DEPARTMENT OF LABOR

29 CFR Part 1910

Occupational Noise Exposure; Hearing Conservation Amendment

AGENCY: The Occupational Safety and Health Administration (OSHA) of the United States Department of Labor.

ACTION: Final rule.

SUMMARY: This final rule establishes a hearing conservation program, including exposure monitoring, audiometric testing, and training, for all employees who have occupational noise exposures equal to or exceeding an 8-hour time-weighted average of 85 dBA. This amendment covers all employees except those engaged in construction or agriculture. This rule is the outgrowth of the proposed revision of the occupational noise exposure standard which was proposed in 1974. By its action today, OSHA is deferring final action on two issues raised in the 1974 proposal: the permissible exposure level for occupational noise and the appropriate method of compliance with the permissible exposure level. These two issues will continue to be governed by the existing standard.

OSHA plans to study these two issues further and will in the near future reopen the record for the submission of new evidence on these issues.

EFFECTIVE DATE: This standard will become effective April 15, 1981. Start-up dates: Employee exposure monitoring shall be completed by October 15, 1981. Dosimeters used to measure employee exposures must meet the specifications in the standard by April 15, 1983. Baseline audiograms shall be completed by April 15, 1982.

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Copies of any portion of the record including the Final Environmental Impact Statement and Regulatory Analysis may be obtained by contacting: Docket Officer, Docket No. OSH–11, Room S–6212, U.S. Department of Labor, 200 Constitution Avenue, N.W., Washington, D.C. 20210, Telephone (202) 523–7894.

I. Introduction

Rationale for Amendment

Noise is one of the most pervasive occupational health problems. It is a by-product of many industrial processes. Exposure to high levels of noise causes temporary or permanent hearing loss and may cause other harmful health effects as well. The extent of damage depends primarily on the intensity of the noise and the duration of the exposure.

There is an abundance of epidemiological and laboratory evidence that protracted noise exposure above 90 decibels (dB) causes hearing loss in a substantial portion of the exposed population, and that more susceptible individuals will incur hearing loss at levels below 90 dB (Ex. 11; Ex. 12; Ex. 17; Ex. 26–2). This is discussed more fully in the Health Effects section below. Noise-induced hearing loss in an irreversible condition that progresses with increased exposure, and is exacerbrated by the normal aging process. Although such a loss may be slight at first, continued exposure may result in a loss that is severe enough to affect seriously an individual's ability to understand speech. In some cases, even slight losses in the audiometric frequencies that are critical for the understanding of speech can adversely affect an individual's ability to earn a living and to function in society in general. It constitutes a serious physical, psychological, and social handicap. Such impairment of a critical functional capacity clearly is the type of material impairment of health, which Congress, in Section 6(b)(5) of the Act, directed the Secretary to prevent.

Noise can also cause other adverse effects, such as degraded job performance, increases in accidents and absenteeism, job dissatisfaction, headaches, fatigue, sleeplessness, stress-related illnesses, and other effects that are more difficult to quantify and identify as noise-related than is hearing loss (Ex. 2C–106, p. 2; Ex. 2C–111, p. 1; Ex. 96, pp. 277–281; Ex. 189–8, p. 2; Ex. 28A, pp. 18–24, 27–28, 41–44, 46–49; Ex. 32, App. B, Gulian, pp. 6–11; Ex. 79, p. 2; Ex. 173, pp. 1–2, 7–8; Ex. 84, attach. 2, pp. 1–2).

OSHA's existing standard for occupational exposure to noise (29 CFR 1910.95) specifies a maximum permissible noise exposure level of 90 dB for a duration of 8 hours, with higher levels allowed for shorter durations. (This level is called a time-weighted average sound level, abbreviated TWA.) Employers must use feasible engineering or administrative controls, or combinations of both, whenever employee exposure to noise in the workplace exceeds the permissible exposure level. Personal protective equipment may be used to supplement the engineering and administrative controls where such controls are not able to reduce the employee exposures to within permissible limits. The standard also requires employers to administer a "continuing, effective hearing conservation program" for overexposed employees, but the standard does not define such a program.

OSHA proposed a revised noise standard in 1974, which maintained the current standard's 90 dB time-weighted average exposure limit, but required exposure monitoring, and articulated the requirements for hearing conservation programs. There was a great deal of controversy in the rulemaking proceedings about alternative permissible exposure limits and their technical and economic feasibility, but few challenged the concept or the appropriateness of a hearing conservation program. (Tr. 551–553; Tr. 210; Ex. 306, Secs. J2C, J1C, J4C; Ex. 305; Ex. 2C–16A; Ex. 2C–16B)

Analysis of the hearing record reveals information gaps in the area of extra-auditory physiological effects of noise (adverse health effects other than loss of hearing, such as high blood pressure), and also in the areas of economic and technological feasibility of noise control. The Agency needs to obtain additional material and to perform additional impact analyses before issuing a comprehensive new regulation. Therefore, for the present, OSHA will leave the permissible exposure level and compliance mechanisms of the current noise standard unchanged and continue its enforcement. The Agency will defer the final decision on methods of compliance and the permissible exposure level until it has obtained and evaluated the necessary information. The decision to implement a hearing conservation program is separate and severable from the remaining issues.

While such information is being obtained, employees must be afforded additional protection against the effects of noise. Information in the record indicates that many employees are not receiving the benefits of engineering controls to reduce their exposures to within the permissible exposure limits. In fact, there are some 2.9 million workers in American production industries with TWAs in excess of 90 dB, and an additional 2.3 million whose exposure levels exceed 85 dB. These workers, who face a significant risk or material impairment of health or functional capacity, will receive greatly increased protection from the promulgation and enforcement of these hearing conservation requirements, which amend certain provisions of the present noise standard. The provision of

this protection in the form of a well-defined hearing conservation program does not depend upon a determination of an appropriate exposure level or compliance strategy. These issues were treated separately in the proposal and the decision to implement a hearing conservation program first is consistent with the mandate of the Act that, insofar as possible, workers be protected from any material impairment of health or functional capacity.

Hearing conservation programs constitute commonly accepted industrial hygiene practice. Many companies already have instituted programs for their noise-exposed workforce (Ex. 306; Ex. 147A; Ex. 147C). This amendment clarifies what a hearing conservation program must be, and gives direction to the implementation of such a program.

Hearing conservation includes noise exposure monitoring, audiometric testing, the use of hearing protective devices where necessary, and employee education. All of these elements are reasonably necessary and appropriate for a continuing effective hearing conservation program. These procedures will result in considerable benefits for more than 5.2 million employees. Hearing protective devices will reduce the incidence of noise-induced hearing loss and also the various extra-auditory effects described below. Audiometric tests will enable employers and employees to take proper precautions to prevent further deterioration of hearing. Monitoring and educational programs will increase general awareness of noise problems, and promote the effective use of ear protectors. Another benefit, which was suggested by a National Institute for Occupational Safety and Health study, is a reduction in workplace accidents and absenteeism (Ex. 26–11, pp. ii, 5–2).

At this time the Agency does not believe that a hearing conservation program alone is the solution to the problem of workplace noise. The Agency continues to support the policy, reflected in the existing standard and not affected by this amendment, that engineering control of noise is preferable to the use of personal protective devices. The record contains considerable evidence that hearing protectors do not always provide as much attenuation in practice as the manufacturer indicates (Ex. 319, B–12, p. 4; Ex. 300A, p. 91; Ex. 301, p. 33), that many workers dislike using hearing protectors (Ex. 79, pp. 7–8; Ex. 94, pp. 9–10; Ex. 78, p. 14), and that protectors can be very uncomfortable (Ex. 73, Attach. 4, p. 1; Ex. 79, p. 7; Ex. 321–45A, pp. 1–11; Ex. 94, p. 10; Ex. 78, p. 14). In fact the degree of protection provided by such devices is questionable since they may become unseated through talking or chewing during the course of the workday.

When hearing protectors are relied upon, the adequacy of protection will depend upon the quality of the hearing protector, the tightness of the fit, and its use by employees. Permanent hearing loss can occur before it is identified by audiometric testing and, of course, extra-auditory effects cannot be detected by audiometry. Thus, none of these measures are as effective as controlling the hazard at the source.

Physical Properties of Sound

Sound consists of pressure changes in a medium (usually air), caused by vibration or turbulence. These pressure changes take the form of alternating compression and rarefaction of molecules, producing waves that propagate away from a vibrating or turbulent source. The magnitude and the type of effect on humans depend on three physical parameters of sound: level, frequency, and duration. Sound pressure level is a logarithmic measure of the magnitude of the pressure change, which is perceived as loudness. Sound pressure level is expressed in decibels, abbreviated dB. The magnitude, or intensity, of sound is perceived as loudness. The entire range of audible sound pressure (for individuals with normal hearing a range of more than ten million to one), can be compressed into a practical scale of 0 to 140 dB. Because of the logarithmic scale, a small increase in decibels represents a large increase in sound energy. Technically, each increase of 3 dB represents a doubling of sound energy, an increase of 10 dB represents a tenfold increase, and a 20-dB increase represents a 100-fold increase in sound energy.

The frequency of a sound is the number of times that a complete cycle of compressions and rarefactions occurs in a second. The descriptor, which used to be "cycles per second," is now hertz, abbreviated Hz. Frequency is perceived as pitch. The audible range of frequencies for humans with good hearing is 20 Hz to 20,000 Hz. Most everyday sounds contain a mixture of frequencies generated by a variety of sources. A sound's frequency composition is referred to as the spectrum. Frequency spectrum can be a determinant of the annoyance caused by noise, with high frequency noise being generally more annoying than low frequency noise. Also, narrow frequency bands or pure tones (single frequencies) can be somewhat more harmful to hearing than is broad band noise.

The third important parameter is the way a sound level varies over time. The duration of a sound can be measured in microseconds (the duration of a gunshot) to indefinitely long periods (typical of the hum of an electrical transformer). Industrial noise is usually described as continuous, fluctuating, intermittent, or impulsive. Continuous noise, like the sound of a fan or a motor, remains relatively constant for a long period of time. Fluctuating noise, such as the sound of a vehicle in different gears, rises and falls in intensity over a period of time. Intermittent noise ceases or falls to low levels between "on-times," or periods of much higher levels. Drilling or sawing operations are examples of intermittent noise. Impulse noise is characterized by a sharp rise in sound pressure level to a high peak, followed by a rapid decay. Impulses can occur in quiet conditions, or they can be superimposed on a background of continuous or fluctuating noise, which is typical of the production industries. Sometimes a distinction is made between impulse noise, which is non-reverberant, and impact noise, which is reverberant. Since impulsive noise in industry can be either reverberant or non-reverberant, and since the relevant parameter is pulse duration, only one term, "impulse noise," will be used.

Sound levels are relevant under this standard only as they affect employees. If the employee is not present while high sound levels are being generated, OSHA is not concerned. The Agency is concerned with employee *exposure*, which is the accumulation of noise levels experienced by employees, as these levels are distributed over the workshift. This distinction is important because some comments in the record reflected a misunderstanding of the difference between workplace sound levels and employee levels (Ex. 14–96, p. 1; Ex. 14–79, p. 1). Although the frequency spectrum of a sound may have some effect on hearing loss, it is primarily the combination of level and duration that determines the degree to which noise will cause hearing loss and extra-auditory health effects. The manner in which level and duration are combined, for purposes of predicting adverse effects or calculating noise "dose" or 8-hour time-weighted average sound level, depends upon the "exchange rate." This combination is sometimes referred to as the "doubling rate," or the "time-intensity" tradeoff. A 5-dB exchange rate is used in 29 CFR 1910.95 and in this amendment. Specifically, a 5-dB increase in level is permitted for each halving of duration,

or conversely, a doubling of duration necessitates a 5-dB decrease in level.

Noise exposure can be described either in terms of an 8-hour time-weighted average sound level or a noise dose. For purposes of Section 29 CFR 1910.95 and this amendment the integration is performed according to a 5-dB exchange rate, referenced to a "criterion" level of 90 dB and a criterion duration of 8 hours. A worker's 8-hour time-weighted average sound level (TWA) is obtained from the time integral of the various noise levels experienced over the entire workshift. For example, for purposes of the hearing conservation amendment, the exposure of an individual who works 12 hours in continuous noise of 90 dB would correspond to a TWA of 93 dB.

Noise dose is the same concept expressed in percent. A dose of 50 percent means that one-half of the permitted TWA has been experienced. It could represent 8 hours at 85 dB, 4 hours at 90 dB, 16 hours at 80 dB, or other such combinations.

Hearing and Hearing Loss

The auditory system has three primary components: the outer ear serves to direct sound into the ear, the middle ear mechanically transmits the sound waves from the air to the fluid-filled inner ear, and the inner ear changes the sound waves from mechanical to neural energy. This last process is done in a small organ known as the cochlea, where sensory cells respond to the mechanical vibrations, change them into electrical energy, and transmit the message to the brain via the auditory nerve.

Noise-induced hearing loss can be temporary or permanent. Temporary hearing loss results from short-term exposures to noise, with normal hearing returning after a period of rest. This temporary decrease in hearing ability is called temporary threshold shift (TTS), a person's hearing threshold being the level of sound that he or she can just barely hear. For example, if a person with normal hearing works all day in a noisy environment, measurements at the end of the day would show that he or she could not hear as well as at the beginning of the day. But by the next morning, after a period of quiet, this person's hearing would have returned to normal. Generally, prolonged exposure to noise over a period of several years causes permanent damage to the sensory cells of the cochlea. A person who regularly sustains TTS will eventually suffer permanent hearing loss, which will occur gradually over time. The occurrence of TTS shows that a worker has been affected by noise, and if that individual continues to be exposed to the same levels of noise, it will result in a noise-induced permanent threshold shift (NIPTS).

The ability to hear sounds with clarity is a distinct attribute of normal hearing. Damage to the outer or middle ear can produce a problem with the perception of sound intensity. Damage to the cochlea or the auditory nerve is termed "sensori-neural," and causes impaired perception of intelligibility as well as intensity. Even if sounds are amplified, they still seem indistinct. Sensori-neural hearing loss is irreversible. People with noise-induced hearing loss sometimes can benefit from the use of a hearing aid, but the aid can never "correct" a hearing loss the way eyeglasses usually can correct for impaired vision (Ex. 231, written testimony, p. 5). Hearing aids merely amplify sound, but they do not make it clearer, or less distorted. Also, they amplify the unwanted noise as well as the wanted speech signals.

Noise-induced hearing loss is sensori-neural. It is a permanent condition, and cannot be treated medically. It is characterized by a declining sensitivity to high frequency sounds, usually to frequencies above 2000 Hz. The loss usually appears first and is most severe for the 4000-Hz frequency; the "4000-Hz notch" in the audiogram is typical of noise-induced hearing loss. With continued exposure, the loss spreads to the other audiometric frequencies, 500 through 6000 Hz. This phenomenon results in difficulties in the perception of speech. Most of the sound energy of speech is in the vowel sounds, and yet most of the intelligibility lies in the consonants. People with noise-induced, high-frequency hearing loss typically have difficulty hearing consonant sounds, and therefore have difficulty understanding speech (Ex. 9, p. 18). These problems will be discussed more fully in the Health Effects section below.

The hearing-impaired person is often frustrated by missing information that is vital for social or vocational functioning. Not only will people have to speak louder, but they must speak more clearly in order to be understood. In addition, background noise, such as radio, TV, or other people talking, has a much more disruptive effect on hearing-impaired individuals than on the normal listener because these individuals are less able to differentiate between the wanted signal and the unwanted background noise (Ex. 50, p. 6; Ex. 321–16 B, pp. 9, 10, 14, 49–50). People with noise-induced hearing impairments may be lost when trying to communicate in a group or on a noisy street.

Studies in the record show that some individuals suffer severe hearing losses as a result of noise exposure (Ex. 12, p. 158; Ex. 310, p. 22; Ex. 279, 11–13, p. 443; Ex. 26–2, p. 51). These individuals would rate themselves as hearing very poorly, or even as deaf (Ex. 29, p. 85).

Social relationships become increasingly difficult as the hearing impairment becomes more severe. Audiologist Dr. W. Grady Thomas of the University of North Carolina explains some of the difficulties experienced by the hearing impaired as follows:

> depression, isolation, suspicion and withdrawal from social contacts . . . can be expected in some individuals with moderate hearing loss. . . . Adjustment problems in adults who lose hearing are difficult because habit patterns are firmly established. . . . Also, the evaluation of self, to a great extent is affected by the individual's perceptions of the evaluation of himself by others. Having to continually ask people to repeat misunderstood speech messages can contribute to feelings of inadequacy and insecurity. (Tr. 815–816)

Other Adverse Effects

In addition to hearing loss, noise can cause other harmful effects. Noise can interfere with conversation to the extent that communication is virtually impossible, causing a feeling of isolation among workers. High levels of noise, even though they may be of relatively short duration, can mask warning shouts or signals. Injuries and even fatalities have been reported in conditions where the noise masked danger signals or cries for help (Ex. 26–1, p. 7; Ex. 78, p. 20).

There is increasing evidence that noise can cause adverse effects on general health. Laboratory and field studies implicate noise as a causative factor in stress-related illnesses, such as hypertension, ulcers, and neurological disorders. These effects, as well as more details on noise-induced hearing loss, will be discussed in subsequent sections of this preamble.

Measurement of Noise and Hearing Loss

There are two major types of instruments that are used to measure occupational noise. These are the noise dosimeter and the sound level meter. Noise dosimeters measure noise dose by directly integrating a function of the various sound levels over the entire workshift. For this reason they are quite useful in workplaces where noise levels vary throughout the workshift. The dosimeter gives a reading in terms of percentage of allowable exposure. The person being monitored wears the dosimeter throughout the workshift. Results of the monitoring are obtained after the dosimeter is taken off, either by pressing a button on the dosimeter or by plugging it into a master unit which then

gives a "readout." Since employee noise exposure is expressed either as percentage of allowable dose, or as a TWA, OSHA has included a chart in Appendix A, which presents the relationship between these forms of measurement.

A sound level meter registers the level of sound that occurs at a particular time. It is useful for measuring the noise level due to a given process, or for measuring a worker's exposure to sound that fluctuates relatively little. Sound level meters contain a microphone, an amplifier with a calibrated attenuator, a set of frequency response networks, and an indicator meter.

Most sound level meters and dosimeters are small, "general purpose" (Type 2) instruments, equipped with "weighting networks," which adjust the meter response to predetermined frequency portions of the measured sounds. The A-weighting network is most commonly used in the measurement of industrial and environmental noise. The A-weighting network discriminates against low-frequency sound and, to a lesser extent, against high-frequency sound. The rationale behind A-weighting is that low frequency sound, and some fairly high-frequency sound, is not as damaging or as irritating as sound in the mid-frequency range. Thus, A-weighted sound level appears to be a good predictor of human response to noise. A-weighted sound levels will be assumed throughout the amendment and preamble unless otherwise specified. Most general purpose sound level meters also have a C-weighting network, which basically reflects sound as it occurs in the environment, without any adjustment for human response. The C-weighting network is useful in determining the effectiveness of hearing protectors for particular noise conditions, since it does not discount the presence of low-frequency sound.

The frequency range is sometimes divided into octave bands. By measuring the sound level in each octave-band one can determine the spectrum of the noise. Each band is identified by its center frequency, such as 125, 250, 500, 1000, 2000, 4000 and 8000 Hz. Octave band measurements are necessary when selecting a room in which to perform audiometric testing, and in certain audiometer calibrations. They can also be helpful for assessing engineering control strategies. To determine the level of noise in different frequency bands, a sound level meter with an octave-band filter set is needed. This instrument is somewhat larger and more complex than the general purpose sound level meter that is used for measuring A-weighted and C-weighted sound levels.

The instrument that is used to test hearing is the audiometer. Audiometers produce pure tones at specific frequencies (e.g., 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz) and at specific sound levels. OSHA has required that employee hearing be tested at the frequencies 500 through 6000 Hz, since these are the most important frequencies for understanding speech, and since they are useful for determining the cause of the hearing loss.

The record of a given individual's hearing sensitivity is an audiogram. An audiogram shows hearing threshold level measured in decibels as a function of frequency in hertz. It indicates how intense or loud a sound at a given frequency must be before it can be perceived, thereby providing a graphic representation of the status of the individual's hearing. With periodic audiometric testing it is possible to trace and document hearing loss, and by doing so, to prevent further loss from occurring. The audiogram is an important indicator of early hearing loss, since losses can occur so gradually that a person may not realize that he or she is becoming impaired until a substantial amount of hearing is lost.

There are two principal types of audiometers, manual and self-recording. When a manual audiometer is used the technician adjusts the level of the tone to the point where the individual being tested can just hear it, and the technician records the level as hearing threshold. A self-recording audiometer allows the test subject to adjust the level of the tone, and the intensity of the tone is constantly recorded by a stylus, which records the results on a moving card.

Hearing threshold levels, as they are recorded from the audiometer, are given in decibels above audiometric zero. Audiometric zero is not the same as 0 dB sound pressure level, the zero reference level to which sound level meters are set. Audiometric zero deviates somewhat from 0 dB sound pressure level at each test frequency. (For example, the deviation is 10 dB at 1000 Hz, and 8.5 dB at 2000 Hz.) Audiometric zero represents the median hearing threshold level of young people with normal hearing. While some individuals may have unusually good hearing sensitivity (as good as −10 dB), others may have hearing thresholds of 10 or 15 dB and still be considered within the range of normal. Therefore, audiometric zero (as opposed to 0 dB sound pressure level) reflects an adjustment to represent normal baseline hearing. Audiometric zero has been standardized for the U.S. population in American National Standard Specification for Audiometers S3.6—1969. This zero reference level is assumed throughout the amendment and preamble unless otherwise specified.

II. Health Effects

The effects of occupational noise can be divided into two principal categories: auditory effects and extra-auditory effects. There is a wealth of information on the relationship between noise exposure and hearing loss. Dose-response relationships have been well established. Numerous studies are available which describe the effects of noise on hearing as a function of level and duration. The effects are stated in terms of the audiometric frequencies at which the loss occurs, degree of hearing loss, anatomical changes (in animal experiments), and differential changes in hearing as variables such as age and sex interact with noise exposure.

The extra-auditory effects of noise involve complex physiological and psychosocial reactions, which are much more difficult to document. Although stress-related illnesses have been associated with noise exposure, isolating all of the factors which contribute to stress confounds efforts to provide a direct "cause and effect" relationship between noise and such stress-related conditions as hypertension or ulcers. Although precise dose-response relationships are lacking at this time, information on the extra-auditory effects is included in this discussion because the data are highly suggestive of adverse effects, and therefore provide added incentive for protecting noise exposed workers.

A. *Hearing Loss.*

There is no doubt that noise exposure causes hearing loss, which grows more severe as exposure continues over the years. Many witnesses spoke with first-hand knowledge of the effect of noise exposure on their hearing, and consequently, on their lives. Ruth Knowles, President of Local 1716 of the Textile Workers Union, testified as follows about her noise-induced hearing loss:

> It has been a gradual loss of hearing for me, so gradual that I never really realized it until a few years ago, when a relative asked me if I did not hear well. After then I started noticing that it was getting worse and that I was having to strain more to hear clearly. I became alarmed and consulted a specialist, only to be told that nothing could be done and that the hearing loss had been caused by high noise exposure.
>
> It is truly a sad, helpless feeling that you have been told that you have lost a significant part of your second most

important sensor. As time has passed, I have been embarassed because I was not able to hear well enough to know what was going on. I have even given an affirmative nod only to find out later that it shoud have been a negative answer. Socially speaking, there have been many, many instances that because of my hearing impairment, I would rather have stayed at home. It is difficult for me to hear and understand most waitresses in restaurants and a few times I have even had to tell them that I did not hear well, after which they speak so loudly that everyone around turns to look. My family has come to realize this problem and usually volunteers their help.

Also, I am never able to hear sales persons in grocery stores or bank tellers. At times it has become so disturbing that I have actually sat down and cried when I would get home. Persons who do not suffer any loss of hearing can't possibly realize the humiliation those of us who have impaired hearing go through. (Tr. 2021–2022).

Material Impairment

Section 6(b)(5) of the Occupational Safety and Health Act indicates that when dealing with a harmful physical agent the Secretary should set a standard which guards against material impairment of health or functional capacity, even if the worker is exposed for a working lifetime. As discussed below, noise is a harmful physical agent. The hearing conservation amendment is reasonably necessary to mitigate the significant risk of noise, which is present in most workplaces. This amendment is necessary to prevent large numbers of workers from suffering material impairment of health and functional capacity resulting from exposure to noise. As shown below, even assuming compliance with the current occupational noise exposure standard, many workers will still be at increased risk of suffering material impairment of functional capacity from noise in the workplace. The hearing conservation program prescribed in this amendment will save at least 189,000 workers from suffering material impairment after the program is fully effective. Accordingly OSHA finds that this amendment is reasonably necessary and appropriate, not only to provide healthful, but to provide safe places of employment.

OSHA defines material impairment of hearing as an average hearing level, with respect to audiometric zero, that exceeds 25 dB for the frequencies 1000, 2000, and 3000 Hz. This hearing level is sometimes called a "fence" in that it provides a demarcation point along the continuum of hearing levels, above which a hearing loss is considered, in the language of the Occupational Safety and Health Act, a "material impairment of health or functional capacity." Most audiologists and acousticians will agree that small amounts of hearing loss can be tolerated. If more than a small amount of loss is suffered, a person cannot function as well as a normally hearing individual. The selection of the point or "fence" beyond which an individual person cannot function as well becomes the definition of material impairment of hearing.

OSHA believes that the capacity to hear and understand speech is the most critical function of human hearing. Therefore the definition of material impairment of hearing is directly related to people's ability to understand speech as it is spoken in everyday social conditions. Assessing this ability can be done by a variety of speech audiometric tests. Since speech audiometry is not well standardized, researchers and administrators have used pure-tone thresholds to estimate hearing for speech. As explained in the introductory section, these thresholds are the lowest levels at which a listener can just barely hear discrete frequency tones.

There is very little debate about the usefulness of pure tones to assess hearing impairment, but there is some disagreement about the hearing level, or fence, at which material impairment begins, and about which audiometric frequencies to use in the assessment. Setting the fence at a high hearing level means that workers are allowed to lose quite a lot of hearing before the loss is considered to be a material impairment to be prevented. Setting the fence at a low hearing level means that relatively little hearing is lost before the loss or impairment is considered material. The lower the fence, the larger will be the number of workers identified as materially impaired. The selection of audiometric frequencies also has an effect on the number of workers that will be identified. Since noise-induced hearing loss affects the high frequencies earlier and more severely than the low frequencies, more workers will be identified as crossing the fence or suffering material impairment when high frequencies are used in the definition. It should be noted that the use of high frequencies in the definition of material impairment more accurately portrays a worker's actual hearing loss, since those frequencies are more severely affected by noise.

The hearing levels and audiometric frequencies that constitute the definition of material impairment of hearing have been identified through studies of the ability to communicate in everyday listening conditions. Some of these studies were submitted to the record, and the issue of material impairment received considerable attention.

Until now, the Agency had not conclusively defined material impairment of hearing. For purposes of the proposal, OSHA had used the definition of hearing handicap developed in 1959 by the American Academy of Ophthalmology and Otolaryngology (AAOO), a subgroup of the American Medical Association (Ex. 3, p. 44; Ex. 6, p. 12337). The AAOO definition, which has been used primarily for workers' compensation purposes, uses a 25-dB fence for average hearing levels at the frequencies 500, 1000, and 2000 Hz. Some comments to the record (Ex. 35, p. 1; Ex. 26–3, p. 5–24; Ex. 26–4, p. 1) favored this definition, because it was thought to describe an individual's ability to communicate under everyday conditions. However, several commenters pointed out that it would not be appropriate to use the same formula for prevention and compensation (Ex. 47, p. 5; Ex. 46, pp. 364–365; Ex. 51, p. 4; Ex. 57, pp. 9–10). Dr. H. E. von Gierke of the U.S. Air Force commented on this subject on behalf of the EPA. He states that: "Formulas developed for assessing hearing handicap for compensation purposes were never intended to be used for purposes of preventive criteria." (Ex. 47, p. 5).

In its criteria document NIOSH recommended that the defintion of material impairment be expanded to include the ability to hear and to understand speech in noisy or difficult listening conditions. NIOSH used an average loss of 1000, 2000, and 3000 Hz in the frequency averaging, still using a 25-dB fence (Ex. 1, pp. VI–11 through VI–14). Various studies and comments supported the 1000, 2000, and 3000 Hz definition as being more realistic than the 500, 1000, and 2000 Hz AAOO defintion, because good hearing in the higher frequencies (2000 and 3000 Hz) is very important for understanding speech especially when there is noise in the background, or when speech is not clear. It was also noted that everyday listening conditions are noisy at least part of the time rather than being completely quiet (Ex. 1, p. VI–13; Ex. 50, p. 16; Ex. 321–16B, pp. 9–10, 61; Ex. 5, p. 43803), which is the assumption in the AAOO formula.

Dr. Aage Moller, Professor of Physiological Acoustics at the Karolinska Institute in Stockholm, commented on the severity of the AAOO definition in his testimony for the AFL–CIO:

> The 26 dB hearing loss average value for frequencies 500, 1000 and 2000 Hz is (by AAOO) assumed to correspond to a beginning loss of ability to understand speech in the quiet. Historically this definition originates from the limit where workmen's

copensation was to be paid for loss of earning power. Such a hearing loss will no doubt by most people be regarded as a rather severe handicap in normal social life. It will with most people make it impossible or at least very difficult to participate in parties where more than one person speaks at a time. People with that degree of hearing loss will also have difficulties to understand novel words and numbers. It is thus somewhat surprising that this *"limit of a handicap"* at present has been accepted as *"the limit of a tolerable"* impairment of the hearing. It has been suggested to exchange 500 Hz with 3000 Hz to give more realistic estimates of beginning loss of intelligibility of speech. (Ex. 88, pp. 3–4).

William C. Sperry, a private individual whose hearing impairment was very close to the AAOO-identified point of beginning handicap, filed a comment (Ex. 184). He believed that his hearing loss was sufficient to warrant buying a hearing aid. Although the hearing aid sometimes helped, there were other times when hearing was extremely difficult. He stated:

In a situation where there is a high ambient noise level, such as parties, I might as well leave my hearing aid at home, and very often, I go home after a short while since the multitude of speakers and all of the noise frequently makes it impossible to follow conversations. In any situation, where there is background noise, such as an air-conditioner, I find that communication is difficult, with or without the hearing aid. . . . I submit to you that people with my hearing loss are considerably more than just barely impaired. A standard that allows an average of 25 dB hearing loss at 500, 1000 and 2000 Hz very definitely allows material impairment to occur, and does not prevent people from losing one of their most valuable abilities, namely the ability to communicate effectively with each other. (Ex. 184, pp. 4–5).

Finally it was pointed out that the AAOO formula does not distinguish between a person who has a noise-induced hearing loss and a person who has a conductive hearing loss since it includes 500 Hz and excludes the frequencies above 2000 Hz (Ex. 1, pp. VI–12 and VI–13). Conductive hearing loss (which can be the result of many nonoccupational factors such as ear infections) tends to be of the same magnitude across all frequencies so that the loss has a flat appearance on the audiogram. Noise-induced hearing loss produces a sloping configuration, the loss being much more severe in the high frequencies than in the low frequencies, especially in the early stages. Since 500 Hz is the last and least severely affected of the test frequencies, it is not nearly so important as 3000 Hz in characterizing the audiogram of the individual with noise-induced hearing loss.

In 1979 the American Medical Association (AMA) (Ex. 321–10, p. 2058) changed its formula for hearing handicap, and now advocates a low fence of 25 dB for hearing levels averaged at the frequencies 500, 1000, 2000, and 3000 Hz. The AMA has chosen to include 3000 Hz because it now recognizes the value of high-frequency hearing in more realistic listening situations (Ex. 321–10, p. 2058). However, the primary use of the AMA formula for "medico-legal" (compensation) purposes remains unchanged.

Another method for describing material impairment, developed by the Committee on Hearing, Bioacoustics and Biomechanics of the National Academy of Sciences (CHABA), was discussed by Dr. W. Dixon Ward (Ex. 222C, pp. 12–13) and Dr. Thomas (Ex. 51, pp. 7, 8). The CHABA report specified that a fence of 35 dB should be used if hearing levels at 1000, 2000, and 3000 Hz were averaged (Ex. 222C, pp. 12–13). CHABA's charge was to find a low fence for the frequencies 1000, 2000, and 3000 Hz that would yield the same compensation as a 25-dB fence at 500, 1000, and 2000 Hz (Ex. 51, pp. 7–8). Since this formula was specifically concerned with compensation, rather than with prevention, OSHA does not consider it appropriate for use in a standard to prevent material impairment of hearing. The CHABA committee made no attempt to define material impairment of hearing by examining research results on the ability to understand speech and to function in everyday life.

EPA (Ex. 189–5, p. 11) recommended a 25-dB fence for hearing levels averaged at the frequencies 1000, 2000, and 4000 Hz, and later submitted a study (Ex. 321–16B, pp. 60, 61) to support the same frequencies but using an even lower fence.

Other witnesses also recommended lower fences or higher frequencies than those employed by the AAOO. Dr. Karl Kryter of the Stanford Research Institute, testifying on behalf of EPA (Ex. 50, p. 6; Tr. 776–778) criticized the AAOO formula, and suggested a fence at least as low as 15 dB if the frequencies 500, 1000, and 2000 Hz were used. Joseph Hafkenschiel of the Communications Workers of America, recommended a 15-dB fence for the frequencies 500, 1000, and 2000 Hz (Ex. 82, p. 4), and others also argued that a 25-dB fence allows too much hearing loss (Ex. 189–5, p. 7; Ex. 184, p. 5; Ex. 50, p. 4). A fence of 15 dB at 500, 1000, and 2000 Hz would be equivalent to a hearing level of 25 dB if the frequencies 1000, 2000, and 3000 Hz were used (Ex. 50, p. 19).

A report submitted by the Center for Policy Alternatives at the Massachusetts Institute of Technology (Ex. 138A, pp. 2–2 to 2–3) recommended using a variety of fences to describe different degrees of hearing loss experienced by a noise exposed population.

Dr. William Burns, professor of physiology at the University of London, pointed out (Tr. 851) that the British Standard, Method of Test for Estimating the Risk of Hearing Handicap due to Noise Exposure (in draft form at the time of his testimony), estimated risk data for the frequencies 1000, 2000, and 3000 Hz, although the standard used a fence of 30 dB. This fence and frequency combination were also recommended by the British to the International Organization for Standardization (Proposal from the UK-Member Body of ISO/TC 43/SC 1 for a revision of ISO 1999—Acoustics—Assessment of Occupational Noise Exposure for Hearing Conservation Purposes). These two documents later were submitted to the record by EPA as Exhibits 266E (p. 15) and 279, 11–10 (p. 1).

Following the original recommendation of NIOSH, OSHA will consider as material impairment a 25-dB fence for the frequencies 1000, 2000, and 3000 Hz. The agency agrees with the many comments and studies cited to show that high-frequency hearing is critically important for the understanding of speech (Ex. 46, p. 363; Ex. 26–1, p. 3; Ex. 26–6, p. 830; Ex. 228, p. 8; Ex. 5, p. 43803; Ex. 51, pp. 6–7), and that everyday speech is sometimes distorted and often takes place in noisy conditions. Therefore, the Agency believes that 3000 Hz should be included in the definition of material impairment, and 500 Hz, since it is not so important for understanding speech (Ex. 1, p. VI–16; Ex. 26–6, p. 830; Ex. 26–7, p. 1217; Ex. 321–16B, pp. 42–44) and since it is last and least affected by noise, should be excluded from the definition.

OSHA has considered including the 4000-Hz frequency in the definition of material impairment as recommended by EPA, since hearing at this frequency appears to be particularly valuable at times when listening conditions are noisy and distorted (Ex. 26–6, p. 830; Ex. 26–7, p. 1217; Ex. 321–16B, pp. 34–45). However, OSHA recognizes that listening conditions are favorable at least part of the time, and until data become available to show the typical proportion of favorable to unfavorable listening conditions, or the average amount of distortion that occurs in everyday speech, OSHA will continue to use the 25-dB fence at 1000, 2000, and 3000 Hz as recommended by NIOSH (Ex. 1, p. VI–11) and others (Ex. 88, pp. 3–4, Ex. 26–7, pp. 1217, 1223; Ex. 50, pp. 6,

19). This is not to say that the 4000-Hz frequency has no importance for the understanding of speech and that unlimited loss should be allowed in that frequency, but only that it is not included in the definition of material impairment at this time. In the typical noise-induced hearing loss pattern, severe losses at 4000 Hz are almost always accompanied by losses at 3000 Hz which are nearly as severe (Ex. 12, p. 136, fig. 10.19; Ex. 26–2, pp. 36–47; Ex. 1, fig. 7). Therefore, losses at 4000 Hz would not be unaccounted for.

The Agency has accepted the recommendation of the Center for Policy Alternatives to examine the effects of noise on hearing by means of a variety of fences. In the discussion of the anticipated benefits of hearing conservation programs, the Agency uses fences at 15 dB, 25 dB, and 40 dB for the frequencies 1000, 2000, and 3000 Hz. The 25-dB fence, however, is considered the point at which impairment may be considered material.

Quantifying the Effects of Noise

The two most useful concepts for describing dose-response relationships for noise-induced hearing loss are the "percentage risk" and the "noise-induced permanent threshold shift" (NIPTS) concepts. The first concept involves predicting the percentage of a population that will develop material impairment of hearing as a result of given levels and durations of noise. The second concept is used to predict the amount of hearing loss in decibels that will occur as a result of given levels and durations of noise after subtracting for presbycusis (hearing loss from aging).

In order to better understand the methods of describing the effects of noise, the concept of presbycusis should first be discussed. Presbycusis is a natural phenomenon that affects most individuals if they live to be old enough. Some people will lose some hearing by the age of 40 or 50, while others will have normal hearing well into their 70s. Mature adults will seldom have hearing levels as low as 0 dB for all audiometric frequencies. As people age, their hearing levels become higher, and most individuals accept some hearing loss as a natural occurrence (Ex. 29, p. 84). However, when even a minor noise-induced hearing loss is added to presbycusis, the resulting loss can be sufficient to cross the fence into material impairment. Whether a hearing loss is one-third presbycusis and two-thirds noise-induced, or the other way around, the loss of functional capacity is the same. In most cases, people will not be materially impaired by presbycusis alone unless they live to be very old. When noise exposure is added, usually from an occupational source, many will become materially impaired when they are young or middle-aged, and the impairments will grow more severe as age increases. In addition, occupational noise exposures have the effect of making some people suffer more hearing loss at a younger age than they would if not exposed to occupational noise.

Since presbycusis, when it occurs, is a natural and inevitable condition, it is only reasonable to examine the impact of noise exposure on a population that includes some amount of presbycusis. After a working lifetime most individuals will be at least 60 years old, and will have experienced some amount of presbycusis. It is also useful to know the extent of damage produced by noise alone, so as to judge the magnitude of the effect at each audiometric frequency as a function of exposure level and duration. Therefore the Agency has quantified the effects of noise on hearing using both the percentage risk and the NIPTS methods.

The percentage risk method allows the inclusion of presbycusis in that the procedure estimates numbers of people whose hearing levels (including presbycusis or any other impairment) will exceed a certain fence due to noise exposure. It does not include people who will exceed a certain fence because of a hearing loss *only* from aging, since the calculation subtracts the percentage of a non-noise-exposed population who would cross the fence anyway from "natural" causes. The remainder is the population at risk of developing material impairment of hearing due to noise exposure.

OSHA believes that the data in Table 1 provide reliable and consistent estimates of the percentages of the population at risk of developing material impairment due to exposure to daily average noise levels of 80, 85 and 90 dB for a working lifetime.

Table 1

[Estimated percentages of the population at risk of exceeding a 25-dB fence at 500, 1000, and 2000 Hz as a function of average noise exposure level for 40 years. (EPA, Ex. 5, p. 43805)]

Organization	Noise exposure in dB	Risk (percent)
ISO	90	21
	85	10
	80	0
EPA	90	22
	85	12
	80	5
NIOSH	90	29
	85	15
	80	3

This table, which was submitted by EPA (Ex. 5, p. 43805), shows the percentage of the exposed population expected to exceed a 25-dB fence at the frequencies 500, 1000, and 2000 Hz. The risk figures were developed by the International Organization for Standardization (ISO) (based on the data for Baughn), EPA, and NIOSH. These organizations estimated percentage risk for the 500, 1000, and 2000 Hz combination since the AAOO definition of hearing handicap still was used widely at the time these percentage risk estimates were developed (ISO in 1975, Ex. 26–4; EPA in 1973, Ex. 31; and NIOSH in 1972, Ex. 1). Two of the three organizations have now advocated the inclusion of frequencies above 2000 Hz in the definition of material impairment (Ex. 5, pp. 43803, 43805; Ex. 1, pp. VI–11, VI–14). The ISO–1980 proposal, which still is in draft form at this time, does not prescribe a specific formula for risk assessment but provides an array of formulas that can be used for predictive purposes (Ex. 321–43A, p. 3).

It can be seen that the risk of material impairment at an average exposure level of 90 dB is a substantial 21 to 29 percent. The risk of incurring material impairment after a working lifetime of 85 dB is 10 to 15 percent, and at 80 dB is 0 to 5 percent. The inclusion of 3000 or 4000 Hz in the definition of material impairment would tend to make the percentages at risk somewhat higher, since hearing loss at these frequencies from noise exposure is almost always greater than it is at 500 and 1000 Hz.

Because these risk figures were developed virtually independently [1] by the three organizations, the percentages for each exposure level are slightly different. These differences are to be expected when using the percentage risk concept because the estimates can be influenced by the extent to which a noise-exposed population is screened to exclude people with nonoccupational hearing loss, and also by the extent to which the population includes hearing loss from aging (Ex. 5, p. 43806). For example, NIOSH suggested that its percentage risk estimates might be slightly higher than those derived from the "severely" screened population (Ex. 1, p. VI–31). (An exposed population that includes some amount of nonoccupational hearing loss and some presbycusis would be representative of the U.S. population, and thus the risk figures should not be unrealistic.)

[1] As mentioned above, the ISO risk estimates were derived from data collected by Dr. W. L. Baughn. The EPA also used Baughn's data, and averaged them with data collected by Drs. Burns and Robinson, and Dr. Passchier-Vermeer. All of these studies will be discussed in further detail below. Since EPA's estimates are based in part on the same data that were used by ISO, the relationship between the EPA and ISO risk estimates is not entirely independent.

Although Table 1 shows small differences, the risk estimates for the same exposure level are very similar.

The percentage risk concept, while easy to understand, is in some ways a limited descriptor of noise-induced hearing loss (Ex. 5, p. 43806; Ex. 47, pp. 9–10; Ex. 231, written testimony, p. 1). First, the use of a single fence such as 25 dB does not adequately describe the effects of noise on all of the impaired workers in that it does not quantify the amount of loss (Ex. 5, p. 43805; Ex. 231, p. 7). Everyone whose hearing threshold has exceeded the 25-dB fence is considered to have the same amount of hearing loss. The single fence conveys nothing about the people who start with excellent hearing and lose up to 25 dB from noise exposure, nor does it indicate how many people suffer severe losses, greater than 40 or 50 dB, for example (Ex. 5, p. 43806; Ex. 231, p. 7; Ex. 47, pp. 9–10). In an attempt to overcome these limitations, OSHA uses three fences to discuss the benefits anticipated from hearing conservation programs.

Noise-induced permanent threshold shift (NIPTS) is the actual shift in hearing level due to noise exposure, after corrections have been made for aging. NIPTS values may be designated for combinations of frequencies, but they are usually given for each audiometric frequency separately, and it can be helpful to examine hearing loss at individual frequencies. (The percentage risk method nearly always averages hearing levels at three or more frequencies.) The NIPTS method allows examination of the effects of noise on hearing level at 4000 and 6000 Hz, which, although they are not usually included in the definition of material impairment, are the frequencies where hearing is earliest and most severely affected by noise. NIPTS usually is presented for certain percentages of the exposed population, such as the median, the 90th and the 10th percentiles, the lower percentiles representing the more severely affected members.

The disadvantage in presenting the data only as NIPTS is that the full impact of noise exposure is not as easily comprehended as it is with percentage risk. Since NIPTS values do not include any hearing loss from nonoccupational causes, they do not reflect actual hearing levels. However, for comparing the effects of one exposure level against another they are very useful.

Table 2 shows NIPTS as a function of exposure level and exposure duration in years (see Johnson's Table 3, Ex. 310, pp. 27–28). NIPTS values are given for each audiometric frequency from 500 Hz to 6000 Hz, and are shown for the less sensitive 90th percentile, the median, and the more sensitive 10th percentile. When added to presbycusis values from a "normal" non-noise exposed population, these resulting hearing levels would reflect realistic hearing levels to be expected in noise exposed populations.

Table 2 is taken from a report by Col. Daniel Johnson of the U.S. Air Force, entitled "Derivation of Presbycusis and Noise Induced Permanent Threshold Shift (NIPTS) to be used for the Basis of a Standard on the Effects of Noise on Hearing" (Ex. 310, pp. 27–28). As in a previous report, which Col. Johnson had prepared for the EPA (Ex. 17), he averaged the hearing loss data from some well-known studies. While in the earlier report Col. Johnson used the data of Baughn, Burns and Robinson, and Passchier-Vermeer, in the more recent report he combined only the data of Burns and Robinson with those of Passchier-Vermeer. Details of these studies will be discussed further below.

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