n-96-01
II-A-313

DESK REFERENCE

TO

HEALTH & WELFARE EFFECTS
OF NOISE

OCTOBER 1979

Office of the Scientific Assistant
Office of Noise Abatement and Control
U.S. Environmental Protection Agency

Prepared for use by EPA staff as a ready reference to information on the health effects of noise. This Desk Reference will be updated periodically. Please address comments to the Scientific Assistant to the Deputy Assistant Administrator.

Prepared under Contract 68-01-4477

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TOPICAL OVERVIEW (SEE ALSO INDEX, SECTION 16)

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EPA'S PUBLIC HEALTH AND WELFARE MANDATE

THE MANDATE

EPA was given a Public Health and Welfare mandate in the area of noise in 1972 with passage of the Noise Control Act. Congress felt that inadequately controlled noise presented a growing danger to the health and welfare of the nation's population and concluded that the policy of the United States was to promote an environment for all Americans that is free from noise which jeopardizes their health or welfare (1/Sect. 2)*. This mandate was extended by the Quiet Communities Act of 1978 (2/Sect. 2, Sect. 5).

How is the national objective to be accomplished?

Under Section 2, the Act is intended to help accomplish the national objective in the following ways:

1. Effectively coordinate Federal research and activities in noise control.

2. Establish Federal noise emission standards for products distributed in commerce.

3. Provide information to the public concerning the noise emission and noise reduction characteristics of the regulated products. (2/Sect. 2)

What is the definition of Health and Welfare?

EPA utilizes the World Health Organization definition that specifies Health and Welfare as complete physical, mental, and social well-being, not just the absence of disease and infirmity (3).

* References are listed in Section 15, e.g.: (Ref. 1, Sect. 2).

1

<u>What specific Public Health and Welfare information is EPA required to provide?</u>

1. To publish criteria that reflect the kind and extent of all identifiable noise effects on public health and welfare (1/Sect. 5(a)1).

2. To publish information on the levels of environmental noise requisite to protect the public health and welfare with an adequate margin of safety (1/Sect. 5(a)2).

<u>What is EPA's responsibility regarding standards and regulations?</u>

1. EPA is given the authority to prescribe and amend standards that limit the noise generation characteristics newly manufactured products that have been identified as a major source of noise. This may include construction equipment, transportation equipment, motors or engines, and electrical or electronic equipment. Standards must take into account the magnitude and conditions of use, the degree of noise reduction achievable by best available technology, and the cost of compliance. (1/Sect. 6(c)1) EPA also has the responsibility to develop in-use regulations for interstate rail and motor carriers.

2. Other agencies are required to consult EPA before prescribing noise regulations. EPA is allowed to require public review of any such regulation that they feel is insufficient to protect public health and welfare according to its criteria (1/Sect. 4(c)2).

<u>What is EPA's responsibility in regard to aircraft noise regulations?</u>

EPA does not have authority to regulate aircraft noise, but is required to submit recommendations for such regulations to the FAA (1/Sect. 7(c)2).

How is Health and Welfare involved in labeling?

EPA is required to label any product emitting noise capable of adversely affecting the public health and welfare (1/Sect. 8(a)1).

What is EPA's authority for enforcement?

The Administrator of EPA may issue enforcement orders for non-compliance or mislabeling of products, specifying the non-compliance penalties under the law (1/Sect. 10(d)1).

THE NATIONAL NOISE PROBLEM

2

Since 1973, the Department of Housing and Urban Development (HUD) (39)* has conducted an Annual Housing Survey for the Census Bureau in which noise has been consistently ranked as a leading cause of neighborhood dissatisfaction. In fact, nearly one-half of the respondents each year have felt that noise was a major neighborhood problem (see Figure 2-1). In the 1975 survey, street noise was mentioned more often than all other unwanted neighborhood conditions. This survey has also shown that aircraft and traffic noise are leading factors in making people want to move from their neighborhoods. Approximately one-third of all the respondents who wished to move because of undesirable neighborhood conditions, did so frequently because of noise. (39)

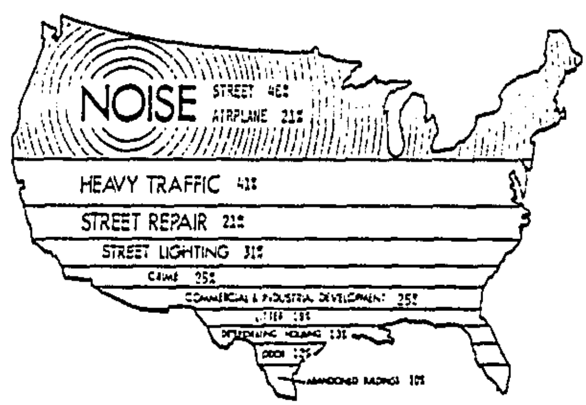

FIG. 2-1. UNDESIRABLE NEIGHBORHOOD CONDITIONS FOR HOMEOWNERS AND RENTERS: UNITED STATES COMPARATIVE RANKING, 1975. SOURCE: Ref. 4, pp. 8-12.

* References are listed in Section 15, e.g.: (Ref. 39).

2

A poll conducted by the Gallup Organization in November 1978 for the National League of Cities and a Harris Survey for the ABC network in January 1979 on attitudes toward environmental issues both indicated that the public views noise as a growing problem warranting more governmental attention and action.

How many people are estimated to live in residential areas with noise levels above EPA's recommended limits?

The Levels Document recommends that the day-night sound level of residential areas not exceed 55 dB to protect against activity interference and annoyance (5). It is estimated that well over 100 million people, nearly half the U.S. population, live in areas where the noise exceeds this level (see Figure 2-2). Twelve million people are estimated to live in areas where the outdoor L_{dn} exceeds 70 dB, and they are likely to experience severe annoyance and possible hearing loss.

What is the relationship between indoor and outdoor levels?

Indoor levels are often comparable to or higher than levels measured outside (5/B-6). However, many outdoor noises still annoy people in their homes more than indoor noises do, and people sometimes turn on indoor sources to mask the noise coming from outside (6/11).

well. Over 100 million persons are estimated to be exposed, in and around their homes, to undesirably high traffic noise levels exceeding L_{dn} = 55 dB. Figures contained in Table 2-1 for each source represent the number of people exposed at or above a given level (L_{dn}) for the source in question and do not take into consideration that an individual may be simultaneously exposed to more than one source culminating in a higher total exposure.

L_{dn} (dB)	Number of People in Millions for Each Noise Category						
	Urban Traffic	Rural Traffic	Aircraft	Rail	Agricultural	Industrial	Home Appliance
80	0.4		0.3				
75	2.0		0.8				
70	7.1	0.2	2.5				
65	21.6	1.0	7.9	0.4			
60	54.1	2.8	$\simeq$19.9	1.1		1.6	
55	102.1	4.8	$\simeq$50.0	2.4	0.1	6.3	15.0

TABLE 2-1. SUMMARY OF THE NUMBER OF PEOPLE EXPOSED TO VARIOUS LEVELS OF L_{dn} OR HIGHER FROM NOISE SOURCES IN THE COMMUNITY.
SOURCE: Ref. 7, pp. C-6,17.

<u>What are typical noise exposures for people throughout the day for various U.S. life styles?</u>

This information is not precisely known. However a study by Schori seems to show an average exposure of $L_{eq(24)}$ = 75 dB. However, his sample is not necessarily typical (8/32).

How many workers and non-workers are exposed to noise levels which may be damaging to their hearing?

An estimated 15 million American workers are exposed to an $L_{eq\ (8)}$ of 75 dB or above which may be hazardous to their hearing. Because of the overlap between persons in occupational and non-occupational noise exposure situations, there is an estimated total of 20 to 25 million persons who may possibly incur hearing losses based on an $L_{eq\ (8)}$ of 75 dB or above (7/47).

What might be considered the typical daily noise exposure pattern?

Figure 2-3 hypothetically depicts an example of what might be considered a typical daily noise exposure of a homemaker, students, and workers.

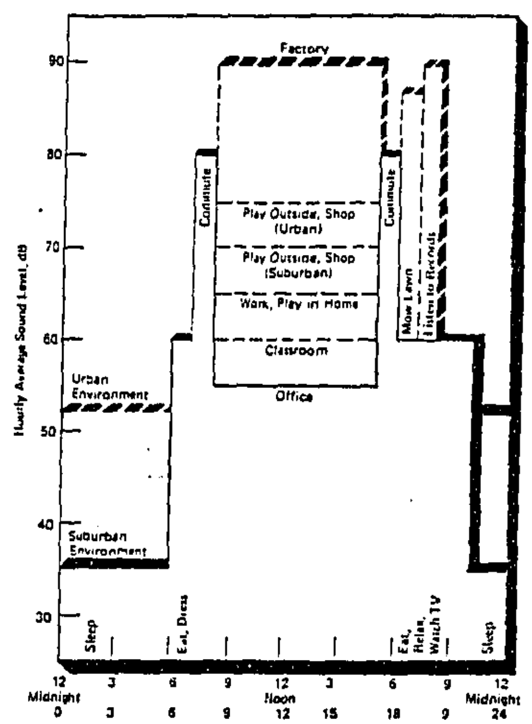

FIG. 2-3. HYPOTHESIZED LIFE STYLE NOISE EXPOSURE PATTERNS.

EPA POLICY STATEMENTS ON NOISE LEVELS

Maximum noise levels EPA has identified to protect the public health and welfare 3

HEARING LOSS	LEVEL (at ear)	AREA
Hearing Loss	$L_{eq(24)} \leq 70$ dB	All areas
Outdoor activity interference and annoyance	$L_{dn} \leq 55$ dB	Outdoors in residential areas and farms and other outdoor areas where people spend widely varying amounts of time and other places in which quiet is a basis for use.
	$L_{eq(24)} \leq 55$ dB	Outdoor areas where people spend limited amounts of time, such as school yards, playgrounds, etc.
Indoor activity interference and annoyance	$L_{dn} \leq 45$ dB	Indoor residential areas
	$L_{eq(24)} \leq 45$ dB	Other indoor areas with human activities such as schools, etc.

SOURCE: Ref. 5, p. 3.*

Explanation:

1. $L_{eq(24)}$ represents the sound energy averaged over a 24-hour period while L_{dn} represents the L_{eq} with a 10 dB nighttime weighting.

2. The hearing loss level identified here represents annual averages of the daily level. (These are energy averages, not to be confused with arithmetic averages.)

*References are listed in Section 15 e.g.: (Ref. 5/p. 3).

3

EPA has determined that for purposes of hearing conservation alone, a level which is protective of that segment of the population at or below the 96th percentile will protect virtually the entire population. This level has been calculated to be an L_{eq} of 70 dB over a 24-hour day, also equivalent to an L_{eq} over a period of 8 hours ($L_{eq\ (8)}$) of 75 dB.

EPA's operational abatement goals as defined in the "Strategy Document"

A. To take all practical steps to eliminate hearing loss resulting from noise exposure;

B. To reduce environmental noise exposure to an L_{dn} value of no more than 75 dB immediately;

C. To reduce noise exposure levels to an L_{dn} of 65 dB or lower by vigorous regulatory and planning actions;

D. To strive for an eventual reduction of noise levels to an L_{dn} of 55 dB;

E. To encourage and assist other Federal, State, and local agencies in the adoption and implementation of long range noise control policies.

(9/vii-viii)

Definition of a major source of noise

From the scientific (health and welfare) perspective, without any regard whatsoever to costs, feasibility, practicality, or policy/political considerations, the definition of a major source of noise as published in the 5(b)(1) notices of the Federal Register is transcribed below. Note that the definition consists of several criteria. These criteria include exceeding the maximum noise levels identified to protect the public health and welfare (see page 3-1):

Basis for the identification of major noise sources

"In determining whether a product (or class of products) is a major noise source for regulation under Section 6 of the Act, the Administrator considers primarily the following factors:

1. The intensity, character and/or duration of the noise emitted by the product (or class of products) and the number of people impacted by the noise;

2. Whether the product, alone or in combination with other products, causes noise exposure in defined areas under various conditions, which exceed the levels requisite to protect the public health and welfare with an adequate margin of safety;

3. Whether the spectral content or temporal characteristics, or both, of the noise make it irritating or intrusive, even though the noise level may not otherwise be excessive;

4. Whether the noise emitted by the product causes intermittent single event exposure leading to annoyance or activity interference."

The second factor is the most salient part of the definition and will for most practical purposes cover almost all products with which EPA is concerned. There may occur, however, a few instances where products may not meet the criterion of factor Number 2 above, but may still be considered acoustically unacceptable from a public point of view. In such cases factors 1, 3, and 4 as cited above apply. (10/6722)

SUMMARY OF HUMAN EFFECTS FROM VARIOUS OUTDOOR NOISE LEVELS

The following five tables present information on the possible effects on people caused by outdoor day-night noise levels of 55, 60, 65, 70, and 75 decibels.

Summary of Human Effects for Outdoor Day-Night Sound Level of 55 Decibels

Type of Effect	Magnitude of Effect
Hearing Loss	Will not occur
Risk of nonauditory disease (stress)	*
Speech** - Indoors	No disturbance of normal conversation. 100 percent sentence intelligibility (average) with a 5 dB margin of safety
- Outdoors	Slight disturbance of normal voice or relaxed conversation with 100 percent sentence intelligibility (average) at 0.35 meter or 99 percent sentence intelligibility (average) at 1.0 meter or 95 percent sentence intelligibility (average) at 3.5 meters
High Annoyance	Depending on attitude and other non-acoustical factors, approximately 4 percent of the population will be highly annoyed.
Overt Community Reaction	None expected; 7 dB below level of significant "complaints and threats of legal action," but at least 16 dB below "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
Attitudes Towards Area	Noise considered no more important than various other environmental factors

* and ** See the notes on page 3-9.

Summary of Human Effects for Outdoor Day-Night Sound Level of 60 Decibels

Type of Effect	Magnitude of Effect
Hearing Loss	Will not occur
Risk of nonauditory health effects (stress)	*
Speech** - Indoors	No disturbance of normal conversation. 100 percent sentence intelligibility (average) with no margin of safety
- Outdoors	Moderate disturbance of normal voice or relaxed conversation with 100 percent sentence intelligibility (average) at 0.2 meter or 99 percent sentence intelligibility (average) at 0.6 meter or 95 percent sentence intelligibility (average) at 2 meters
High Annoyance	Depending on attitude and other non-acoustical factors, approximately 9 percent of the population will be highly annoyed.
Average Community Reaction	Slight to moderate; 2 dB below level of significant "complaints and threats of legal action," but at least 11 dB below "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
Attitudes Towards Area	Noise may be considered an adverse aspect of the community environment

* and ** See the notes on page 3-9.

Summary of Human Effects for Outdoor Day-Night Sound Level of 65 Decibels

Type of Effect	Magnitude of Effect
Hearing Loss	Will not occur
Risk of nonauditory health effects (stress)	*
Speech** - Indoors	Slight disturbance of normal conversation 99 percent sentence intelligibility (average) with a 4 dB margin of safety
- Outdoors	Significant disturbance of normal voice or relaxed conversation with 100 percent sentence intelligibility (average) at 0.15 meter or 99 percent sentence intelligibility (average) at 0.5 meter or 95 percent sentence intelligibility (average) at 1.5 meters
High Annoyance	Depending on attitude and other non-acoustical factors, approximately 15 percent of the population will be highly annoyed.
Average Community Reaction	Significant; 3 dB above level of significant "complaints and threats of legal action," but at least 7 dB below "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
Attitudes Towards Area	Noise is one of the important adverse aspects of the community environment

* and ** See the notes on page 3-9.

Summary of Human Effects for Outdoor Day-Night Sound Level of 75 Decibels

Type of Effect	Magnitude of Effect
Hearing Loss	May begin to occur in sensitive individuals, depending on actual noise levels received at-ear.
Risk of nonauditory health effects (stress)	*
Speech** - Indoors	Some disturbance of normal conversation. Sentence intelligibility (average) approximately 98 percent
- Outdoors	Very significant disturbance of normal voice or relaxed conversation with: 100 percent sentence intelligibility not possible at any distance or 99 percent sentence intelligibility (average) at 0.15 meter or 99 percent sentence intelligibility (average) at 0.5 meter
High Annoyance	Depending on attitude and other non-acoustical factors, approximately 37 percent of the population will be highly annoyed.
Average Community Reaction	Very severe; 13 dB above level of significant "complaints and threats of legal action" and at least 3 dB above "vigorous action" (attitudes and other non-acoustical factors may modify this effect).
Attitudes Towards Area	Noise is likely to be the most important of all adverse aspects of the community environment.

* and ** See the notes on page 3-9.

The following notes should be kept in mind when examining the preceding five tables:

* Research implicates noise as a factor producing stress-related health effects such as heart disease, high-blood pressure and stroke, ulcers and other digestive disorders. The relationships between noise and these effects have not yet been quantified, however.

** The speech effects data in these tables are drawn from the Levels Document, as follows. Indoor effects are based on Table 3, and on Figure D-1, with 15 dB added to the indoor level to obtain the outdoor reading. Outdoor effects come from Figure D-2, using L_d (as determined with Figure A-7). Both Figures D-1 and D-2 are based on steady noise, not on L_{eq}. Table D-3 shows that for fluctuating noise, the average percent interference can be higher or lower than for steady noise with the same L_{eq}. The values given in this report are the best estimates of the interference.

HEARING LOSS

NORMAL HEARING

<u>How does the human ear work?</u>

The Figure 4-1 shows a schematic diagram of how the human ear functions.

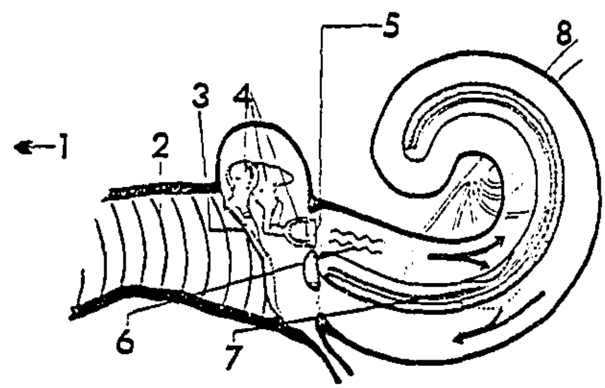

FIG. 4-1. A SCHEMATIC DIAGRAM OF HOW THE HUMAN EAR FUNCTIONS
Source: Ref. 11, p. 9.

The outer ear consists of the auricle or pinna [1 not shown] and the auditory canal [2]. The pinna of the human ear is a residual structure although it may aid in the localization of sound entering the ear. The sound wave entering the ear is enhanced by resonant characteristics of the auditory canal (12/61-65).* Sound waves travel up the auditory canal [2] and set up vibrations in the eardrum or tympanic membrane [3].

* References are listed in Section 15, e.g.: (Ref. 12/pp. 61-65).

Behind the tympanic membrane is a cavity called the middle ear. The middle ear functions as an impedance matcher.* Specifically, sound pressure from waves traveling through the air (low impedance) is amplified about 21 times so that it may efficiently travel into the high impedance fluid medium in the inner ear. This is accomplished by the leverage action of the three middle ear bones: the malleus, incus, and stapes [4]. The footplate of the stapes, in turn, moves in and out of the oval window [5].

The movement of the oval window sets up motions in the fluid [6] that fill the inner ear or cochlea. Movement of this fluid causes the hairs that are immersed in fluid to move [7]. The movement of these hairs stimulates the cells attached to them to send impulses along the fibers of the auditory nerve [8] to the brain. The brain translates these impulses into the sensation of sound. (12/67-73)

<u>What is considered to be normal hearing?</u>

The ability to hear means being capable of detecting sounds within the frequency range of 16-20,000 Hz. The threshold of audibility or the point at which sounds are barely detectable is shown in Figure 4-2. In clinical hearing assessment, normal hearing falls within a range of 0 to 25 dB of the threshold of audibility. (12/176-177)

* Impedance is comprised of frictional resistance, mass, and stiffness, and thus acts in opposition to the incoming sound wave.

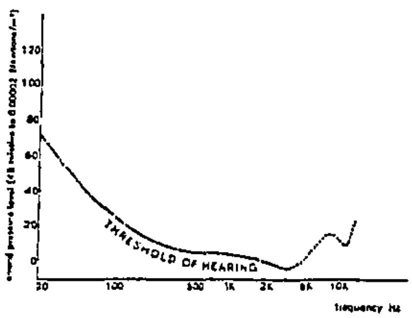

FIG. 4-2. AVERAGE THRESHOLD OF HEARING
Source: Ref. 13, p. 12.

<u>At what level is the threshold of pain?</u>

The threshold of pain is located at the upper boundary of audibility and in normal hearers is in the region of 135 dB for all frequencies (13/223).

<u>Are there differences in normal adult hearing based on sex?</u>

Starting in the early teenage years, and particularly in the age range of 25 to 65, women in industrial countries have better hearing than do men. However, the rate of hearing loss in men over 50 declines while that of women of the same age increases. Above 75 years of age the difference in hearing between the sexes tends to become insignificant. These differences most likely exist because noise exposure is primarily greater for men due to the occupational noise they usually encounter in their early and middle years (14/4-4).

Are there differences in normal adult hearing based on age?

The threshold of hearing rises (hearing becomes less sensitive) with age. This effect involves primarily, and is most marked at, the higher frequencies above 3000 Hz (14/4-7). Studies of large population samples have shown that this loss begins at around age twenty and increases with each decade (13/51). Refer to Figure 4-7 which shows curves representing changes in the average threshold of hearing with age for males and females. (Also see section on Presbycusis.)

Are there differences in normal adult hearing based on race?

There is no inherent difference in hearing levels between the races that make up the population of the U.S. Human ears are essentially the same around the world. Any demographic differences that have appeared in some studies is most likely attributable to differing environmental noise exposures. (15/1-5)

How is hearing measured?

Hearing is commonly measured by the use of a pure-tone audiometer. Test tones are produced by the audiometer at known intensities and are presented to the subjects' ears through earphones. This is known as air conduction testing. Each ear is tested separately and commonly at the following test frequencies: 250, 500, 1000, 2000, 4000, and 8000 Hz. At each test frequency, the hearing threshold for that test tone is identified by responses to the tone at least 50 percent of the time at the lowest intensity heard by the subjects (13/77). Hearing loss is measured by the difference between the zero dB hearing level and the intensity required for the subject to hear each test tone half the time (13/68). The results are plotted on an audiogram. The sample audiogram shown in Figure 4-3 reflects hearing loss ranging from 45 dB at 250 Hz to 25-35 dB at 8000 Hz. Each ear is represented separately (O = right, X = left). The modified brackets indicate bone conduction thresholds; (< = right, > = left).

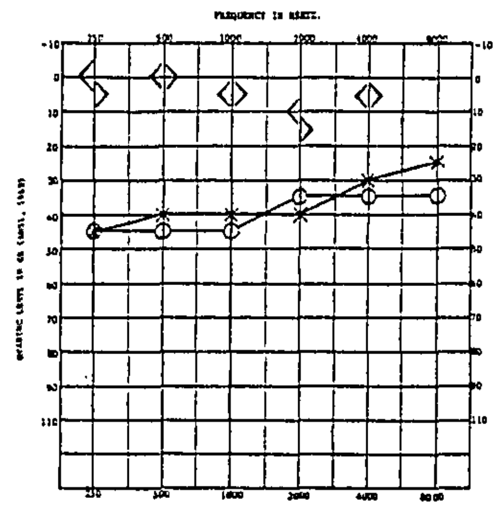

FIG. 4-3. SAMPLE AUDIOGRAM
Source: Ref. 13, p. 105.

HEARING LOSS

What different types of hearing loss are there?

There are two major types of hearing loss: conductive and sensori-neural. A conductive loss is usually associated with the outer or middle ear. This kind of loss is usually caused by a perforation or infection in the middle ear or an inflammation of the middle ear bones. This loss blocks transmission of sound to the cochlea or inner ear. Conductive losses are correctable by surgery.

A sensori-neural loss results from damage to the cochlea or neural structures of the ear. Birth defects, noise, ototoxic drugs, fever, or trauma may cause this type of loss. Sensori-neural losses are not medically correctable. In addition, sensori-neural hearing loss can be classified in several ways: noise-induced, presbycusis, sociocusis, or due to birth defects, congenital problems, disease, injury, or drugs.

How is the type of hearing loss determined?

If air conduction testing indicates that a hearing loss exists, it is necessary to determine whether it is of the conductive or sensori-neural type through bone conduction testing. To do this a bone-conduction vibrator is attached to the mastoid process of the skull just behind the ear. Test tones are presented at differing intensities just as with tones presented through earphones. Again each ear is tested separately. Often a masking tone has to be applied to the untested ear to ensure that responses are heard only by the test ear. If the hearing threshold determined by bone conduction testing is essentially normal, the hearing loss indicated by air conduction is of the conductive type. If the threshold for bone conduction is consistent with that determined by air conduction, the hearing loss is of the sensori-neural type. A mixed loss exists if there is a sensori-neural loss with a superimposed conductive loss. (16/298)

Can conductive losses be caused by noise?

Yes. Rupture of the ear drum and disturbance of the middle ear bones can result from a very high amplitude impulse or blast. This is often called traumatic hearing loss. The maximum degree of a conductive loss is usually around 55 to 60 dB (12/85-87).

What are some common causes of sensori-neural hearing loss in newborn babies?

Most babies born with hearing impairments have sensori-neural hearing losses. These can be either congenital (genetically inherited from the parents) or due to damage to the embryo in utero. Certain diseases such as rubella (German measles) or influenza that the mother contracts during pregnancy can result in a sensori-neural hearing loss as a birth defect in the child (13/50-51).

What diseases can lead to sensori-neural hearing loss?

Diseases such as measles, mumps, scarlet fever, diphtheria, whooping cough, influenza, and certain other viral infections can lead to sensori-neural hearing loss. The processes of these diseases can have a toxic effect on the sensitive nerve endings in the cochlea. Infections of the cerebrospinal fluid such as meningitis can also cause damage to the cochlea. Tumorous growths near the auditory nerve can cause sensori-neural hearing loss due to pressure on the nerve. (13/52)

Can drugs lead to sensori-neural hearing loss?

High doses of ototoxic drugs such as quinine, dihydro-streptomycin, neomycin, and kanamycin can have toxic effects on the cochlea and cause subsequent sensori-neural hearing loss (13/55). The use of these drugs is now restricted.

What is the extent of hearing loss among the U.S. population?

Based on the audiometric results in 1960-62 Public Health Survey, it is estimated that approximately 19 million Americans or 13 percent of the U.S. population have hearing losses that can be described as handicapping. Criteria recommended by the National Institute of Occupational Safety and Health (NIOSH) (25 dB HL averaged at 1000, 2000, and 3000 Hz) as the beginning point of handicap was used to derive these estimates. The population suffering such losses increases with age and the number of people significantly accelerates after age 40.

Information gathered by EPA and the National Association of the Deaf show that 13,362,842 Americans of all ages have some type of hearing impairment, from mild to severe. One-half of these people are age 65 or older. There are 6,548,842 Americans of all ages with significant bilateral damage. There are 1,767,046 Americans of all ages that are deaf. Of these, 410,522 are prevocational (prior to age 19) and 201,626 are prelingual (prior to age 3). The prelingual figure essentially represents those who were born deaf. Three out of every 100 school children have some type of hearing impairment and 30 out of every 1000 Americans age 65 or older have a hearing loss. In 1971 the U.S. Public Health Service conducted a survey which found that hearing impairment is the most frequently reported health problem in the country, with seven out of every 100 people reporting a hearing problem. (19)

NOISE INDUCED HEARING LOSS

What is Noise-Induced Permanent Threshold Shift (NIPTS)?

NIPTS is a permanent shift in the hearing threshold (a lowering of the sensitivity) of the ears due to exposure to noise. It is a sensori-neural type of hearing loss, and is not reversible (14/5-2). NIPTS can result from either a single exposure to high intensity impulsive noise such as blasts or explosions, or to longer exposures to lower, but still damaging noise levels. Typically, hearing loss due to noise exposure occurs *first* at the higher frequencies, particularly around the 4000 Hz level (3000 - 6000 Hz) (13/54). Figure 4-4 shows an example of NIPTS relative to exposure levels of 87-102 dB (17/114).

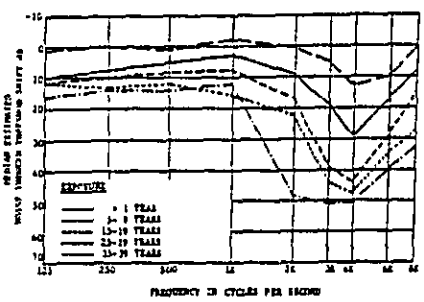

FIG. 4-4

What type of relationship exists between hearing loss and the level and duration of noise exposure?

In general, the magnitude of noise-induced hearing loss depends upon the noise levels to which the ear has been habitually exposed, the length of time for which it has been exposed to those levels, and the susceptibility of the individual. Short-term (time in minutes) to high intensity noise, or long-term exposure to noise of lesser intensity, may cause temporary or permanent hearing loss. With an adequate time before the next noise exposure, the ear will generally recover to a previous pre-exposure threshold. Repeated noise exposures without adequate time for recovery between exposures can lead to a Noise-Induced Permanent Threshold Shift (NIPTS). (See References 18 and 20 for a general discussion.)

What factors can increase a person's susceptibility to noise-induced hearing loss?

A significant factor that is known to increase the likelihood of noise-induced hearing loss is continued exposure to hazardous noise. Defects or diseases of the ear are hypothesized to cause a predisposition to noise-induced hearing loss (14/5-21). Some evidence exists that persons are especially susceptible to suffering hearing damage from noise when they are going through physiological changes or are enduring physical stress such as rapid growth or illness (20/493-497).

<u>Does noise act synergistically with drugs on hearing? Are there other kinds of synergistic effects?</u>

There is some evidence in the literature which suggests that ototoxic drugs such as kanamycin, and a class of antibiotics known as aminoglycosides may cause more severe damage to the ear when treatment with these drugs occurs concurrent with noise exposure (21/19-27). However, only little research has been done in this area, and the data are limited to animals.

Continuous noise may also interact with impulse noise and body vibrations to exacerbate hearing loss, although the magnitude of this effect is not exactly known.

<u>What factors protect the ear against noise-induced hearing loss?</u>

There are several factors which can mitigate the risk of noise-induced hearing loss. The acoustic reflex (tightening of the ossicular chain due to contraction of the muscles in the middle ear in response to high level sound) protects hearing from noise exposure to a very limited degree. The use of hearing protection such as earplugs or earmuffs reduces the risk of hearing damage from noise. Avoidance of noisy areas, limiting exposure to short periods of time, or ensuring intermittent rather than continuous exposure will mitigate the risk of hearing loss from noise. Increased public awareness of the dangers of hearing damage from noise can lead to the use of ear protectors and the avoidance of dangerous noise exposure. (14/5-2)

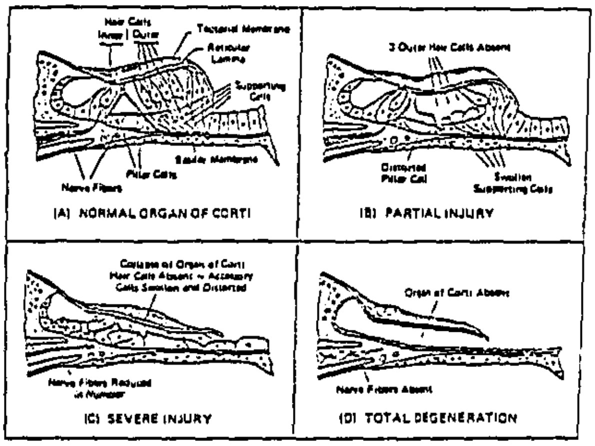

FIG. 4-5. DRAWINGS OF THE ORGAN OF CORTI ARE SHOWN THAT ILLUSTRATE THE NORMAL STATE, PANEL A, AND THE INCREASING DEGREES OF NOISE-INDUCED PERMANENT INJURY, PANELS B, C, AND D.
Source: Ref. 11, p. 10.

<u>How does the "Equal Temporary Effect" Hypothesis predict NIPTS on the basis of NITTS?</u>

This theory states that Noise-Induced Permanent Threshold Shift due to long-term steady-state noise exposure is predicted by the average Noise-Induced Temporary Threshold Shift produced by the same daily noise in a healthy young ear. The hypothesis is based on the contention that noise intense enough to cause NIPTS in the long run is intense enough to cause NITTS in the normal ear, and that noise that does not produce NITTS will not produce NIPTS. (14/5-3, 24/791) The hypothesis states that a NITTS measured two minutes after cessation of an eighthour noise exposure closely approximates the NIPTS incurred after a 10- to 20-year exposure to that same level (20/140-147).

What is the "Equal Energy" hypothesis?

The "Equal Energy" hypothesis is another way to attempt to predict NIPTS. The hypothesis states that equal amounts of sound energy will cause equal amounts of NIPTS regardless of the distribution of the energy across time (18/422). This means that the hazard to hearing is determined by the total energy (product of sound level and duration) that enters the ear on a daily basis. The "Equal Energy" rule allows a 3 dB increase in sound pressure level for each halving of the duration of continuous daily steady-state noise exposure (14/5-3).

In determining permissible exposures for the workplace to prevent NIPTS, OSHA adopted a 5 dB equal energy rule to account for various breaks in noise levels which occur during the day (25/37774).

EPA has identified an $L_{eq(24)}$ of 70 dB as the maximum 24-hour exposure necessary to protect hearing. If exposure time is reduced to 8 hours, a maximum $L_{eq(8)}$ of 75 dB, a 5 dB increase, has been identified as a protective level for hearing (5/19-21).

IMPULSE NOISE

What is impulse noise and what are its effects on hearing?

This is noise characterized by a short duration, abrupt onset and decay, high intensity, and a rapidly changing spectral composition. Impulse noise describes the kinds of sound made by explosions, drop forge impacts, and the discharge of fire arms. Exposure to impulse noise may result in temporary and permanent shifts in the threshold of hearing (22/186-187).

What are the criteria for impulsive noise inside and away from the workplace?

OSHA regulations define impulse or impact noise as "sound with a rise time of not more than 35 milliseconds to peak intensity and a duration of not more than 500 milliseconds." The regulations specify that employees shall not be exposed to impulse or impact noise which exceeds 140 dB peak pressure level. (25/181)

The Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) of the National Academy of Sciences has also recommended damage risk criteria for impulse noise. The CHABA impulse curve is based on peak sound pressure level and the duration of the impulses. Figure 4-6 shows the criteria currently in use, assuming an exposure of 100 impulses per day. The A-duration is the time that the impulse is initially within 20 dB of the peak level. The B-duration measures the total time that the sound is within 20 dB of the peak level. The B-duration also accounts for any reflections or reverberation that may be present, and thus allows less exposure under these conditions. A correction factor for daily exposures other than 100 impulses is provided (74).

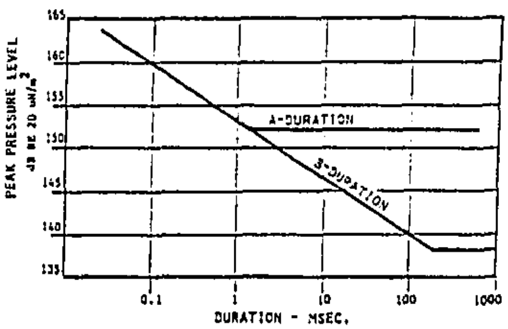

FIG. 4-6. BASIC LIMITS FOR IMPULSE NOISE EXPOSURE ASSUMING 100 IMPULSES PER DAY AND OTHER CONDITIONS AS STATED IN THE TEXT.
Source: Ref. 74.

PRESBYCUSIS - SOCIOCUSIS

What is presbycusis?

Presbycusis is a hearing loss associated with increasing age. It is most marked at higher frequencies, especially those above 3000 Hz. The causes of presbycusis are believed to be deterioration of the central nervous system and changes in the auditory system (12/101, 330).

What is sociocusis?

Sociocusis is noise-induced permanent threshold shift (loss of hearing sensitivity) attributed to environmental noise (hearing loss from non-occupational noise exposure) (27/12). It is difficult to separate sociocusis from hearing loss due to aging (presbycusis) or to occupational noise exposure. Exposures to high levels of environmental noise may accelerate loss normally due to aging (18/410).

What is the progression of presbycusis with age?

The threshold of hearing rises naturally (hearing becomes less sensitive) with increasing age. This effect involves primarily the frequencies above 3000 Hz (14/4-7). Figure 4-7 presents data that depict the progression of presbycusis with age and the degree of loss. As age increases, losses at high frequencies become greater and hearing loss progresses further down the scale to lower frequencies.

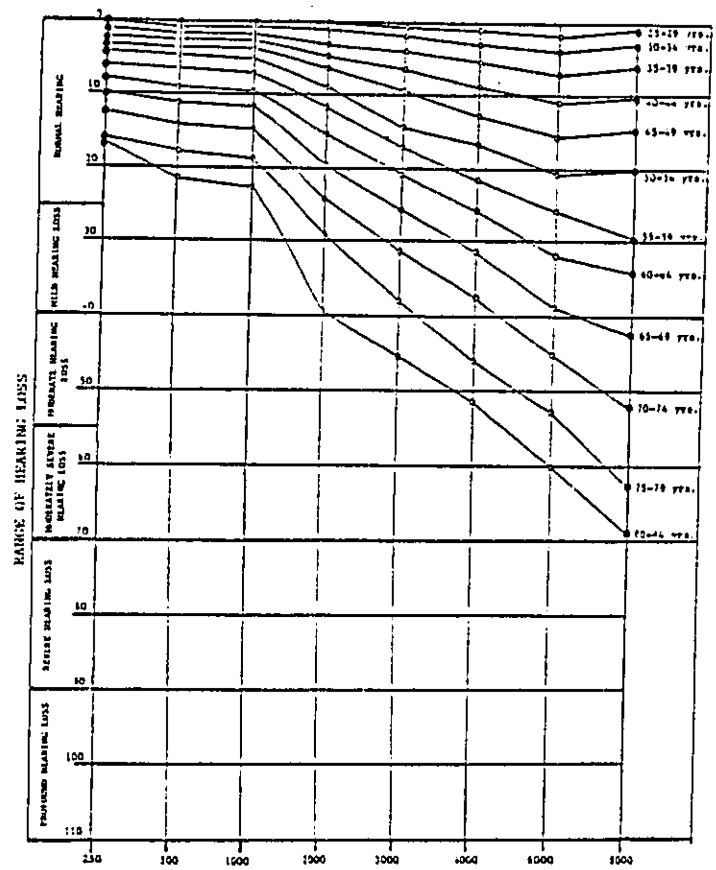

FIG. 4-7. AVERAGE HEARING LOSS FROM AGING FOR MEN AND WOMEN (WITHOUT THE EFFECTS OF OCCUPATIONAL NOISE)
Source: Ref. 36, pp. 48-57.

Due to our complex, noisy environment it is difficult, if not impossible, to separate hearing loss due to aging from noise-induced hearing loss, both from occupational and environmental noise. Few people live their whole lives in quiet surroundings. Almost everyone suffers some exposure to damaging noise; either at home, at work, at leisure, or during transportation between these activities.

The data found in Figure 4-7 are not meant to be taken as an exact prediction of the magnitude of hearing loss at each age. Different researchers have found differing values. The figure is presented to represent an average amount of hearing loss that can be expected. However, it is possible that some of the hearing loss described in the graph is due to exposure to environmental noise and not to presbycusis. Some researchers contend that presbycusis consists mainly of hearing loss due to lifetime exposure to the aggregate of noise found in the environment. Another view states that environmental noise only accelerates the losses at high frequencies that would have occurred anyway through aging. (27/19)

<u>What evidence exists that sociocusis (hearing loss caused by environmental noise) occurs?</u>

Rosen conducted a study of the primitive Mabaans of the African Sudan. Their environment was almost free of noise with a typical background level of 40 dB (A-weighted). Among the Mabaans, the hearing abilities of men in their seventies and eighties is equal to that of healthy children at age ten. (28/741-742)

These findings suggest that the Mabaans show little if any hearing loss due to aging (presbycusis). The implication of these findings is that much of the hearing loss observed with age in industrial countries could really be due to environmental noise exposure (sociocusis) rather than aging (presbycusis). Rosen's findings may be attributable to diet or other causative factors.

Is rock music considered to be a hearing hazard?

Studies have confirmed that overall sound levels of loud rock and roll, either at concerts or from domestic stereos, frequently exceed current hearing damage risk criteria. These noise levels can produce large amounts of noise-induced temporary threshold shifts (NITTS) in both the musicians and the listeners. Sound levels in the area of the band vary from 105-115 dB and in the dance area from 100 to 110 dB (A-weighted levels), which are within hazardous levels according to damage risk criteria established by EPA, OSHA, and NIOSH. (29/8) Attendance at a rock concert as a fan, or playing and practicing in a rock band, can impair hearing (30/27). Figure 4-8 shows before and after audiograms of musicians and dancers at a loud rock concert (27/14-15). NITTS from exposure to the loud music is clearly visible. Generally, however, the incidence of hearing loss is not as large as would be predicted (29/11).

One factor that can lessen the effects of rock music on hearing is its intermittency. Rock music is characterized by on-times of approximately three to five minutes alternating with off-times of approximately one minute (27/16).

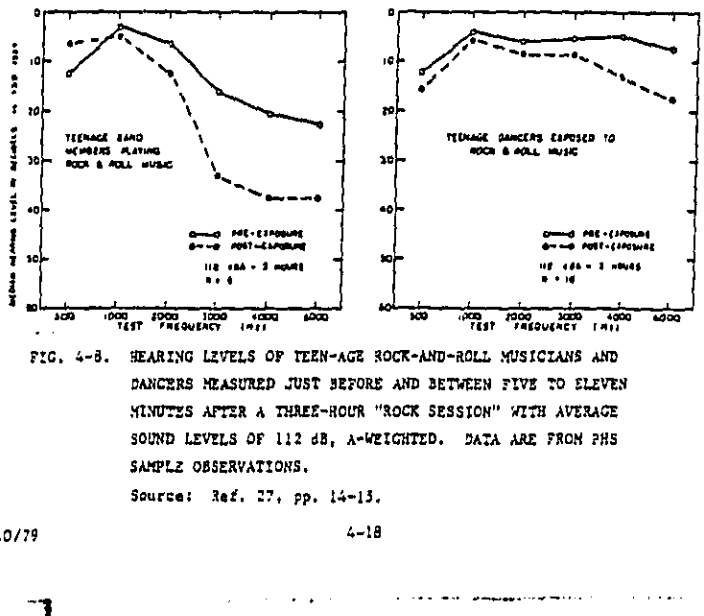

FIG. 4-8. HEARING LEVELS OF TEEN-AGE ROCK-AND-ROLL MUSICIANS AND DANCERS MEASURED JUST BEFORE AND BETWEEN FIVE TO ELEVEN MINUTES AFTER A THREE-HOUR "ROCK SESSION" WITH AVERAGE SOUND LEVELS OF 112 dB, A-WEIGHTED. DATA ARE FROM PHS SAMPLE OBSERVATIONS.

Source: Ref. 27, pp. 14-15.

THE CONSEQUENCES OF HEARING LOSS

How is the ability to discriminate and understand speech affected by noise-induced hearing loss?

Often, the first awareness of hearing loss comes with missing occasional words in general conversation and having difficulty understanding speech on the telephone. Many sufferers of noise-induced hearing loss say that speech is frequently garbled and distorted. Typical noise-induced hearing loss is in the high frequency range and persons with this type of hearing loss can have normal or almost-normal hearing up to 1000 Hz. They exhibit little difficulty in hearing voices at normal intensities but they can have trouble understanding them especially with noise in the background. This is because consonants are characterized by high frequencies and weak intensities and vowels by low frequencies. A person with a noise-induced hearing loss can miss hearing consonants like s, f, and p that give information and meaning to speech and language. It is often difficult for people with this type of loss to understand speech in lectures, meetings, parties, theatres; or on TV, radio, or the telephone.

What is recruitment?

Recruitment is a rapid increase in the perception of loudness at levels above hearing thresholds. It is often characteristic of a sensori-neural hearing loss (13/48) and it may cause discomfort and pain. Once a sound is intense enough for the subject to perceive it, an additional increase in intensity causes a disproportionate increase in the sensation of loudness. For example, a person with a 40 dB hearing loss would just barely detect a sound of 40 dB above the normal threshold of hearing. However, he would hear a sound of 50 dB above the normal threshold with a loudness that was greater than that with which a normal hearing person would hear a sound of 10 dB above the threshold of hearing. (13/48 - 49)

What is tinnitus and how many people incur it?

Tinnitus is buzzing, high pitched ringing, or roaring in the head that is a common complaint of a person with a hearing loss, particularly those losses associated with noise. Tinnitus is often the first recognizable indicator of hearing damage. It can be in one or both ears, although there may not necessarily be a hearing loss present. (13/50)

According to the National Health Examination Survey (1960) 32 percent of the population or 48 million Americans have experienced some form of tinnitus, at one time or another.

What other effects can hearing loss have?

Hearing loss can lead to reduced employability of the sufferer. It is especially damaging if children suffer hearing loss during their developmental and educational years (32/771). Hearing loss can also be a safety hazard and can contribute to accidents because warning signals or calls for help can be missed by a person with a hearing loss (33/74).

What are the social consequences of hearing loss?

Many times, friends and associates become less willing to be partners in conversation or other activities with a person who suffers a hearing loss. It becomes difficult for a person with a hearing loss to participate in lectures, meetings, parties, theatres, and other public gatherings; or to listen to the TV, radio; or have telephone conversations. A severe sense of isolation can set in as hearing decreases. As hearing loss increases so does the sense of being cut off from the rest of the world. Eventually hearing may decrease to the point that the person no longer feels a part of the living world. Emotional depression can be the result. (12/438-439)

HEARING LOSS CRITERIA

What level has been identified by EPA as protective of the hearing of the general population in the workplace?

Taking into account that 4000 Hz is the frequency most sensitive to hearing loss and that losses of less than 5 dB are generally not considered noticeable or significant, EPA identifies an 8-hour exposure level not exceeding 75 dB in order to protect 96 percent of the population from greater than a 5 dB NIPTS (5/13). This recommendation is based on steady noise levels of 8 hours per day, 5 days per week, over a period of 40 years (5/30).

What levels have been identified by EPA as protective of the hearing of the general population from significant damage due to environmental noise?

Environmental noise differs from workplace noise in that it is generally intermittent, covers 365 days per year rather than 250 work days, and covers 24 hours per day rather than 8 hours. Taking these factors into account, EPA has identified an environmental noise level of $L_{eq(24)}$ = 70 dB in order to protect 96 percent of the general population from a hearing loss of greater than 5 dB at 4000 Hz (5/19-20). For details, see Table 4-1.

		Steady (Continuous) Noise	Intermittent Noise	With Margin of Safety
L_{eq}, 8 hour	250 day/year 365 day/year	73 71.4	78 76.4	75
L_{eq}, 24 hour	250 day/year 365 day/year	68 66.4	73 71.4	70

TABLE 4-1. (AT-EAR) EXPOSURE LEVELS THAT PRODUCE NO MORE THAN 5 dB NOISE-INDUCED HEARING DAMAGE AT 4000 HZ OVER A 40-YEAR PERIOD

Source: Ref. 5, p. C-14.

If the assumptions underlying this identified level were changed, how would that affect the level?

- "*How would the identified level be affected by a change in the percentage of the population protected?*

  Reducing the 96th percentile value to the 50th percentile (i.e., protecting half the population) would increase the protective level value from 70 dB to 77 dB.

- "*Since agreement on the value of the intermittency correction is imperfect, what other values might be used?*

  The estimated intermittency correction used in the Levels Document is 5 dB. The true intermittency correction is probably within the range 0 to 15 dB.

- "*How accurate is the equal energy assumption?*

  The equal energy assumption when applied to the long times (8 hours to 24, or 250 to 365 days) is fairly accurate. It may be subject to error when applied to short exposures of extreme level.

- "*How meaningful are the basic studies of hearing damage risk?*

  The probable errors of estimates in the three basic studies cannot be stated with absolute accuracy. There are a number of problems in extrapolating percentages of the population damaged from relatively high exposure levels to the protective level. Also, there is the problem of determining the amount of hearing damage when the control (non-exposed) population is subject to high levels of non-occupational noise. Thus, the 70 dB protective level is simply the best present estimate, subject to change if better data become available."

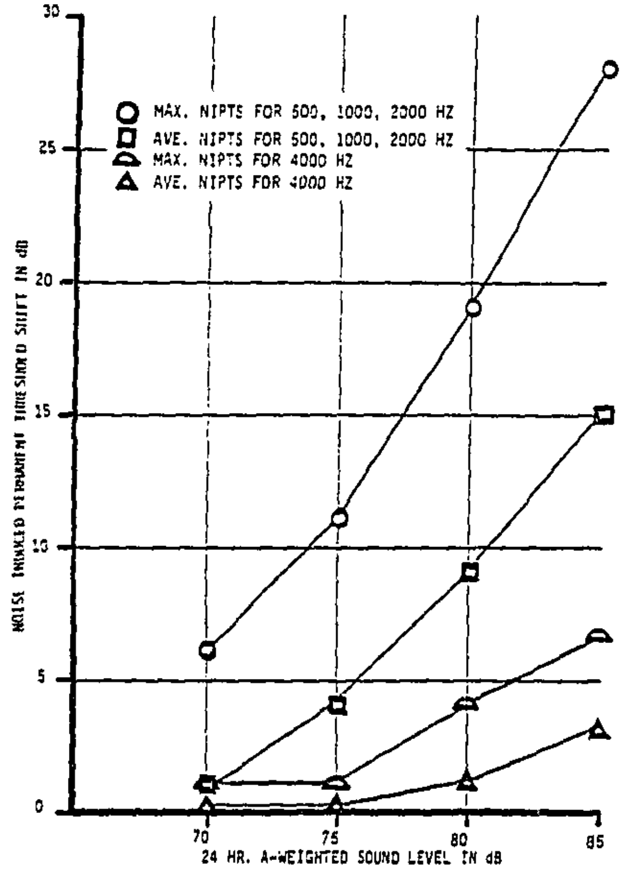

FIG. 4-9. AVERAGE NOISE-INDUCED PERMANENT THRESHOLD SHIFT (NIPTS) (BEYOND PRESBYCUSIC LOSSES) EXPECTED AS A FUNCTION OF THE CONTINUOUS A-WEIGHTED EQUIVALENT SOUND LEVEL.

What criterion has been developed for exposure to steady-state noise?

Figure 4-9 shows curves developed from data used in the EPA Levels Document (5/C-5) which depict the maximum and average noise-induced permanent threshold shift expected averaged over a 40-year exposure to a 24-hour continuous A-weighted equivalent sound level. For example, over a 40-year (age 20 to 60) exposure to a continuous A-weighted equivalent sound level of 75 dB, the average noise induced permanent threshold shift (NIPTS) expected is approximately 4 dB at 4000 Hz. This means that at age 20, the individual will have hearing equal to the non-exposed population (0 dB NIPTS). At age 60, the individual will have an NIPTS considerably greater than 4 dB. The average expected shift in threshold is 4 dB. This change in hearing is caused by the workplace noise exposure. This is in addition to the expected loss of hearing due to aging which at the age of 60 is approximately an average loss of 24 dB for each frequency in the range of 250 - 8000 Hz (26/52). The maximum values indicated in Figure 4-9 show the worst case expected from the given sound level.

HEARING CONSERVATION

In what ways can noise problems be approached in order to lessen the chances of hearing loss due to exposure to noise?

Attempts to solve a noise problem can be made by attacking any combination of the three basic elements of the problem:

- By modifying the source to reduce its noise output
- By altering the transmission path to reduce the noise level reaching the listener
- By altering the receiver's exposure either through limiting the exposure time or by providing personal protective equipment (11/16)

In what ways can a source be modified to reduce its noise output?

Noise sources can be quieted by:

- o Reducing impact or impulsive forces
- o Reducing speed in machines, and flow velocities and pressures in fluid systems
- o Balancing rotating parts
- o Reducing frictional resistance
- o Isolating vibrating elements within the machine
- o Reducing noise radiating areas
- o Applying vibration damping materials
- o Reducing noise leakage from the interior of the machine
- o Choosing quieter machinery when replacing appliances (11/17-29)

In what ways can the transmission path be altered to reduce the noise level reaching the listener?

Noise transmission paths can be altered by:

- o Separating the noise source and receiver as much as possible
- o Using sound absorbing materials
- o Using sound barriers or deflectors
- o Using acoustical linings
- o Using mufflers, silencers, or snubbers
- o Using vibration isolators and flexible couplers
- o Using enclosures (11/33-40)

If it is impossible technologically or unfeasible economically to solve a noise problem by modifying the source or altering the transmission path, what other methods can be used to protect the listener from hearing damage?

Limiting the amount of continuous exposure to high noise levels is one approach. This can be accomplished either by conducting noisy operations for only short periods of time or by allowing listeners to be exposed to high levels of noise for only short periods of time. After all other methods have failed to reduce noise to acceptable levels, as a last resort where exposure to these high levels is required, personal hearing protectors can be used. (11/40-41) Hearing protectors do not solve the noise problem; they only treat the symptoms of the problem.

How is the exposure of workers to high levels of noise regulated by the Federal government?

The Walsh-Healey Public Contracts Act of 1938 as amended in 1969 requires that all companies doing at least $10,000 annual business with the Federal government limit the exposure to noise at various levels of their workers to the durations detailed in the table below. Table 4-2 shows that as the noise exposure level increases by 5 dB, the allowable time of exposure is halved. (25/37775)

These same occupational exposure levels were promulgated covering industries engaged in interstate commerce by the Occupational Safety and Health Administration (OSHA) under the mandate of the Occupational Safety and Health Act of 1970.

Duration Per Day (h)	Noise Level dB Slow Response
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
1/2	110
1/4 or less	115 max

TABLE 4-2. PERMISSIBLE NOISE EXPOSURES UNDER THE WALSH-HEALEY PUBLIC CONTRACTS ACT, 1969
Source: Ref. 25, p. 10518.

<u>If noise exposure exceeds these limits what additional protective measures do the OSHA regulations require?</u>

If noise exposure exceeds these duration and noise level limits, after economically feasible engineering remedies are exhausted, employees are to wear hearing protectors issued by the employer (25/10516).

<u>What different types of hearing protectors are available?</u>

Hearing protectors can either be earplugs or muffs. Earplugs can be made of many materials, such as soft flexible plastic, wax, paper, glasswool, cotton, and mixtures of these materials. To be effective they must provide a snug, airtight and comfortable seal. Muff-type protectors cover the entire external ear and generally provide greater protection than do earplugs. (23/182-185) Figure 4-10 depicts the sound attenuation characteristics of several representative types of hearing protectors.

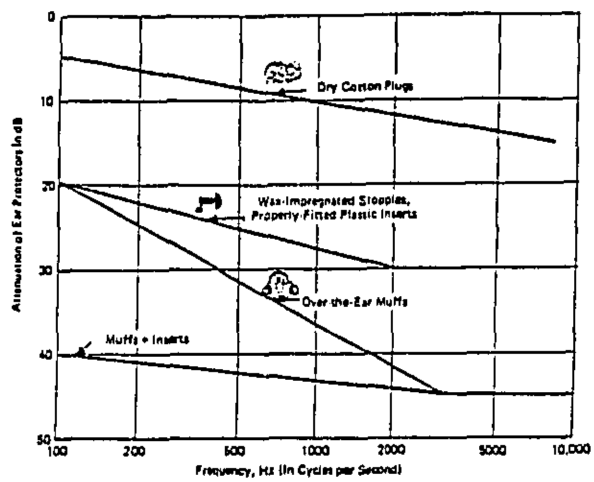

FIG. 4-10. SOUND ATTENUATION CHARACTERISTICS OF VARIOUS TYPES OF EAR PROTECTORS
Source: Ref. 23, p. 185.

<u>What other requirements must be fulfilled under the OSHA Act of 1970?</u>

The Act requires yearly audiograms for all employees whose noise exposure exceeds the OSHA limits. In addition, these employees are to be issued hearing protection devices.

What are baseline and follow-up audiograms and why are they useful?

Baseline or reference audiograms are the results of hearing tests performed on new employees at their time of hire. Follow-up audiograms are periodic tests performed to identify any deterioration in the employee's hearing due to on-the-job noise exposure. Baseline and follow-up audiograms are important because employers are only liable for hearing loss incurred during the time that a claimant was employed by them. Baseline audiograms pinpoint the extent of hearing loss prior to starting work and also can serve as a placement mechanism. An effort can be made to place employees with an existing hearing loss in areas that are less damaging to their remaining hearing. Follow-up audiograms point out developing hearing loss problems and determine those susceptible individuals who are at risk. Their exposures should be modified immediately to protect against continued deterioration of hearing. The follow-up periodic audiograms help in pinpointing those individuals needing further testing and in documenting compensation claims (13/290-291).

Why is compensation paid for hearing impairments?

In recent years occupational diseases have become compensable, and loss of hearing has been recognized by the Federal government and most states as an occupational disease. Today, there are some state laws that consider gradual hearing impairment as a series of traumas or accidents, and therefore treat it as a safety rather than a health problem. At the present time nearly all states have provisions for compensating hearing loss but the statutes vary considerably. While a few states compensate fairly liberally, some states require "total" loss of hearing in one or both ears, and others still require proof of disability and lost wages (34/1-2). (For general information and discussion see Reference 38.)

In terms of compensation and criteria, how are disability, impairment, and handicap defined and used?

- Disability: actual or presumed inability to remain employed at full wages

- Impairment: a deviation or a change for the worse in either structure or function, usually outside of the range of normal

- Handicap: the disadvantage imposed by an impairment sufficient to affect one's personal efficiency in the activities of daily living

Clearly, the term handicap is meant to apply to the compensation situation, whereas the term impairment is more appropriate to preventive criteria (35/740-751). The decision of what is an unacceptable amount of impairment continues to be somewhat in dispute.

What are the two most often used hearing impairment compensation formulas?

1. AMA/AAOO Formula (1979)

This recently revised formula was developed by the American Academy of Ophthalmology and Otolaryngology. The formula averages hearing loss at 500, 1000, 2000, and 3000 Hz (prior to the revision, the 3 KHz test frequency was not used) with a 25 dB low fence below which no hearing impairment is considered to exist. An average hearing impairment of 92 dB is considered total hearing loss with each decibel loss between 25 and 92 dB representing a 1.5 percent impairment rate of growth (36/2055-2059).

2. Compensation Formula for Federal Employees (NIOSH Formula)

The original AMA (AAOO) formula was used until 1969. It was modified at that time by the Department of Labor to include test frequencies of 1, 2, and 4 KHz with the same high and low fence as before. It was again modified in 1973 to the present form. This later modification was largely based on NIOSH recommendations in its criteria document, "Criteria for a Recommended Standard Occupational Exposure to Noise" (37/IV,4-8). NIOSH recommended that hearing impairment should be assessed by the ability to hear and understand speech not only in quiet surroundings, but in everyday conversational settings where significant background noise may be present. The NIOSH formula averages hearing loss at 1000, 2000, and 3000 Hz, also using a 25 dB low fence below which no hearing loss is considered. A 1.5 percent hearing impairment rate of growth occurs for every decibel loss above 25 dB. The inclusion of the 3 KHz test frequency while deleting the 500 Hz makes the formula more sensitive to noise-induced hearing loss since such losses are incurred initially at higher frequencies. In view of this, a number of states have incorporated similar high frequency components in their formulas in recent years.