new worker. This action serves two purposes, a) it provides a baseline record of hearing levels against which future audiograms can be compared, to provide an earlier warning of possible hearing damage, and b) it is likely to provide some legal protection for the employer against later claims of hearing loss, possibly incurred before hiring, when the workplace is in fact safe. **It is recommend that all employers conduct audiometric testing at intervals that depend on exposure levels and past history of the individual worker.** For example, in Germany[10], testing is conducted every 60 months if the exposure level is about 85 to 90 dB, and every 30 months at exposure levels of 90 dB or greater. In Hungary[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 levels above 115 dB.

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