Commission of the European Communities

industrial health and safety

Correlation between hearing impairment risk and exposure to noise

Present level of research

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EUR 7874 DE, EN, FR

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1. Introduction -

Protection from noise-induced hearing impairment risks

In 1974, the International Labour Office in Geneva appointed a group of experts to analyse the occupational risks caused by noise and vibration, and in particular to draft proposals for measures to protect workers against such occupational risks. The results of this study were published in 1977 as the "ILO Code of Practice : Protection of Workers against Noise and Vibration in the Working Environment" /8/ and in June of the same year, the ILO International Labour Conference adopted Agreement 148, /13/, and Recommendation 156, /14/, which, apart from considering the occupational risks caused by air pollution, dealt with the protection of workers against health risks in the working environments affected by noise and vibration.

In the introduction to this Code of Practice /8/, the ILO experts point out that today "noise and vibration were regarded as being two important factors among the many that contributed to the pollution of the working environment" and that "noise and vibration exceeding certain thresholds they impaired health and working capacity, causing not only mental or physical inconvenience but also organic disorders". The Code of Practice also refers to the "economic losses due to tempory or permanent elimination from workforce (throuth sich leave or early retirement) of many workers affected by occupational disease or accidents caused by noise or vibration".

Of the various effects of noise on man, hearing impairment is particularly important since this type of disease is irreparable and the noise-induced hearing handicap is very widespread in the industrialized countries : in some countries,hearing handicap has been the most frequent of all recognized occupational diseases since many years /3/ /3a/. This does not mean that we should underestimate the importance of other occupational diseases, since the number of recognized occupational diseases generally depends on the criteria for recognition, which can vary considerably from country to country. The impairment of communicative and perceptive capacities involves a reduction in the quality of his life. His difficulties in communication may reduce his professional efficiency and may increase the risk of an occupational or road accident.

Finally, various references are made to the increasing number of occupational diseases caused by noise over the past ten years in several industrialized countries /3/, /3a/, (Fig. 1), and some authors concluded that the amount of noise to which workers in industry and handicraft are exposed must have increased sharply in the last decade. Carefully undertaken investigations show that this assumption is not generally valid. Over the long term, the number of persons exposed to high-intensity noise in all probability can be expected to decrease as a result of the general technological development. In fact, it is forecasted /1/ that the number of workers in the noisy manufacturing industries is expected to remain constant or decline, whereas the number of employees in the quieter services occupations is expected to increase (Fig. 2). Currently, however, approximately 6 to 10% (figures vary depending on the branches and countries) /3a/, /92/, of workers in industry and trade are exposed to noise levels which could damage unprotected ears.

The actual causes of the increasing number of noise-induced occupational diseases are closely linked with the large-scale introduction of medical check-ups for the protection of workers. Furthermore it is necessary to take into consideration the influence of exposure time and the phenomenon of "age-related hearing impairment". The conspicuous increase in noise-induced occupational diseases merits closer attention especially since the relatively slow development of hearing impairment provides opportunities for the introduction of precautionary measures to prevent loss of hearing.

The substantial increase in noise-induced occupational diseases recorded in many countries over the past 10 years can mainly be explained by the following three phenomena :

Phenomenon A

Impairment of human hearing by noise is a "long duration effect" (with the exception of extremely high noise levels). Only after many years, and in most cases after decades of exposure permanent hearing loss can be detected in any significant number of employees in noisy jobs x). Consequently, the number of recognized cases of noise-induced hearing impairment increases in employees of over 50 years of age (Fig. 3). The development of hearing loss is therefore dependent on both high noise intensity and a long exposure period. Loss of hearing therefore cannot generally be scribed solely to the working conditions prevailing during the years immediately preceding its detection. Instead, the reason for the impairment must be tradec over a much longer period of several decades.

Phenomenon B

The impairment of hearing following exposure to occupational noise develops in parallel with age-induced i.e. "natural" loss of hearing. Moreover, since the two effects develop very slowly over a period of

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x) NIEMEYER /2/, referring to the Federal Republic of Germany, states the following : "The number of cases of hearing loss for which compensation was awarded (20% reduction in working capacity) has increased 27 times over from 1961 to 1970 : i.e. from 22 to 577. Some 60% of all new occupational diseases for which compensation was grated in 1970 consisted of noise-induced hearing loss (Bernhardt). Only a some of these, however, were actual new cases. A large percentage consisted of 60 to 70 year old persons who had worked in noisy jobs for many years, some of whom had already retired and whose loss of hearing was only detected at an advanced stage and/or compensation could only be claimed after the 7th Occupational Disease Order (7. Berufskrankheitenverordnung) came into force in 1968. Within the scope of our own studies, since 1.1.1970, 74% of all persons for whom pensions were proposed were over fifty years old with an average exposure period of 32 years".

many years, the worker in most cases is not sufficiently aware of his additional hearing impairment caused by noise. The actual loss of hearing, which may have existed for a long time, is only detected by objective audiometrical cheks and medical examinations. When such checks are performed systematically over entire branches or occupational groups, a large number of previously unknown cases can be discovered within a relatively short time. The close connection between the increase in hearing lossrelated occupational diseases and the large-scale application of audiometrical checks is shown by the time sequence of these two occurrences in several countries. In the FR of Germany, for example, large companies and trade associations introduced large-scale audiometrical checks in the early 1970s, and a major increase in the reported and recognized noise-induced occupational diseases began afterwards, in about 1973 (Fig. 1). The two events occurred at short intervals in Austria and East Germany also /3/ (see also Fig. 1/1 in /3/).

Phenomenon C :

Loss of hearing is recognized as an occupational disease directly on the basis of an established minimum loss of hearing or an associated established minimum reduction in working capacity. Formerly, the loss of hearing had to reach the stage of deafness in order to be recognized as an occupational disease. By contrast, according to current regulations in the Federal Republic of Germany, for example, since 1968, compensation has been granted for a reduction in working capacity of 20% /4/, /5/, /6/, where a 10% reduction in working capacity corresponds to a loss of hearing of 40 dB at 3 kHz /4/. A lowering of the limit value of the minimum reduction in working capacity or corresponding minimum permanent threshold shift (PTS), results in an increase in the number of recognized noise-induced occupational diseases in proportion to other diseases, both in aboslute and relative terms. Higher demands for improved working conditions result in a reduction in the maximum permissible degree of hearing loss required for the award of compensation and in an increase in the number of noise-induced occupational diseases.

In short, therefore, the widespread increase in the number of registered and recognized noise-induced occupational diseases can be explained as follows :

- a substantial majority of the cases of noise-induced hearing impairment detected in a large number of persons over the past 10 years were caused by exposure earlier in life (Phenomenon A);

- the increase in the number of noise-induced occupational diseases largely coincided with the start of systematic, large-scale audiometrical checks (Phenomenon B), which began at different stages in the various industrialized countries - from about 5 to 15 years ago in Europe;

- a portion of the large number of recognized noise-induced occupational diseases can be assisted to stricter criteria for recognition (Phenomenon C).

Irrespective of these considerations, there are a large number of noise-induced occupational diseases in all the industrialized countries which are in fact caused by the occupational noise to which the unprotected ear has exposed. According to a representative survey conducted by the Federation of Mutual Accident Insurance Associations of the FR of Germany (Haupverbandes der Berufsgenossenschaften), about 8% of Germany blue-collar workers in 1975 were employed in jobs with noise levels which are sufficient to cause a high risk of noise-induced occupational disease, after many years of continuous exposure without ear protection.

Moreover, it is roughly known how workplaces are distributed across the various noise level classes in a "normal" industrial undertaking such as a metal working plant, where noise levels are admittedly high (Fig. 10a). If, in the example given, the threshold value for taking noise prevention measures is lowered from 90 dB(A) to 85 dB(A) and then to 80 dB(A), the number of workplaces affected rises from 10% to 30% and 50% respectively.

However, the time progression of the number of noise-induced occupational diseases (Fig. 1) also shows that, after the introduction of large-scale systematic audiometrical checks, although the number of these occupational diseases increases steeply for several years, this was followed by a clear declining trend (in the case in question, approx. 5 years later). Very similar trends can be found in several industrial countries, e.g. Austria, Switzerland and East Germany /7/, /94/. This decline in the number of occupational diseases detected based on the same criteria for recognition is, in the cases studied, the result not only of

- approaching a situation where most of the cases of hearing impairment caused in earlier years have been detected, but is most probably also

- an indication of the effectiveness of the various measures to reduce risks caused by occupational noise which were introduced at about the same time as the audiometrical checks.

The main sections of the above mentioned ILO documents /8/, /13/ and /14/ list measures for the protection of workers from health risks in the working environment, some of which serve only as a general framework. The maximum allowable noise exposure levels beyond which health risks can be expected for example, are not defined precisely by measurement codes or stated in figures in the documents. However, such definitions and specifications are indicated as being necessary by the ILO documents, but it is left to the various countries to draw then up because of the substantial economic and social problems associated with noise limit specifications in particular. In addition, however, the documents mention numerous other steps to protect workers from noise-induced risks, such as the reduction of noise at its source (machines, work processes), acoustical measures in areas where sound propagates, organizational measures, personal noise protection, medical supervision and the registration and storage of personal data, such as previous levels of noise exposure and hearing impairment.

On the basis of the experience obtained in several countries over the past ten years, the following specific measures x) for the protection of workers from dangerous noise have already proved successful (for details, of for exemple /8/, /9/, /10/, /11/, /12/ :

- Preparation of a measurement code for the determination of the noise exposure at the workplace;
- establishment of a noise exposure limit;
- stipulation of further measures for the working environment where the maximum allowable noise exposure is exceeded;

Such measures include :

- periodical medical examinations to supervise the persons at risks, pre-employment medical examinations for persons starting work in noisy areas;
- reduction of noise exposure by technical and/or organizational means; where this is technically and economically feasible; more stringent noise radiation limitations for the establishment of new workshops and workplaces. The obligatory use of advanced noise abatement techniques, labeling of machines with noise emission levels : prescribed noise emission limits for technical equipment;
- provision and obligatory use of personal means of noise protection equipement;
- establishing of medical records and data banks for persons employed in noisy areas;

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x) These steps are generally introduced by way of administrative measures. The national bodies responsible for this vary from country to country within the Community. They are either state authorities (the Ministres of labour or social affairs, the Factory Inspectorate) and/or independently administered accident insurance institutions (e.g. mutual accident insurance associations) and finally national or international standardization bodies.

- appointment of doctors responsible for medical examinations in respect to suitability, precaution and halth supervision;
- establishment of a ruling on cost allocation for the various measures and their consequences, including compensation;
- stipulation of penalties for non-compliance.

A review of the programmes and regulations (laws, standards) on noise protection existing in the major countries up to about 1979 is given in a publication by KRACHT et al. /15/ and an up-to-date description of the medical aspects of the noise problem has been provided by MERLUZZI /16/.

To summarige the analysis of the medical and technical/organizational measures applied in various countries for the past ten years at least shows that, immediately after the introduciton of audiometrical checks, a large number of persons were found to have impaired hearing, but after a few years it was possible to stop the proportional increase in noise-induced occupational diseases and reverse the trend by various measures introduced in conjuction with the checks. Such measures are therefore likely to lead to success provided they are applied to the highly exposed occupational groups on a sufficiently wide basis and continue to be applied constantly over a long time.

2. Criteria relating to the scope of the report and the period covered

In Novembre 1973, the Commision of the European Communities appointed Prof. H. Bastenier, Prof. W. Klosterkötter and Prof. J.B. Large to compile a report on the main effects of noise on human beings. Chapter 2 of this report /17/, which was published in 1975, is a summary of the data available at that time on risks to hearing caused by noise too. The relevant chapter contains the most important definitions and basic information on hearing impairment and splitted up the effects into "acute noise effects", i.e. those caused by a single, very intensive acoustic burst and "chronic noise effects", i.e. those caused by noise levels usual for working environments and effecting over a long period. Furthermore, most of the data available up to first years of the 1970s is contained in two books by BURNS and ROBINSON /18/ (specifically in Appendices 9-15) and KRYTER /19/ (specifically in Chapters 4, 5 and 6), as well as in the Proceedings of the International Congress on Noise as a Public Health Problem /20/ (held in Dubrovnik in 1973).

The purpose of this report is to supplement the above-mentioned data and describe the development of research from about 1974 on the link between hearing impairment risks and noise exposure. Because of their much greater importance as the cause of occupational noise risk, the chronic noise effects shall be investigated preferably.

Moreover, in 1980, the Commission of the European Communities awarded contracts for separate reports on two specific questions related to hearing impairment risk :

- a report on medical checks (to be drawn up by the institute of Occupational Medicine, Lyons, France),

and

- a report on the influence of impulsive noise components on hearing impairment risk (to be drawn up by the Institute for Sound and Vibration Research, Southampton University, United Kingdom).

In the present report, therefore, these questions will be referred to only when required by the context.

A new description of data available on hearing impairment risk beginning at about the year 1974 seems to be justified since the information collected up to the middle of the 1970s left several questions unsolved and the basis for certain data seemed inadequate. For many problems, one of the main reasons was that not enough relevant data which had been obtained from practical occupatonal noise situations were available up to the beginning of the 1970s.

Such data are now available in much larger quantities since the marked increase - already referred to - in the number of medical and acoustical surveys at workplaces in many countries. In the past six years, they have made it possible to establish, correct and extend basic ideas on the correlation between hearing impairment and noise exposure.

With regard to the long-duration effects of hazard noise, a period of six years must still be regarded as relatively short, and therefore further data will be necessary for the future; consequently, this report cannot claim to provide conclusive solution of this problem.

The establishment of a link between permanent hearing impairment and a specific noise exposure level from actual data obtained under conditions similar to those found at the workplace is rendered difficult even today by the fact that, although hearing impairment is measured individually, the noise exposition causing such damage is only known on the basis of measurements for a very few years in the past and the important noise levels of the period prior to this can only be roughly estimated retrospectively, by way of enquiries into medical histories, for example. The uncertainties of such methods is increased even further if, apart from occupational noise the person's past exposure includes other noise sources (military service, leisure time noise, discotheques, etc.).

3. Hearing impairment risk caused by long-duration exposure to occupational noise

3.1. Definition of hearing impairment

Hearing impairment can be characterized in various ways. The most important effect of hearing impairment in everyday life is the impairment of communicative and perceptive abilities, resulting in an overall reduction in the quality of life and difficulties in communication, which may cause a reduction in professional efficiency and increase the risk of an occupational or road accident.

These main consequences of impaired hearing are also the basis of the following definition of the American Medical Association (AAOO) /21/ :

> "Ideally, hearing impairment should be evaluated in terms of ability to hear everyday speech under everyday conditions. The ability to hear sentences and to repeat them correctly in a quiet environment is taken as satisfactory evidence for correct hearing of everyday speech."

This very general definition must be put into more specific terms if it is to be used as a criterion in practice (Glorig, Baughn /21/). Examples of such specific terms are regulations on the use of the "speech audiometer" and "whisper tests". Such tests are used in some countries (e.g. /4/ § 3.6) (except in cases concerning foreigners) as the main criteria for the recognition of occupationally induced hearing impairment. These regulations contain a description of the testing procedure and require the type of equipment and rooms to be used, and in particular indicate as a quantity the limit for the minimum degree of hearing loss necessary for recognition as a noise-induced occupational disease (e.g. /4/).

On the other hand, all noise-induced hearing impairment is accompanied by a threshold shift (TS), and hearing defects are accompanied by a permanent threshold shift (PTS). The permanent threshold shift is defined as the difference between the individual threshold, and the normalized threshold both as a function of frequency. The normalized threshold is defined internationally according to age, sex and the range of individual variation (ISO/DP 7029 /22/, formely ISO/R 386).

Most experts are now of the opinion that a noise-induced permanent threshold shift (NIPTS) within the range of 500 Hz to 4 kHz can be used approximately to characterize a lack of ability to understand everyday speech /21/, /23/, /24/. An important advantage of this criterion is that the permanent threshold shift is relatively easy to measure monaurally by means of the pure-tone audiometer. The frequency range used as a basis covers the most important frequencies for understanding of most languages. Calibration of the pure-tone audiometer is simpler than that of the speech audiometer and there are fewer possible sources of measurement errors in pure tone tests as in other known methods. The main objection of critics to threshold tests is that in everyday speech, the ear is exposed to much higher intensities (L_p = 40 ... 80 dB) than in the examined threshold range (0 dB for 1 kHz). Today, however, the pure tone threshold test which was called the "interim method" as early as 1974 in Dubrovnik /21/ is widely recognized internationally and was included in the ISO 1999 standard /23/, /24/ on the detection and characterization of loss of hearing.

The permanent threshold shifts for a specific degree of hearing loss generally vary at the testing frequences of 500 Hz, 1 kHz and 2 kHz, and at other possible testing frequencies of 3 kHz and 4 kHz but statistically they are linked by a simple linear correlation (PLUNDRICH /25/ Fig. 4). Accordingly, there are proposals to represent the actual, i.e. frequency-depending threshold shift by a single number, by means of :

- an average permanent threshold shift expressed as the "average hearing level" (AHL). This value is the arithmetical average of the threshold shifts of specific testing frequencies. The international standard ISO 1999-1975 /23/, which is still in force, uses the average of the shifts at 500, 1000 and 2000 Hz abbreviated as $\overline{PTS}_{0.5/1/2\ kHz}$.

  LAFON /26/, /27/ recommends that the shifts for the frequencies of 2 kHz and 4 kHz only should be averaged.

  ROBINSON proposes using the average of the shifts at 1, 2 and 3 kHz and discusses in detail the advantages and disadvantages of the various testing frequencies selected /28/.

  In paragraph 6.1 of the new ISO-1999 draft /24/, a total of 7 combinations of threshold shifts at various testing frequencies are offered for use as equivalent possibilities.

Or alternatively :

- a threshold shift for a single selected testing frequency. PLUNDRICH /29/ recommends, for example, for the overall assessment of hearing impairment, the use of the PTS at testing frequency 4 kHz, which is the most sensitive in its reaction to noise exposure, and in the Federal Republic of Germany, particular attention is given to the threshold shift at 3 kHz.

With the aid of the correlations of the threshold shifts at various testing frequencies (Fig. 4) as illustrated by PLUNDRICH /25/, it is possible to establish a link betwen the various designations of hearing damage. However, in order not to extend the existing span of statistical spread even further, only one of the testing frequency combinations recommended in ISO/DP/1999/1 should be used in an official regulation.

The limit value of a single or average hearing threshold shift (PTS_{limit} or AHL_{limit}, also known as "fence"), below which hearing can be described as having no impairment, was indicates as

$$\overline{PTS_{0.5/1/2\ kHz}} = 25\ dB \qquad \text{(ISO 1975)}$$

several years ago in ISO 1999-1975 /23/ and by GLORIG/BAUCHN /21/. Today, the main international standards do not specify this limit by a value /24/; instead, they leave that decision to the national authorities, considering the social and economic factors involved, as well as variations of understanding caused by different languages. At the national level, on the other hand, this limit value is not specified uniformly. In the Federal Republic of Germany /4/, for example, a loss of hearing of under 15 dB at 1 kHz, under 30 dB at 2 kHz and under 40 dB at 3 kHz is considered to be "approximately normal hearing" if this is also substantiated by further tests and examinations. British Standard 5330 /33/ specifies for this limit

$$\overline{PTS_{1/2/3\ kHz}} = 30\ dB \qquad \text{(British Standard, 1975)}$$

Taking into account the various testing frequencies, the BSI and ISO limits are roughly equivalent to each other.

Finally, it should be mentioned that all the above limit values are not criteria for the award of compensation. Today for compensation, significant higher values of permanent threshold shift (approximately 50 dB for certain frequencies) are required.

Von GIERKE, on the other hand, takes much lower permissible PTS values in his definition of "hearing impairment per se" /30/, but when applied to groups of middle-aged and elderly persons in addition to the wide spread of individual age-induced hearing impairment they do not appear to be very suitable.

With increasing age, persons who have not been exposed to any hazard noise in their lives and are in a normal state of health (otologically normal persons) also suffer considerable permanent threshold shifts, especially in the high frequency ranges. These age-induced threshold shifts (ATS x)), also called presbyacusis, are described as the statistical average of the PTS of persons from a specific age group who have not been exposed to hazard noise /22/, /24/.

Finally, it is usual (ISO 1999/1) /24/, to introduce an age-influenced threshold level (AITL xx)) with the value A_{QM}, which is just exceeded by Q% of a M-year old age group of persons.

The age-influenced threshold level can be described statistically as a function of age M, frequency and sex /22/, /24/, /18/, /29/. An increase in the PTS with the square of the age is recognized as being significant. According to ISO/DP 1999/1/,

$$A_{Q.M} = a_A \cdot (M - 18)^2 + A_{50,18} \pm K \cdot S_{u,l} \qquad \text{Equ.(1)}$$

Where, $A_{50,18}$ is the median value of the hearing threshold level of otologically normal persons of the same sex aged 18 years whose hearing capability were selected as a zero reference for practical reasons, as

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x) ATS = AGE-INDUCED THRESHOLD SHIFT

xx) AITL = AGE-INFLUENCED THRESHOLD LEVEL indicated in ISO R 389 and ISO/DP 7029 /22/. The empirical constants a_A, K, S_u for $0 < Q < 0.5$ and S_l for $0.5 < Q < 1$ are published as a function of audiometer frequency and sex (/24/, Annex A, for a "hughby screened" population ^{x}). Using Equ. (1) and the constants mentioned in ISO, the median value (Q = 50%) of PTS - for example, $A_{Q,M} = A_{50,60}$ of 28.2 dB at 4 kHz - is calculated for a 60 year-old man. Values of 55 dB and 6.8 dB, however, are also just exceeded by 10 and 90% of the persons of this age-group respectively (cf. also Table C.1 in ISO/DP 7029, /22/). This underlines the large spread in the individual distribution of hearing capability.

Therefore the audiometrical test of a persons who have been exposed to noise, established an individual PTS which covers both the age-induced (ATS) and noise-induced (NIPTS) components. In order to separate the two effects, BURNS and ROBINSON /18/ assumed that the two influences were added together as levels :

$$\text{PTS} = \text{NIPTS} + \text{ATS} \qquad \text{Equ. (2)}$$

Consequently the noise-induced component, also called "age-corrected" threshold shift, is thus represented as a difference :

$$\text{NIPTS} = \text{PTS} - \text{ATS} \qquad \text{Equ. (2a)}$$

This correction means that the individually determined PTS, is reduced by an statistical average of the ATS. This procedure is criticized by some experts (e.g. NIEMEYER /2/ and KRAAK, PLUNDRICH /29/). NIEMEYER recommends individual differential diagnosis instead and considers that age-induced hearing loss probably has no influence on the understanding of everyday speech and nor on the degree of hearing impairment; difficulties in this respect are more likely to be caused by an age-induced reduction in cerebral (mental) functions. Finally, NIEMEYER /2/ on the basis of 150 carefully selected cases

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x) Besides on otological normal population "highly screened" (data base A, Annex A of ISO/DIS 1999) this Standard defines as "unscreened population typical for an industrial country" (data base B, Annex B). The age-related hearing threshold levels of this otherwise equivalent group is significant higher (table 7) compared with that of the "highly screened population" (table 6 of ISO/DIS 1999).

points out that, after subtraction of the statistically averaged ATS values, the remaining NIPTS levels decrease with increasing noise exposure duration, a trend which is basically incompatible with the characteristics of a permanent threshold shift.

PLUNDRICH /29/ suggests that age-induced hearing loss should be presumed to be caused by an equivalent amount of noise exposure. This amount, however, is given as a linear dose rather than a logarithmic one and as such is added to the actual (linear) noise dose. Contrary to previous correlations, this the risk model yields in a median PTS value which in the absence of noise exposure converges against age-induced impairment.

More recent assumptions (ISO 1999/1, /24/) relate "age correction" not to the individual threshold shift but to the threshold shifts established within a specific group of persons, i.e. those statistically existing under given noise influences :

$$H_{Q,M} = A_{Q,M} + N_{Q,T} - \frac{A_{Q,M} \cdot N_{Q,T}}{120} \qquad \text{Equ. (3)}$$

Here,

$H_{Q,M}$ is the audiometrically established hearing threshold level (HTL), which is just exceeded in Q% of a highly screened population within the M year-old age group after T years of noise exposure.

$N_{Q,T}$ is the potential noise-induced, i.e. "age-corrected", permanent threshold shift (NIPTS) exceed in Q% of a population after T years of noise exposure.

$A_{Q,M}$ is the age-induced threshold shift (AITL) for Q% of a population belonging to a group at age M years.

Noise-induced hearing loss (NIPTS) is normally not just the result of exposure to occupational noise but the overall effect of all noise exposure occurring in the course of a day, i.e. not only during working hours. Substantial noise exposure may occur outside working hours, e.g. during travel to and from work, at home in do-it-yourself work and in certain sports and recreational activities (discotheques). In the assessment of noise-induced hearing impairment, therefore, these further possibilities should be carefully checked during examination of case histories. The rules listed in Section 4 make it possible for the occupational noise risk to be estimated only if the noise exposure outside of working activities is negligible compared with exposure at the workplace. On the other hand, the correlations indicated in that Section provide the possibility of calculating the risk of hearing loss as a result of the combined effects of occupational noise and non-occupational noise or estimating the effects of non-occupational noise alone, by applying some relevant changes, especially alterations to the exposure periods.

On the basis of current knowledge, /24/, /30/, it is not possible to make an accurate forecast for any individual person which changes in his threshold level will be caused by a specific amount of noise exposure. However, for a large group of persons exposed to a specific noise level, it is possible to determine the changes in the statistical distribution of the hearing thresholds /24/, /30/. Parameters such as median noise-induced permanent threshold shifts (median NIPTS) etc., can be found as difference in hearing threshold levels of two groups of persons who are similar in all relevant respects except that one group was exposed to a well-defined noise exposure (specifically, occupational noise exposure), whereas the other was not exposed to any hazard noise. Information on the individual variations of PTS of members of the "same" group described by statistical quantities is also of interest in this respect. Consequently recent standards /24/ use NIPTS only to describe changes in a group of persons in the statistical sense, and do not apply such values to individual persons.

The risk of hearing handicap (RHH) is also defined on this basis. The RHH is given as the fractile of people in a population whose hearing loss exceeds a certain limit ("fence") designated as the beginning of hearing handicap /24/.

The risk of hearing handicap due to exposure to noise (RHN) is the RHH in a noise-exposed population minus the RHH of a different, but otherwise equivalent group of persons not exposed to noise /24/.

Experimental studies on the correlation between hearing impairment and noise exposure, i.e. the mechanism of noise-induced hearing loss, briefly referred to above under practical conditions, are difficult for at least two reasons :

(1) In practice, in most cases of normal noise exposure the PTS only occurs after a exposure period of years, and frequently only after several decades. Accordingly, the influence of certain changes in the parameters of noise exposure on hearing impairment can only be established either retrospectively, with a large degree of uncertainty, or only after decades of observation.

(2) The hearing loss constitutes irreversible harm to human health and cannot be inflicted indefensible to inflect such damage deliberately.

One alternative would be the use of animal tests; however, the results of such tests are not entirely applicable to human behaviour, and if at all, only within a greater range of uncertainty.

Sound intensities effecting during a normal period of a working day, followed by a 16-hour recovering phase cause a temporary threshold shift (TTS). This threshold shift reaches its maximum shortly after the end of the exposure period and recovers entirely or only partially in the subsequent recovering phase. If the recreation process is not completed after 16-hour because of the magnitude of the TTS, or because the recovering time is too short compared with the TTS - decrease-time-function and if on the following next day the same exposure/recovering cycle effects which again does not result in a complete decline of the TTS, and if this process continues for years, it results in a permanent threshold shift, and finally, hearing impairment. It is therefore evident that there is a connection between PTS and TTS. The actual cause of the permanent hearing damage can be assumed to be a chronic lack in the oxygen supply for the sensory receptors and a resulting toxication when the sensory cells are exposed to very high acoustic intensities (VOSTEEN /32/).

Since a long time a precise formulation of the relationship between PTS and TTS has been the subject of much interest since it would make it possible to forecast from the effects (TTS) of temporary noise exposure, the important long-duration effects (PTS) of the same noise over a period of years for a certain individual. In the first formulations (e.g. /18/), it was assumed that the temporary threshold shift occuring after an 8-hour period of exposure to occupational noise measured at a specific time Δ t after the end of exposure ($TTS_{\Delta t}$) is a direct indication for the determination of a permanent threshold shift (PTS), provided the person is exposed to this level of noise every working day for several (Xo) decades :

$$TTS_{\Delta t} = PTS_{x_o} . 10 \text{ years} \qquad \text{Equ. (4)}$$

It was assumed, for example, that the TTS_2 recorded 2 minutes after an 8-hour exposure period indicated a permanent threshold shift (NIPTS) if the person concerned was exposed to the same level of steady-state broad-band noise every working day for twenty years.

At the beginning of the 1970s, it was shown, especially following studies of Ward (PASSCHIER-VERMEER /34/), that recovering from a TTS depends on how the TTS was produced in function of time, and that the recovering process could be delayed. This caused Ward, for practical reasons, to propose use of the threshold shift 30 minutes after the end of exposure (TTS_{30}) instead of the TTS_2, especially where intermittent noise was involved /34/. Initially, however, the correlation between TTS_{30} and NIPTS for exposure to intermittent noise remained more or less unknown /34/.

On the basis of the above mentioned influence of the time-behaviour of TTS establishment and TTS recovering to future PTS, several authors (KRAAK, FUNDER, KRACHT /35/) have recently proposed the use of the time integral, i.e. the 'area' under the time-function of TTS history, instead of considering a momentary measured value of the TTS at one given point in time after exosure :

$$S = \underset{t_E\,-\,t_R}{\quad} (TTS)\,dt \qquad \text{Equ. (5)}$$

t_E = noise exposure period

t_R = recovering period.

On the basis of their own studies and using data of other investigators KRAAK et al. /35/ came to the conclusion that a TTS measured at one given point in time after the end of exposure, could not be a suitable quantity for the description of the physiological effects, and that on the other hand a close correlation between the integrated TTS, i.e. quantity S according Equ. (5), and the noise dose exists. Where this dose covers the sound pressure with the first power. Objects of these investigations were steady-state and interrupted steady-state noises of up to 94 dB(A). ROBINSON agrees with the general line of these arguments in a more recent publication /36/.

The important link between S and NIPTS is still the subject of detailed studies and first results have become available in the modified 'Dresden risk model' (e.g. /29/).

Further studies along these lines (e.g. RICHARTZ /37/) were concerned with the question of whether information on individual differences in sensitivity to noise could be obtained from TTS-quantities measured after the noise exposure of one working day (TTS_2, TTS_{30}, S, ...). Such differences might be useful in helping to detect persons who are particularly sensitive to noise. This is also the purpose behind certain noise exposition tests which can provide evidence of pathological auditory fatigue (a summary on this point is given by DIEROFF /38/).

RICHARTZ /37/ showed that the TTS could not be regarded as a relevant quantity to asses the belonging to long-duration harmful effect, nor could it be used as a parameter for an individual sensitivy. The same study, however indicates a link between the indivudal NIPTS and the TTS-effects caused by a single (8-hour) daily exposure dose, but with very low correlation coefficients. Because of the substantial fluctuations within individual reactions, several values (S) were determined and averaged over a period of several weeks during the workplace analysis. This resulted in a much better correlation with NIPTS. A significant sensitivity test based on quasi-steady-state noise must threfore comprise several S-measurements and consequently must be spread over a longer period /35/. Individual sensitivity tests based on intermittent, impulsive and, in particular, single bursts of noise must still be regarded as not being pee of contradiction.

3.2. Definition of noise exposure

The noise exposure of a person or group of persons in a working environment is defined objectively in physical quantites by measurement codes, which are published in particular in the form of national or international standards (Review of existing standards are given in /15/ and /39/). Such standards are updated at intervals of about five years to take account of the latest scientific and technical knowledgement and, when reviewed ore revided, submitted to national or international experts and other interested parties to allow objections to be made. Such standards can therefore be assumed to have taken due account of the latest scientific knowledgement at the time of publication. Because of its worldwide focus of relevant scientific and practical knowledge, special attention should be given to the standards of the International Organisation of Standardization (ISO) especially to the International Standard 1999 "Acoustics - Assessment of occupational noise exposure with respect to hearing impairment". In the first edition of this standard (ISO 1999, issued 1975) certain questions concerning the definition of noise exposure which were important for the practical application had to be left undecided or could not be answered thoroughly. On the other hand the new draft of this standard (ISO/DP 1999/1) contains a detailed description of the determination and measurement procedure of noise exposure which leaves scarcely any questions open with regard to application.

The small number of alternative procedures given in this standard lead to very similar results. Especially the section dealing with the measurement of noise exposure can be expected to gain general acceptance around the world.

Nevertheless, it is felt that this study should also include a summary and analysis of the developments in determination of noise exposure over the past five years, since some national measurement regulations still contain some differences compared with ISO/DP 1999/1.

Such different requirements may lead to noise exposure values for the same occupational noise which are significantly different (cf Fig. 5 for example). Therefore, in order to create European regulation on the reduction of hearing impairment risk which contains noise exposure limits, the relevant national measurement regulations will have to be harmonized.

An up-to-date description of these problems with special reference to historical developments for example was given by HÜBNER in his report to the ILO's (International Labour Office) international symposium on "The Protection of Workers against Noise" held in November 1979 /40/.

A main reason for some divergent trends in previous years is the lack of a well defined aim in some measurement regulations for "noise immission".

Noise may have very different effects on man : apart from hearing impairment it can interfere speech communication, cause annoyance, interfere or reduce man's efficient by the work or render certain tasks more difficult, activate the vegetative nervous system and increase accident risks and other health hazards. These various effects of noise are the result of "noise immission" as a single or cumulative cause. It is now realized that one single quantity characterizing "noise immission" cannot be expected to be well correlated with all these different effects simultaneously. Therefore several immission quantities must be selected which are specially adapted to the specific effect under consideration.

Previously, these circumstances were not fully recognized and therefore attempts were often made to define "multi-purpose" immission quantities, which were more or less correlated with a composition of various types of effects. This explains, for example, at least the start of the discussion about "impulse corrections". Where noises with impulsive components are concerned, such corrections are most adequate if annoyance is regarded; however, careful analysis is required before this correction is used for other types of effects too, such as the risk of hearing impairment. Nevertheless, since several years the aims of research in the field of hearing impairment are well defined and the more recent work on the subject are focused on the belonging to effects only.

The measured acoustical quantity (hearing impairment relevant noise immission) : $L_{Aeq,T}$

The specific acoustic immission quantity which causes hearing impairment is defined in the draft standard ISO/DP 1999/1 /24/. According to this the relevant quantity, the noise exposure, is splitted up into the measured acoustical quantity ("hearing impairment relevant noise immission") an the exposure time. The most important attributes of the measured acoustical quantity are the following :

a. The quantity to be measured is the A-weighted sound pressure level L_{pA}, which is generally abbreviated to L_i for a single measured value.

b. The measurement location (= microphone position) is as close and practical to the ear of the person at risk : (near the entrance of the external canal) when the person is present; the position where the middle of the head would be, without the person present.

c. The time constant of the measuring equipment (e.g. sound level meter) corresponds to the "slow" or "fast" caracteristics. This also includes the measurement of impulsive noises.

d. The quantity to be determined is the energy-equivalent A-weighted continuous sound pressure level $L_{Aeq,\Delta tj}$ measured over an observation period of t_j to t_{j+1}. This quantity is called short-duration energy-equivalent A-sound pressure level, if $t_{j+1} - t_j = \Delta t_j$ is small compared with the period of 8 hours.

The general definition of the equivalent continuous A-weighted sound pressure level is given by the following equation :

$$L_{Aeq,\Delta t_j} = 10 \lg \left\{ \frac{1}{\Delta t_j} \int_{t_j}^{t_{j+1}} 10^{0,1.L_i} \, dt \right\} \qquad \text{Equ. (6)}$$

where $\Delta t_j = t_{j+1} - t_j \leqq 8$ h

and

L_i is the instantaneous value of the A-weighted sound pressure level in function of time: $L_i = L_i(t)$

This equation applies for continuous measurement of pressure levels $L_i = L_i(t)$, which are in most practical cases fluctuating in time. This method became relevance using an integrating sound level meter.

If a sampling method is used, with visual or automatic readings at constant Δt time intervals within the measurement period Δt_j, the equivalent continuous A-weighted sound pressure level in determined by using the following equation :

$$L_{Aeq,\Delta t_j} = 10 \lg \left\{ \frac{1}{N} \sum_{k=1}^{N} 10^{0,1.L_i} \right\} \qquad \text{Equ. (7)}$$

where $\frac{\Delta t_j}{\Delta t} = N$ Total number of samples taken within Δt_j

and L_i= A-weighted sound pressure level at the time of the i-th sample

If a statistical distribution analyser is used the measured values L_i shall be grouped in classes with a width of 5; 2,5; 1 or lesser numbers of dB as appropriate. The equivalent continuous A-weighted sound pressure level is calculated by using the formula :

$$L_{Aeq,\,\Delta t_j} = 10 \lg \left\{ \frac{1}{N} \sum_{k=1}^{N} N_k \cdot 10^{0,1\,L_k} \right\} \qquad \text{Equ. (8)}$$

where L_k = mid-level $L_{pA,k}$ of class k

N_k = number of samples in class k

$N = \frac{\Delta t_j}{\Delta t}$ total number of samples.

M = total number of classes

The pattern of the statistical time-frequency of the level-classes L_k gives information on the time structure of occupational noise : the average value $L_{Aeq,\Delta t_j}$ according to equation (8) but also information on the spread of the time variations of the level values and statistical information suche as standard deviation s, variance s^2, and the level percentiles, e.g. : L_{10}, L_{90} (cf also /40/, /41/) can be derived.

e. The noise immission of an 8-hour working day with respect to the risk of hearing impairment caused by occupational noise is given by the equivalent A-weighted continuous sound pressure level determined for the working day ($t_E - t_A$ = 8 h, t_A = time of start of work, t_E = time of end of work) :

$$L_{Aeq,8h}$$

If the measurement duration covers the entire 8 h working day $L_{Aeq,8h}$ can be obtained directly form equations (6), (7) or (8) using Δt_j = 8 h.

If measurement durations Δt_j are less than 8 hours and if the 8 hours are splitted up into several measurement periods Δt_j according Equ. (9a), $L_{Aeq,8h}$ is obtained by averaging, on the basis of equivalent energy, the short-duration levels $L_{Aeq,\Delta t_j}$ registered during the different observation periods of 8 hours

$$L_{Aeq,8h} = 10 \lg \left\{ \frac{1}{8h} \sum_{j=1}^{N} \Delta t_j \cdot 10^{0,1\,L_{Aeq,\Delta t_j}} \right\} \qquad \text{Equ. (9)}$$

$$\text{with} \sum_{j=1}^{N} \Delta t_j = 8\text{ h} \qquad \text{Equ. (9a)}$$

It is not necessary in every case to take measurements throughtout all the time spans Δt_j, i.e. throughout the entire 8-hour day. If L_i is more or less constant for long intervals Δt_j, it will suffice to take measurements only during a short interval of Δt_j, during $\Delta t_i < \Delta t_j$. In equation (9),

$$L_{Aeq,\Delta t_j} = L_{Aeq,\Delta t_i}$$

but for Δt_j, the entire period of the constant noise is taken. This makes it possible to shorten the measurement period considerably in several cases.

- In order to determine the daily noise immission of a group of M persons, an energy-equivalent mean value of the individual noise exposures $L_{Aeq,8h,l}$ is used :

$$\overline{L_{Aeq,8h}} = 10 \lg \{ \frac{1}{M} \sum_{l=1}^{M} 10^{0.1 \cdot L_{Aeq,8h,l}} \} \qquad \text{Equ. (10)}$$

f. The long-duration immission of occupational noise is characterized by the immission of a working day typical for the long-duration T or by the energy-equivalent mean value of the different daily values $L_{Aeq,8h,m}$ for a long period :

$$\overset{\sim T}{L}_{Aeq,8h}$$

These 'long-duration' T can be several days, weeks or months. They must be defined in order to obtain a precise specification of $\overset{\sim T}{L}_{Aeq,8h}$.

g. The acoustic cause quantity of a hearing impairment occuring during the long time period T or expected impairment in the future is characterized by the noise exposure level (also known as the "noise dose level") :

The noise exposure level $L_{A,EX,T}$ in decibels is basically defined as

$$L_{A,EX,T} = 10 \lg \frac{E_T}{E_o} \quad \text{in dB} \qquad \text{Equ. (11a)}$$

where the noise exposure :

$$E_T = \int_o^T p_A^2 (t) \, dt \text{ in } Pa^2.s \qquad \text{Equ. (11b)}$$

with p_A = instantaneous A-weighted sound pressure

E_o is a reference value

and T is the relevant duration of the exposure.

The ISO-standardized noise exposure level is obtained for

$$E_o^{ISO} = P_o^2.T_o = 1,15 \,.\, 10^{-5} \; Pa^2.s$$

with $P_o = 2.10^{-5}$ P_a

$T_o = 60.60.8 = 2,88.10^4 s$ (= 8 hours)

$$L_{A,EX,T}^{ISO} = 10 \lg \frac{E_T}{E_o^{ISO}} \qquad \text{Equ. (11c)}$$

or

$$L_{A,EX,T}^{ISO} = L_{Aeq,8h}^{\sim T} + 10 \lg \frac{T}{8h} \qquad \text{Equ. (11d)}$$

By this specific choice of the reference value E_o, the (ISO-standardized) noise exposure level and the corresponding 8-hour (energy) equivalent continuous sound pressure level $L_{Aeq,8h}^{\sim T}$ are numerically equal, if T = 8h.

Equ. (11d) can also be written as

$$L_{A,EX,T}^{ISO} = 10 \lg \left\{ \frac{1}{8h} \int_o^T \frac{P_A^2(t)}{P_o^2} \, dt \right\} \qquad \text{Equ. (11d)}$$

This value, called in the Federal Republic of Germany as "8 Stunden Beurteilungszeit bezogener Beurteilungs-pegel" /62/ (rating level related to an 8-hour rating time) is according this formula identical to $L_{A,EX,T}^{ISO}$. This german rating value is therefore fundamentally a dose level, and not an energy-equivalent continuous sound pressure level. Only if the exposure period T is precisely equal to 8 hours that value can be considered as a continuous sound pressure level.

The choice of other values for E_o gives for the same noise dose, noise exposure levels which are numerically different from $L^{ISO}_{A,EX,T}$:

$$L_{A,ex,8h,T} = \tilde{L}^{T}_{Aeq,8h} + 10 \lg \frac{T}{T_o} \qquad \text{Equ. (11f)}$$

T = Number of working days x)
within the long duration T
to be assessed

T_o = 1 day

Between $L_{A,ex,8h,T}$ and the "noise dose" D, expressed in percentages, we have the folowing relation :

$$L_{A,ex,8h,T} = 10 \lg \frac{D}{100}_{se} + \text{Level of the exposure limit set for the time period T} \qquad \text{Equ. (12)}$$

The use of $L_{A,ex,8h,T}$ renders the (linear) quantity D superfluous and vice-versa.

h. The minimum requirements to be satisfied by the measurement equipment to be used are given in ISO/DP 1999 by references to relevant IEC standards.

The individual ISO/DP 1999/1 specifications listed above for the definition and measurement of acoustic immission and exposure quantities shall be discussed below, with reference to the scientific background on which they are based :

Point a) : Measurement quantity

The use of the sound pressure level as the measurement quantity for noise immission is generally accepted. A great majority of experts also accept its use as an A-weighted overall level for hearing risk

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x) A noise exposure level can also be related to a time unit of T^*_o = 1 year, T should then be expressed in years :

$$L^*_{A,ex,8h,T} = \tilde{L}^{T*}_{Aeq,8h} = 10 \lg \frac{T^*}{T^*_o} \qquad \text{Equ. (11g)}$$

A corresponding definition can also be drawn up for weeks.

assessment. There have been some proposals to modify the frequency weighting or to take account the presence of one or more predominant pure tone components by means of positive "tone corrections", but there are no data being ensured enough to give significant reasons to change the method of assessing hazard noise.

Historically, the A-weighted sound pressure level has its origine in an approach to the loudness level /40/ and is relatively closely correlated with this quantity /42/.

Point b) : Measurement location

The measurement location for hearing risk assessment is also more or less undisputed. The sound pressure level should be measured near the ear, of the person at risk, i.e. it is "man-orientated". This location, is in full agreement with the aim to protect the man. For frequent changes of man's location, therefore, a microphone should be used which is attached to the person : e.g. on one side of the helmet. For stationary work or even work involving variation of man's position within a well defined area, the measurments may be taken with one or several microphones which are fixed in space, "space-orientated". Furthermore a space-fixed microphone may be used, if the sound pressure field varies so little within the working area that the variation of microphone location causes no significant differences of the results compared with measurements taken near the ear.

Finally, space field measurements can be recommended for the determination of noise exposure of a group of persons working at different places within a certain area. (see Appendix figure A.1)

Space fixed noise measurements are also usual in working areas /43/ in order to demarcate "noise areas "/9/. It is clear that such measurements when performed correctly, also provides a hearing damage risk assessment with a tendency most by on the safe side for the person of risk. For this reason, these demarcations are generally also used for an alarm level indicating the start of preventive measures including the provision and use of personal hearing protection.

Point c) : Measurement equipment, time constant

The time characteristics of a sound level meter can be described by a RC-circuit with time constant t_o which is the same for loading and discarging and follows the square-law rectifier. The term required for the determination of an equivalent continuous noise level (ECNL) according to Equ. (6) : $10^{o.1\,L_i}$ can then always be presented as :

$$10^{\grave{a},1\,L(t)} = \frac{p^2(t)}{p_o^2} = \frac{1}{p_o^2 \cdot t_o} \int_o^t p\,(\tau)^2 . e \; \frac{t-\tau}{t_o} \, . \, d\tau \qquad \text{Equ. (13)}$$

Apart from slight instrument-caused errors which may occur if, for example, the time constant t_o is not very small compared with the integration period /44/, the value of the term $10^{o.1.L(t)}$ is thus <u>independent</u> x) of the time constant t_o for noise level measurement instruments according to IEC 179 xx), and consequently independent of response setting "slow" or "fast" /46/ :

$$L_{eq} = L_{Fm} = L_{Sm} \qquad \text{Equ. (14)}$$

(Index m represents the (squared) time average : indices F and S indicate the display response using "slow" or "fast" characteristic of the instrument).

The requirements of a sound level meter having characteristics as specified in IEC 179 (1973) xx) /45/, whether using analogue or digital techniques, means that readings or recorded values can be used for determination of energy-equivalent sound pressure level, independent of the use of time response "slow" or "fast".

This does not apply to a measurement taken by an impulsive sound level meter as specified in IEC 179 A /72/ xx) if using the meter characteristic "impulse". The reason for this lies in the difference of the time constants for the increasing display and for the decay. The greater decay time constant lead to a resulting mean value L_{Im} which is equal or <u>greater</u> than L_{eq} according Equ. (6) :

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x) The measuring instrument must have an adequate dynamic range of at least 65 dB(A) for occupational noise measurements.

xx) Or as specified in the more recent publication IEC 651 (1979), /73/.

$$L_{Im} \geq L_{eq} \qquad \text{Equ. (15)}$$

For noises with increasing "impulsiveness" the difference between the two values L_{Im} and L_{eq} increases. Examples of measured occupational noise in practise are shown in Fig. 5.

The difference :

$$L_{Im} - L_{eq} = K_I \qquad \text{Equ. (16)}$$

is used in some countries, e.g. the Federal Republic of Germany (DIN 45 645, Parts 1 and 2), as a characteristic of the impulsiveness of a noise and added to the L_{eq} value as an "impulsive correction" for specific noise effects.

V. LÜPKE /59/ analysed 200 carefully selected noise-related occupational disease cases in the iron and steel industry and calculated the correlation coefficients between hearing loss and the acoustical cause quantity using variously defined noise assessment factors. The correlation coefficient between hearing loss and the Robinson risk quantity /18/ based on L_{Aeq} proved to be 10 to 20% smaller than a correlation coefficient for a quantity based on $L_r = L_{eq} + K_I$. This would favour the use of the impulse correction. But furthermore v. LÜBKE had found that the correlation increase, he had established was not significant according the rules of statistics.

Finally a further effect which may be produced by impulsive noise, apart from L_{eq}, was examined in numerous studies on the basis of TTS measurement in which, the tested persons were exposed to short duration noises exposure in the range from several minutes to several hours. The latest studies on this subject, which use an integrated TTS (see Equ. (5)) in order to estimate hearing impairment risk, used noise dose quantities without impulse corrections /35/, /57/, /50/, /29/. KRAAK and his colleagues /35/, however, propose the use of different q-values ("exchange rates") for impulsive noises, depending on the intensity, impulse sequences and impulse duration, for averaging when calculating the causative quantity (cf Equ. 25), q-values of 3 dB and 6 dB are quoted. The 3 dB value, which is to be used for intensities of over 108 dB(A), corresponds to the principle of energy equivalence (for further information on this, see page 40). The q-value of 6 dB recommended by Kraak for lower intensities would result in smaller noise dose quantities than calculated for on the basis of $q = 3$ dB. If, therefore, $q = 3$ dB was used in the whole intensity range usual for occupational noises according to these proposals, the results for an impulsive noise would be either completely accurate or on the safe side, for the person at risk.

Finally, Fig. 6 presents a direct comparison of the correlation between the PTS and the noise dose, where various types of steady-state and impulsive noises are handled on the same basis in the noise dose. No significant differences between these different types of noise can be established from this comparison.

Numerous studies carried out in the United Kingdom and the USA in particular within the past 10 years point out that for the evaluation of the hearing impairment risk of noises, including impulsive noises, the equivalent continuous noise level L_{eq} (without an impulse correction) is a very useful quantity. This is evidenced in particulary by the numerous and varied studies performed by Martin and his colleagues /46/, /48/, /49/, /56/ and /63/ - issued in particular in ISVR Report N° 77. These investigations are based on the PTS data of various group of persons exposed to industrial noise, mainly from forging shops.

On the other hand, other relevant studies published up to now, e.g. V. LÜPKE /59/ or PASCHIER-VERMEER /94/, do not provide conclusive evidence that an L_{eq} adjusted with an impulse correction is a better cause quantity for the prediction of hearing impairment risk than an uncorrected L_{eq}. Reliable conclusions on this matter cannot be drawn without precise data on the actual individual noise exposure of the previous 20 to 30 years. Such information, however, cannot be obtained today without the inaccuracies which are characteristic of retrospective surveys.

As mentioned in Section 2 of this study, the possible supplementary effect of impulse component in noise on hearing impairment risk will be the subject of a special study organized by the Commission and therefore it will not be treated in advance in this study.

Point d : Short-duration average/long-duration average

Point e : $L_{Aeq,8h}$, $\overline{L_{Aeq,8h}}$

Point f : $\tilde{L}^{T}_{Aeq,8h}$

Point g : $L_{A,ex,T}$

In practice, the sound pressure level at a work place is only seldom constant in time.

Variations in levels of occupational noises frequently occur not only for short periods, e.g. as a result of the presence of impulses or because of the more or less intermittent and varied use of machines and tools in the course of a working day. The ears of workers are also exposed to further fluctuations caused by work breaks, tea and lunch breaks. Furthermore, in a very large number of workshops, it must also be assumed that the L_{eq} value measured for a single 8-hour day will not be reproduced on the next or subsequent days within a measuring tolerance but may vary significantly more. Such variations may occur as a result of daily changes in the use of capacities and fluctuations in the number of components and/or goods produced.

Fig. 7 and 8 indicate L_{Aeq} measurements from a plate processing plant which typify the situation in large and small-scale industry. They also illustrate the practical problems involved in the determination of long-duration exposure.

In order to determine the noise impact representing many years of exposure it is generally necessary when such fluctuations are possible to take measurements over a correspondingly long period. On the other hand an increase in the measurement period automatically entails a rise in measurement costs, which generally hinders the large-scale introduction of such measurements in practice. But there are some possibilities of solving these problems. The cost of measurements can be reduced, for example, if the measuring engineer is verywell experienced : by interviewing the competent people, he can first determine the various working processes which are significant in noise generation. Then he take measurements only of these typical processes over a short periods, evaluate the partial results on the basis of the actual periods and combine them into an overall noise exposure level. For the next few years, however, some doubt exist not be enough experts available to make such surveys at the numerous noisy workplaces.

A further solution to these problems, which is already applicable, are automatic measuring instruments operating over long periods : e.g. the "integrating" sound level meters or "dosimeters" (sound exposure meter). The use of such equipment is expressly permitted by ISO/DP 1999/1.

Finally, in certain cases, a large degree of uncertainty in the L_{eq} determination can be tolerated as a means of reducing the number of measurements required. This is possible especially in cases where it is only necessary to check whether an L_{eq} or L_{ex} lies below a specific limit, i.e. the value itself does not have to be determined, and where it is evident that this L_{eq} or L_{ex} probably lies well above or below the limit. .

For all physical measurements, including those taken to determine noise exposure, there is a link between the significance of a measured result and the range of variation of measured single values and number or duration of the measurements. It is usual to supplement a measured result, and therefore, in this case, the L_{eq} also, with a confidence interval. For randomly varying noises this interval is defined as (cf. /60/, /62/, for example) :

$$\omega = \frac{t \cdot s}{\sqrt{n}} \qquad \text{Equ. (17)}$$

where

t = statistical variable $^{x)}$ of the (two-sided) t ("student") distribution

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (\bar{L} - L_i)^2} \text{ standard deviation} \qquad \text{Equ. (17a)}$$

$\bar{L}$ = the arithmetical average of L_i, where $\bar{L} \approx L_{eq}$

n = number of random samples

For noises with a Gaussian distribution of the L_i sample values, it indicates that the actual value of L lies with a certain degree of probability, e.g. 90%, within the following range :

$$\bar{L}_{measured} - \omega \leqq \bar{L} \leqq \bar{L}_{measured} + \omega \qquad \text{Equ. (18)}$$

Appropriate statistical criteria can also be obtained from a measured value $L_{eq,measured}$ to determine probability of a limit not being reached or exceeded (see footnote).

This consideration shows that for the determination of exposure levels, always required over the long period, short duration measurements are only acceptable in the case of steady-state or quasi-steade-state noise (variations of $L_A \leqq 5$ dB(A) over an 8-hour day), especially if it is expected that $L_{eq,meas}$ lies near the risk limit. The use of a single shortduration measurement for noise with greater long-term fluctuations leads to highly uncertain results, even if within the time period of the single short-duration measurement the confidence interval is determined as a small value.

Therefore, for the evaluation of the accuracy of the result, the measurement period, time and date should be noted, and if possible, the relevant 90% - L_{eq} - confidence interval determined also.

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x) For footnote see page 36

When these considerations are being applied and errors calculated in this way, it is essential to relate this to the appropriate assessment period T_B. As indicated below, the noise exposure for the entire duration T_A of a individual period of the employment is to be taken ($T_B = T_A$) for the prediction of a future hearing impairment risk or for cost sharing of hearing impairment which has already occurred. Sampling must therefore be representative of this entire period. The variations within one working day or part of one working day should only be used if it has been stated that these are farly identical noise situations at the workplace on all other working days throughout the period of employment.

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x) The values of t are published in well-known statistical standards (Cf. DIN 55 303 Part 2, for example) and in technical publications. For an assumed confidence level ($1 - \alpha$) of at least 90%, the value of t can be approximated for a minimum of 6 measurements ($n \geq 6$) by means of $t \approx 2$. Where $t = 2$ is slightly greater than the actual t and grows with an increasing number of samples n. When n = 100, the difference is approx. 15%. For a confidence level ($1 - \alpha$) = 95% and for the two/one - sided confidence interval using 6 measurements, the exact t value is t = 2,447 respectively t = 1,943 and for 100 measurements t = 2,0 respectively t = 1,66

The standard DIN 45 645/2, /62/, defines classes of accuracy for occupational noise measurements with the aid of confidence interval (Equ. 17), as in the following table.

Accuracy class	1	2	3
ω in dB	≤ 1.5	≤ 3	≤ 6

On this basis, it is possible to check the significance of the fact that a measured level L_R (eg L_{eq} or L_{ex}) does not exceed a limit value L_{gr} :

	Statement :	Accuracy class		
		1	2	3
		Difference $L_R - L_{gr}$ in dB		
Limit value L_{gr}	Not exceeded	< 0	< -3	< -6
	No decision possible	-	- 3 to + 3	- 6 to + 6
	EXCEEDED	≥ 0	$> +3$	$> +6$

The causative quantity : Noise exposure, noise dose, energy principle

More than 10 years ago fundamental research was understaken by a team led by BURNS and ROBINSON /18/ dealing with the effects of continuous occupational noise on the hearing capability of persons exposed to noise throughout their working lives. These investigatious came to the conclusion that the A-weighted "sound energy" received during the working period was a representative quantity for noise exposure as far as risk to hearing impairment was concerned. According to this "energy principle", in order to determine noise exposure, both the sound pressure level and the appropriate exposure time must be determined. This principle was fully accepted by several experts from different countries and finally the International Organization for Standardization (ISO) in the period 1971 - 1975 includes the "energy principle" in its document dealing with the assessment of hearing impairment risk in Standard 1999 /23/.Initially this was considered reliable only for steady-state noises.

An important step towards the extension of this principle to impulsive and intermittend noise was made by ATHERLEY and MARTIN /63/ and by MARTIN an RICE /48/, who showed that the energy concept of BURNS and ROBINSON could also be applied to impulsive occupational noise, i.e. that the A-weighted "sound energy" was a suitable quantity for the assessment of hearing risk. Further studies conducted by RICE and MARTIN /48/ dealt with gunfire noise, which exposes the unprotected ear to intensities of up to 135 dB ("high-intensity impulsive noise") and came to the even broader conclusion that the energy principle can be applied to all types of noise.

The latest information from investigations of the "Dresden School" /35/, /29/, /57/, in which the character of the noise was also varied considerably and in which integrated TTSs and actual PTSs were used, also define the cause quantity as a "noise dose", i.e. as a quantity representing the product of sound pressure and time. In this product, only the exponent of sound pressure is varied : within the range of 1 to 2. This definition of a "dose" simply modifies but does not basically change the "energy concept". The long-duration "dose" was also successfully used by V. LÜPKE /60/ for the assessment of hearing impairment risk. These studies are based on actual PTS cases involving over 200 persons with recognized noise-induced occupational diseases.

A summary of definitions and comparison of the various noise doses, their levels and of the noise exposures which are now under discussion are given below.

The synthesis of sound pressure and time takes account of the fact that noise-induced hearing loss can be caused both by high sound pressure intensities within a short time and by lower sound intensities over a long period.

Since sound pressure is measured by the sound level meter as sound intensity, i.e. $\sim p^2$, it was natural at first to express the noise dose as :

$$D^* \sim p^2 \; . \; T \qquad \text{Equ. (19)}$$

Here, the sound pressure is expressed as a power of 2; the dimension of this dose is Pa2. sec and can be indicated as energy (per unit of area) after reference to the acoustic impedance ρc.

The most important definitions of a noise dose level to be found in publications, can be summarized in a "general noise exposure level" :

$$L_{EX} = 10 \lg D / D_o \qquad \text{Equ. (20a)}$$

where

$$L_{EX} = F (L_A) + k \; . \; \lg_{10} \frac{T}{T_o} \qquad \text{Equ. (20)}$$

Here, $F(L_A)$ is a function of the A-weighted sound pressure level L_A, k is a value "approaching 10" (cf. ROBINSON/BURNS /18/, pag. 103) and T is the exposure time determined on the basis of an 8-hour day and 5-day week, and which is intended to provide the assessment of occupational noise effects over the assessment period T_B. T is expressed in days, months or years and T_o is the corresponding reference period (1 day, month or year).

The simplest special case is the classical formulation of the noise dose in accordance with Equ. (19) and as contained in Equ. (20). The noise exposure was formulated by ROBINSON and BURNS /18/ as :

$$L_{ROB} = L_A + 10 \lg \frac{T}{1 \text{ year}} \qquad \text{Equ. (21)}$$

ROBINSON and BURNS, however, also worked with

$$E_{A2} = L_{A2} + 10 \lg \frac{T}{1 \text{ year}} \qquad \text{Equ. (22)}$$

where L_{A2} is the L_A value which is just exceeded in 2% of the observation period.

In the studies from by V. LÜPKE /64/, the following is used :

$$L_{L\ddot{u}} = l_r + 10 \lg \frac{T}{1 \text{ year}} \qquad \text{Equ. (23)}$$

where the "assessment level" L_r is either equal to L_{eq} or equal to L_{eq} plus the impulse correction K_I (cf. Equ. (16)) : $L_r = L_{eq} + K_I$.

The "Dresden School" (e.g. /35/, /29/, /25/) proposes a dose whose quantity expressed as a level is given by :

$$L_{EX}^{DR} \sim 10 \lg \int_{t_E} \left(\frac{p(t)}{p_o} \right)^{\kappa} dt \qquad \text{Equ. (24)}$$

where p(t) = instantaneous value of the sound pressure, t_E = exposure time and exponent κ has the value 1 or 2, depending on the character of the noise. For $\kappa = 2$, this quantity is equal to the level of the "usual" dose x) 'Equ. (19)).

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x) Where $\kappa = 1$, the value of Equ. (24) corresponds to an $L_{EQ,q}$ in accordance with equation (25), with q = 6 dB.

Finally, the formula for a generalized equivalent sound pressure level L_{EQ} should be noted; in publications, this is also used for the quantity $F(L_A)$:

$$L_{EQ,q} = \frac{q}{\lg 2} \cdot \lg \left(\frac{1}{T} \sum_{i=1}^{n} T_i \cdot 10^{\frac{\lg 2 \cdot L_i}{q}} \right) \qquad \text{Equ. (25)}$$

This quantity becomes precisely the energy-equivalent continuous noise level if the q-factor ("exchange rate") of 3 is selected :

$$L_{EQ,q=3} = L_{eq} \qquad \text{Equ. (26)}$$

where $q \neq 3$, it is assumed that the effect of a noise level is not proportional to the exact value of the sound energy integrated in this period.

The value $q = 5$, which is no longer accepted by most experts in the United States of America x), is still included in the occupational noise protection regulations of the US Department of Labor (OSHA Regulations /65/). When $q > 3$, the value $L_{EQ,q}$ is smaller or at the most equal to the energy-equivalent value L_{eq} for one and the same noise. Accordingly, the ratio for L_{EQ} is reversed when q is less than 3.

The exposure level introduced by ROBINSON (Equ. (21)) is based on the assumption that the hearing impairment expressed in dB steadily progresses with the logarithm of time. Although this does not met the often mentioned principle of "saturation", but PASSCHIER-VERMEER has proved /66/ that no saturation occurs at about 2 kHz. On the other hand this frequency range, however, is very important for the effect of the impairment in respect to speech interference. The application of the

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x) H.E. von GIERKE and D.L. JOHNSON write the following /30/ : "In summary the 3-dB rule is more conservative, as well as more protective. The 5-dB rule leads with the anchor point at 90 dB(A) definitely to levels too high for short durations, namely, 115 dB(A) for 15 min. A further point in favor of the 3-dB rule is its incorporation into the ISO Standard R 1999. The United States voted in favor of this standard in 1970. The basis for this vote was that of all the technical, industry, government, and interest group representatives in the United States, 26 voted affirmative on this standard, 5 negative, and 1 abstained".

ROBINSON formula with its original time function therefore appears to be justified in order to be on the safe side for persons at risk.

On the basis of the above facts, it can be taken as certain that the noise dose, i.e. the sound pressure level and the exposure time combined, is the cause of hearing impairment. Nevertheless, risk determination are frequently to be found which are not based on the dose itself but on the two parameters L_{eq} and exposure time T expressed separately. The reasons for this type of two-parameter expression lie partly in the practical advantages of the use of graphs or formulae and partly in the two quite distinct purposes which a risk determination may serve :

A. The retrospective determination of noise exposure in the context of a decision on whether an already existing hearing impairment may have been caused by occupational noise.

For such cases, the present state of preventive hearing protection is such that no country has available the precise data on the noise dose experienced from the age of 18 by each worker exposed to hearing risk. Attempts are being made in some countries to compile such collections of personal exposure data with the introduction of files or data banks (cf /67/, for example), especially for the purpose of 'sharing the costs' /64/ between various insurance companies. So far, however where the majority of persons are elderly workers with hearing impairment, the only solution in most cases is to estimate in retrospect the mean sound pressure level to which the person has been exposed for many years of his working life or to take a rather uncertain short-duration measurement for the most recent past. Where the work has remained relatively the same, it must then be assumed that the quality of the working environment has remained the same during the period of employement. Finally, the second parameter, is the relevant exposure period of the past, must be determined from this. In the case of retrospective assessment of hearing damage risk, this exposure period is generally based on the actual period of employment at the job in question or, in cases where a very long working life is being assessed, for lack of any other information, it is based on age. In the latter case, the normal practice is to allow the exposure period to begin at the age of 18 or 20. The retrospective assessment of noise-induced cause thus always requires the separate measurement or determination of the two dose parameters : sound pressure level and exposure time. Only in the more distant future will it be possible to replace these data with directly measured, i.e. already combined, dose (= noise exposure) data.

B. The assessment of a future noise risk to be applied in particular to young and middle-aged workers.

For this purpose, a noise dose covering the entire expected future period of employement cannot be measured but only 'extrapolated' : on the basis of a mean sound pressure level (L_{eq}), which has been measured over an observation period which is short (e.g. several weeks of the work in question) in relation to the probable period of employement, or is obtained with the aid of a dosimeter measured within this relatively short period. In order to determine the risk for the entire expected future period of employment however, the excepted period must be estimated and used separately as a further parameter.

When a specific model is used to describe hearing impairment risk which is based on the energy principle, it is evident that risk calculations will not depend on whether a given noise dose (noise exposure) as such is used as a whole or split into mean sound pressure levels, e.g. L_{eq}, and exposure time.

Point h) : Measuring instrument requirements

The rapid progress of the past few years in the field of electronic measuring equipments opens up new possibilities for the measurement of exposure quantities in relation to hearing impairment risk. The general trend in measuring instrument technology since about the beginning of the 1970s is characterized by the growing supply of increasingly smaller, lighter, and to some extent cheaper instruments with higher capacities. The increasing use of microprocessors in acoustic measurement technology is the key to this development, which cannot yet be considered at an end. An up-to-date summary of the state of acoustic measurement technology can be found in two special editions of the journals "Noise Control Engineering" /68/ and "Sound and Vibration" /69/.

As mentioned above, to obtain a reliable calculation of the long term noise dose, three partly contradictory conditions must be met as far as possible, especially where noise levels vary considerably over the relevant period of time : (1) an accurate result, characterized by a small conficence interval, (2) the representativeness of the result for a very long period, e.g. for the duration of an employment period of several years in most cases and (3) a minimum of measurements respectively a minimum of measurement costs. The above-mentioned new developments in measuring instruments brings this 'three sided problem' closer to a solution, especially with the newly developed integrating sound level meter and dosimeter. Both instruments are of the type which will allow measurement costs - and especially evaluation costs - to be reduced and at the same time increase the accuracy of results by providing long term measurements. Measurement and evaluation costs decrease for two reasons when such instruments are used : the measurements to not have to be taken by highly qualified acoustical experts and the instruments perform the entire evaluation work shown in Equ. (6) 'automatically'. It is relatively easy to prevent the distortion of results by misuse of such instruments. If demand is sufficiently high the cost of individual instruments can be reduced by large-scale production. Low-priced instruments make it possible to perform exposure measurements for a large group of persons in a relatively short time.

It is also possible in many cases to reduce the measuring period substantially and with it the cost of measurements by means of statistical measuring methods, i.e. random sampling [x)], which can be performed automatically, semi-automatically or without automation, if these methods are applied correctly. The savings which the method involves become particularly apparent when it has to be decided by means of measurements whether the L_{eq} of a specific workplace exceeds a given limit L_{gr} or not.

A small number of sample measurements may then suffice to answer the question and indicate the decision risk at the same time, especially if the actual L_{eq} lies well above or below L_{gr} (cf also the footnote on page 37). ISO/DP 1999/1 allows the use of integrating sound level meters, or alternatively dosimeters or sample measurement methods and therefore the above-mentioned basic requirements for practical implementation can be met with the application of this standard.

The measurement tolerances of all instruments used must be kept within specific limits, taking into account especially the interference factors occurring in practice, such as electric or magnetic fields, extreme temperatures, differences in air pressure, wind speeds etc. Furthermore, the instruments must be strongly built i.e. they must be suitable for use in the often very rough conditions of the working environment. A further important condition is coverage of a minimum dynamic range of 65 dB(A) for the measurement of occupational noise. Such minimum requirements are specified in publications of the IEC (International Electro-technical Commission) : for precision sound level meters in publications numbers 179 and 179A /72/, for sound level meters with less stringent precision requirements in number 123 /71/, and finally both grades of accuracy classes in the latest publication : number 651 /73/. The latter IEC publication is incorporated in ISO/DP 1999/1 by way of reference. For the other types of measuring instruments for which the IEC has not yet published technical standards, ISO/DP 1999/1 provides the necessary supplementary requirement for the meantime until such IEC publications become available.

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x) A special measurement method of this type useful for practical applications is the acoustic multi-moment sampling, the use of which for the calculation of L_{eq} in practical occupational noise situations has been described by GRIMM /70/ and HÜBNER /40/.

4. Noise-induced hearing impairment risk expressed in terms of the cause factors

In the context of the definition of noise-induced hearing impairment risk it was mentioned in section 3.1 that, on the basis of the latest knowledge, it is not possible to forecast the risks of hearing impairment for a certain single person but only for well-defined groups of persons and that such a forecast can be made in terms of the statistics only. The main reason for this behaviour is given by the individually varying relevant sensitivity x). These variations, however, also provide justification for continuing individual audiometrical checks. Nevertheless, we shall treat the following description of hearing impairment risk as a 'group risk' and as a function of the relevant cause quantities in accordance with the ISO definition given here in 3.1.

The main cause of noise-induced hearing impairment is naturally the exposing noise, and noise exposure is the main causal factor. In this section, therefore, the risk in question will also be discussed in detail as a function of noise exposure. Before hand, however, some supplementary points require examination.

In the working environment, noise which risks the ears is closely linked with specific activities, work processes, production methods and machines, and thus with specific professions and industries. Accordingly, the risk of a person suffering a hearing impairment towards the end of his working life is also dependent on the industry or profession in which he worked (fig. 9). It may therefore be logical to introduce an 'occupational group risk' for groups of persons of a specific profession (cf also LAFON /26/).

The simplest definition of such a risk r_B is based on the number of recognized cases of noise-induced occupational diseases recorded in the past whithin this occupational group, which is related to the total number of persons employed in the group :

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x) cf also the figures listed on page 15 showing examples of the pattern of age-induced hearing loss.

$$r_B = \frac{\text{number of persons compensated}}{\text{number of persons insured in the occupational group}} \qquad \text{Equ. (27)}$$

Relevant data compiled from the reports of the Federation of Mutual Accident Insurance Associations in the Federal Republic of Germany /74/ of 1976/1978 are evaluated in this way and yield in the comparison of occupational group risks shown in fig. 10. It is also possible, as suggested by LAFON and DUCLOS /26/, /27/, to define the occupational group risk more differentiating by additional introduction of age or exposure time.

The main advantage in the use of an occupational group risk is its simplicity. A disadvantage, however, lies in the fact that there is no possibility of differentiating between jobs within the same occupational group where noise has been reduced and those where it has not been reduced, and thus there is little motivation to reduce the actual cause of the hearing impairment : noise at specific workplaces.

Before the correlations between hearing risks and noise are considered more closely, paragraph 3 of Article 8 of ILO agreement 148 /13/ should be examined briefly. This paragraph contains a reference to a possible cumulative effect of several simultaneous hazards in the working environment : e.g. noise and vibration. The simultaneous influence of several risk factors at the workplace and the resulting increase in occupational risks was discussed in detail in the tripartite committee of noise and vibration experts of the ILO in 1974 and 1977, where it was found that there were no definite data nor experience on the effect of cumulation of greater risks than those caused by one of the factors under consideration. Cumulative effects must therefore be omitted from any further discussion of hearing impairment risk at that time.

The correlation of hearing risk with acustic and personal causal quantities

Hearing risk can be regarded as a function of 3 independent variables (/18/, Appendix 10, Section 1.2)) : sound pressure level L, exposure time T and age M. Also the sex of the person at risks has a slight influence but can be regarded only in connection with the age-induced hearing impairment. This statement, basing on the 3 main parameters and published over 10 years ago by ROBINSON, still applies today. Since then, the only changes have been a more precise definition of the risk itself and of the content of the cause factors, especially 'sound pressure level L'. Finally, the application of risk prediction has been extended to various types of noise.

Different ways to express the hearing impairment risk by means of the parameters mentioned before shall be demonstrated by the examples of 3 corelation models. Model 1 is one of the first 10-year old ROBINSON models. It is presented mainly for historical reasons. Model 2 is the result of investigations of the 'Dresden School' published within the last 5 years, and model 3 is the cause-effect correlation published by the International Standard ISO/DP 1999/1 in 1980.

Model 1 :

The ROBINSON risk quantity R /18/ is probably the simplest representation of hearing impairment risk :

$$R = \frac{L_{EX} - 85}{5} \qquad \text{Equ. (28)}$$

Here, $L_{EX} = L_r + 10 \lg \frac{T}{1 \text{ year}}$ is a certain exposure level x) and L_r the immission assessment level x) which, when extended and generalized, is quoted as :

$$L_r = L_{eq} + \Delta \qquad \text{Equ. (29)}$$

V. LÜPKE /64/ analysed data from recognized occupational disease cases and, using measurements or estimation of the exposure levels concerned, established a link between the ROBINSON risk quantity and the

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x) Remark : In his former publication Robinson used names for these quantities which differ significantly from those given in ISO 1999/1, 1980. Especially Robinson took the term "immission" for the quantity which in ISO and in this study is called "exposure level". Our definition of "immission" is given in chapter 3.2.

probability of a reduction in working capacity of 20% being exceeded (the German criterion for recognition of an occupational disease), as shown in Fig. 11. The result is the following correlation between this risk quantity R and assessment :

Robinson risks R	Assessment
0 to 1	The conditions are not met for a hearing impairment to be caused by the effect of noise experienced so far
2	The development of hearing impairment is unlikely
3	The possibility of development of hearing impairment cannot be fully excluded
4	The development of hearing impairment is possible
5	The development of hearing impairment is probable
6 to 9	The development of hearing impairment is highly probable

On the basis of 30 years' employment, corresponding to $10 \lg \frac{T}{1 \text{ year}} = 15$ dB, and taking as the limit for the value of the risk quantity = R 3 from the above table, for which the minimum reduction in working capacity is 20%, with a probability of only 3% (cf Fig. 11), a limit value for noise assessment level $L_{r,limit}$ of

$$\underline{L_{r,limit} = 85 \text{ db(A)}} \qquad \text{(ROBINSON/ v. LÜPKE, 1975)}$$

is obtained from Equ. (28).

BURNS' and ROBINSON's publication /18/ (especially Appendix 10, Fig. 10.1) presents a link between the mean 4kHz hearing threshold shift, exposure time and immission levels.

On the basis x) of a limit value (fence) of 53 dB for PTS_{4kHz} and an exposure period of 30 years, a maximum permissible exposure

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x) In accordance with Fig. 4, a PTS_{4kHz} of 53 dB corresponds to the most widely used limit $PTS_{0.5/1/2\ kHz} = 25$ dB (cf also PLUNDRICH /25/).

level L_{EX} of 107 dB(A), and thus an assessment level limit of

$$\underline{L_{r,limit} = 92 \text{ db(A)}} \qquad \text{(Robinson, 1970)}$$

is obtained.

This sound pressure level limit is therefore 7 dB(A) higher than the more recent evaluations of v. LÜPKE.

Risk model 2

The "developed Dresden model" presented by PLUNDRICH in 1979 /29/ uses a somewhat modified definition of the noise dose (cf Section 3.2) and finally presents the mean PTS for the testing frequency of 4 kHz in a correlation of the causal factors as follows :

The mean value (Q = 50%) of the permanent hearing loss of a group of persons exposed to noise is given by :

$$\overline{PTS_{4\ kHz}} \sim \lg \{ 10^{\frac{PTS_{AK}}{40}} + 0,55\ (p_E - 0,2).\ t_E \} \qquad \text{Equ. (30)}$$

$$\text{with} \quad PTS_{AK} = (\left(\frac{t_L}{10}\right)^2 - 6) \qquad \text{Equ. (30a)}$$

Here,

p_E = the rms value of the sound pressure in Pa

t_E = the exposure period in years

t_L = age in years

PTS_{AK} = age-induced PTS.

The spread of the hearing loss is presented in this model by the standard deviation s as a function of the size of the group and the mean PTS. The model is based on the evaluation of the data published by 12 authors and 20 other sources, making up over 10 000 sets of measured personal data.

The following two results of the Dresden studies are interesting :

- noise has no further effect on the PTS if

  $$P_E \leqq 0.2 \text{ Pa},$$

  to which a sound pressure level of

  $$L_{Aeq,limit} \leqq 80 \text{ dB(A)} \quad \text{(PLUNDRICH, 1979)}$$

  corresponds. For sound pressure levels of 80 dB(A) or less, only the age-induced PTS becomes relevance.

- An evaluation of this model compared with other cause-effect correlations shows that the Dresden model is in good agreement with the ISO 1999 - 1975 for the high, i.e. critical intensities, and indicates smaller risks than ISO 1999 - 1975 for the lower intensities.

Model 3 : ISO/DP 1999/1

The precisely defined group risks of the latest ISO draft for the determination of hearing impairment risk have already been explained in Section 3.1. To begin with, we shall only deal with the noise-induced hearing threshold shift $N_{Q,T}$ which, without the additional, age-induced PTS, is exceeded as a result of a specific noise exposure over T years in Q% of a group of persons screened as homogeneous. The following equations are valid for the important prediction of small Q values (Q < 0.5) and large T values (10 years $\leqq$ T $\leqq$ 40 years) :

$$N_{Q,T} = N_{50,T} + k \cdot d_u \qquad \text{Equ. (31)}$$

$$\text{for } L > L_o \text{ with } N_{50,T} = (a + b \cdot \lg T) \cdot (L - L_o)^2 \qquad \text{Equ. (31a)}$$

$$d_u = (a_u + b_u \cdot \lg T) \cdot (L - L_o)^2 \qquad \text{Equ. (31b)}$$

$$\text{for } L \leqq L_o, \; N_{50,T} = o \qquad \text{Equ. (31c)}$$

Here, T is the exposure time in years

$L = L_{A,EX,T^*}$ is an average of daily ISO-noise exposure level, tipical for the long-duration exosure time T. If the non-occupational noise exposure away from the workplace can be neglected compared with the occupational exposure received during one spell :

$$L \approx L^{ISO}_{A,EX,spell} \qquad \text{Equ. (31d)}$$

Espressing noise exposure level by A-weighted continuous sound pressure level and duration T^* of the daily spell in hours

$$L \approx L^{ISO}_{A,EX,spell} = \tilde{L}^{T}_{Aeq,T^*} + 10 \lg \frac{T^*}{8h} \qquad \text{Equ. (31e)}$$

Where T^* is the actual duration of the spell expressed in hours

k, a, b, a_u, b_u are constants given in ISO/DP 1999/1 as functions of testing frequencies and percentile Q

L_o is the maximum daily noise exposure level which gives, for the mean of a population, no NIPTS even for a great many years of exposure time.

These specific noise exposure levels L_o depend on frequency. Expressed as L^{ISO}_{A,EX,T^*} or approximately expressed as A-weighted equivalent continuous sound pressure level $\tilde{L}^{T}_{A,eq,T^*}$ the L_o-levels have the following values :

for f = 500 Hz : 93 dB(A)
f = 1 kHz : 89 dB(A)
f = 2 kHz : 80 dB(A)
f = 3 kHz : 77 dB(A)
f = 4 kHz : 75 dB(A)
f = 6 kHz : 77 dB(A)

These values are outside of the range of validity of the statistical description of the model however, and therefore it is better to obtain data based on the smallest Q value for which the model is relevant. The basic experience with the latest risk model is sufficient (cf ISO/DP 1999/1, Section 5.3.2, Note), to obtain data between Q = 2% and 98%, but not for values below 2% or over 98%. We therefore examined the NIPTS for percentiles down to 2% (Fig. 14). A general presentation of the noise-induced hearing threshold shifts as functions of the relevant factors, calculated on the basis of ISO/DP 1999/1, is given in Figs 12, 13 and 14.

The following is an example of one of these calculations : on the basis of a 'fence" value of 30 dB for 3 kHz, and a 30-year period of noise exposure with a specific $\tilde{L}_{Aeq,8h}^{30\ years}$ the following $\tilde{L}_{Aeq,8h}^{T}$ values cause the $NIPTS_{3kHz}$ = 30 dB to be exceeded in Q% of the group of exposed persons :

f = 3 kHz : $\tilde{L}_{Aeq,8h} = 80$ dB(A) : $Q << 2\%$
$\tilde{L}_{Aeq,8h} = 85$ dB(A) : $Q << 2\%$
$\tilde{L}_{Aeq,8h} = 90$ dB(A) : $Q < 2\%$
$\tilde{L}_{Aeq,8h} = 95$ dB(A) : $Q = 3\%$

The corresponding dose levels valid for the total exposure period of 30 years x) (exposure levels) $L_{A,ex,T}$ are obtained from the $\tilde{L}_{Aeq,8h}$ in the case in question by adding 15 dB.

Finally, the auditory threshold shifts caused by noise are compared with the hearing loss resulting from age alone. As an example, the figures below are age-induced PTS-value (ATS) which represents the mean PTS within the relevant group - respectively this PTS-value will be just exceeded by 50% of the persons in this group (Q = 50%). Furthermore the relevant PTS-value are given for the small percentile (Q = 10%) meaning the PTS-value which is just exceeded by 10% of the persons of the group.

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x) Remark : This dose level $L_{A,ex,T}$ is related on one year. If using the ISO-exposure level which is related on one working day (8 hours) the $L_{Aeq,8h}$ -values must be enlarged by appx. (15 dB + 23 dB) = 38 dB. Thereby one year is assumed appr. 200 working days.

The values are given at various testing frequencies and for a group of 50 and 60-year old men (taken from ISO/DP 7029, Table C.1 for highly screened population) :

		A_Q	
		Q = 50%	Q = 10%
f = 2 kHz	50 years :	7,2 dB	20,5 dB
	60 years :	12,3 dB	28,6 dB
f = 3 kHz	50 years :	11,3 dB	28,5 dB
	60 years :	20,3 dB	41,8 dB
f = 4 kHz	50 years :	16,4 dB	36,4 dB
	60 years :	28,2 dB	55,0 dB

The percentages at the bottom of the previous page are those of a group of persons who were exposed to noise of various $\tilde{L}_{Aeq,8h}$ intensities for 30 years and who suffered an $NIPTS_{3\ kHz} = 40$ dB as a result of this noise alone. We shall now compare this percentage with the permanent threshold shift caused by advanced age alone, i.e. without noise exposure. The ISO Draft DP 7029 /22/ provided the data given in Fig. 15. We find values x) exceeding a 'fence" of 40 dB at 3 kHz in Q% of the highly screened male age group of :

Effect of age (highly screeened population) :

f = 3 kHz Age 40 years : Q << 5%
Age 50 years : Q < 5%
Age 60 years : Q = 12%

In the group of 60 year old men, the very high percentage of 12 exceeds the 3 kHz fence value generally recognized for hearing handicaps, although these persons were never exposed to the relevant noise in their lives.

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x) Statistical data on age-induced permanent threshold shifts are considered reliable by ISO DP 7029 only between $0.05 \leq Q \leq 0.95$. Accordingly, the description cannot be applied for $Q < 0.05$.

Finally the ISO documents should be evaluated, presented and interpreted with regard to the cumulative effect of noise and age. This cumulative effect is established according to Equ. (3). Fig. 16 shows an example of the calculated 3 kHz threshold shift for a group of 50-year old men who were exposed to noise intensities of 100 dB(A) $\leq L_{Aeq,8h} \leq$ 85 dB(A) for 30 years. Also indicated is the percentage Q which exceeds the relevant 40 dB fence value within this group of persons.

Effect of noise and age x):

$$f = 3\ \text{kHz} : \tilde{L}_{Aeq,8h} = 85\ \text{dB(A)} : Q < 5\%$$

$$\tilde{L}_{Aeq,8h} = 90\ \text{dB(A)} : Q = 13\%$$

$$\tilde{L}_{Aeq,8h} = 95\ \text{dB(A)} : Q = 31\%$$

A comparison of these results with the correlated effects caused by noise alone and by age alone shows that a large-scale hearing handicap preferably develops as a result of the cumulation of both causes : noise and age.

5. Summary of PTS threshold values

The limit values of the threshold shifts as the 'fence' of an "hearing handicap" by various experts, various countries and various standards, as already mentioned, differ in most cases only in the selection of testing frequencies or combinations of testing frequencies, but are generally similar in content /25/.

The various figures are summarized again as follows :

$$\overline{PTS_{0.5/1/2\ Khz}} = 25\ \text{dB}$$

$$\overline{PTS_{1/2/3\ kHz}} = 30\ \text{dB}$$

$$PTS_{2\ kHz} = 30\ \text{dB}$$

$$PTS_{3\ kHz} = 40\ \text{dB}$$

$$PTS_{4\ KHz} = 53\ \text{dB}$$

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x) The age-induced components of these values an based on data (data base A of ISO/D/S 1999) derived for a highly screened population.

A comparison of these figures with the age-induced threshold shifts shows that there is quite a considerable difference according to whether these 'fence' values are only applied to the noise-induced part of the threshold shift (NIPTS), as on page 52, or wether these limits are taken by authorities for the sum of age-induced (ATS) and noise-induced (NIPTS) threshold shift (page 54). In the latter case the Q percentages of the example quoted on page 52 are increased considerably for the same 'fence'.

6. Conclusions

The present state of knowledge and recent publications which have been taken into account and which refer mainly to developments since 1975 are the basis of the following conclusions for the protection of workers against noise which may cause hearing impairment.

6.1 The increase over the past ten years in the number of persons with impaired hearing caused by occupational noise is the result of exposure to noise in the course of previous decades.

The start of the increase in cases of noise-induced occupational diseases recorded in many countries is very closely connected with the start of large-scale audiometrical check-ups in the countries in question. The check-ups thus resulted in the discovery of a relatively large number of previously unknown cases.

More humane criteria for the award of hearing impairment also result in an increase in the number of recognized cases of noise-induced occupational diseases.

6.2 The noise-induced hearing impairment risk can be successfully reduced, as already seen in many countries, by :

- definitions of the cause of risks by means of measurement code for noise exposure at workplaces;
- the establishment of a noise exposure limit based on such a measurement code;

- the introduction of certain further measures at workplaces where the noise exposure limit is exceeded.

Such measures for the reduction of the individual risks are :

. preventive medical examinations and audiometrical check-ups for the persons at risks; suitability tests at the start of employment in noise areas;

. reduction of noise exposure by technical and/or organizational means, where this is technically and economically feasible; more stringent noise emission regulations for the installation of new workshops and workplaces. Requirements concerning the use of advanced noise control techniques, noise emission labelling for relevant working equipment (machines, production plant);

. provision and obligatory use of personal means of noise protection;

. introduction of a medical file for persons working in noisy areas;

. appointment of doctors for suitability examination and check-ups;

. cost allocation ruling for the various measures and associated expenditure, compensation;

. establishement of penalty provisions for non-compliance.

6.3 Persons without ear protection should not be exposed to very high sound intensities occuring with sound pressure peaks of over 140 dB. Measures should be taken to prevent such risks by technical or organizational means, even if they occur only very rarely, or care must be taken to ensure that suitable personal hearing protection is always used.

6.4 With the aid of 'hearing impairment risk models', which have now been developed even further, it is possible to forecast noise-induced hearing impairment for years to come, or to make retrospective calculations of the causes of noise-induced hearing impairment with the help of noise intensity, exposure period, age and, a factor of only slight influence, sex. These forecast and calculations are statistical in character. Therefore the hearing impairment risk can only be expressed as a percentage of persons from a group exposed to a specific amount of noise belonging to the same age group, whose hearing loss exceeds a specific limit ('fence').

6.5 The model prepared and issued by the International Standards Organization (ISO/DP 1999/1, 1980) which is being discussed in many countries at the moment, can be recommended as a basis for the calculation of hearing impairment risk as a function of noise intensity, exposure time and age. The present version, however, could be further simplified in respect to some factors, e.g. more precise specification of the testing frequencies are possible instead of the present general requirements.

The ISO document does not specify a limit value to serve as a basis for legal recognition of a hearing handicap. This specification is left to the competent national or international bodies for social and economic reasons.

6.6 Noise- and age-induced hearing impairment can vary considerably depending on the individual. In a group of otological normal 60-year old men, for example, has a age-induced PTS of 28.2 dB at 4000 Hz which exists in this group as the mean. However, 10% of persons of the same age group with normal hearing, but who have aged more quickly, have a PTS of over 42.3 dB, and another "more youthful" sub-group of 10% of the same age group has a PTS of no more than 6.8 dB.

Similar variations in hearing impairment can be found in noise-induced hearing damage.

It is therefore not possible to predict noise- or age-induced hearing impairment accurately for specific individuals either retrospectively or in advance : only statistical statements relating to groups of otherwise similar persons can be made.

6.7 If for an officially specified mean hearing handicap to be tolerated as a maximum allowable limit ("fence") (long-duration) dose limit can be determined with the aid of a risk model. Thereby it is possible to make a probability statement on what percentage of the population working in certain noisy conditions not exceeding the dose limit must nevertheless expect to suffer a "hearing handicap" as prescribed in the "fence" specification.

6.8 The PTS limits ("fence"-value) used in various countries for the recongition of noise-induced occupational diseases are similar to each other in quantitative terms. They differ mainly in the selection of testing frequencies or testing frequency combinations only. The following are PTS values which, when exceeded, are assumed to be accompanied by a "hearing handicap".

$$\overline{PTS_{0.5/1/2\ kHz}} = 25\ dB; \qquad \overline{PTS_{1/2/3\ kHz}} = 30\ dB$$

$$PTS_{4\ kHz} = 53\ dB; \qquad PTS_{3\ kHz} = 40\ dB; \qquad PTS_{2\ kHz} = 30\ dB$$

The values can be transformed in each other on the basis of the most recent knowledge.

6.9 After continuous exposure to occupational noise at a specific level of $L_{Aeq,8h}$ over a period of 30 years, the "fence" values given here in 6.8 will be exceeded according to the latest ISO risk model, with the following degree of probability, after subtracting of the age-induced threshold shift :

$\overset{\sim T}{L}_{Aeq,8h} = 80\ dB(A) \quad : \quad Q \ll 2\%$

$\overset{\sim T}{L}_{Aeq,8h} = 85\ dB(A) \quad : \quad Q \ll 2\%$

$\overset{\sim T}{L}_{Aeq,8h} = 90\ dB(A) \quad : \quad Q < 2\%$

$\overset{\sim T}{L}_{Aeq,8h} = 95\ dB(A) \quad : \quad Q = 2\%$

The cumulative effect of noise and age results in much higher hearing impairment risks. In a group of male highly screened persons of the 50-year old age category, who had been exposed to an occupational noise level of $L_{Aeq,8h}^{\sim T}$ for 30 years, the respective fence values were exceeded in Q% of the persons :

$L_{Aeq,8h}^{\sim T}$ = 85 dB(A) : $Q < 5\%$

$L_{Aeq,8h}^{\sim T}$ = 90 dB(A) : $Q = 13\%$

$L_{Aeq,8h}^{\sim T}$ = 95 dB(A) : $Q = 31\%$

$L_{Aeq,8h}^{\sim T}$ = 100 dB(A) : $Q > 50\%$

Only when occupational noise exposure and age are cumulated does permanent hearing loss become a very serious problem.

6.10 The descriptions derived from the risk model are suitable for the specification of a dose limit. Because of the substantial individual variations in human sensitivity to noise-induced hearing impairment, however, it appears necessary to have audiometrical monitoring studies and medical checks performed for noise exposures with values in the vicinty of the limit and especially in the noise intensity range above it.

By specifying a risk-orientated noise limit dose, it is possible to separate those persons who are completely or most probably safe, from those subjected to a high degree of risk. The restricted high-risk group, i.e. the workplaces of this group of persons, are then selected for the introduction of further steps.

6.11 It is also possible to define a hearing impairment risk for a specific occupational group, industry or job. This risk can be quantified and specified easily on the basis of the occupational disease statistics of the past (Fig. 10). This type of risk description has the draw-back that there can be no differentiation between jobs where noise has been reduced and those without noise abatement measures because the scope of the group is too broad, and as a result, there is little motivation to introduce technical noise reduction measures at specific workplaces.

6.12 The causative quantity for hearing impairment is the noise exposure respectively the noise dose. This quantity in expressed by the noise exposure level $L^{ISO}_{A,EX,T}$ and may be splitted up into two terms : (1) the energy-equivalent continuous sound level $\tilde{L}^{T}_{Aeq,8h}$, which represents the long-term situation during employment, and (2) the belonging to exposure period T.

To prevent workers against the risk of hearing impairment a limitation of noise exposure shall be prescribed by a certain maximum allowable noise exposure level, not to exceed e.g. at the end of each day. The noise exposure is the quantity adequate to realize the aim to protect workers because this quantity covers and limitate both : noise intensity and exposure time.

The quantities can be determined on the basis of the requirements given for the measurement procedures and definitions in ISO/DP 1999/1, which are now generally agreed internationally.

When the measurement specifications of ISO/DP 1999/1 are adopted in official regulations, however, the supplement of some precisions and details, and a selection of alternative procedures should be considered for the sake of clarity and simplicity.

The relevant new ISO noise exposure measurement procedure make no provision for corrections to the energy-equivalent permanent sound level if the noise containes impulsive or intermittent components; however, the use of such corrections is not fully excluded.

6.13. Normally, the daily noise exposure of a worker in industry and handicraft shows significant fluctuations in time. A more precise determination of the exposures relevant for numerous years seems therefore difficult or expensive. There are however solutions - e.g. by use of dosimeters, giving up some accuracy when exposures are not in the vicinity of limiting values - which in practice enables us to screen the persons exposed to a significant noise-risk.

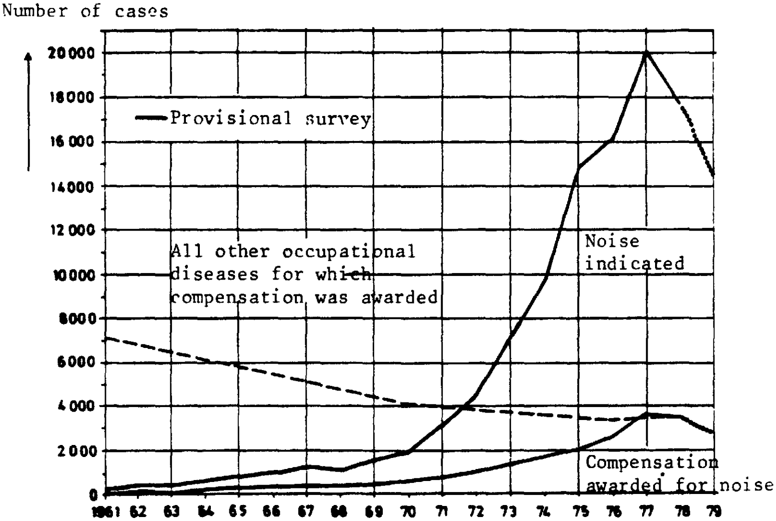


Fig. 1 : Trend of occupational diseases in the FR of Germany

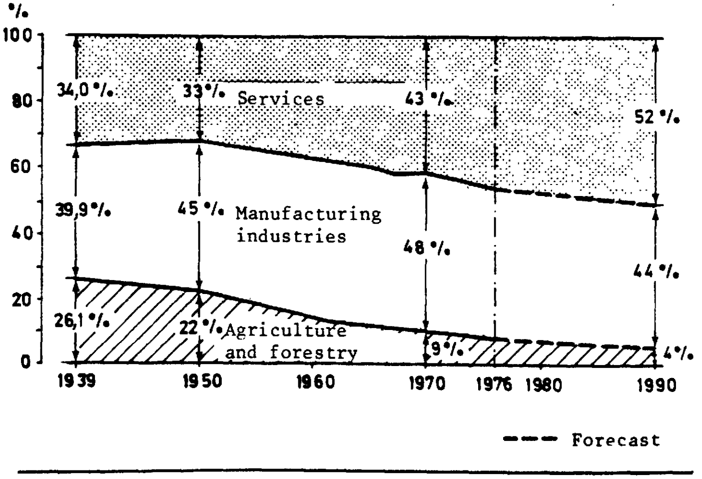
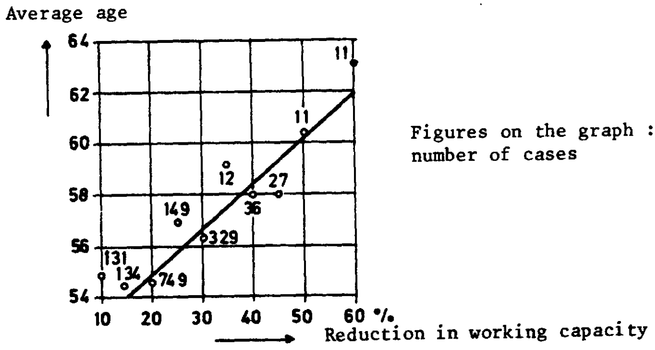


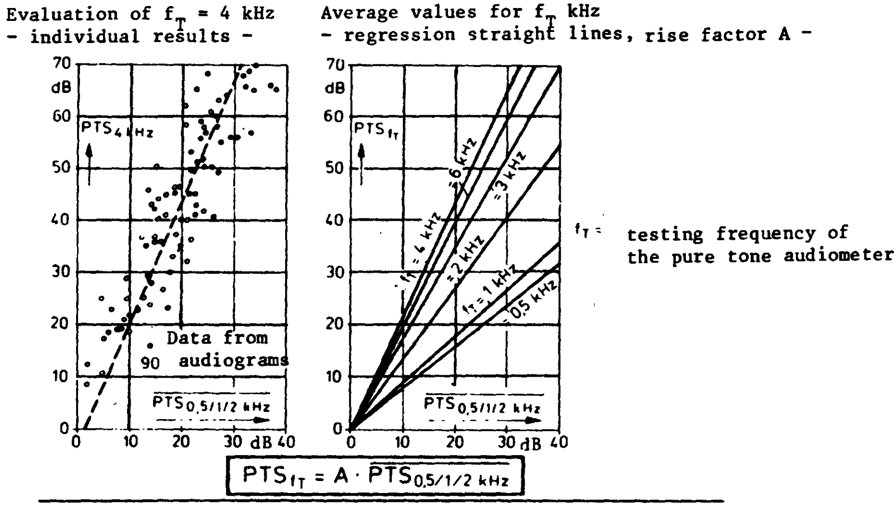
Fig. 2 : Distribution of workers in the FR of Germany according to economic sectors



Figures on the graph : number of cases

1.4 million insured members of the South-German Iron and Steel Industry Mutual Accident Insurance Association from 1969 to 1978
Source: Institutė of Noise Control of the Federation of Mutual Accident Insurance Associations

Fig. 3 : Average age of persons awarded compensation, as a function of reduction in working capacity


Evaluation of f_T = 4 kHz - individual results -

Average values for f_T kHz - regression straight lines, rise factor A -

f_T = testing frequency of the pure tone audiometer

$$PTS_{f_T} = A \cdot \overline{PTS}_{0.5/1/2\ kHz}$$

Fig. 4 : Correlation between PTS_{fT} and average value $\overline{PTS_{0.5/1/2}}$ kHz

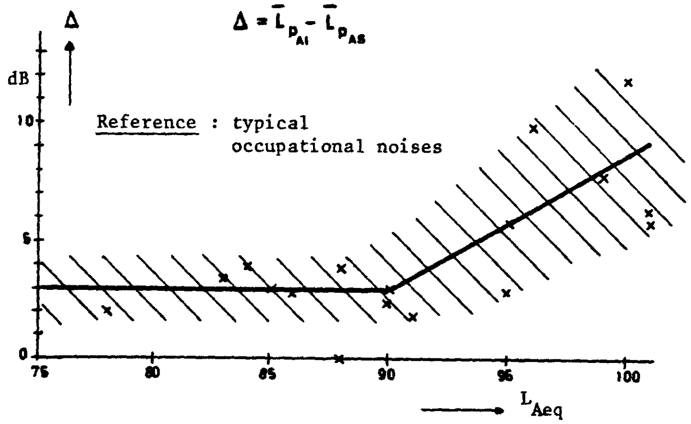


Fig. 5 : Differences Δ in the display of a sound level meter when different display response time settings are used.

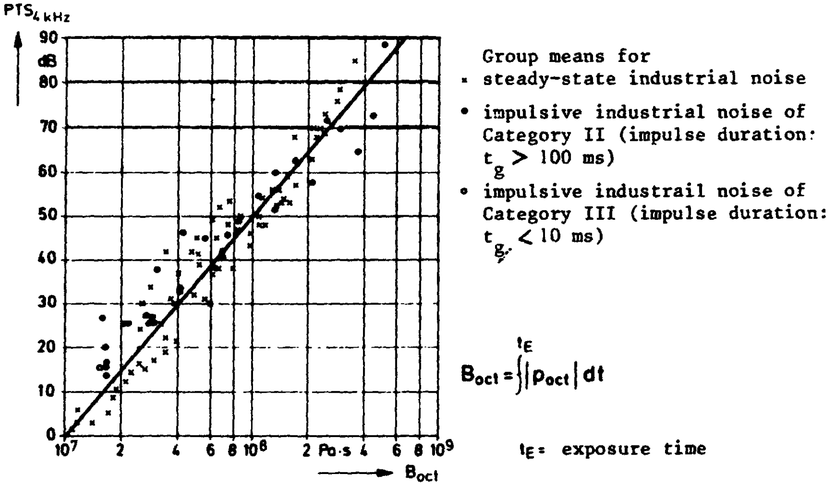


Fig. 6 : Correlation between hearing loss (PTS_{4kHz}) and noise dose (B_{oct}) according to Fuder and Kraak /57/ for noises with varying level- histories

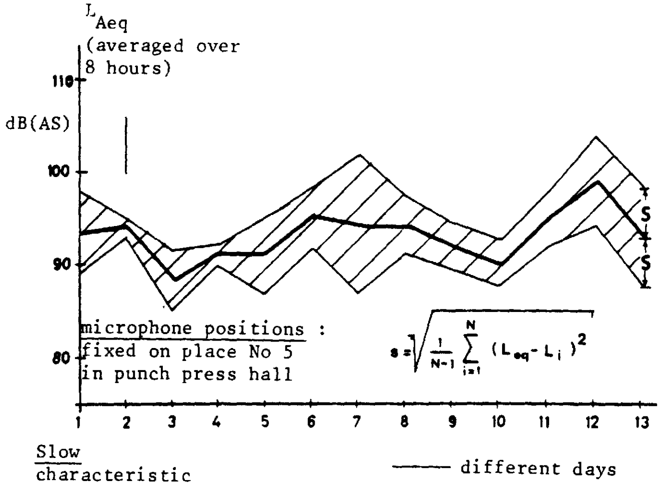


Fig. 7 : Change in $L_{Aeq,8h}$ in time at a typical workplace in the metal industry
(see Hübner /40/)

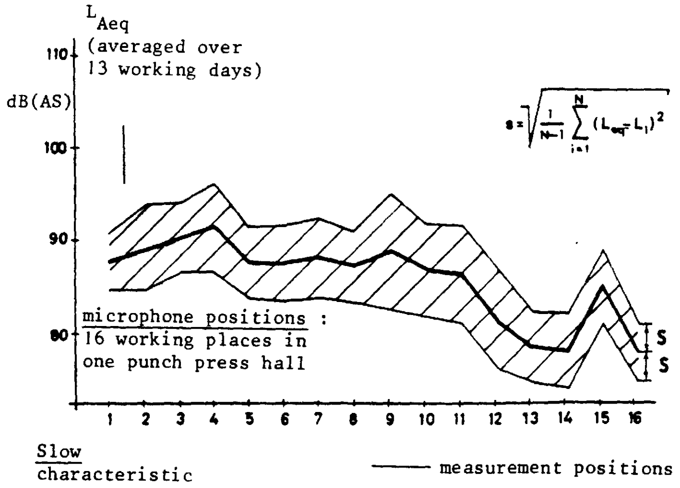


Fig. 8 : Changes in $L_{Aeq,8h}^{13\ days}$ at various workplaces in the same production shop
(see Hübner /40/)

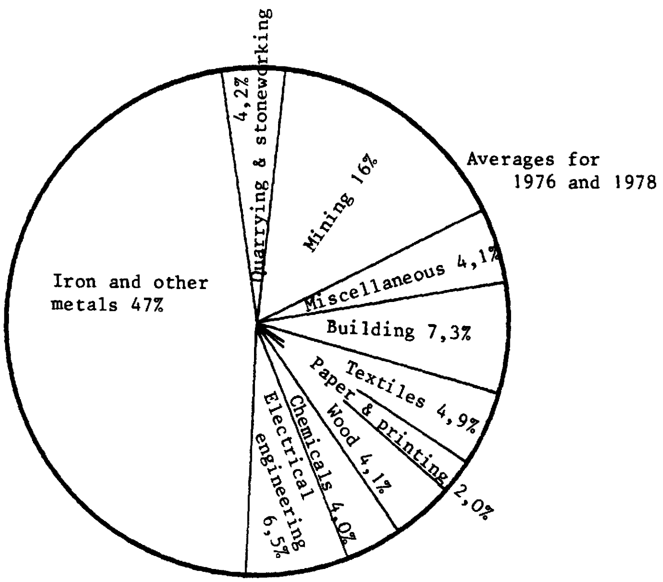


Fig. 9 : Cases of compensation for noise-induced deafness in the Federal Republic of Germany in 1976 and 1978 - Distribution according to the individual industries

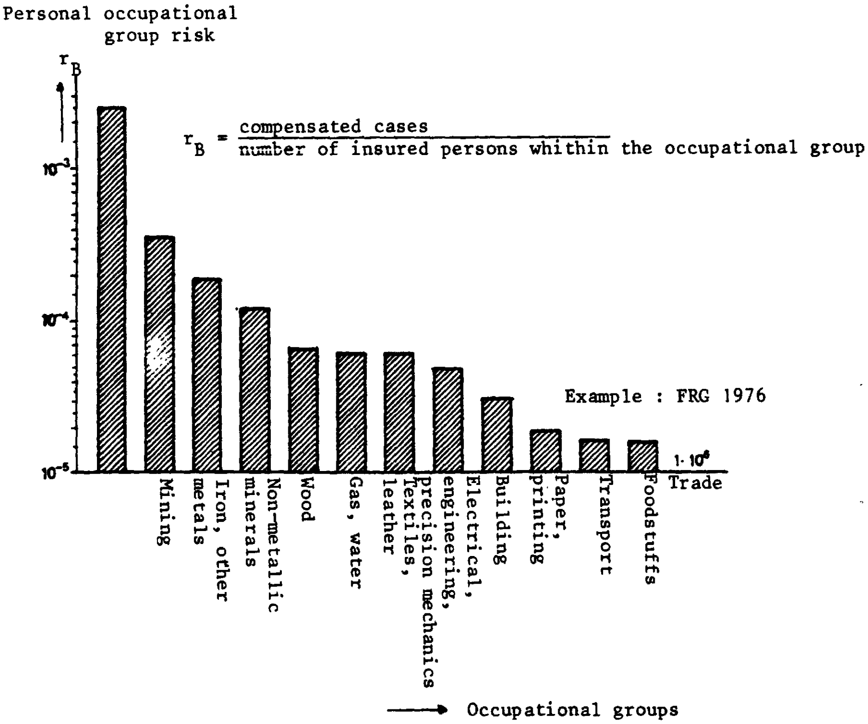


Fig. 10 : Personal noise-induced hearing impairment -g to occupational groups

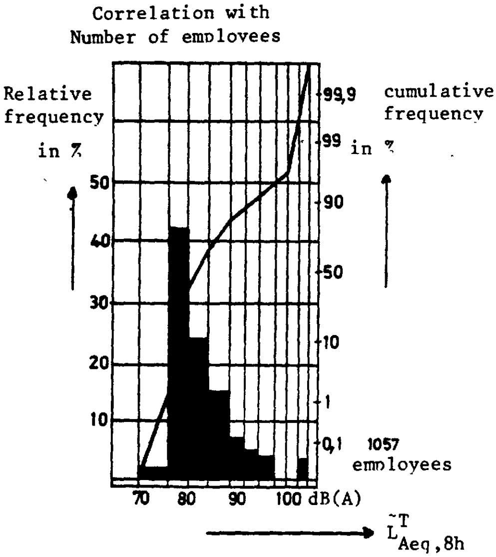


Fig. 10a : Distribution of workplaces:employees across L_{Aeq} classes in a noisy metal-working plant, according to Hübner /92/.

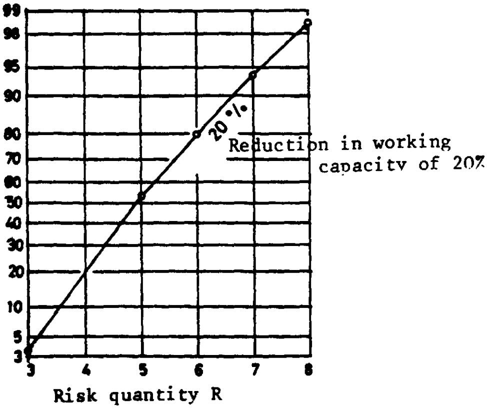
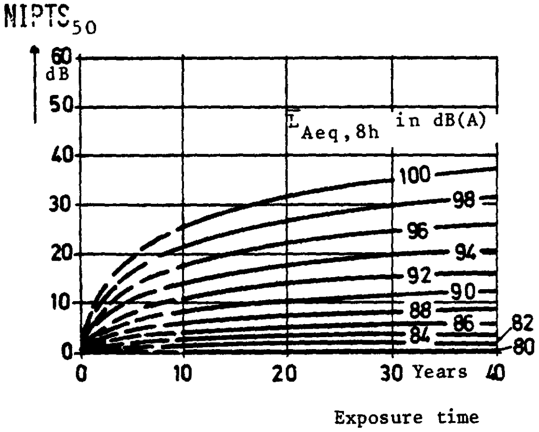
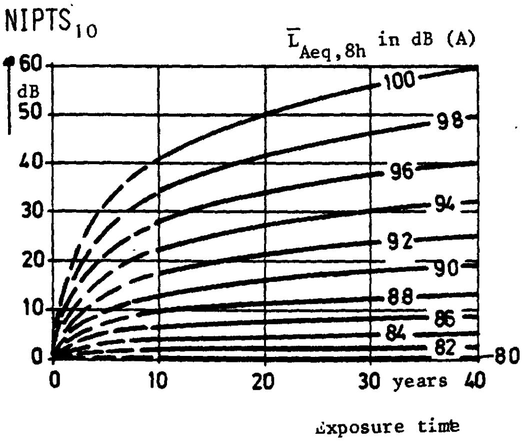


Fig. 11 : Correlation between the Robinson risk quantity R and the cumulative probability of compensated cases of noise-induced occupational diseases

f_T = 3000 Hz



Q = 0,5 (group mean)



Q = 0,1

Fig. 12 : Noise-induced permanent threshold shift (NIPTS) as a function of $\overline{L}_{Aeq,8h}$ and exposure time T for testing frequency 3 kHz.

Basis : ISO/DP 1999/1

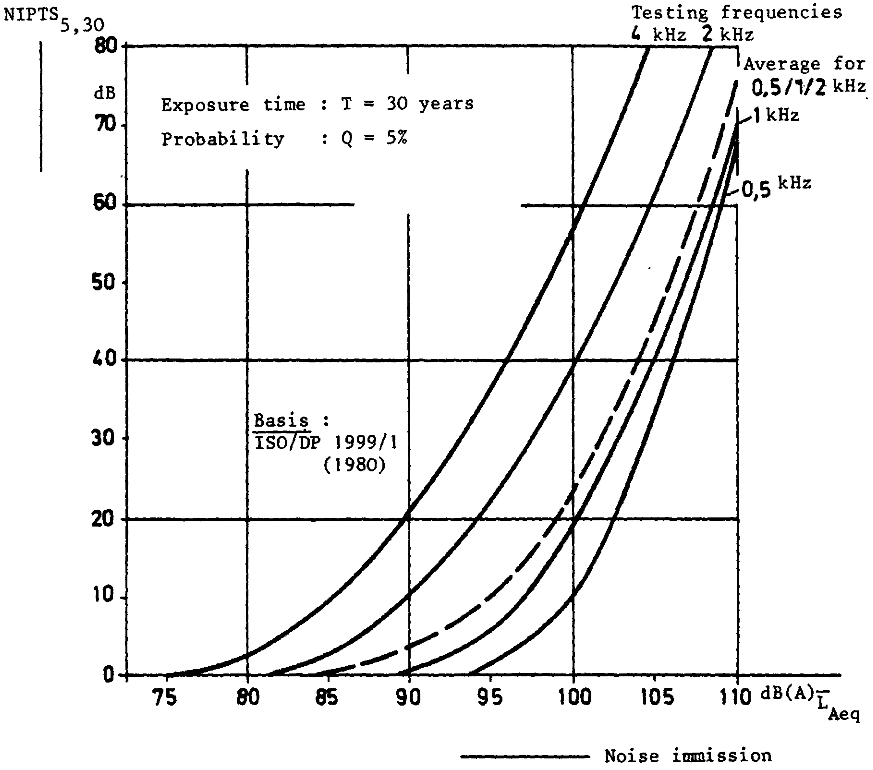


Fig. 13 : Noise-induced permanent threshold shift (NIPTS) a a function of $\bar{L}_{Aeq,8h}$ for various testing frequencies and an exposure period of 30 years.

Basis : ISO/DP 1999/1

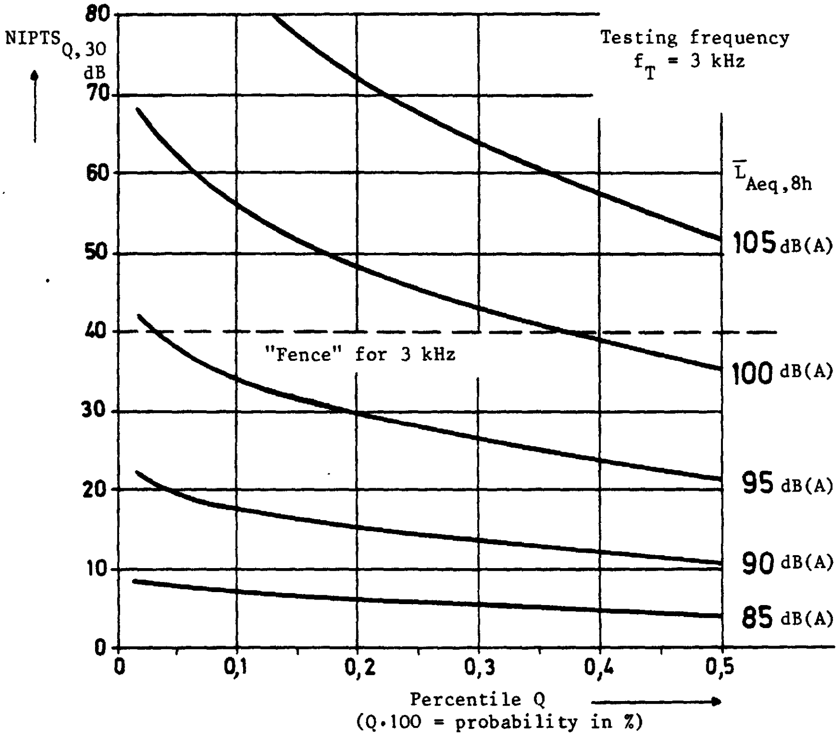


Fig. 14 : Noise-induced permanent threshold shift (NIPTS) a a function of percentiles Q for 30 years' exposure time T - Testing frequency 3 kHz.

Basis : ISO/DP 1999/1

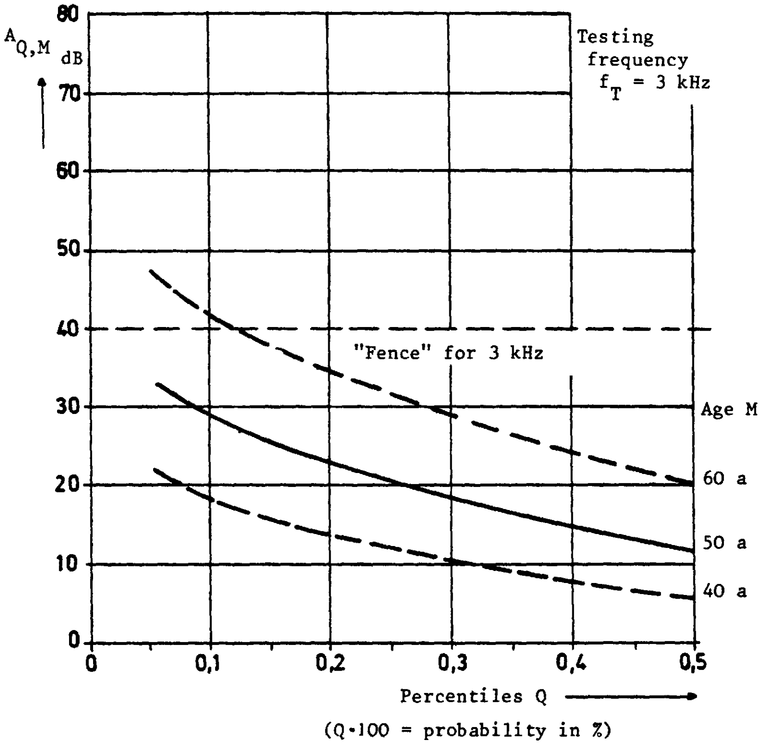


Fig. 15 : Age-induced permanent threshold shift $A_{Q,M}$ in males as a function of the percentiles Q for various age group M, testing frequency 3 kHz.
Basis ISO/DP 1999/1, Annex A, and ISO/DP 7029 (1980)
(Highly screened population)

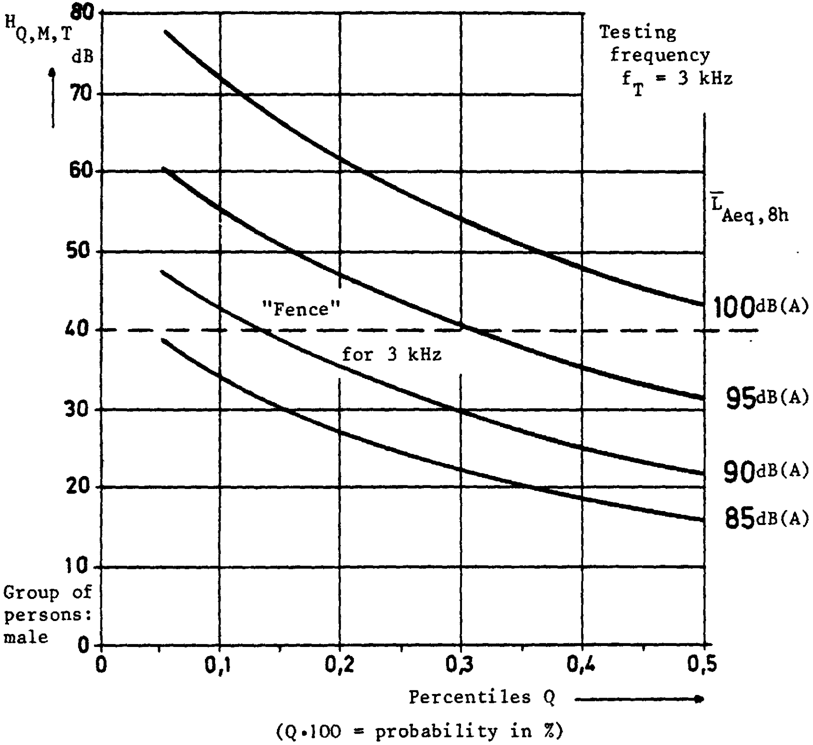


Fig. 16 : Cumulation of noise- and age-induced threshold shift $H_{Q,M,T}$ as a function of the percentiles Q for 30 years' exposure time (T = 30) and for a group of 50-year old males (M = 50 a), testing frequency 3 kHz.
Basis : ISO/DP 1999/A, Annex A, (1980)
(Highly screened population)

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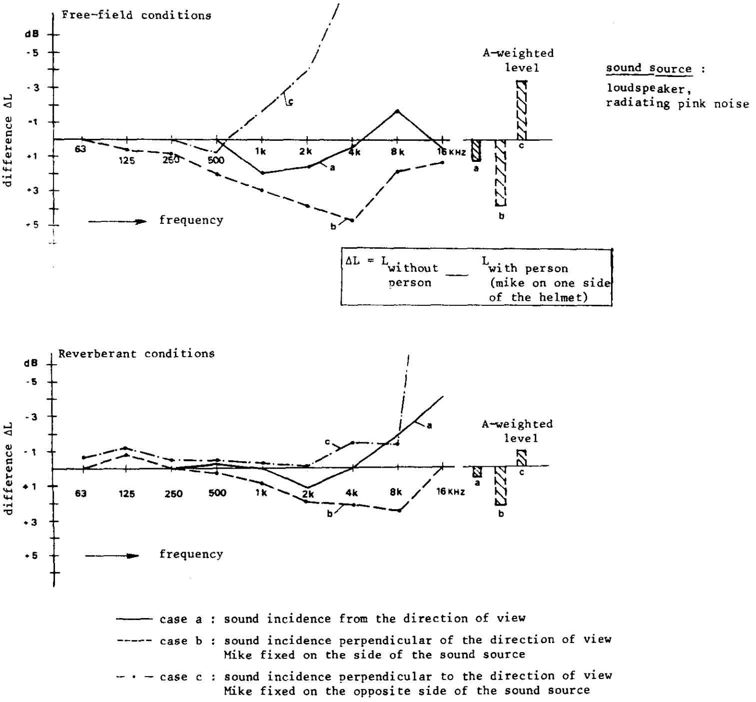
APPENDIX

Modifications of measured sound pressure levels caused by the presence/absence of the body of the exposed person

An investigation published[1] in 1981 gives information dealing with the modification ("error") of measured sound pressure levels which is caused by the following two situations : (1) the microphone is fixed on one side of the helmet respectively fixed on one side of the head of the person and (2) the microphone is located at the same position in space but the measurements are carried out in absence of the person. Therefore the sound pressure modifications reported here are caused by the influence of presence and absence of the person respectively by a scattering effect only. A possible movement of the exposed person in several spaces having different sound pressure levels would result in an additional effect of sound pressure level variation, which is not the object of the graph given in figure A.1.

Especially for free field conditions the figure A.1 shows that sound pressure measurements in absence of the person lead in the most relevant frequency range to values being smaller compared with those obtained for the situation where the person is present, except the microphone is fixed in the "shadow" of the noise incidence.



ΔL = $L_{without\ person}$ — $L_{with\ person}$ (mike on one side of the helmet)

—— case a : sound incidence from the direction of view

----- case b : sound incidence perpendicular of the direction of view Mike fixed on the side of the sound source

– · – case c : sound incidence perpendicular to the direction of view Mike fixed on the opposite side of the sound source

Fig. A.1 Modification of the sound pressure caused by the body of the exposed person.

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EUR 7874 — Correlation between hearing impairment risk and exposure to noise — Present level of research

G. Hübner

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Approximately 8% of persons working in industry and handcrafts today are exposed at their jobs to noise levels which are a danger to unprotected ears. The large number of noise-related occupational diseases recorded in several industrial countries over the past 10 years is evidence of the high degree of risk and widespread occurrence of high-level occupational noise. This can be stated independently of national differences in the criteria for the assessment of noiseinduced occupational diseases.

The example of several European countries shows that by publishing certain administrative measures and ensuring that they are applied, it is possible to protect the worker against the risk of hearing impairment.

The main purpose of this study is to make a critical analysis and examination of the practicability of measures to protect workers at risk recommended by various bodies and issued in various countries.

The establishment of a limit for the individual noise exposure and of measurement procedure to check such a limit are important first steps in this direction. This exposure limit is based on a model offering the correlation between noise exposure and its effect on hearing capability.

The internationally harmonized standard ISO 1999 (1980 draft) covers both a required noise exposure measurement procedure and a model for the 'exposure-impairment correlation'. The use of the main results of this document can be recommended. The ISO-correlation model makes it possible to estimate by statistical means the hearing impairment risk which remains after having established a specific noise exposure limit.

The wide range of individual variations in human sensitivity to the harmful effects of noise and the practical problems of enforcement of the use of personal ear protection requires strongly that the establishment of noise exposure limits should be combined with large-scale audiometric checks and other measures for all persons working in noisy areas. Appropriate occupational medical services should be established, if not already available.

Particular attention, however, should be given to the reduction of noise intensities in the working environment by technical and/or organizational means. In order to limit the costs of such measures, information on technical means of noise control should be propagated and techniques developed even further. Moreover, people should be motivated to construct and produce quieter machines and to develop manufacturing processes resulting in better working environmental conditions.

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