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EXPOSURE CRITERIA, OCCUPATIONAL EXPOSURE LEVELS

Dr D.L. Johnson
Brüel, Bertrand, Johnson Acoustics Inc.
4719 Mile High Dr.
Provo, Utah 84604
USA
FAX 001-901 224 6386
danielljohnson@compuserve.com

Dr. P. Papadopoulos
Ministry of Labour & Social Security,
Head of Unit, SEPE Stadiou 29,
GR – 101 10 Athens,
GREECE,
Fax: +30.1.37.02.329

Dr N. Watfa and Dr J. Takala
Occupational Safety and Health Branch
International Labour Office (ILO)
Geneva 11
SWITZERLAND
watfa@ilo.org takala@ilo.org

4.1. GENERAL CONSIDERATIONS

Airborne sound can be described as propagating fluctuations in atmospheric pressure capable of causing the sensation of hearing. In occupational health, the term "noise" is used to denote both unwanted sound and wanted sound as they can both damage hearing. Noise-induced hearing loss has been recognized and reported for several hundred years. However, prior to about 1950, reliable dose-effect data were not available. Before World War II, due to lack of uniformity in instrumentation and related units and scales, studies from various parts of the world often yielded significantly different results.

Present day American, European, and International standards (ANSI S3.6-1989, ANSI S1.4-1983, ANSI S1.25-1991 and IEC 60804-1985) relating to the instrumentation and methodology of both noise and hearing acuity measurements are now in reasonable accord. Recently, this accord resulted in an International Standard, ISO 1999-1990. This standard, although generally well accepted internationally, is not universally accepted (Bies & Hansen 1990, Bies 1990, Clark and Popeika 1989, Kraak et al. 1977 and Kraak 1981). It has been available for more than 12 years for review. It is the standard that is the basis of the occupational noise exposure limits, the time-intensity trading relation, and the method for combining continuous noise with impulse noise.

The exposure criteria for the following sections 4.2 and 4.3 are an adaptation of the background documentation supporting the American Conference of Governmental Industrial Hygienists (ACGIH) Occupational Exposure Levels (OEL). However, the same criteria can also be used to support different OEL.

4.2. CRITERIA FOR CONTINUOUS AND INTERMITTENT NOISE

4.2.1. Introduction

The statement in the occupational exposure limit that the proposed OEL (85 dB(A)) will protect the median of the population against a noise-induced permanent threshold shift (NIPTS) after 40 years of occupational exposure exceeding 2 dB for the average of 0.5, 1, 2, and 3 kHz comes from ISO-1999-1990. Specifically, Table 4.1 provides median NIPTS values for a 40-year exposure to 85 dB(A). These values are 0, 0,2, and 5 dB for the audiometric frequencies of 0.5, 1, 2, and 3 kHz, respectively. Table 4.2 provides the same data for a 40-year exposure to 90 dB(A). These values are 0, 0, 6, and 12 dB for 0.5, 1, 2, and 3 kHz, respectively. The average value for the audiometric frequencies of 0.5, 1, 2, and 3 kHz is 4.5 dB. The corresponding average value for a 40-year daily exposure of 95 dB(A) is more than 10 dB.

Table 4.1: NIPTS values (dB) for a 40 year exposure to 85 dB(A).

Frequency, Hz	Exposure Time, Yr								
	10			20			40		
	Fractiles								
	0.9	0.5	0.1	0.9	0.5	0.1	0.9	0.5	0.1
500~~0~~	0	0	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0	0	0
2000	0	1	1	1	1	2	1	2	2
3000	2	3	5	3	4	6	3	5	7
4000	3	5	7	4	6	8	5	7	9
6000	1	3	4	2	3	5	2	4	6

Table 4.2. NIPTS values (dB) for a 40 year exposure to 90 dB(A).

Frequency, Hz	Exposure Time, Yr								
	10			20			40		
	Fractiles								
	0.9	0.5	0.1	0.9	0.5	0.1	0.9	0.5	0.1
500~~0~~	0	0	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0	0	0
2000	0	2	6	2	4	8	4	6	1
3000	4	8	13	7	10	16	9	12	1
4000	7	11	15	9	13	18	11	15	2
6000	3	7	12	4	8	14	6	10	1

The ISO 1999-1990 standard provides a complete description of NIPTS for various exposure levels and exposure times. From these tables, it can be seen that there is clearly no fully obvious level at which to set the OEL. The 85 dB(A) limit for 8 hours is recommended by the ACGIH and has found acceptance in most countries. Because some countries still use 90 dB(A) or both for different steps of action and indeed the early OEL was at 90 dB(A), a short review of the ACGIH recommending an A-weighted 8-hour equivalent level of 85 dB(A) is in order.

4.2.2. Octave Band vs. A-Weighting

Before 1950, overall sound pressure levels, in decibels, were used to define the noise aspect of damage-risk criteria (Olishijski and Hartford 1975). Following recognition that the overall intensity of a noise by itself was not sufficient to describe the potential for damage, and that the frequency characteristic must also be considered, criteria incorporating spectral levels, usually octave-band levels, were developed.

Since 1954 different national and internationl committees discussed this issue.

In 1961, the ISO/TC 43 discussed a series of noise rating curves and proposed that the noise rating curve, NR-85, be used as the limit for habitual workday exposure to broadband noise.

An octave-band analysis is a relatively lengthy procedure requiring expensive instrumentation. There was some concern that the layman had difficulty in interpreting the results. Recognizing the desirability of a single reading and the fact that most industrial data on NIPTS were available for single-weighted noise levels, the Intersociety Committee, in 1967, proposed the use of A-weighted sound levels in the development of criteria (Ad Hoc Intersociety Guidelines 1967). The A-weighted characteristic of a sound level meter is designed to approximate the frequency selective response of the human ear at low sound pressure levels. In one report, Botsford demonstrated that A-weighted levels are as reliable as octave-band levels in the prediction of effects on hearing in 80% of the occupational noises considered and slightly more conservative (more protective) in 16% of the cases (Botsford 1967). Passchier-Vermeer (1968) and Cohen et al. (1972) similarly demonstrated that A-weighted levels provide a reasonable estimate of the hazard to hearing in most industrial environments. The abbreviation dB(A) is used to denote decibels A-weighted and can be described as a unit of measurement of sound level corrected to the A-weighted scale as defined in IEC 60651. Today, A-weighted sound levels are in general use in hearing damage risk criteria.

4.2.3. 85 dB(A) vs. 90 dB(A)

Permanent noise-induced hearing loss is related to the sound pressure level and frequency distribution of the noise, the time pattern and duration of exposure, and individual susceptibility. The ability to hear and understand everyday speech under normal conditions is regarded as the most important function of the hearing mechanism. Thus, most present-day studies focus on the resultant or predicted hearing loss in the speech frequency range.

The zero settings on the audiometer are based on response levels derived from the testing of large groups of young people. There is general agreement that progression in hearing loss at frequencies of 500, 1000, 2000, and 3000 Hz eventually will result in impaired hearing, i.e., inability to hear and understand speech..

Among several other studies a study by Burns and Robinson (1978) included such factors as the use of A-weighted decibels (dB(A)), (which was supported), variability in audiometric measurement, relationship of temporary threshold shift to permanent loss, and use of the equal-

energy approach. The results from the study are discussed in the 1972 NIOSH criteria document and summarised in the following paragraph.

The NIOSH, in 1972, published “Criteria for a Recommended Standard–Occupational Exposure to Noise” (National Institute of Occupational Safety and Health 1972). Audiometric and noise exposure data were obtained from 792 noise-exposed workers from various industries and 380 non-noise exposed workers from the same industries. An analysis of the data indicated approximately 19% risk of impairment (HLI[O.5,1,2] >25 dB(A)) for workers exposed for more than 30 years to 85 dB(A). The NIOSH document contained a comprehensive review of published data from other studies.

In 1974, the U.S. Environmental Protection Agency (EPA 1974) published the "levels" document. In this document, an 8-hour level of 75 dB(A) was established as the level that would protect "public health and welfare with an adequate margin of safety." Much of this result was based on the work of Johnson (1973). He combined the works of Passchier-Vermeer (1968), Baughn (1973), and Burns and Robinson (1978). These were the same data available to the TLV Committee. A major difference, however, was the use of 4000 Hz as the most sensitive indicator of hearing loss. Johnson (1973) observed that the difference between protecting 4000 Hz and the average of 0.5, 1, and 2 kHz from the same amount of noise-induced permanent threshold shift, is that protecting 4000 Hz requires 10-15 dB(A) lower exposure levels.

In 1978, there was general agreement that the hearing level at 3000 Hz is related to the hearing and understanding of speech, particularly in the presence of noise. In 1978, in the summary of an investigation by Suter it was reported that: "Correlation tests revealed that frequency combinations that included frequencies above 2000 Hz were significantly better predictors of speech discrimination scores than the combination of 500, 1000, and 2000 Hz" (Suter 1985).

In 1979, the AAOO included 3000 Hz in their hearing impairment formula (American Academy of Ophthalmology and Otolaryngology 1970). For this reason, the TLV is based on a formula that includes 3000 Hz. Using ISO-1999, the median amount of NIPTS after 40 years of exposure to 90 dB(A) is 2 dB for the average of 500, 1000, and 2000 Hz. The same 40-year exposure at 85 dB(A) for the average of 500, 1000, 2000, and 3000 also is 2 dB. Thus, everything else being equal, inclusion of 3000 Hz will drop the 8-hour criterion level from 90 dB(A) to 85 dB(A).

4.2.4. 3 dB(A) vs. 5 dB(A)

If hearing damage is proportional to the acoustic energy received by the ear, then an exposure to a particular noise level for one hour will result in the same damage as an exposure for two hours to a noise level which is 3 dB lower than the original level. This is referred to the 3 dB(A) trading rule and is generally accepted in many parts of the world. However, 4 dB(A) and 5 dB(A) rules exist in the USA and the purpose of this section is to discuss the relative merits of the various trading rules in current use.

After experimenting with and proposing the equal energy or 3 dB(A) rule and after extensive study by the National Academy of Sciences-CHABA, the U.S. Air Force introduced the equal energy rule in its regulation on Hazardous Noise Exposure in 1956 (Eldred et al. 1955 and Air Force Medical Services 1956).

While not all researchers have supported the 3 dB(A) rule, (Bies & Hansen 1990, Bies 1990, Clark and Popeika 1989, Kraak et al. 1977 and Kraak 1981). an overwhelming general consensus favoured its use at a special meeting of the TLV Committee at Aberdeen, MD, in 1992 (Sliney

1993).

There was also a special meeting in 1982 at Southampton, England. Many leading investigators of noise-induced hearing loss reviewed the available literature with respect to the use of equal energy (von Gierke et al. 1981). The group endorsed the use of equal energy as the most practical and reasonable method of measuring both intermittent and impact/impulse noise between 80 dB(A) and 140 dB(A). This meeting produced the international consensus that is the basis of ISO-R-1999.

Suter (1992) also concluded that the 3 dB(A) exchange rate was the method most firmly supported by the scientific evidence now available. Some key arguments summarized were:

"1. TTS2 (TTS measured 2 minutes after exposure) is not a consistent measure of the effects of a single day's exposure to noise, and the NIPTS after many years may be quite different from the TTS2 produced at the end of an 8-hour day. Research has failed to show a significant correlation between TTS and PTS, and the relationships between TTS, PTS, and cochlear damage are equally unpredictable.
2. Data from animal experiments support the use of the 3 dB(A) exchange rate for single exposures of various levels within an 8-hour day. But there is increasing evidence that intermittentcy can be beneficial, especially in the laboratory. However, these benefits are likely to be smaller or even nonexistent in the industrial environment where sound levels during intermittent periods are considerably higher and where interruptions are not evenly spaced.
3. Data from a number of field studies correspond well to the equal-energy rule.
4. CHABA's assumption of the equal temporary effect theory is also questionable in that some of the CHABA-permitted intermittent exposures can produce delayed recovery patterns even though the magnitude of the TTS was within "acceptable" limits, and chronic, incomplete recovery will hasten the advent PTS. The CHABA criteria also assume regularly spaced noise bursts, interspersed with periods that are sufficiently quiet to permit the necessary amount of recovery from TTS. Both of these assumptions fail to characterize noise exposures in the manufacturing industries, although they may have some validity for outdoor occupations, such as forestry and mining."

In addition to Suter's (1992) conclusions, there are several other reasons to change to the equal energy rule. These reasons should benefit industry as well as increase assessment accuracy. One of the foremost reasons is the elimination of the all-or-nothing limit of 115 dB(A). A short burst of noise, such as an aircraft flyover or a siren, might exceed this limit. Yet, a burst of broadband noise as long as 10 msec at 130 dB has been shown to cause almost no TTS (Kryter et al. 1965, Schori 1976, Johnson and Schori 1977). On the other hand, research has shown that broadband noise of 115 dB for 15 minutes is likely to cause excessive TTS (Schori 1976). Use of equal energy eliminates this arbitrary 115 dB limit.

Second, use of equal energy better predicts the hazard of noise for exposure durations greater than 8 hours. For an 8-hour criterion level of 85 dB(A), the 5 dB(A) rule would dictate a 16-hour exposure at 80 dB(A) and a 24-hour exposure at 77 dB(A). The equal energy rule will allow 82 dB(A) for 16 hours and 80 dB(A) for 24 hours. The threshold of any TTS to broadband noise for periods as long as 24 hours has been shown to be between 78 and 80 dB(A) (Stephenson et al. 1980). On the other hand, 85 dB(A) for 8 hours will cause some TTS. It is certainly more reasonable to anchor the 24-hour point to 80 dB(A). The only time that a lower limit than 80 dB(A) would be appropriate is the very unusual circumstance when the exposure consists of a steady pure tone.

A third reason is the inclusion of 3000 Hz. What is often forgotten is that the benefit of

intermittency, as shown in the CHABA WG46 curves (1956), did vary with the audiometric frequency considered. Higher audiometric frequencies required smaller trading relations than the lower audiometric frequencies to produce equal TTS. Therefore, even if the equal TTS2 model was correct, inclusion of 3000 Hz would dictate reducing the 5 dB(A) trading relation to a lower number. In some cases, this number might even be slightly lower than 3 dB(A).

In summary, the equal energy rule (3 dB(A) rule) appears to be a better predictor of noise hazard for most practical conditions and is strongly recommended by the TLV Committee.

Note: Reference is made to the following formula for determining hearing impairment. The main point at issue is the inclusion of the hearing threshold level at 3000 Hz in such a formula.

In 1970 the American Academy of Opthalmology and Otolaryngology (AOO) developed a new formula for determining hearing impairment. The formula includes the 3000 Hz frequency, and is as follows:

"1. The average of the hearing threshold levels at 500, 1000, 2000, and 3000 Hz should be calculated for each ear.
2. The percentage of impairment for each ear should be calculated by multiplying by 1.5 percent the amount by which the average hearing threshold level exceeds 25 dB(A). The impairment should be calculated up to 100 percent reached at 92 dB(A).
3. The impairment then should be calculated by multiplying the percentage of the better ear by five, adding this figure to the percentage from the poorer ear, and dividing the total by six."

4.3. CRITERIA FOR IMPULSE NOISE

The previous approach for assessing impulse/impact noise was to allow 100 impulses or impacts per day at 140 dB(A), or 1000 per day at 130 dB(A), or 10,000 per day at 120 dB(A). Impacts or impulses referred to discrete noise of short duration, less than 500 ms, where the SPL rises and decays very rapidly. One of the problems with this approach is that it is difficult, if not impossible, to properly measure impact duration. A manufactured instrument is available that can sum the number of measured impulses at each 1 dB(A) increment and divide by the number of allowable impulses. From this sum, a dose can be calculated. However, the calculation of this dose requires several assumptions that were not explicit in the previous TLV. While these assumptions could be clarified here, there exists a more accurate approach for addressing impulse/impact noise.

Besides the complexity of using the previous TLV for impulse noise, there were several fundamental problems with the old TLV limit. The first problem is that the duration of the impulse or impact was not considered. A short 1-ms pulse was considered as harmful as a long 200-ms pulse. This is not consistent with the CHABA guidelines on impulse noise (National Research Council 1968, Kryter et al. 1965) or any known research. Second, impulse or impact noise was treated separately from non-impact noise. This separate treatment is inconsistent with the research of Hamernik et al. that has shown that at exposures that cause moderate or high levels of TTS, combined impact and continuous noise can cause a synergistic effect, that is, the resultant effect is greater than just the addition of the results from the impact exposures and the results from the continuous noise exposures (Hamernik et al. 1974). Fortunately, these same researchers have shown that at exposure levels that will cause only a small amount of TTS, as much as the proposed 8-hour 85 dB(A) threshold, this synergistic effect disappears (Hamernik et al. 1980).

The proposed method of assessing impulse or impact noise resolves both these problems. By combining all sound energy between 80 dB(A) and 140 dB(A), impact/impulse noise is combined

with continuous and intermittent noise. Longer impulses are considered more dangerous than short impulses. Finally, the measurement of noise becomes greatly simplified.

It should be noted that the previous TLV limit on impulse noise was already based on equal energy so the major change is the combining of all noise in one measure.

Support of this procedure comes from numerous documents and standards. The current ISO standard, ISO 1999-1990, uses this approach. The published draft standard, ANSI S3.28- 1986 also has adopted this measurement approach.

There have been several European field studies that also support the combining of impact noise with continuous noise. At the Southampton meeting on this subject (von Gierke et al. 1982), Passchier-Vermeer (1968) presented data that indicated the possibility that equal energy may slightly underestimate the combined effect, especially for 8-hour criteria levels above 90 dB(A). The majority of the researchers did not see the need for adjusting for the combined effect; however, the current ISO-1999-1990 states in note three: "The prediction method presented is based primarily on data collected with essentially broad-band steady non-tonal noise. The application of the data base to tonal or impulsive/impact noise represents the best available extrapolation. Some users may, however, want to consider tonal noise and/or impulsive/impact noise about as harmful as a steady non-tonal noise that is approximately 5 dB(A) higher in level."

Because the TLV is an 8-hour criterion level of 85 dB(A), such a correction was not used nor is such a correction recommended.

The selection of 140 dB(A) for unprotected ears remains a reasonable level. This level was reviewed by the working group that prepared ANSI S3-28. After this review, the working group recommended the continuation of this limit. The key research on which that limit was based was that of Ward (1961) and of Price (1981). A recent CHABA report (1992) also suggested this level as the break point above which the CHABA criteria of 1969 should be used.

The use of a C-weighted peak resolves a long standing problem with measurement of the peak. The term "unweighted peak" is undefined. Without specifying the low end cutoff frequency of the measurement devices, measurements with different devices could vary greatly. For example, an innocuous car door slam might cause a unweighted peak greater than 140 dB on some instruments but not on others. Use of C-weighting defines the frequency response of the instrument and eliminates very low frequency impulses and sounds. The C-weighting discounts such sounds. Thus, the harmless effect from a low-frequency impulse that comes from closing a car door or other such innocuous very low-frequency impulses can be more properly assessed. Infrasound exposures (exposures below 20 Hz) will also be better assessed.

The TLV limits do not address the case in which the impulse exposure exceeds a C-weighted peak of 140 dB. It is expected that the TLV for noise for 1995 will add the recommendation that, in such cases, the military standard (MIL-STD-1474C) should be used. The MIL-STD recommends that hearing protection be worn whenever exposures exceed a peak level of 140 dB(C). In addition, guidance is provided for those situations in which double hearing protection (both muffs and plugs) should be worn. However, this military standard is too conservative and various governments are researching the actual protection that is available from hearing protective devices. In general, hearing protection protects better for impulse noise than for continuous noise. The problem is to ensure that protection is worn.

Many of these exposure conditions are summarized in the U.S. National Institute of Occupational Safety and Health (NIOSH) Noise Criteria Document (NIOSH, 1998).

4.4. EXAMPLES OF OCCUPATIONAL EXPOSURE LIMITS TO NOISE

4.4.1. Control of noise exposure in workplaces. (Policy and guidance documents of the International Labour Organization (ILO))

Convention No. 148, concerning the Protection of Workers against Occupational Hazards in the Working Environment Due to Air Pollution, Noise and Vibration, adopted by the General Conference of the International Labour Organization in 1977, provides that, as far as possible, the working environment shall be kept free from any hazard due to air pollution, noise or vibration. To this end, national laws or regulations shall prescribe that measures be taken for the prevention and control of, and protection against, occupational hazards in the working environment due to air pollution, noise and vibration. Provisions concerning the practical implementation of the measures so prescribed may be adopted through technical standards, codes of practice, and other appropriate procedures. Technical measures shall be applied to new plants or processes in design or installation, or added to existing plants or processes. Where this is not possible, supplementary organisational measures shall be taken instead.

The provisions of the Convention also specify that the national competent authority shall establish criteria for determining the hazards of exposure to air pollution, noise and vibration in the working environment and, where appropriate, shall specify exposure limits on the basis of these criteria. The criteria and exposure limits shall be established, supplemented and revised regularly in the light of current national and international knowledge and data, taking into account as far as possible any increase in occupational hazards resulting from simultaneous exposure to several harmful factors at the workplace.

Employers are responsible for compliance with the prescribed measures. Workers shall be required to comply with safety procedures. Supervision shall be ensured by inspection services. The Convention enumerates various measures for prevention, co-operation at all levels, the information of all concerned, the notification of authorities, and the supervision of the health of workers.

Neither Convention No. 148 nor the accompanying Recommendation No. 156 concerning the Protection of Workers against Occupational Hazards in the Working Environment Due to Air Pollution, Noise and Vibration, also adopted in 1977, specify exposure limits for noise at the workplace.

As of June,1997, 39 countries have ratified the Convention No. 148 of which 36 have accepted its obligation in respect of noise. The ratification of a Convention by an ILO member State involves the obligation to apply, in law and in practice, its provisions.

The Code of practice on the protection of workers against noise and vibration in the working environment was adopted by a meeting of experts in 1974 and published by the International Labour Office in 1977. Its third impression (with modifications) dates from l984. The Code provides guidance for governments, employers and workers. It sets out the principles that should be followed for the control of workplace noise and vibration (organising principles, measurement and assessment, identification of risk areas, protection equipment and reduction of exposure time, health supervision and monitoring). International standards and other international provisions existing before l984 are appended to the code. In the light of knowledge at the time of publication, a warning limit value of 85 dB(A) and a danger limit value of 90 dB(A) are recommended.

In response to technological developments, the codes of practice on the protection of workers against noise and vibrations in the working environment and on occupational exposure to

airborne substances harmful to health (adopted in l980) were updated in the l996-97 biennium in the form of a single draft code covering all types of air pollutants and other ambient factors in the working environment, such as noise and vibration, temperature and humidity, illumination and radiation. The draft was submitted to a tripartite meeting of experts for final revision and approval in 1999 and is expected to be published in the 2000-01 biennium . It will provide guidance on the implementation of the ILO Convention, 1977 (No. 148) and the ILO Recommendation, 1977 (No. 156), both cited above.

4.4.2. Occupational Exposure Levels reported and recommended by I-INCE

In 1997 the final report on “Technical Assessment of Upper Limits on Noise in the Workplace“ had been approved and published by the International Institute of Noise Control Engineering (I-INCE). It comprises the results of a Working Party started in 1992 to “review current knowledge and practice“ in this field. The executive summary says:“The setting of specific limits on exposure to noise is a political decision, with results that vary between jurisdiction depending on economic and sociological factors. It is however also important that regulations be harmonized internationally. The report therefore makes specific recommendations...“ Its elements are shown in the following :

1. Limit of 85 dB(A) for 8 hour workshift for jurisdiction desirable as soon as possible.
2. Maximum sound pressure level as limit of 140 dB for C-weighted peak..
3. Exchange rate of 3 dB per doubling or halving of exposure time.
4. Efforts to reduce levels to the lowest economically and technologically reasonable values.
5. In the design stage consideration to sound and vibration isolation between noisier and quieter areas, significant amount of acoustical absorption in rooms occupied by people.
6. Purchase specifications for machinery should contain clauses specifying the maximum emission values.
7. A long-term noise control program at each workplace where daily exposure exceeds 85 dB(A).
8. Use of personal hearing protection should be encouraged when engineering noise control measures are insufficient to reduce daily exposure to 85 dB(A), should be mandatory when exposure level is over 90 dB(A).
9. Employers should conduct audiometric testing of workers exposed to more than 85 dB(A) at least every three years, test results should be preserved in the employee‘s file.

The I-INCE report includes also a table of examples of the legislation in various countries, see table 4.3.

Table 4.3 Some features of legislation in various countries (I-INCE, 1997)

Country (Jurisdiction)	8-hour average A-weighted sound pressure level (dB)	Exchange rate (dB)	8h-average A-wtd limit for engineering or administrative controls (dB)	8h-average A-wtd limit for monitor-ing hearing (dB)	Upper limit for peak sound pressure level (dB)
Argentina	90	3			110 A Slow
Australia (varies by state)	85	3	85	85	140 unwgted peak
Austria (a),(c)	85		90		
Brazil	85	5	90, no exposure > 115 if no protec-tion, no time limit	85	130 unwgted peak or 115 A Slow
Canada (Federal) (ON, PQ, NB) (Alta, NS, NF) (BC)	87 90 85 90	3 5 5 3	87 90 85 90	84 85 (b)	140 C peak
Chile	85	5			140 unwgted peak or 115 A Slow
China	70-90	3			115 A slow
Finland (c)	85	3	90		
France (c)	85	3	90	85	135 C peak
Germany (c),(d)	85	3	90	85	140 C peak
Hungary	85	3	90		140 C peak or 125 A Slow
India	90				140 A peak
Israel	85	5			140 C peak or 115 A Slow
Italy (c)	85	3	90	85	140 C peak
Japan	90		85 hearing protection mandatory at 90	85	
Netherlands (c)	85	3	90	80	140 C peak
New Zealand	85	3	85	85	140 unwgted peak
Norway	85	3		80	110 A slow
Poland	85	3			135 C peak or 115 A Slow
Spain (c)	85	3	90	80	140 C peak

Sweden (c)	85	3	90	80	140 C peak or 115 A Fast
Switzerland	85 or 87	3	85	85	140 C peak or 125 ASEL
United Kingdom	85	3	90	85	140 C peak
USA (e) USA (Army and Air Force)	90 (TWA) 85	5 3	90	85 85	140 C peak or 115 A Slow 140 C peak
Uruguay	90	3			110 A Slow
This Report recommends	85 for 8-hour normalized exposure level limit	3	85. See also text under recommen-dend engineering controls	on hiring, and at intervals thereafter, see text under audiometric programs	140 C peak

See the notes to the table

* Information for Austria, Japan, Poland, and Switzerland was provided directly by these Member Societies of I-INCE. For other countries not represented by Member Societies participating in the Working Party the information is taken with permission from Ref. 15

(a) Austria also proposes 85 dB (AU-weighted according to IEC 1012) as a limit for high frequency noise, and a separate limit for low frequency noise varying inversely as the logarithm of frequency.

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

(c) All countries of the European Union require the declaration of emission sound power levels of machinery, the use of the quietest machinery where reasonably possible, and reduced reflection of noise in the building, regardless of sound pressure or exposure levels. In column 4, the limit for other engineering or administrative controls is 90 dB or 140 dB C-weighted peak. In column 6, the upper limit for sound pressure level is 140dB C-weighted peak (or lower) or 130 dB A-weighted impulse.

(d) The rating level consists of time-average, A-weighted sound pressure level plus adjustments for tonal character and impulsiveness.

(e) TWA is Time Weighted Average. The regulations in the USA are unusally complicated. Only A-weighted sound pressure levels of 80 dB or greater are included in the computation of TWA to determine whether or not audiometric testing and noise exposure monitoring are required. A-weighted sound pressure levels less than 90 dB are not included in the computation of TWA when determining the need for engineering controls.

4.4.3. Occupational Exposure Levels recommended by NIOSH

In 1972, NIOSH published Criteria for a Recommended Standard: Occupational Exposure to Noise, which provided the basis for a recommended standard to reduce the risk of developing permanent hearing loss as a result of occupational noise exposure (NIOSH 1972).

The NIOSH document contained a comprehensive review of published data from other studies. The NIOSH percent risk values for long-term exposures to various noise levels were compared with those derived from three other studies:

1) the Intersociety Study, (Ad hoc Intersociety Guidelines 1967).
2) the earlier ISO Standard 1999-1990 and
3) the Burns and Robinson Study (1978).

NIOSH has now evaluated the latest scientific information and is revising some of its previous recommendations (NIOSH 1998),as it is summarized in the foreword of the new document.

The NIOSH recommended exposure limit (REL) of 85 dBA for occupational noise exposure was reevaluated using contemporary risk assessment techniques andincorporating the 4000-Hz audiometric frequency in the definition of hearing impairment. The new risk assessment reaffirms support for the 85-dBA REL. The excess risk of developing occupational noise-induced hearing loss (NIHL) for a 40-year lifetime exposure at the 85 dBA REL is 8%, which is considerably lower than the 25% excess risk at the 90 dBA permissible exposure limit currently enforced by the Occupational Safety and Health Administration (OSHA) and the
Mine Safety and Health Administration (MSHA).

NIOSH previously recommended an exchange rate of 5dB for the calculation of time-weighted average exposures to noise, but it is now recommending a 3-dBexchange rate, which is more firmly supported by scientific evidence. The 5-dB exchange rate is still used by OSHA and MSHA, but the 3-dB exchange rate has been increasingly supported by national and international consensus.

NIOSH recommends an improved criterion for significant threshold shift, which is an increase of 15 dB in hearing threshold at 500, 1000, 2000, 3000,4000, or 6000 Hz that is repeated for the same ear and frequency in back-to-back audiometric tests. The new criterion has the advantages of a high identification rate and a low false-positive rate. In comparison, the criterion recommended in the 1972 criteria document has a high false-positive rate, and the OSHA criterion, called the Standard Threshold Shift, has a relatively low identification rate.

Differing from the 1972 criteria document, NIOSH no longer recommends age correction on individual audiograms. This practice is not scientifically valid, and would delay inter-vention to prevent further hearing losses in those workers whose hearing threshold levels have increased due to occupational noise exposure. OSHA currently allows age correction only as an option.

The Noise Reduction Rating (NRR) is a single-number, laboratory-derived rating required by the Environmental Protection Agency to be shown on the label of each hearing protector sold in the U.S. In calculating the noise exposure to the wearer of a hearing protector at work, OSHA has implemented the practice of derating the NRR by one-half for all types of hearing protectors. In 1972, NIOSH recommended the use of the full NRR value, but now it recommends derating the NRR by 25%, 50% and 70% for earmuffs, formable earplugs and all other earplugs, respectively. This variable derating scheme, as opposed to OSHA's straight derating scheme, takes into consideration the performances of different types of hearing protectors.

This document also provides recommendations for the management of hearing loss prevention

programs for workers whose noise exposures equal or exceed 85 dBA . The recommendations include programme evaluation, which was not articulated in the 1972 criteria document and is not included in the OSHA and MSHA standards.

Adherence to the revised recommended standard will minimize the risk of developing occupational NIHL.

4.4.4. Occupational Exposure Levels in the European Union

The European Union has already established a common policy aimed at controlling the risks due to the exposure of workers to noise and harmonising the relevant legal requirements existing at national level. Its principal instrument is the Council Directive 86/188/EEC on the protection of workers from the risks related to exposure to noise at work (Official Journal No L 137 / 24 - 5 - 1986 p.28).

Council Directives are legal instruments binding on the Member States as to the result to be achieved, but leave to the national authorities the choice of forms and methods. They are decided on by the Council of Ministers following a proposal made by the Economic and Social Committee. During this procedure extensive consultation of workers and employers organisations take place. Council Directives concerning safety and health at work set out minimum requirements and Member States have power to introduce more stringent measures of protection.

The EU health and safety legislation concerning noise addressed the risk of hearing impairment caused by occupational noise, because there was sufficient scientific documentation of the exposure - effect relationship. As regards the non - auditory effects of noise (which range from physiological disorders to interference with the proper execution of tasks requiring attention and concentration) scientific knowledge was not sufficiently advanced to justify a quantitative limitation of exposure. In this context decisions were taken on some fundamental issues:

1. The mandatory values will apply only to the noise reaching the ear, so if noise emission cannot be prevented or reduced at source, other measures should be taken to regulate noise energy emission; furthermore the situation in the member States did not make it possible to fix a noise - exposure value below which there is no longer any risk to workers hearing.
2. If a worker is exposed to noise bursts, the peak sound pressure must be limited and the acoustic energy must be included in the allowable daily exposure; in order that this requirement is fulfilled, an instrument capable of measuring directly the maximum (peak) value of the unweighted instantaneous sound pressure is needed (an instrument having an onset time constant not exceeding 100μs is suitable for industrial situations). See Section 4.3 for more detailed guidance and a discussion on the unsuitability of “unweighted” measurements.
3. A 3 dB rate was chosen as the most appropriate rule for managing intensity and exposure duration, because it is consistent with international standardisation and is simple to use in industrial situations, when a given level of workers’ protection has to be guaranteed.

For the purposes of the Directive on “noise”, the following terms have the meaning hereby assigned to them:

1. Daily personal noise exposure of a worker $L_{EP,d}$

The daily personal noise exposure of a worker is expressed in dB(A) using the formula:

$$L_{EP,d} = L_{Aeq,T} + 10\log_{10}\frac{T}{T_0}$$

where:

$$L_{Aeq,T} = 10\log_{10}\left\{\frac{1}{T}\int_0^T\left[\frac{p_A(t)}{p_0}\right]^2 \mathrm{d}t\right\}$$

T = daily duration of a worker's exposure to noise (hours),
T_0 = 8 hours
p_0 = 20 µPa,
p_A = A-weighted instantaneous sound pressure in pascals to which is exposed, in air at atmosphere pressure, a person who might or might not move from one place to another while at work; it is determined from measurements made at the position occupied by the person's ears during work, preferably in the person's absence, using a technique which minimises the effect on the sound field.

If the microphone has to be located very close to the person's body, appropriate adjustments should be made to determine an equivalent undisturbed field pressure. The daily personal noise exposure does not take account of the effect of any personal ear protector used.

(The term "*Daily personal noise exposure of a worker* $L_{EP,d}$ " is the same as the term " *noise exposure level normalised to a normal 8hr working day,* $L_{EX,8h}$ ", adopted later on by the ISO 1999 standard and used in Chapter 7 - ed).

2. Weekly average of the daily values $L_{EP,w}$

The weekly average of the daily values is found using the following formula:

$$L_{EP,w} = 10\log_{10}\left\{\frac{1}{5}\sum_{k=1}^{m} 10^{0.1(L_{EP,d})_k}\right\}$$

where ($L_{EP,d}$)$_k$ are the values of $L_{EP,d}$ for each of the m working days in the week being considered. *(The term $L_{EP,w}$ is the same as the quantity $L_{EX,w}$ used in Chapter 7 - ed)*

The Directive specifies the employers obligations in reducing the risks arising from exposure to occupational noise to the lowest level reasonably practicable, taking account of technical progress and the availability of measures to control the noise, in particular at source. In this context different values are used, which trigger the specific actions. These values are:

1. 200 Pa as peak (140 dB in relation to 20 µPa). If the maximum value of the 'A' - weighted sound pressure level, measured with a sound - level meter using the time characteristic I (according to IEC 60651) does not exceed 130 dB(AI), the maximum value of the

unweighted instantaneous sound pressure can be assumed not to exceed 200 uPa)

2. 85 $L_{EP,d}$,
3. 90 $L_{EP,d}$.

When the daily personal noise exposure of a worker is likely to exceed 85 dB(A) or the maximum value of the unweighted instantaneous sound pressure is likely to be greater than 200Pa, workers and / or their representatives must be informed and trained on the potential risks to their hearing, the specific locations of the risk, the preventative measures taken, the wearing of personal protective equipment's and the role of hearing checks, the results of noise assessments and measurements as well as their significance, - personal ear protectors must be made available to workers.

When the daily personal noise exposure of a worker is likely to exceed 85 dB(A), workers shall be able to have hearing examinations in order to diagnose any hearing impairment by noise.

When the daily personal noise exposure of a worker is likely to exceed 85 dB (A) or the maximum value of the unweighted instantaneous sound pressure is likely to be greater than 200Pa, the areas in question must be appropriately signed, be delimited and access to them must be restricted. The employer has to identify the reasons for the excess levels, to draw up and implement a programme of measures of technical nature (engineering control) with a view to reducing the noise exposure as far as reasonably practicable. Personal ear protectors must be worn, which have to be adapted to the individual worker and to his / her working condition, taking account of his / her safety and health.

Finally, *whenever work equipment, intended for use at work, emits a noise that is likely to cause*, for a worker who uses it properly for a conventional eight-hour period, a daily personal noise exposure greater than 85 dB(A) or the maximum value of an unweighted instantaneous sound pressure is equal to or greater than 200Pa, the employer must be informed of that risk in order to take necessary measures to meet his / her obligations.

4.4.4.1. Checking workers hearing under the EU directive on noise

Council Directive 86/188/EEC has particular provisions concerning the hearing check of workers as part of an overall preventative policy aiming at reducing the risks to hearing.

The purpose of the check is the early diagnosis of any hearing impairment by noise, so that further deterioration can be prevented by various means.

There is a specific Annex with instructions for checking workers' hearing, which includes an audiometric test which should comply with the specifications of standard ISO 6189, but also covers the frequency of 8000 Hz; the ambient sound level must be sufficiently low to enable a hearing threshold level equal to 0 dB in relation to ISO 389 to be measured.

4.4.5. ACGIH Occupational Exposure Limits to Noise

The American Conference of Government Industrial Hygienists (ACGIH) has recommended threshold limit values (TLV) for occupational noise. The Occupational Exposure Limits (OEL) presented herein are an adaptation of the ACGIH's TLV limits. It should be noted that membership on the committee includes members from both Europe and Asia.

4.4.5.1. Foreword

The OEL's refer to sound pressure levels and exposure durations that represent conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse effect on their ability to hear and understand normal speech. Prior to 1979, the medical profession had defined hearing impairment as an average hearing threshold level in excess of 25 dB(A) (ISO-7029-DIS) at 500, 1000, and 2000 Hz. The limits that are given here have been established to prevent a hearing loss at 3000 and 4000 Hz. The values should be used as guidelines in the control of noise exposure and, due to individual susceptibility, should not be regarded as fine lines between safe and dangerous levels. The proposed limits should protect the median of the population against a noise-induced hearing loss exceeding 2 dB(A) after 40 years of occupational exposure for the average of 0.5, 1, 2, and 3Hz.

It should be recognized that the application of the OEL for noise will not protect all workers from the adverse effects of noise exposure. A hearing conservation program with all of its elements including audiometric testing is necessary when workers are exposed to noise at or above the OEL.

4.4.5.2. Continuous or Intermittent Noise

The sound pressure level should be determined by a sound level meter, integrating sound level meter or dosimeter conforming, as a minimum, to the requirements of the IEC 60804.-1985. The measurement device should be set to use the A-weighted network. The duration of exposure should not exceed that shown in Table 4.4.

These values apply to total duration of exposure per working day regardless of whether this is one continuous exposure or a number of short-term exposures.

When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered rather than the individual effect of each. If the sum of the following fractions:

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \ldots\ldots\ldots\ldots \frac{C_n}{T_n}$$

exceeds unity, then the combined exposure should be considered to exceed the TLV. C_i indicates the total duration of exposure at a specific noise level and T_i indicates the total duration of exposure permitted at that level. All on-the-job noise exposures of 80 dB(A) or greater should be used in the above calculations. With sound level meters, this formula should be used for sounds with steady levels of at least 3 seconds. For sounds in which this condition is not met, a dosimeter or an integrating sound level meter must be used. The limit is exceeded when the dose is more than 100% as indicated on a dosimeter set with a 3 dB(A) exchange rate and a criterion level of 85 dB(A).

The OEL is exceeded on an integrating sound level meter when the average sound level exceeds the values given in Table 4.4.

Table 4.4 Allowable exposure durations[A] (per IEC 60804).

Duration per Day	Sound Level, dB(A)[B]
Hours	
24	80
16	82
8	85
4	88
2	91
1	94
Minutes	
30	97
15	100
7.50*	103
3.75*	106
1.88*	109
0.94*	112
Seconds*	
28.12	115
14.06	118
7.03	121
3.52	124
1.76	127
0.88	130
0.44	133
0.22	136
0.11	139

A No exposure to continuous, intermittent, or impact noise in excess of a peak C-weighted level of 140 dB.

B Sound levels in decibels are measured on a sound level meter, conforming as a minimum to the requirements of the American National Standard Specification for Sound Level Meters, S1.4 (1983) Type S2A, and set to use the A-weighted network with a slow meter response.

* Limited by the noise source, not by administrative control. It is also recommended that a dosimeter or integrated sound level meter be used for sounds above 120 dB.

Editors‘ note **:** *Although formally correct the table looks as a 24 h exposure with 80 db(A) is permitted but the presumptions of the OEL should be observed, see section 4.5.*

4.4.5.3. Impulsive or Impact Noise

By using the instrumentation specified by the IEC 60804-1985, impulse or impact noise is automatically included in the noise measurement. The only requirement is a measurement range between 80 and 140 dB(A) and the pulse range response as defined in IEC 60804-1985 must be at least 63 dB. The frequency response must be equivalent to or better than a type 2 instrument. No exposures of an unprotected ear in excess of a C-weighted peak sound pressure level of 140 dB should be permitted. If instrumentation is not available to measure a C-weighted peak, an unweighted peak measurement below 140 dB may be used to imply that the C-weighted peak is below 140 dB.

Note: For impulses above a C-weighted peak of 140 dB, adequate hearing protection should be worn. The military of some governments have standards that provide guidance for those situations in which single protection (plugs or muffs) or double protection (both muffs and plugs) should be worn (e.g., U. S. Army's MIL-STD-1474C).

4.5. OTHER CRITERIA

The exposure criteria discussed above are based on a statistical average of population with normal health and should not be used to predict the generation of hearing loss of an individual person. In so far the exposure criteria constitute a minimum standard for prevention and conservation. Therefore one should have in mind that not only individuals but also groups of them with properties differing from average may follow more stringent criteria, e.g. young persons, pregnant women (e.g.ACGIH 1999a) ,or handicapped individuals especially with hearing disabilities. Another issue is the combined exposure, e.g. noise-vibration, noise-solvents or noise-metal dust, which is discussed in chapters 3 and 8 and in Carter and Job (1998), ACGIH (1999a) .

It should be considered also that these exposure criteria are based on the presumption of an 16 hour hearing recovery time under a noise level of less than 75 dB(A).Therefore in spaces for workers to relax or sleep and which are related to workplaces as on ships or on drilling platforms the background noise level should be below 70 dB(A) or below, see e.g. ACGIH (1999b).

Another issue is the effect of noise containing sound of frequencies outside the usual auditory capabilities from 20 Hz up till 20 kHz, i.e. infrasound beneath 20 Hz and ultrasound above 20 kHz with its extraaural effects and also effects on hearing in case of higher levels.

Noise of high levels can affect the general safety of workers when the recognition of danger signals is disturbed or destroyed.

Noise of every kind and also low level noise can disturb or damage badly the speech intelligibility which might be an important prerequisite for communication in dangerous situations.

Noise of levels beneath 80 dB(A) can be such an annoyance that the efficiency to achieve a certain goal or quality in the progress of work is diminishing.

4.5.1. Exposure to infrasound and ultrasound

Before the nineties it was said infrasound exposures are rare and, even if they could occur, are not likely to be dangerous, at levels found in industry directly, to a person's hearing or health (von

Gierke and Parker 1976, Johnson 1975, 1982). Complaints of persons working with ultrasound equipment were more frequent, but very often it shows that the reason for complaining was audible sound generated as subharmonics of the original sound source which caused e.g. workpieces to vibrate. So one started to ask if the frequency range of audible sound was real or only the result of inappropiate technical means to shape audiometric tests for frequencies called infra- and ultrasound. It seems now that there is a hearing threshold level outside both ends of the range 20 Hz to 20 kHz investigated by Ising (1980) and Herbertz (1984). Unfortunately the existence of these thresholds is not sufficient to define OELs, because in practice one cannot suppress either the extraaural effects of infrasound to cause body vibrations or the general impact of ultrasound on the complete hearing organ which generates a vague sensation. But the dicussion of the last years resulted in some standards to define boundaries between the different kinds of sound as ISO 7196 or IEC 1012 for measurement purposes, and in some recommendations containing OELs for ultrasound, e.g. IRPA (1984), ACGIH (1999a) . Internationally agreed recommendations on infrasound are missing. There is the tendency to use the hearing thresholds in frequency bands as limits for the exposure in this frequency region considering aural as well as extraaural effects (Moeller 1985,Vercammen 1989, ACGIH 1999a).

4.5.2. Recognition of danger signals

If there is the risk of an unpredictable event like fire or the outflow of dangerous materials in a working area one of necessary precautions will be the installation of devices generating an appropiate auditory danger signal. Naturally this installation needs a check of recognition at the most critical working positions taking into account the worst case of ambient noise and the use of hearing protectors and personal electroacoustical systems. Because of certain properties of the hearing it is required to determine the ambient noise, the insertion loss of protectors and headsets and the danger signal itself in octave band levels. Then the standards ISO 7731 and 8201 give sufficient advice. The situation can also be roughly assessed with help of the A-weighted signal-to-noise ratio, that should be 10 till 15 dB at the listener‘s position according to the standards as discussed by Lazarus (1993). If octave band levels are known the signal-to-noise ratio should be more than 10 dB in more than one octave band.

4.5.3. Speech intelligibility

In many situations at normal production lines as well as on construction sites and during maintenance of large installations but even in control rooms a sufficient communication by talking or shouting is a prerequisite for safety at the workplace and good working results. It can be a more important prerequisite for difficult tasks like medical treatment. The International Standard ISO 9921 is dealing with “ergonomic assessment of speech communication“ and gives in part 1 “speech interference level and communication distances for persons with normal hearing capacity in direct communication...“ with respect to these parameters: ambient noise at the speaker‘s and the listener‘s position and the vocal effort.

There are several assumptions concerning physical and personal conditions. Most important seems to be a reverberation time less than 2 s at 500 Hz , normal hearing capacity of the persons communicating and hearing protectors worn by the speaker . ISO 9921-1 gives then first a relation between the seven steps of vocal effort from relaxed to shouting and the ambient noise level at the speaker‘s position and secondly for the same seven steps defined by the speech

interference level for satisfactory speech communication the relation to the maximum distance between the speaker and listener. The communication can be assessed with the A-weighted signal-to-noise ratio at the listener‘s position also in seven steps from excellent to insuffcient. The standard says:“In order to decide what quality level of speech communication is useful for a given communication situation, the frequency, the necessity of speech communication and size of vocabulary (group of specific words, e.g. commands or warning shouts) shall be taken into consideration. For examples in homes and conference rooms, the quality “very good “ or “excellent“ should be achieved, for department stores and training workshops the quality “good“ should be adopted and for workshop the quality “satisfactory“ or at least “sufficient“ is recommended “. “Good“ refers to a signal-to-noise ratio of 6 till 12 dB and the vocal effort assumed as lower than “raised“, i.e. the average speaker‘s level in 1m distance is lower than 66 dB(A), (ISO 9921-1, Lazarus 1993).

4.5.4. Annoyance and efficiency

Whereas hearing damage is the main concern of safety regulations the other physical and psychological effects should not be neglected. There are provable psychological reactions, e.g. anger, strain or nervousness, and physical reactions, e.g. increase of blood pressure or increased excretion of magnesium, which may give rise to long-term disorders of regulation mechanisms also at A-weighted sound pressure levels below 85 dB. The efficiency can be affected too, the more likely, the more complex the task to be performed. The complexity is given by task characteristics, to be described objectively, and by the individual judgement of a person‘s ability to perform the task. So the same task can be more complex for untrained personnel. Generally a job is more complex e.g. the more information must be kept in mind, the more intellectual operations have to be performed, the higher the requirements for precise fine motor activity or the more responsible the worker is for consequences of mistakes.The more complex a task, the more sensitive a person will react to disturbances like noise, in the end with an increase of the number of mistakes and a slowdown of completion of the task , i.e. a decrease of the efficiency. ISO 11690-1 gives maximum values for the A-weighted equivalent sound pressure level for the 8 hour workshift at industrial workplaces in the range 75 to 85 dB, for routine office work in the range 45 to 55 dB and for meeting rooms or tasks involving concentration in the range 35 to 45 dB.

A further detailed description of the mechanisms that lead to a decrease of efficiency and an allocation of tasks of different complexity to proposed rating levels down to 40 dB(A) is given in the bilingual German standard VDI 2058 part 3 (1999).

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INTERNATIONAL STANDARDS

Titles of the following standards referred to in this chapter one will find together with information on availability in chapter 12:

ISO 1999, ISO 7196, ISO 7731, ISO 8201, ISO 9921-1, ISO 11690-1, IEC 60651, IEC 60804, IEC 61012.