NOISE

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A-96-01
II-A-722

FINAL REGULATORY ANALYSIS
OF THE
HEARING CONSERVATION AMENDMENT

U.S. Department of Labor
Occupational Safety and
Health Administration
Office of Regulatory Analysis

January, 1981

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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, the degree of hearing loss, the anatomical changes (in animal experiments), and the 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, the multitude of 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.

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 embarrassed 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 should 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, to provide healthful 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, p. 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 stated 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 definition 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 definition, 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 compensation 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 speak 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 IV-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 <u>only</u> 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.

The data in Table 1 were developed by other Agencies in an effort to provide reliable estimates of the percentages of the population at risk of developing hearing 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 Expected to exceed a 25-dB Fence at 500, 1000, and 2000 Hz as a Function of Average Noise Exposure Level for 40 Years.

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

Source: EPA, Ex. 5, p. 43805

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* 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. V1-31). (An exposed population that includes some amount of nonoccupational hearing loss and some presbycusis would be representative of the U.S.

*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.

population, and thus the risk figures should not be unrealistic.) 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

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 is an irreversible condition that progresses with increased exposure, and is exacerbated by the normal aging process. Although such a loss may be slight at first, continued exposure may result in a loss that is severe enought 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. 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 OSHA 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. 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.

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 TWA's in excess of 90 dB, and an additional 2.3 million whose exposure levels exceed 85 dB. These workers, who face a significant risk of 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 consitute 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 protection 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 protection devices will reduce the incidence of noise-induced hearing loss and also the various extra-auditory effects decribed 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 Insitute for Occupational Safety and Health study, is a reduction in workplace accidents and absenteesim (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, 8-12, 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, producting 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 and is expressed in decibels, abbreviated dB. The magnitude, or intensity, of sound is perceived as loudness. Through the use of a logarithmic scale, 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 range from 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 the 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 continous or fluctuating noise, which is typical of the production industries.

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 <u>exposure</u>, 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 differences between workplace sound levels and employee exposure 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.

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 calls 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, measurments 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 affectd 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 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. 321-16B, 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 the Health Effects section.

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. 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."

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.

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.

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 so doing, to prevent futher 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.

Table 2

Noise-Induced Permanent Threshold Shift
(90th, 50th, and 10th Population Centiles)

Sound Level [dB]	Freq. [Hz]	10 yrs. .9	10 yrs. .5	10 yrs. .1	20 yrs. .9	20 yrs. .5	20 yrs. .1	30 yrs. .9	30 yrs. .5	30 yrs. .1	40 yrs. .9	40 yrs. .5	40 yrs. .1
75	500	0	0	0	0	0	0	0	0	0	0	0	0
80	500	0	.1	.6	.1	.1	.3	.4	.1	.4	.8	.2	.4
85	500	.1	.2	1.4	.1	.3	1.2	.5	.7	1.5	.9	.4	1.1
90	500	.2	.5	2.3	.2	.7	2.4	.6	.8	2.5	1.1	1.0	2.4
95	500	.3	.9	3.5	.5	1.3	4.0	.6	1.7	4.5	1.0	1.9	4.6
100	500	1.7	3.9	7.6	2.8	5.1	9.2	3.9	6.2	10.6	4.9	7.2	11.4

Sound Level [dB]	Freq. [Hz]	10 yrs. .9	10 yrs. .5	10 yrs. .1	20 yrs. .9	20 yrs. .5	20 yrs. .1	30 yrs. .9	30 yrs. .5	30 yrs. .1	40 yrs. .9	40 yrs. .5	40 yrs. .1
75	1000	0	0	0	0	0	0	0	0	0	0	0	0
80	1000	.1	.1	.7	.1	.2	.4	.4	.2	.6	.8	.2	.6
85	1000	.1	.3	2.0	.2	.5	1.9	.5	.6	1.9	.9	.7	1.7
90	1000	.3	.7	2.9	.4	1.0	3.3	.8	1.3	3.6	1.3	1.5	3.6
95	1000	.5	2.7	5.9	.8	3.7	7.2	3.3	4.6	8.4	4.3	5.3	8.9
100	1000	3.1	6.1	11.0	4.8	8.1	13.5	6.4	9.9	15.6	8.3	11.3	16.9

Sound Level [dB]	Freq. [Hz]	10 yrs. .9	10 yrs. .5	10 yrs. .1	20 yrs. .9	20 yrs. .5	20 yrs. .1	30 yrs. .9	30 yrs. .5	30 yrs. .1	40 yrs. .9	40 yrs. .5	40 yrs. .1
75	2000	0	0	0	0	0	0	0	0	0	0	0	0
80	2000	.1	.3	1.6	.1	.4	.9	1.1	.5	1.2	1.8	.6	1.3
85	2000	.3	.9	4.9	.7	1.3	4.8	1.8	1.8	4.6	2.8	2.1	3.9
90	2000	.6	2.4	8.0	1.6	3.9	9.3	3.6	5.4	11.8	5.3	6.6	10.6
95	2000	1.2	5.6	14.2	3.7	8.7	17.4	7.4	12.0	20.1	10.6	14.8	21.9
100	2000	2.3	9.2	21.6	6.5	14.6	26.6	12.0	19.9	35.9	16.7	24.1	33.9

Sound Level [dB]	Freq. [Hz]	10 yrs. .9	10 yrs. .5	10 yrs. .1	20 yrs. .9	20 yrs. .5	20 yrs. .1	30 yrs. .9	30 yrs. .5	30 yrs. .1	40 yrs. .9	40 yrs. .5	40 yrs. .1
75	3000	0	0	0	0	0	0	0	0	0	0	0	0
80	3000	.2	2.0	4.1	1.9	2.4	3.4	3.5	2.7	2.7	5.1	3.0	2.3
85	3000	1.6	4.4	7.7	3.6	5.3	7.8	5.5	6.2	7.6	7.4	6.7	7.2
90	3000	3.9	9.2	16.9	6.6	11.0	17.9	8.5	12.6	18.4	11.3	13.7	18.4
95	3000	8.1	16.0	26.8	11.6	18.9	29.1	14.9	21.4	30.1	17.8	23.1	30.5
100	3000	15.8	25.4	37.5	20.6	29.5	39.7	24.8	32.7	41.0	28.6	35.0	41.6

Sound Level [dB]	Freq. [Hz]	10 yrs. .9	10 yrs. .5	10 yrs. .1	20 yrs. .9	20 yrs. .5	20 yrs. .1	30 yrs. .9	30 yrs. .5	30 yrs. .1	40 yrs. .9	40 yrs. .5	40 yrs. .1
75	4000	0	0	0	0	0	0	0	0	0	0	0	0
80	4000	.3	3.1	1.9	.3	3.4	2.1	1.8	3.7	6.3	3.3	3.8	5.3
85	4000	1.6	6.7	12.3	3.4	7.4	12.2	5.0	8.0	11.9	6.7	8.3	11.0
90	4000	6.3	11.9	19.1	8.4	13.3	19.5	10.3	14.4	19.4	12.1	14.9	18.6
95	4000	13.7	20.4	28.2	16.4	22.5	28.7	18.7	23.9	28.5	20.7	24.6	27.6
100	4000	22.3	30.2	37.8	25.6	32.6	37.8	28.4	34.1	37.2	30.6	34.8	36.1

Sound Level [dB]	Freq. [Hz]	10 yrs. .9	10 yrs. .5	10 yrs. .1	20 yrs. .9	20 yrs. .5	20 yrs. .1	30 yrs. .9	30 yrs. .5	30 yrs. .1	40 yrs. .9	40 yrs. .5	40 yrs. .1
75	6000	0	0	0	0	0	0	0	0	0	0	0	0
80	6000	.3	2.0	4.0	1.8	2.2	3.1	3.2	2.4	2.2	4.6	2.5	2.1
85	6000	1.1	4.8	8.9	2.8	5.3	8.6	4.3	5.8	8.2	5.8	6.1	7.3
90	6000	1.9	8.5	15.6	3.8	9.5	16.0	6.6	10.4	16.0	7.3	10.9	15.3
95	6000	4.3	13.7	23.5	6.7	15.5	24.4	8.9	16.8	24.5	10.8	17.6	23.8
100	6000	9.2	20.3	32.2	13.3	23.7	33.9	17.0	26.5	34.9	20.2	28.4	35.1

Source: Johnson, Ex. 310, pp. 27-8.

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.

Studies of Noise and Hearing Loss

Numerous studies of the effects of noise on hearing were submitted to the record. For purposes of this discussion, the studies have been divided into the categories of continuous and impulsive noise. The word "continuous" refers here to time-varying exposures as well, since in most of the studies noise levels varied somewhat throughout the day (Ex. 11, p. 2-3; Ex. 12, pp. 93-99; Ex. 26-2, p. 10).

Exposure to intermittent (on and off) noise will not be treated separately since the same methods for predicting hearing loss from continuous noise apply to losses resulting from intermittent noise (Ex. 279, 11-3, p. 447; Ex. 54, pp. 16-17; Ex. 29, p. 217). There was some disagreement as to whether the 5-dB or the 3-dB exchange rate should be used in calculating the time-weighted average exposure level from noncontinuous noise. But since the current noise standard (29 CFR 1910.95) uses the 5-dB exchange rate, and since the permissible exposure level remains unchanged at this time, the debate over the exchange rate will not be treated extensively here.

OSHA has examined the many studies and reports in the record that describe the effects of continuous noise on hearing (Ex. 11; Ex. 17; Ex. 310; Ex. 12; Ex. 26-2; Ex. 36; Ex. 266 A; Ex. 304), and the Agency believes that they comprise the best available data on the subject. The results of the various studies are relatively consistent, both in terms of the population at risk, and the extent of NIPTS as a function of noise exposure. The various studies, if considered together, contain data on more than 10,000 subjects.

As stated above, Col. Johnson averaged the data of different researchers in the preparation of a report for EPA. Later, the EPA used Col. Johnson's analysis of those data in the development of criteria for the effects of noise (Ex. 31, p. 5-17) and for the identification of safe levels of noise (Ex. 30, p. C-5). The three studies that were used in the EPA reports were the subject of much discussion during the hearings. Although some criticisms were raised, they were also widely supported (Tr. 734, 738, 779, 785, 834). The three studies were the following:

"Relationship between Daily Noise Exposure and hearing loss based on the evaluation of 6,835 industrial noise exposure cases" by W. L. Baughn (Ex. 11).

"Hearing and Noise in Industry" by W. Burns and D. W. Robinson (Ex. 12).

"Hearing Loss Due to Exposure to Steady-state Broadband Noise" by W. Passchier-Vermeer (as displayed and used in "Prediction of NIPTS due to continuous noise exposure" by D. L. Johnson (Ex. 17).

The study by Dr. William L. Baughn of the General Motors Corporation was performed between 1960 and 1965 (Ex. 11). These data have been used in the development of the Air Force report "Hazardous Noise Exposure" (Ex. 48) and for the current ISO standard 1999, "Assessment of Occupational Noise Exposure for Hearing Conservation Purposes" (Ex. 11, p. iii). The data were published in 1973 as an Air Force technical report (Ex. 11). Dr. Baughn studied the effects of average noise exposures of 78 dB, 86 dB, and 92 dB on 6,835 industrial workers employed in midwestern plants producing automobile parts. Approximately 20,000 subjects had been excluded from the study because there was insufficient information about their exposure histories, or because they had "mixed" exposures (including nonoccupational sources). Subjects with anatomical abnormalities (such as ear infections) were not screened from the noise-exposed or control groups. Noise measurements had been taken over a period of 14 years, and through interviews, exposure histories were estimated as far back as 40 years (Ex. 11, p. 2). Dr. Baughn "smoothed" the data and presented families of curves showing the numbers of people exceeding a 15-dB fence at 500, 1000, and 2000 Hz referenced to the ASA 1951 audiometric zero, which is the equivalent of a 25-dB fence referenced to the ANSI 1969 zero level. He also provided data for fences of 5 dB to 40 dB (ASA), which would translate to 15 dB to 50 dB (ANSI). Since the exposure categories were for 78 dB, 86 dB and 92 dB, Dr. Baughn interpolated so as to provide estimates for exposures to 80 dB, 85 dB and 92 dB. He also extrapolated to exposure levels up to 115 dB, but the data above 95 dB were not used in Col. Johnson's report or the comparisons shown earlier.

Figure 1 shows Baughn's estimates of the percentages of the exposed population that will cross a 25-dB fence as a result of exposure to daily average noise levels of 80 dB to 115 dB. Since these estimates use the frequencies 500, 1000, and 2000 Hz, the numbers of people crossing a 25-dB fence at 1000, 2000, and 3000 Hz would be expected to be greater.

Baughn's study was criticized because in some cases as little as 20 minutes of recovery time was allowed prior to audiometric testing (Ex. 17, p. 2; Ex. 3, p. 39; Ex. 26-3, p. 5-15; Ex. 138A, p. 2-17). As a result the data may have been influenced to some extent by temporary threshold shift, which

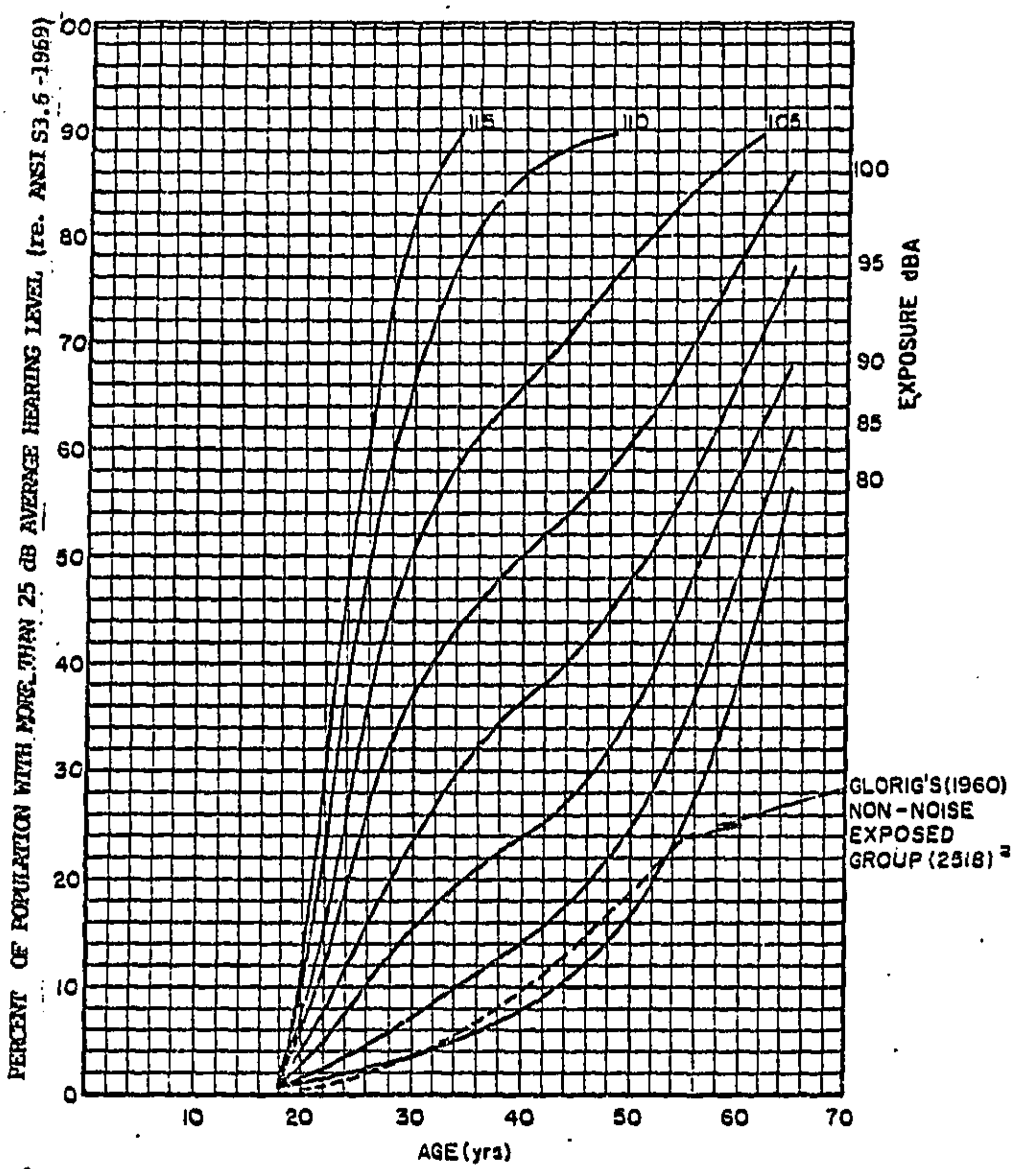

Figure 1. Percent of the population with more than a 25 dB average hearing level for the frequencies 500, 1000, and 2000 Hz as a function of Noise exposure level. From Baughn (Ex. 11, p. 41).

would have the effect of making the noise-exposed group's hearing threshold levels appear worse than they should. The study was also criticized because the control group may have had average exposures as high as 78 dB so that they may also have had a small amount of occupational hearing loss (Ex. 17, p. 2; Ex. 138A, p. 2-17). If the control group's hearing levels were slightly inflated, this would tend to reduce the difference between the hearing levels of the exposed and control groups. These potential flaws would have the tendency to offset each other when NIPTS is calculated. In addition, Dr. Kryter (Ex. 50, pp. 9-12) pointed out that any residual TTS after 20 minutes would be quite small (only 1 to 2 dB) for those subjects who had already incurred a noise-induced hearing loss. (TTS tends to become smaller after significant permanent loss is incurred.)

One practical limitation of the Baughn study is that the author did not provide hearing loss data at separate frequencies, but only at the combined frequencies of 500, 1000, and 2000 Hz, and then separately for 4000 Hz (Ex. 11, pp. 4, 30; Ex. 5, p. 43804). Thus, it is not possible to estimate hearing loss, for example, at only 2000 Hz, or for the combined frequencies 1000, 2000, and 3000 Hz. While this may result in some procedural problems for researchers and administrators, it does not detract from the validity of the study. The sample size appears to be the largest in any single hearing loss study, and the study has received support from other scientists and organizations. The results are not incompatible with other data in the record. Therefore, OSHA believes that the Baughn study represents a valuable contribution to the public record.

Dr. W. Passchier-Vermeer's data on steady-state noise exposure do not appear in the hearing record except as they are presented by Col. Johnson (Ex. 17 and Ex. 310). Dr. Passchier-Vermeer presented in 1968 an exhaustive review of hearing loss as a function of exposure to average noise levels of about 80 dB to 102 dB, having summed, analyzed, and correlated data from many sources (Ex. 17, pp. 2,3, 12-14). The data consisted of laboratory and field studies conducted by British, Dutch, Swedish, and U.S. investigators.

Figure 2 shows median NIPTS at various frequencies as a function of noise exposure for a period of 10 years. Figure 3 shows median NIPTS after 40 years of noise exposure. These figures, which were submitted by EPA (Ex. 5, p. 43803), are taken from Dr. Passchier-Vermeer's reports. Of course the noise-induced permanent threshold shift would be expected to be more severe for the more susceptible individuals in the higher centiles of the population, such as the 90th or the 95th centiles.

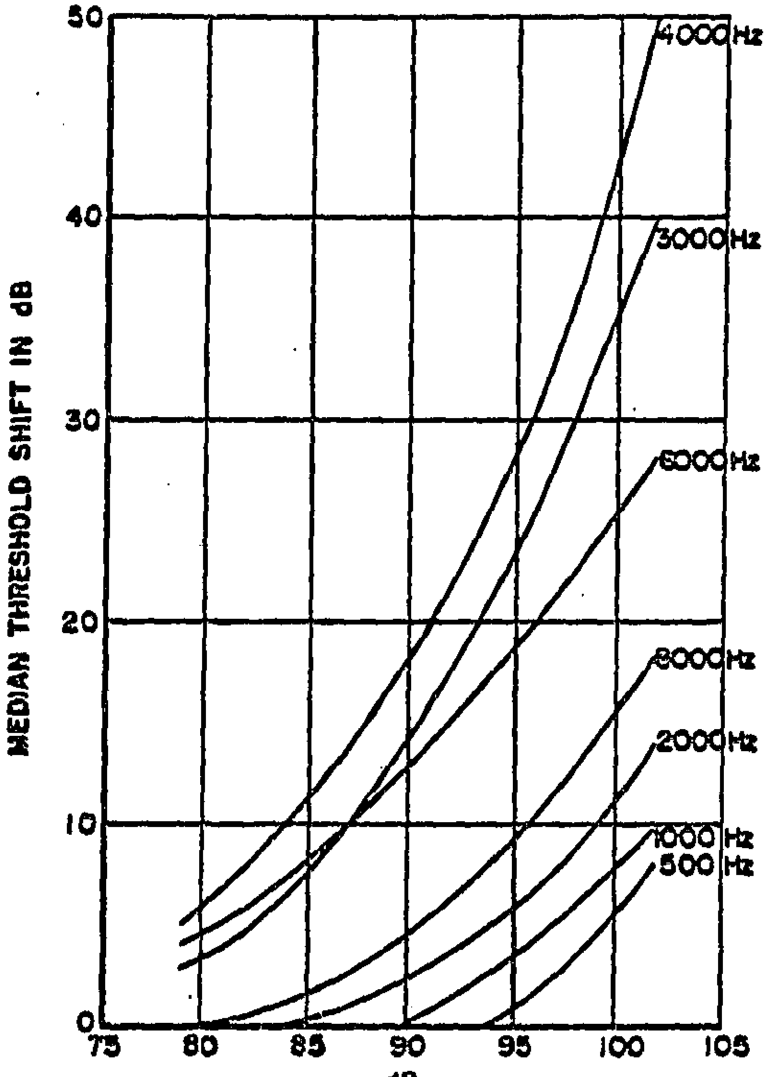

Figure 2. Median noise-induced threshold shift for various audiometric frequencies as a function of average daily noise exposure level for 10 years. Data are from Passchier-Vermeer (in Ex. 5, p. 43803).

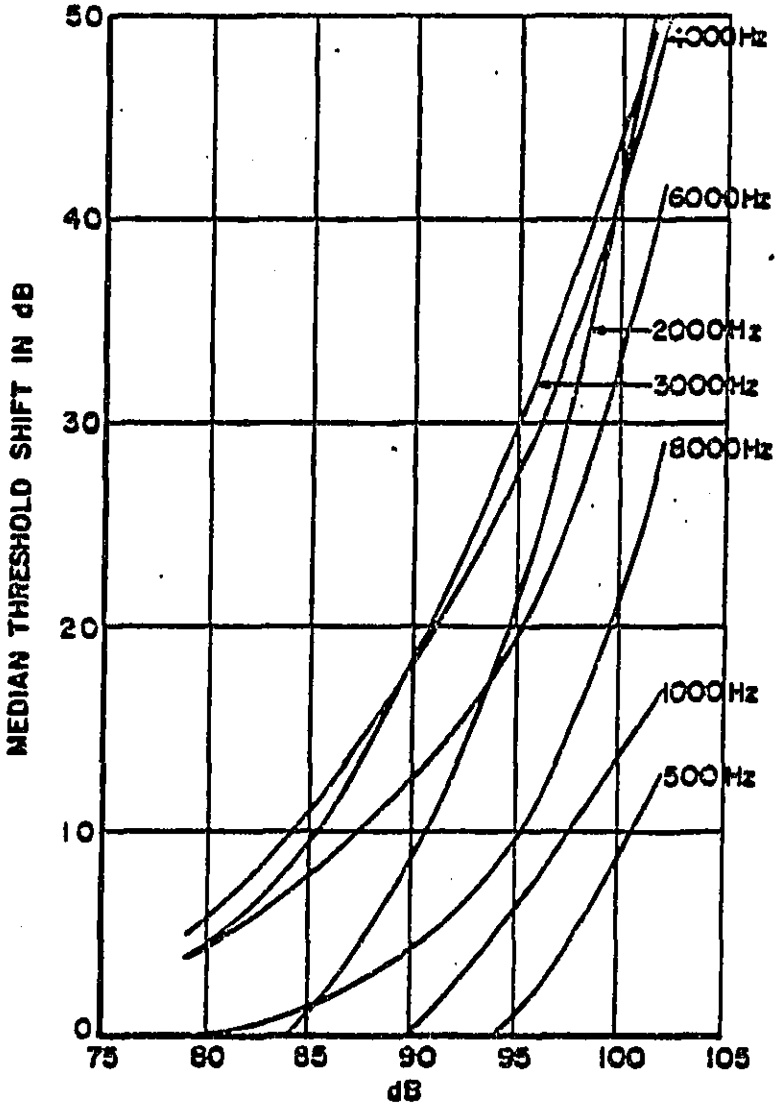

Figure 3. Median noise-induced threshold shift for various audiometric frequencies as a function of average daily noise exposure level for 40 years. Data are from Passchier-Vermeer (in Ex. 5, p. 43803).

Four of the 10 studies analyzed by Dr. Passchier-Vermeer were discussed briefly in documents prepared by NIOSH (Ex. 1), EPA (Ex. 31), and Drs. Burns and Robinson (Ex. 12). The NIOSH criteria document reported that Drs. Taylor, Pearson, Mair, and Burns studied 251 working and retired jute weavers who were exposed to average overall sound pressure levels of 99 to 102 dB. The investigators found the greatest deterioration of hearing occurred in the first 10 to 15 years of exposure (Ex. 1, p. 5 Table IV). NIOSH also reported on a study by Drs. Burns, Hinchcliffe, and Littler of 174 textile spinners and weavers exposed to average overall (unweighted) sound pressure levels of 100 to 101 dB. Hearing losses were found to be greater for the weavers than for the spinners (Ex. 1, p. 6 of Table IV).

EPA's document entitled Public Health and Welfare Criteria for Noise described a study by Gallo and Glorig, which also was used by Dr. Passchier-Vermeer, as well as the study by Taylor et al., mentioned above. According to EPA (Ex. 31, p. 5-5), Drs. Gallo and Glorig measured the hearing levels of 400 men aged 18-65, and 90 women, aged 18-35, exposed to an average overall sound pressure level of 102 dB. The population had been screened to exclude nonoccupational noise exposure and otological abnormalities. The results showed that high-frequency hearing loss rose rapidly during the first 15 years of exposure, but that hearing loss in the mid-frequencies continued to rise in a linear manner up to 40 years of exposure.

Drs. Burns and Robinson (Ex. 12, pp. 220-228) also discussed the studies of Gallo and Glorig, and Taylor et al. In addition, they described a study by Dr. B. Kylin, which also was used by Dr. Passchier-Vermeer, of 89 men exposed for durations of 10 to 15 years, and 29 male controls. Neither population was screened for military noise exposure or for ear disease. (These factors should not have influenced the actual NIPTS since they were distributed evenly among the noise exposed and control populations (Ex. 12, p. 226).) Drs. Burns and Robinson compared the results of their study with those of the three selected studies (Gallo and Glorig, Taylor et al., and Kylin), and with the results predicted by Dr. Passchier-Vermeer on the basis of all of the studies she analyzed. They found, using median hearing loss values, that agreement among all of the results was good for the mid-frequencies (500, 1000, and 2000 Hz), but that their own data and method of prediction showed somewhat lower values (less hearing loss) for the higher frequencies (3000, 4000, and 6000 Hz) (Ex. 12, p. 227). The authors suggested that this finding might be due to differences in noise monitoring and subject selection techniques used by the various investigators (Ex. 12, p. 228).

Because the Passchier-Vermeer data resulted from a synthesis of many studies, some people argued that their quality was difficult to judge (Ex. 50, p. 8). Others noted that the original report only presented data for quartile groups (25th, 50th and 75th centiles) and neglected to address the more variant hearing levels found in the extremes of the population (Ex. 3, p. 39; Ex. 17, p. 2; Ex. 26-3, p. 5-14). Col. Johnson has extrapolated the data to the 10th and 90th centiles so that it would be averaged with those of the other studies (Ex. 17, p. 14 and Ex. 310, p. 7). Col. Johnson reported (Ex. 17, p. 14) that in a paper published in 1971, Dr. Passchier-Vermeer did publish the data for the 10th and 90th centiles, and these data were in agreement with Johnson's extrapolations.

The Passchier-Vermeer data are useful in that hearing levels are given for the discrete audiometric frequencies 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz, resulting from exposure levels of 80 dB, 85 dB, and 90 dB. Also, the Agency believes that averaging the results from a number of studies may be considered an advantage in that it ought to minimize any anomalies that might occur as a result of any one study. The Passchier-Vermeer data also were supported by various witnesses and comments to the record, (Ex. 47, p. 8; Ex. 216 A, p. 5).

Dr. W. Burns (Ex. 54) reported on a study of British factory workers that he and Dr. D. W. Robinson conducted between 1963 and 1968. The complete study was submitted to the record by OSHA as Exhibit 12. The study's population consisted of 759 subjects exposed to average noise levels between 75 dB and 120 dB and 97 non-noise exposed control subjects. The range of exposure durations was one month to 50 years. Exposure levels were taken in octave bands from 63 to 8000 Hz, and A-weighted measurements also were taken. Approximately 4000 audiograms were performed. Subjects were screened thoroughly to exclude exposure histories that were not readily quantifiable (to some extent unknown), exposure to gunfire, ear disease or abnormality, and language difficulties (Ex. 12, p. 12). The investigators found that hearing levels of people exposed to certain noise levels for certain durations were much the same as those of others exposed to higher levels for shorter times (Ex. 12, p. 17). They found that this relationship held for relatively short durations as well as for many years of exposure (Ex. 12, pp. 17-18). Consequently, they developed a mathematical formula to predict hearing levels in the frequencies 500 through 6000 Hz in various percentages of the exposed population due to specific levels and durations of noise (Ex. 12, pp. 100-151). Data from the Burns and Robinson study are shown combined with those of Dr. Passchier-Vermeer in Table 2 above.

The Burns and Robinson study has been criticized on the grounds that eliminating all workers with any form of nonoccupational hearing loss by extensive screening (which appeared to be more rigorous than in the other studies) would cause the resulting hearing levels to be an underestimate of the total "real-life" hearing loss picture (Ex. 40, p. 7; Ex. 50, p. 17). This problem has been eliminated in the analyses performed by Col. Johnson (Ex. 17 and 310) and by OSHA in the Benefits section, by using only the NIPTS data from Burns and Robinson and adding values for presbycusis from a normal, unscreened population (such as the U.S. Public Health Survey data).

The Burns and Robinson study was also criticized by Terrence Dear of the DuPont Company for including subjects exposed to impulse noise (Tr: 864-866), although the authors maintained that they tried to minimize such exposures, and that impulse noise exposures only would have occurred in a relatively small number of cases where subjects were exposed to high levels of continuous noise (Tr: 864-866; Ex. 12, p. 97).

On the whole, OSHA believes that the study by Burns and Robinson represents a very through, well-controlled study, with results that are extremely useful in predicting the effect of noise exposure on hearing.

NIOSH submitted to the record a report entitled "Occupational Noise and Hearing", 1968-1972 (Ex. 26-2). The dose-response relationships described in this report had been used by NIOSH in making the recommendations in its criteria document (Ex. 1). The report (Ex. 26-2, p. vi) presented background information about the study, and statistical analyses that were meant to complement the analyses that had already been published in the criteria document. NIOSH studied a population of 792 industrial workers exposed to average noise levels of 85 dB, 90 dB, and 95 dB, and a control population of 380 subjects who were exposed to average levels below 80 dB. (Since the control population was exposed to levels as high as 80 dB, a few members of the group may have incurred some amount of occupational hearing loss, and therefore the study would be subject to the same criticism as the study of Dr. Baughn.) Although the exposures were primarily to steady-state noise, exposure levels fluctuated slightly within each category. The total population was screened to exclude subjects who had been exposed to noise from gunfire, and who showed some sign of ear disease or audiometric irregularity (Ex. 26-2, pp. 6-7). Subjects ranged in age from 17 to 65 years. Data were presented for hearing levels of the 10th, 25th, 50th, 75th, and 90th centiles for various age groups and exposure durations, resulting from average exposures to 85 dB, 90 dB, and 95 dB. The authors concluded that the data substantiated the results of other similar investigations, but that they pertained only to simple or "ordinary" noise environments, as opposed to complex environments such as lengthened exposures, seasonal exposures, impact or impulsive noise, and high frequency noise (Ex. 26-2, p. 15).

Data from the NIOSH study have not been used in the prediction of benefits from the hearing conservation amendment. Col. Johnson stated in his report (Ex. 17, p. 10) that he did not use the NIOSH data in the analysis performed for EPA because the data had not yet been "smoothed," which would make it difficult to make predictions. Also, the NIOSH data were limited to exposures of 85, 90 and 95 dB, thus preventing hearing loss estimates for exposures to 80 dB and 100 dB. Nevertheless, the data are generally consistent with the results of the other studies discussed above.

Results of the NIOSH study are shown in Figure 4 (Ex. 26-2, p. 41). This figure shows hearing level by audiometric

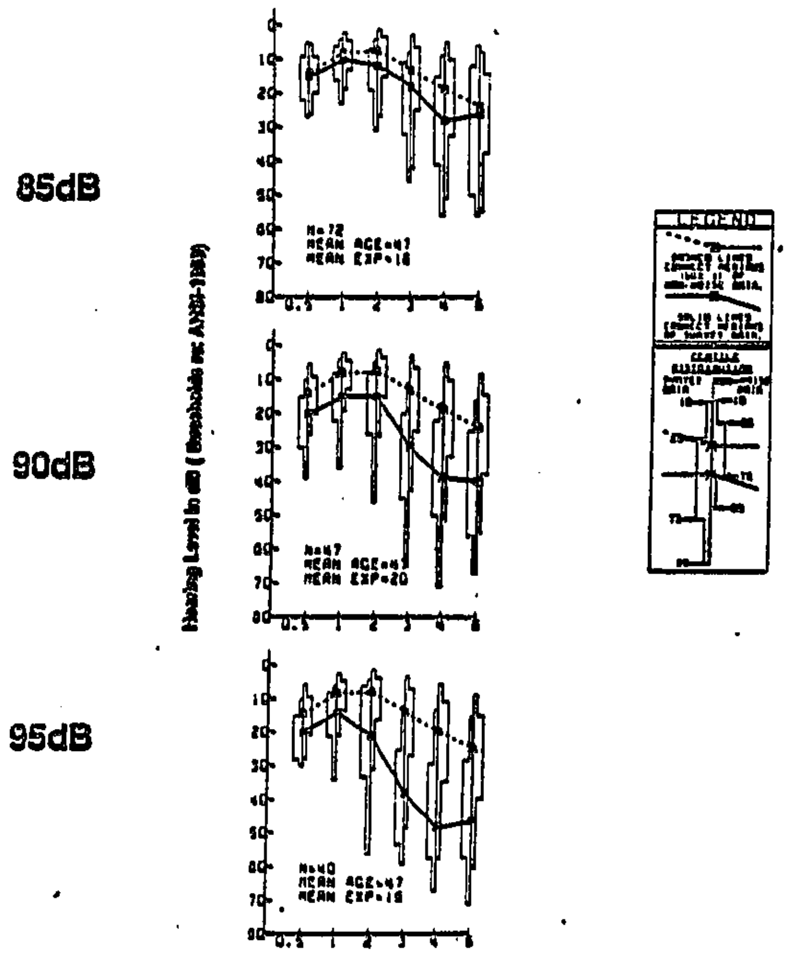

Figure 4. Hearing level distribution for workers aged 43 to 51 years exposed to daily average noise levels of 85dB, 90dB, and 95dB, and for non-noise-exposed workers.

frequency as a function of noise exposure to levels of 85, 90, and 95 dB. Population distributions are shown for the least sensitive (labeled in this case the 10th centile) to the most sensitive (the 90th centile) groups, and are compared to the non-noise-exposed control group. This study shows that differences between median hearing levels increase with exposure level and duration. Also, more importantly, the distribution of hearing levels becomes considerably greater as exposure level, duration, and age increase.

In another study, Dr. R.H. Martin, Dr. E.S. Gibson, and J.N. Lockington (Ex. 36) related the degree of employee hearing loss to average noise levels of 85 and 90 dB in industrial plants. The population consisted of 228 Canadian industrial workers ranging from 18 to 65 years of age who were screened to exclude non-occupational hearing loss. The control group consisted of 143 subjects with minimal occupational noise exposure. The study concluded that the risk of hearing loss at 500, 1000, and 2000 Hz increases significantly between 85 and 90 dB, leaving a portion of the population at risk (up to 22 percent) by a noise exposure standard of 90 dB.

Elliott Berger, with Drs. Royster and Thomas (Ex. 266A) examined a North Carolina industrial population that had been exposed for 10 to 12 years to daily average noise levels of 88 to 89 dB. The population consisted of 42 men working in one location of the plant and 58 women working in another location. Control subjects were drawn from the same geographical area, and were screened to exclude any occupational noise exposure. Because of the relatively short exposure duration and the moderate exposure levels, the investigators analyzed only the losses at 4000 Hz, where they found hearing levels somewhat worse for men than for women (Ex. 266A, pp. 82-83). They concluded that the observed hearing losses were compatible with the data of Baughn, Passchier-Vermeer, Burns and Robinson, and NIOSH, with compatibility being greater for the male than for the female subjects (Ex. 266A, pp. 81-85).

In the Inter-Industry Noise Study (IINS) (Ex. 304) the authors measured noise exposure and hearing levels of 348 industrial subjects. Daily average noise exposure levels were between 82 and 92 dB for durations ranging from 3 years to greater than 30 years. There were 228 matched control subjects whose noise exposures were less than 75 dB. After analyzing the data the authors concluded that differences in hearing levels between the control and experimental populations were not statistically significant at the frequencies 500, 1000, and 2000 Hz. Differences at 3000, 4000, and 6000 Hz were statistically significant for male subjects, but not for females (Ex. 304, p. 8). In an editorial immediately following the IINS Research Report in the Journal of Occupational Medicine (JOM), Dr. Robert O'Connor stated:

> From this study it appears that 90 dB is as protective as 85, as far as women's hearing is concerned. In the case of men, if a small amount of hearing loss in frequencies that are well beyond the speech range is considered unacceptable, then this study supports a standard of 85. (Ex. 304, p. 8) (in JOM, 17: 760-770, 1975, p. 770).

The Environmental Protection Agency (Ex. 321-16A, p. 2) stated that there were major technical problems in the design, administration, and analysis of the Inter-Industry Noise Study which "raise serious questions concerning the technical appropriateness and usefulness of a number of the conclusions which were presented in the 1978 JOM publication."

A NIOSH report prepared by Barry Lempert also criticized the study by stating that the results included only mean or average hearing level comparisons while much more highly significant effects are found when the full distribution of hearing levels is presented (Ex. 321-36A, p. 1). After reviewing and reanalyzing the IINS raw data, and using evaluation techniques developed for the 1972 criteria document, NIOSH reaffirmed that "exposure to 85 dBA should allow no more than an increase of 10 to 15 percentage points in the incidence of hearing impairment" relative to a non-noise exposed population (Ex. 321-36A, p. 4).

Col. Johnson and Dr. Thomas Schori also analyzed the raw data from the IINS, and submitted a review of the data (Ex. 321-21A). The authors concluded that the hearing levels found in the IINS were essentially the same as those found in other noise and hearing loss studies (Ex. 321-22A, p. 16).

Having reviewed the study, the critiques (Ex. 321-16A; Ex. 321-36A; Ex. 321-21A), and a critique of a critique (Motor Vehicle Manufacturers Assoc., Ex. 321-8A), OSHA has determined that the findings of the IINS do not contradict those of the studies described earlier. The Agency disagrees with the conclusions of Dr. O'Connor that 90 dB is as protective as 85 dB. Although the IINS did not find the differences between mean hearing levels of the female experimental and control groups statistically significant, there were differences at every frequency, showing greater hearing loss for noise-exposed than for control subjects (Ex. 804, p. 4). As Lempert pointed out, these differences would have been much larger if the full distribution of hearing levels had been presented, showing the more susceptible elements of the population. The same argument would apply to the differences between mean hearing levels of the male experimental and control groups, where systematic differences are shown. The fact that the standard deviations were greater for noise-exposed than for non-noise-exposed groups at nearly every frequency (Ex. 304, p. 4) supports this argument. In addition, OSHA disagrees with Dr. O'Connor that the frequencies above 2000 Hz "are well beyond the speech range," on the basis of the many studies and comments cited earlier, showing the importance of high-frequency hearing for understanding speech in everyday conditions (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).

Dr. Royster submitted a series of reports to the record (Ex. 321-22 A through H). Some of these reports discussed recent findings by Dr. Royster and his colleagues that differences in sex and race are evident in the growth of NIPTS (Ex. 321-22A, pp. 18-19), as well as in the growth of presbycusis (Ex. 321-22B, p. 510; Ex. 321-22C, pp. 116-118; Ex. 321-22D, pp. 1-2). After examining the audiograms of a large North Carolina industrial population (Ex. 321-22A), Drs. Royster and Thomas concluded that hearing threshold levels differ significantly according to race and sex and that these differences are greater for the higher audiometric frequencies and increase with age. In their subject population, black women had the best hearing, followed by white women, black men, and finally, white men after noise exposure (Ex. 321-22A, pp. 15, 18-19).

Sex differences in hearing levels have been noted in numerous studies of non-noise-exposed populations (Ex. 31, p. 4-4, Ex. 321-22, p. 7 Ex. 279, pp. 11-8, pp. 41-44). OSHA has incorporated the NIOSH presbycusis data (Ex. 1, pp. I-16 to I-17) for men and women separately in Appendix F of the amendment. Also, the Agency has calculated the benefits anticipated from hearing conservation programs using separate presbycusis data for men and for women. Actual NIPTS values have not been differentiated according to sex because data for men and women shown separately were not available for the major studies mentioned above (Burns and Robinson, Passchier-Vermeer, Baughn, and NIOSH).

Drs. Burns and Robinson (Ex. 12, pp. 145-147) found small but persistent sex differences in noise-induced hearing loss, suggesting that NIPTS developed slightly more rapidly in men than in women. However, they did not present separate data for men and women. The IINS also showed slightly larger NIPTS values for men than for women both in the control and in the experimental populations (Ex. 304, pp. 4-8). Col. Johnson (Ex. 17 and Ex. 310) did not display NIPTS values separately for men and women, but he did show different data for certain non-noise-exposed populations, and therefore for certain estimates of the percentage at risk (Ex. 310). The studies by Baughn (Ex. 11), NIOSH (Ex. 26-2), Passchier-Vermeer (as reported by Johnson in Ex. 17), and Martin et al. (Ex. 36) did not present different NIPTS data for male and female subjects. OSHA believes that there is relatively little evidence available at this time to show that the hearing of men and women is differently affected by noise exposure, but that there is considerable evidence that differences exist in non-noise-exposed populations. Therefore, for estimating the benefits of hearing conservation programs, the Agency has used Col. Johnson's analysis of the Burns and Robinson and Passchier-Vermeer data, which shows sex differences for presbycusis but not for NIPTS. For any additional breakdown by sex or race the Agency will await further experimental evidence.

OSHA believes that the above studies are meritorious and are sufficient to make good estimates of the benefits to be derived from hearing conservation programs, despite any criticisms raised. Dr. von Gierke stated that "in spite of some uncertainties and everybody's desire for the 'perfect' study, there is adequate information available to predict with reasonable confidence the hearing impairment produced in the general population by a lifetime's exposure to continuous noise" (Tr. 705-706).

Conclusions from Hearing Loss Studies

Having established a definition of material impairment of hearing and discussed the various studies, some attention must be given to the various interpretations of the noise exposure and hearing loss data. Not all of the commenters interpreted the data in a similar manner.

Generally the argument for protecting workers above 85 dB is made on two grounds: analysis of NIPTS and of the percentage at risk. These data showed that not only is the amount of hearing loss significantly greater at an average daily exposure level of 90 dB than at 85 dB, but also considerably more people are at risk of incurring material impairment (Ex. 40, p. 3; Ex. 47, p. 19; Ex. 57, p. 8; Ex. 82, pp. 1-4; Ex. 6, p. 12337; Ex. 26-1, p. 2).

Using the data of Baughn, Passchier-Vermeer, and Burns and Robinson, the Environmental Protection Agency found that half as many people are at risk of impairment at a daily average noise level of 85 dB as at 90 dB (Ex. 138A, p. 1-4; Ex. 5, p. 43805; Ex. 189-5, p. 6). In addition, the amount of NIPTS doubles between 85 dB and 90 dB, especially for the frequencies

1000, 2000, and 3000 Hz (Ex. 5, p. 43804). In order to prevent <u>any</u> measurable hearing loss over a 40-year period the EPA identified a maximum 8-hour average daily noise exposure level of 75 dB (Ex. 5, p. 43803; Ex. 30, p. 4).

NIOSH also found that the population at risk due to lifetime exposures to average daily levels of 90 dB would be twice the size of the population at risk from 85 dB. The estimates were 29 percent and 15 percent, respectively (Ex. 1, Tables XV and XVII). Dr. Moller also noted that the number of impaired people doubles when average levels are increased from 85 to 90 dB (Ex. 88, p. 33).

There were numerous comments in the record concerning the amount of protection afforded by an average daily exposure level of 90 dB. Estimates of the percentage of unprotected workers ranged from 1 percent to 30 percent. Many commenters supported the 90-dB level based on OSHA's estimate that 98 percent of the population would be protected (Ex. 14-11, p. 1; Ex. 14-45, p. 1; Ex. 14-81, p. 1; Ex. 14-157, p. 2; Ex. 14-189, p. 1).

In OSHA's draft Environmental Impact Statement (Ex. 3, App. D, p. 12337) the Agency incorrectly stated that an exposure level of 90 dB would protect 98 percent of the exposed population. This estimate was based on the data and method of

Burns and Robinson, using a 25-dB fence for the frequencies 500, 1000, and 2000 Hz, and a 30-year exposure duration. Later, an EPA representative (Ex. 40) pointed out that OSHA had neglected to perform one of the steps in the Burns and Robinson method, (step 7 on p. 132 of Ex. 12). Using the same data and method, the risk would actually be much greater than 2 percent (Ex. 40, pp. 5-6). Dr. Burns clarified the matter by explaining the distinction between hearing level, which includes presbycusis, and hearing loss, which does not (Ex. 54-2, pp. 1, 2).

Dr. Ward (Ex. 222C, p. 7) based his recommendation exclusively on Passchier-Vermeer's data, which, he claimed, showed that no workers would exceed a 25-dB hearing loss at the frequencies 500, 1000, or 2000 Hz due to exposure between 85 and 90 dB. For this reason Dr. Ward concluded that 90 dB protects workers from a "noticeable" hearing loss (Ex. 64, p. 3). This interpretation of Passchier-Vermeer's data is at variance with the interpretation of EPA and Col. Johnson. EPA submitted a graph of Passchier-Vermeer's data showing hearing loss as a function of noise exposure (Ex. 5, p. 43803). Although the median NIPTS from a 40-year exposure to 90 dB is essentially zero at 500 and 1000 Hz, it is nearly 10 dB at 2000 Hz. While the resulting median hearing levels would be quite small when added to the hearing loss from aging, they would be sufficient to ensure that some members of the exposed population would cross a 25-dB fence. Considering that nearly 3 million workers are exposed to daily average noise levels of 90 dB and above, 50 percent of the population, or 1.5 million workers, would be expected to have at least this much NIPTS. Also, the NIPTS values would be expected to be larger for more sensitive individuals. Median NIPTS data say very little about actual hearing levels in the more susceptible members of the exposed population. As described above, when Johnson and EPA combined the data of Passchier-Vermeer with those of Baughn, and Burns and Robinson, the risk of crossing a 25-dB fence at 500, 1000, and 2000 Hz was 12 percent from exposure to 85 dB, and 22 percent from exposure to 90 dB (Ex. 5, p. 43805). Finally, as mentioned earlier, both the NIPTS and the risk are greater when 3000 Hz is included in the averaging and 500 Hz is eliminated.

OSHA has considered the definition of material impairment as it relates to hearing loss in light of a large body of data on the effects of noise on hearing. The Agency has determined that many workers will be at risk of material impairment of hearing, and possibly incur other kinds of physiological damage, when they are exposed to daily average sound levels above 90 dB over a working lifetime. Some workers will be expected to develop a material impairment of hearing if they are exposed to daily average sound levels between 85 and 90 dB, and a few will even develop a material impairment from average levels between 80 and 85 dB. Since it is possible to incur noise-induced hearing loss as a result of exposure to daily average levels less than 90 dB, OSHA has determined that it is necessary to initiate audiometric testing and other aspects of the hearing conservation program at a time-weighted average sound level of 85 dB. The practice of requiring an "action level," a point well below the permissible exposure level at which protective action is taken, is consistent with OSHA's policy of protecting workers before they are overexposed. Moreover, the final standard will identify those in the exposed population that might be more sensitive to noise, and protect them before they suffer further adverse effects. In keeping with this policy, employers may wish to provide audiometric testing for employees whose TWA's are between 80 and 85 dB, so that the few most susceptible workers might be identified and protected.

Extra-Auditory Effects of Noise

The most obvious physiological effect of noise is damage to the auditory system. However, depending upon the level, type, and duration of the noise, a variety of extra-auditory effects have been observed, which will be discussed in the following paragraphs. In addition, it should be noted that people who are exposed to noise at work may also be exposed to noise during their non-working hours. For example, many workers live in areas where there is highway and aircraft noise as well as noise from industrial plants. Industrial workers who live in the urban settings are sometimes stressed by noise 24 hours a day without respite, and without adequate opportunity to recover, either physiologically or psychologically. Thus, effects that might otherwise have been temporary would tend to become chronic.

Although there is a substantial body of data suggesting a wide variety of noise-induced physiological responses, specific responses to specific noise doses have not yet been identified. The evidence of noise-induced health effects is not conclusive for 8-hour exposures of 85 dB, or 90 dB, or even higher levels experienced over a working lifetime. However, to ignore this large body of data is to undervalue the significance of the adverse effects (Ex. 5, p. 43806; Ex. 138A,

p. 2-31). Both testimony and written exhibits, including subjective and experimental evidence, indicate that noise can be harmful to human health (Ex. 2C-106, p. 2; Ex. 2C-111, p. 1; Ex. 2C-4, 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, pp. 6-11; Ex. 79, p. 2; Ex. 173, pp. 1-2, 7-8; Ex. 84, Attach. 2, pp. 1-2).

During the 1975 and 1976 public hearings most of the evidence that was submitted was anecdotal, although some studies were submitted by individuals (Ex. 28A), unions (Ex. 88, Ex. 95, Ex. 96, Ex. 97, Ex. 98), and government agencies (Ex. 26-9; Ex. 26-10; Ex. 26-3; Ex. 26-11; Ex. 32; Ex. 40). Leonard Woodcock, then president of the United Auto Workers, stated:

> I am sure that there are many limitations to these studies, as there always seems to be in this sort of work. But we think there is truth to these studies since it matches our subjective experience. We expect that future research into this important area will offer more definitive data. (Ex. 79, p. 5)

According to Ruth Knowles, then president of Local 1716 of the Textile Workers Union (Tr. 2024), "Some workers have been forced to retire long before retirement age because of hypertension." She goes on to state that in her opinion the high noise exposure in the weave department could have been a factor in those instances.

The major concern over extra-auditory health effects from noise arises from the fact that noise has the ability to act as a general, non-specific, biological stressor (Ex. 138A, p. 2-31). Evidence suggests that the stress reaction produced by noise is not unlike that produced by other stressors; that is, a generalized reaction governed by sympathetic activation of the autonomic nervous system.

The concept of biological stress, first introduced by Dr. Hans Selye, has been described as "the nonspecific response of the body to any demand made upon it; a stereotyped, phylogenetically old adaptation pattern primarily preparing the organism for physical activity, e.g., fight or flight." (Ex. 138A, p. 2-32).

This stress reaction produces a widespread change in bodily activity. There is a rise in blood pressure, a rise in pressure inside the head and an increase in sweating. The heart rate increases, there are changes in breathing and there may be a sharp constriction of the muscles over the whole body (Ex. 26-9, p. 10-8). These changes are likely to be mediated by increased adrenal secretion of the catecholamine hormones, epinephrine and norepinephrine (Ex. 138A, p. 2-32).

In the hearing record two theories were proposed to explain the mechanisms by which these stress-related physiological changes can have an impact on human health. Two conceivable damage pathways were developed:

1. Abnormalities in blood pressure regulation that lead to hypertension.
2. Increased blood platelet adhesiveness that accelerates the development of atherosclerotic plaques in the walls of the arteries.

Each of these stress-related damage pathways is discussed in turn.

1. The theory that noise stress can result in hypertension is supported by Dr. Bruce Welch (Ex. 321-16E, pp. 1-11) and Dr. Ernest Peterson (Ex. 321-16D, pp. 1,4,10) as well as by numerous other researchers, referred to in these and other exhibits (Ex. 88, p. 6; Ex. 96, p. 279). Intense industrial sound impairs the regulation of blood pressure, the most distinct manifestation of which is an increased prevalence of hypertension (Ex. 321-16E, p. 2).

According to Dr. Welch, hypotension, or reduced blood pressure levels, also can result from noise stress (Ex. 321-16E, pp. 3-4). Both hyper- and hypo-tension fundamentally are disorders of circulatory regulation. They are characterized by exaggerated and inappropriate cardiac and vasomotor response to changes in body position or physical and psychological stimuli (Ex. 321-16E, p. 8). This increase in vascular lability (or changeability) under noise stress affects the circulatory adjustments that must normally be made during the course of a working day (Ex. 321-16E, p. 9). For those who already have impaired circulation, excessive vascular lability can lead to congestive heart failure, cardiac ischemia, or cardiovascular stroke. In fact it has been established that hypertension, even at moderate elevations, is associated with increased risk of coronary and cerebrovascular disease (Ex. 321-16E, p. 3).

2. In a report submitted by EPA (Ex. 138A, p. 2-40) Hattis et al. proposed another pathway theory, which involves an increase in the adhesiveness of blood platelets. Increased platelet adhesiveness has clear potential for negative side effects, due to an increased tendency for the formation of thrombi, small aggregates of platelets and other blood components involved in the clotting process. These thrombi contribute to the buildup of atherosclerotic plaques, which gradually narrow the arteries and reduce the oxygen supply to vital tissues. A heart attack can occur when there is complete blockage of an artery to the heart muscle, or when the demand

for blood oxygen is greater than that which can be supplied through a narrowed coronary artery. These effects can be cumulative, for the same thrombi that contributed to a gradual narrowing of the arteries can complete the sequence by forming the final occlusion leading to tissue death in the heart.

Two epidemiological studies that were submitted to the record are of particular importance. In a classic study of German iron and steel workers (Ex. 98, p. 219), Dr. Gerd Jansen found that 62 percent of the workers chronically exposed to noise levels above 90 dB had "peripheral circulatory symptoms" compared to 48 percent of those exposed to lower levels. Physiological and psychological examinations were performed to determine the extent to which the difference could be caused by non-occupational factors. Dr. Jansen concluded that noise interferes with involuntary bodily functions, and as such could be a serious health risk.

A NIOSH-sponsored study (Ex. 29, pp. 441-452) performed by the Raytheon Service Company lends further support to these findings. The medical records of factory workers routinely exposed to high noise levels (at or above 95 dB) were compared to those of a population exposed to lower noise levels (at or below 80 dB). Statistically significant differences in the number of cardiovascular and circulatory disorders as well as other health problems and complaints were found between the two groups. In a follow-up study the Raytheon Service Company compared medical records of workers exposed to high noise levels (prior to the implementation of a hearing conservation program) with records of the same workers after a hearing conservation program had been put into effect.. The overall results indicated fewer accidents, diagnosed medical disorders, and absences during the period when workers were involved in a hearing protection program. The Raytheon report summarizes: "In general, the results were interpreted as adding strong support to the hypothesis that prolonged exposure to high intensity noise increases the incidence of various medical, accident and attendance problems." (Ex. 26-11, pp. 5-1 and 5-2).

In an experimental study (Ex. 28A, pp. 42, 46-50) on the effects of prolonged exposure to tonal pulses, Dr. Robert Cantrell found statistically significant increases in plasma cortisal and blood cholesterol levels when compared with the pre-exposure levels of his experimental subjects. Significant increases were noted at noise levels of 80 and 85 dB, and were pronounced at 90 dB.

However, there was skepticism during the hearings about the importance of extra-auditory effects. The Edison Electric Institute maintained that:

> since there is no clear evidence on non-auditory noise impact, an occupational noise standard should not consider this area. We recommend that the federal government undertake additional long-term research as provided for in the OSH Act before promulgating standards for non-auditory noise effects (Ex. 73, p. 2).

According to Dr. Bruce Karrh of DuPont:

> I know of no significant report of extra-auditory physiological effects for persons with noise exposure levels below 115 dBA. We have not conducted a controlled scientific study on non-auditory effects of noise at our plants because our experience with our hearing conservation program has not indicated a need for such a study (Ex. 114, p. 14).

In May of 1973 three Swedish researchers (Carlestam, Karlsson, and Levi in Ex. 29, p. 485) pointed out that "the evidence in favor of noise as a major pathogenetic environmental agent is rather shaky."

Between the 1975 hearings and the recent reopening of the record (April 1980), considerable research activity has occurred, and new and more persuasive evidence has been submitted to the record.

The EPA submitted an analysis by Dr. Welch (Ex. 321-16E) of over forty studies from European and Soviet bloc nations of the effects of noise exposure on the cardiovascular system. Dr. Welch found evidence of noise-induced structural changes in the heart, increased cardiac morbidity, cerebrovascular and peripheral vascular disorders, and hypertension (Ex. 321-16E, pp. 2-21). Dr. Welch admits that many of these studies suffered from methodological problems, although approximately half of them presented data in a statistically verifiable manner. Viewed as a whole, these studies represent a consistent body of data containing significant evidence that noise levels greater than 90 to 95 dB may increase the risk of cardiovascular disease in exposed workers. He concludes:

> In a practical sense, the available evidence now demands that prolonged exposure to high intensity sound be viewed in a much broader sense than heretofore as a serious threat to general human health. The evidence for associating long-term sound exposure with cardiovascular disease, in particular, is comparable to that for associating it with loss of hearing (Ex. 321-16E, p. 37).

In another report submitted by EPA (Ex. 321-16D, pp. 1-2), Dr. Peterson also discusses recent developments in research on the extra-auditory effects of noise. He finds that by far the largest body of evidence centers about the relationship between prolonged exposure to intense noise and cardiovascular performance. The most common occurrence is one of impaired regulation of blood pressure, which may be manifested either as hypotension or hypertension. Other signs and symptoms that occur more frequently in noise-exposed workers are abnormalities in cardiac pacing, reduced stroke volume, various EKG abnormalities, and narrowing of retinal arteries. Dr. Peterson also reported on his own work (Ex. 321-16D, pp. 6-10), a laboratory study of the effects of protracted noise exposure on rhesus monkeys. Monkeys were chosen as an animal model so as to closely approximate human response. As a result of life-like exposure scenarios (averaging 85 dB) for 9 months, the monkeys showed significant alterations in blood pressure that were sustained even after cessation of the stimulus.

A third submission by EPA (Ex. 321-16F) is a study of German brewery workers by Dr. H. Ising et al., who attempted to quantify the risk to the cardiovascular system associated with exposure to noise levels averaging 95 dB. Dr. Ising used each individual as his own control by comparing various cardiovascular indicators with and without the use of hearing protectors. In so doing he overcame some of the methodological problems discussed by Dr. Peterson (Ex. 321-16D, pp. 2-4) and Dr. Welch (Ex. 321-16E, pp. 35-37). Dr. Ising found that on days when people worked without hearing protection, there was a significant elevation in systolic blood pressure, changes in arterial wall elasticity, and increased levels of catecholamine hormones excreted in the urine. (The catecholamines are characteristically secreted in response to stress, and have been associated with increased blood platelet adhesiveness and with increases in blood pressure (Ex. 138A, pp. 2-32 and 2-33)).

Despite the quantity of evidence in the studies discussed above, clear dose-response relationships do not yet exist for the cardiovascular effects of noise. However, if, as the evidence suggests, there is a cause-effect relationship between noise and hypertension, the health implications would be widespread and serious (Ex. 79, p. 5; Ex. 266B, pp. 2,13,14-15; Ex. 138A, p. 2-31; Ex. 321-16E, p. 37; Ex. 29, p. 485).

Other extra-auditory effects are also discussed in the record. The report of the initial Raytheon study, mentioned above, described other possible effects of noise (Ex. 29, pp. 449, 451). In addition to cardiovascular effects, the investigators found evidence of digestive, respiratory, allergenic, and musculo-skeletal disorders. Over a period of 5 years the number of diagnosed disorders in every category was significantly higher for workers exposed to high noise levels than it was for those exposed to lower noise levels.

In his report (Ex. 321-16E, p. 31), Dr. Welch discusses neurological changes associated with long-term exposure to occupational noise. After reviewing the scientific literature, he finds that the sense of balance can be altered, that reaction time is impaired, and that there is decreased tactile sensitivity in the hands and feet. Dr. Cohen and Dr. Joseph Anticaglia (Ex. 96, pp. 277) suggest that noise-induced neurological changes may occur as a result of overstimulation of the brain's reticular formation, leading to a state of reflex hyperactivity and abnormal EEG response. The authors noticed that laboratory subjects complained about feelings of disorientation after exposure to high levels of noise (Ex. 96, p. 278). Studies cited by Dr. Edith Gulian (Ex. 97, pp. 38-39) support this observation with factory workers as well. It has also been suggested that high levels of noise reduce the eye's ability to focus clearly, and narrow the visual field (Ex. 97, p. 35; Ex. 96, p. 278). These effects can be significant from the standpoint of potential accidents and injuries (Ex. 96, p. 279).

III. BENEFITS

Introduction

Workers will derive substantial benefits from the hearing conservation amendment. The primary benefit of the amendment will be a sizable reduction in the incidence of occupational hearing impairment for U.S. workers. This reduction will substantially improve the health and quality of life of these workers. In addition, there will be possible declines in the number of workplace accidents and in the incidence of cardiovascular disease following the implementation of the amendment. The hearing conservation amendment will also create financial benefits stemming from reductions in worker absenteeism and medical costs, which will partially offset the costs of the amendment. Employers will profit by the decline in workers' absences, while workers will benefit from the reduction in medical costs. Consumers and taxpayers as a whole will gain from a reduction in the societal subsidy to medical costs. These financial benefits furnish additional support for the amendment.

Occupational hearing loss damages the social relationships of impaired workers by hindering their ability to communicate with other workers, their families, and their friends. OSHA's hearing conservation amendment, by substantially reducing the incidence of occupational hearing loss, will improve the quality of life for these individuals since they will no longer need to endure the difficulties and hardships experienced by those who associate with impaired workers. These improvements are also benefits of this amendment.

In addition, other indirect benefits will occur. For example, audiometric testing will indicate that there are workers with non-occupationally caused hearing difficulties, thereby enabling their referral to otologists for treatment. (For an example, see Ex. 321-1, p. 2.) Monitoring will provide information on workplace noise levels that may be used by workers and their union representatives in collective bargaining negotiations concerning work conditions. However, these informational benefits are not easily quantified, and the following discussion will focus on the benefits resulting from the increased use of personal hearing protectors as required by the amendment.

The hearing conservation amendment will also lead to a more equitable distribution of the costs and benefits of industrial production. Currently, one undesirable side effect of industrial production is the loss of hearing ability among a substantial number of workers. Although workers bear this cost of industrial production, the benefits of this production are shared by firms, stockholders, and consumers, as well as by workers. One traditional principle of distributional equity is that those who benefit from an activity should share in its costs. In order to prevent occupational hearing loss, implementation of the hearing conservation amendment will impose compliance costs on firms. Depending on the particular economic circumstances of these firms, these costs may be passed on to consumers or borne by stockholders. In both cases, most workers will no longer bear the cost of occupational hearing loss, while those who share the benefits of industrial production will share the costs of preventing that loss.

Moreover, the benefits of the reduced incidence of occupational hearing loss will be experienced to a greater extent by poorer and lesser educated workers who often have little choice except to work in the noisiest and least healthful jobs. Evidence derived from a U.S. Public Health Service Survey shows that for every age group, those of lower educational attainment have a higher risk of hearing impairment than those with higher levels of education (Center for Policy Alternatives, "Some Considerations," Ex. 138A, 3-2 to 3-3). Thus, the reduced incidence of occupational hearing impairment will more than proportionately benefit those with fewer material resources.

In this section, the various benefits of the hearing conservation amendment are discussed. The primary benefit of the amendment--the prevention of occupational hearing impairment--is treated extensively by including first, an examination of the major studies in the record, second, a description of OSHA's methodology for updating the estimates of the benefits and third, a presentation of the results of OSHA's calculations. Several other effects of the amendment, including improved workplace safety, and possible reductions in cardiovascular illness, absenteeism, medical costs, and workers' compensation payments, are also discussed. Finally, although the current record lacks the information needed for a final evaluation, two possible benefits are analyzed: reduced annoyance and improved productivity.

Material Impairment of Hearing Prevented

Previous Estimates

Four major studies present in the record estimate the number of hearing impairments that would be prevented by an OSHA standard regulating occupational noise exposure. Although each has certain inadequacies, taken together they reveal that occupational noise $\geq$ 85 dB impairs a substantial number of workers. Based on these studies and OSHA's own calculations and analysis, presented below, the Agency has concluded that regulatory action is necessary.

Bolt, Beranek, and Newman, Inc. (BBN), a counsulting firm under contract to OSHA, prepared a report entitled "Impact of Noise Control at the Workplace" (Ex. 7), which was dated January 1, 1974. They estimated, based on "informal discussions with industry spokesmen", their extensive experience conducting noise surveys, and 1973 employment data, that 8,524,000 workers (59.3 percent of the 14,382,000 production workers in 19 two-digit industries) were exposed to noise levels > 85 dB, while 3,755,000 workers (26.1 percent) were exposed to levels > 90 dB (BBN, Ex. 7, p. C-2). For demonstration purposes they assumed that 30 percent of production workers were exposed to levels > 90 dB and an additional 40 percent were exposed between 85 and 90 dB. (Ex. 7, p. D-3). Then using the risk data of Baughn, they calculated that maximum compliance with a 90 dB Permissible Exposure Limit (PEL), which they referred to as "the present standard," would reduce the number handicapped at retirement by 700,000 (25 dB fence at 500, 1000, and 2000 Hz); and that compliance with an 85 dB PEL would reduce this number by an additional 770,000.

This study formed the basis for BBN's testimony at the 1975 hearings. After those hearings, OSHA contracted with BBN for a more extensive study of workplace noise and the impact of 85 and 90 dB PEL's. The resulting study, entitled "Economic Impact Analysis of Proposed Noise Control Regulation" (Ex. 192), was released by OSHA in 1976. In it, BBN estimated that 4,468,400 workers (34.5 percent of the 12,939,300 production workers in the 19 industries studied) were exposed to noise levels > 85 dB, while 2,393,200 workers (19.3 percent) were exposed to levels > 90 dB (BBN, Ex. 192, p. 2-7).

Using dose-response relationships for noise exposure and hearing impairment developed by Baughn and the team of Burns and Robinson, BBN estimated the number of hearing impairments that would occur under a number of alternative regulations, definitions of material impairment, and assumptions concerning job mobility. They estimated that after implementation of a 90 dB PEL, between 86,400 and 875,100 workers would still be impaired (25 dB fence at 500, 1000, and 2000 Hz) while an 85 dB PEL would reduce this to between 44,400 and 631,200. Therefore, the additional impairments prevented by an 85 dB PEL would be between 42,000 and 243,900 (BBN, Ex. 192, p. 2-35). (The range of estimates was due to the use of two measures of the risk of impairment: the Burns and Robinson data for the lower bound and the Baughn data for the upper bound.)

In addition, BBN made estimates of the benefits of requiring hearing protector use in combination with the 90 and 85 dB PEL's. They did this using three different assumptions concerning hearing protector use. First, that all workers required would wear hearing protectors and three-fourths of them would wear them correctly. Second, that three-fourths of the workers required to do so would wear hearing protectors and three-fourths of them would wear their hearing protectors correctly. Third, that one-half of the workers required to do so would wear hearing protectors and one-half of them would wear them correctly. In all cases, correct use of hearing protectors was assumed to yield a 30 dB attenuation.

Using these assumptions, BBN calculated that a 90 dB PEL for engineering controls, with hearing protector use for those exposed above 85 dB, would leave between 10,800 and 324,200 impairments after 20 years of exposure if everyone who required hearing protectors wore them. The number of impairments remaining in the workforce was larger under the second and third assumptions. For these two assumptions, the estimates of impairments remaining in the population were between 30,000 and 488,400 impairments (second assumption), and 32,900 and 634,900 impairments (third assumption) (BBN, Ex. 192, p. 2-35). Compared to the effects of a 90 dB PEL, the use of hearing protectors by those exposed above 85 dB was therefore estimated to prevent at least an additional 53,500 to 75,600 impairments (lower bound estimate based on the Burns and Robinson data) or an additional 240,200 to 550,900 impairments (upper bound estimate based on the Baughn data).

The estimates provided by BBN require updating for several reasons. First, the production work force of 12,939,300 for the 19 industries studied by BBN was based on employment data for 1975. Second, BBN calculated the benefits of noise control assuming a workforce composed entirely of 20-year-olds who would be exposed to noise for 20 years. This inaccurately depicts the effects of noise on a real work force that also contains older workers and retirees who have been exposed for more than 20 years. Third, in most cases, the number of hearing impairments was calculated for hearing thresholds greater than or equal to a 25 dB average of 500, 1000, and 2000 Hz. For reasons discussed in the Health Effects section, OSHA believes that this combination of frequencies is not the most appropriate measure of material hearing impairment and that a 25 dB average of hearing threshold levels at the frequencies of 1000, 2000, and 3000 Hz is preferable.

A third benefits estimate was performed by the Center for Policy Alternatives (CPA) under contract to the Environmental Protection Agency (EPA). Entitled "Some Considerations in Choosing an Occupational Noise

Exposure Regulation," it was presented at the first hearings. Using the risk data of Baughn throughout their report, CPA estimated that present noise exposures (based on the estimates in BBN's first report and assuming no job mobility) would lead to 1,649,000 impairments (25 dB at 500, 1000, and 2000 Hz) after 40 years of exposure. They calculated that if noise exposures for all workers above 90 dB were brought down to 90 dB, the number of impairments could be reduced to 1,106,000, while if all exposures above 85 dB were brought down to 85 dB, the number of impairments could be reduced to 710,000 (CPA, Ex. 138A, p. 2-26). Thus a 90 dB PEL could prevent 543,000 hearing impairments while an 85 dB PEL could prevent an additional 396,000 impairments.

A fourth estimate of the impairments prevented by the proposed noise regulation that was submitted to the record and subjected to examination at the 1976 hearings was also performed by CPA under contract to EPA. ("Economic/Social Impact of Occupational Noise Exposure Regulations," Ex. 232). This report continued the earlier research CPA had performed for EPA (Ex. 138A). The noise exposure profile used in the second CPA report was based on the same raw exposure data that BBN had collected for their second report (Ex. 192), although the data were modified by CPA. CPA estimated that after the establishment of equilibrium, compliance with a 90 dB PEL would prevent 770,000 workers from impairment (25 dB fence at 500, 1000, and 2000 Hz) while an 85 dB PEL would prevent 1,350,000 impairments (CPA, Ex. 232, p. 5-7). Thus the additional impairments prevented by the 85 dB PEL would total 580,000.

For various reasons the CPA estimates also require updating. First, the estimates were based on 1974 employment levels rather than on the latest available data. Second, although CPA used an age distribution of the exposed population, they excluded retirees and did not distinguish between men and women. OSHA has determined that these calculations should include future retirees because they will also benefit from hearing conservation programs. In addition the calculations must distinguish between men and women because of the presbycusis differences between the sexes. Third, CPA used the frequencies 500, 1000, and 2000 Hz instead of the more appropriate 1000, 2000, and 3000 Hz. Fourth, the CPA study discussed the benefits of engineering control strategies to reduce noise levels to 90 and 85 dB, but not the benefits of hearing conservation programs that require the issuance and use of hearing protectors.

OSHA's Methodology

In order to improve upon the estimates of BBN and CPA, OSHA has decided to revise and update the calculation of the benefits of the hearing conservation amendment. The principal benefit of the hearing conservation amendment will be to prevent occupational hearing impairments through the inter-related aspects of effective hearing conservation programs. For example, monitoring provides information on the need for hearing protection and the type of protectors required. The use of these hearing protectors will reduce worker exposures. Training sessions will instruct workers in properly fitting, maintaining, and using hearing protectors. Audiometric testing detects temporary and permanent shifts in hearing ability, thereby detecting workers who are susceptible to hearing loss, identifying workers who may be wearing their hearing protectors improperly, and motivating those who would not otherwise wear them.

OSHA's estimates of the benefits of hearing conservation programs were calculated by comparing the number of hearing impairments that would occur if no hearing conservation programs exist with the number that will occur after they are established. The methodology used to estimate the benefits is derived from the studies summarized above as well as from other evidence contained in the record. Specifically, OSHA has determined that the methodology of the CPA report is more appropriate than the simpler methodology followed by BBN. BBN's methodology was based on a hypothetical work force composed of 20-year-olds, while CPA's methodology used the actual age distribution of the noise-exposed population. OSHA's calculations do, however, use the noise exposure distribution developed by BBN since it is the best available evidence on occupational noise exposures.

The benefits of preventing hearing impairment are described here by presenting (1) the number of persons who will be prevented from incurring material impairment of hearing after the full effects of hearing conservation programs are realized, (2) the number of persons prevented from incurring material impairment of hearing at years selected from the interim time period before the full effects are realized, and (3) the accumulated person-years of impairment prevented over that time period.

People in the <u>current</u> workforce will only gain a limited benefit from the hearing conservation programs established by this hearing conservation amendment since many of these workers have already suffered noise-induced hearing loss. The full benefits of the amendment will be realized only by workers who spend their entire working lives covered by its provisions. It will take a number of years for the current worker population to be completely replaced by people who have been covered by hearing conservation programs for all of their working lives. Over time, the number of people prevented from incurring a material impairment will rise until an equilibrium is reached after the entire pre-hearing conservation work force has been replaced. With the continued provision of hearing protectors and hearing conservation programs, this equilibrium level of impairments prevented should continue for the years following the establishment of equilibrium.

Although the benefits of preventing occupational hearing impairment are not fully realized until equilibrium is reached, benefits will accrue during the period prior to equilibrium. As the years advance, the number of workers prevented, at any one time, from having a material impairment of hearing will increase. In order to describe this progression, the number of material impairments prevented during the 10th, 20th, 30th, and 40th years following implementation were calculated and are referred to as the interim benefits of the hearing conservation programs.

These first two descriptors, the number of impairments prevented at equilibrium and the number prevented at 4 interim years, provide only views of the benefits at particular time points. These "snapshot" views fail to capture the differences in the number of impairment-free years each person has enjoyed. For example, the number of impairments prevented at the 40th interim year will include some people who have been free from impairment for 40 years, as well as some people free from impairment for as short as 1 year. In fact, as time passes after implementation, the average number of impairment-free years per impairment prevented increases.

In order to describe this pattern, OSHA has calculated the accumulated number of person-years of impairment prevented over the interim time period. The number of person-years of impairment prevented is derived by multiplying the number of impairments prevented by the number of years each individual was kept free from impairment. For example, 2 people prevented from incurring a material impairment of hearing for 10 years apiece equals 20 person-years of impairment prevented. This would also be equal to 1 person for 20 years or 4 people for 5 years.

The accumulated person-years of impairment prevented were estimated from the interim benefits using the procedures suggested and used by CPA (Ex. 232, p. B-21), and described in Appendix A below. Estimates of the accumulated number of person-years of impairment prevented were calculated for 10, 20, 30, 40, and 70 years after the implementation of hearing conservation programs. Seventy years was chosen to approximate the length of time required for equilibrium to be reached. Since these calculations were based on a population that included retirees, and since many retirees live well into their 80's, it will take at least 70 years for people in the existing workforce, who have spent some of their working lives without the benefits of hearing conservation programs, to be replaced by people who have had those benefits.

Noise Exposure Distribution. These updated hearing impairment calculations are based on the same set of 19 industries and the same noise exposure data used by BBN for their second study of the proposed regulation. (CPA used the same set of industries, but modified the exposure data.) BBN, in their economic impact analysis, presented a noise exposure distribution based on surveys of 68 different establishments in 19 two-digit standard industrial classification (SIC) industries. The industries selected by BBN were the ones believed to contain most of the noisy workplaces in the U.S. (BBN, Ex. 192, p. 2-1). These industries and the number of production workers in them during 1979 are listed in Table 3. (Note that the total number of workers in these industries today is about 2 million greater than BBN's 1976 estimate.) The selection of industries

Table 3

Industries Studied

SIC Code*	Industry Title*	Production Workers** (thousands)
20	Food	1,176.2
21	Tobacco	52.5
22	Textiles	777.0
23	Apparel	1,122.2
24	Lumber & Wood	646.3
25	Furniture & Fixtures	398.0
26	Paper	541.5
27	Printing & Publishing	702.2
28	Chemicals	636.9
29	Petroleum & Coal	139.7
30	Rubber & Plastics	601.1
31	Leather	207.4
32	Stone, Clay, & Glass	560.5
33	Primary Metals	978.3
34	Fabricated Metals	1,305.9
35	Machinery, Except Electrical	1,616.2
36	Electrical Machinery	1,378.6
37	Transportation Equipment	1,404.2
49	Utilities	659.3
	Total	14,904.0

Source: U.S. Department of Labor, Bureau of Labor Statistics, Employment and Earnings, 27, (March 1980): 58-66, Table B-2.

*Executive Office of the President, Office of Management and Budget, Standard Industrial Classification Manual, 1972.

**Average Number of Production Workers in 1979.

and establishments was based on BBN's extensive experience with industrial noise and its control. During the survey, BBN estimated the number of workers exposed to various noise levels within 5 dB ranges. Because of uncertainty in the classification of workers by exposure level, BBN adjusted the raw data by distributing one-fourth of the workers in each 5 dB range to the next highest 5 dB range and one-fourth to the next lowest 5 dB range. Although CPA judged this adjustment to be inappropriate (See Ex. 232, p. B-4), OSHA has retained it because BBN was more familiar with the raw data and its peculiarities.

These exposure estimates, which were published in the 1976 BBN report (BBN, Ex. 192, pp. 2-4 and 2-7) and discussed at the hearings, have been recalculated to correct minor errors in the original profile. Thus, the noise exposure profile used here differs slightly from the profile published by BBN as Table 2.1 of their report. These differences are small--no more than one-half of one percentage point for any 5 dB exposure range. This recalculation has also corrected the inconsistency of Tables 2.1 and 2.2 of the 1976 BBN report (BBN, Ex. 192, pp. 2-4 and 2-7). Except for the total percentage exposed above 85 dB, the exposure profile used here is consistent with BBN's Table 2.2. The total percentage above 85 dB differs by only one-tenth of one percentage point. (See also Table 11 in the Cost of Compliance section below.) Table 4 presents the corrected noise exposure distribution for the 19 industries.

OSHA has chosen to use the BBN exposure estimates because they remain the most comprehensive and detailed estimates of occupational noise exposures in U.S. industry. Although these estimates were briefly criticized at the hearings (See Hearing Transcript, Sept. 21, 1976, pp. 139-43; Sept. 22, 1976, pp. 237-42, 360-1) as well as in the post-hearing

Table 4

Noise Exposure Distribution

Exposure Level (db)	Percent
less than 80	46.88
80-85	18.74
85-90	15.06
90-95	10.98
95-100	5.47
100+	2.87
Total	100.00

Source: Bolt, Beranek, and Newman. This is a corrected version of Table 2.1 from "Economic Impact of Proposed Noise Control Regulation," Ex. 192, p. 2-4.

comments (Ex. 279-8, pp. 37-8, 69-72), no one came forward with another set of exposure estimates that includes both the full range of industries and the detailed exposure levels of the BBN estimates. The American Road Builders Association (Ex. 186B) and the Motor Vehicle Manufacturing Association (Ex. 242D) presented estimates limited to the specific industries in which their member companies operate. Evidence, based on samples drawn from a wider range of industries, is included in surveys by Hearing Conservation Noise Control (Ex. 240B) and NIOSH (Ex. 321-14B and Ex. 321-14D). These surveys present the number of workers exposed above either 90 or 85 dB but do not provide a detailed classification of employees by 5 dB exposure level ranges as do the BBN estimates. This classification is necessary for the matching of the exposure distribution with the risk matrices to estimate the number of hearing impairments prevented by hearing conservation programs.

OSHA has concluded that three simplifying assumptions were necessary in order to use the BBN noise exposure distribution to estimate the number of hearing impairments prevented. First, that BBN's noise exposure distribution adequately describes the occupational noise environment in the 19 industries studied, and that the 19 industries encompass all substantial occupational noise exposure. Second, that the noise exposure distribution and the size of the work force in the 19 industries will remain unchanged for the 70-year period used to calculate benefits. If there are changes in the noise distribution and the size of the work force which increase the number of persons exposed to harmful noise levels, this assumption will lead to an understatement of the number of hearing impairments prevented. On the other hand, if these changes decrease the number of persons exposed, then there will be an overstatement of the number of impairments prevented. Third, in industries with fluctuating noise levels, it was assumed that a 5 dB exchange rate adequately represents time-weighted exposure levels. The BBN data are based on a 5 dB exchange rate. The CPA report argued that these data should be adjusted to take into account a 3 dB exchange rate (CPA, Ex. 232, p. B-5).

The exchange rate or the "doubling rate" is a way of either averaging or comparing exposure levels and durations. Under a 5 dB exchange rate, for a 5 dB increase in the exposure level the exposure duration must be halved to obtain an equivalent time-weighted exposure. Thus, 8 hours of exposure to a level of 90 dB is equal to 4 hours at 95 dB. Similarly, under a 3 dB rate, an increase of 3 dB necessitates halving the duration--e.g., 8 hours at 90 dB equals 4 hours at 93 dB. Since OSHA is currently retaining the 5 dB exchange rate used in 29 CFR 1910.95, and since the procedure used by CPA to adjust the BBN data does not appear to be based on actual exposure data, the Agency did not adjust the noise exposure distribution to account for a 3 dB exchange rate. This adjustment would have increased the effective exposure level of the work force and would have increased the estimated number of hearing impairments. By not performing this adjustment, OSHA may be understating the number of hearing impairments prevented by the final amendment.

<u>Fences</u>. The methodology used to estimate the number of people suffering impairments of hearing continues the standard practice of drawing fences to demarcate "normal" from "materially impaired" and then calculating the number of persons with hearing abilities worse than the level of that fence. An important issue is the choice of appropriate fences, both in terms of the levels used as well as the frequencies to be

examined or averaged. BBN did most of their calculations using a 25 dB average of hearing threshold levels at the frequencies of 500, 1000, and 2000 Hz. However, BBN also examined the effects of choosing other levels, 15 and 35 dB, as well as an average of the frequencies of 1000, 2000, and 3000 Hz (BBN, Ex. 192, pp. 2-27, 2-28). CPA correctly pointed out that the effect of noise on a population of workers is to cause a change from one population distribution to another. They state:

> Essentially the entire population of workers has worse hearing because of the influence of noise. Those which, without noise, might have had excellent hearing are shifted so that they have less than excellent hearing. Those which without noise, would have had only fair or poor hearing have their hearing handicaps increased. (CPA, Ex. 232, p. 5-2)

Thus, the usual practice of drawing a single fence does not adequately describe the shift of the entire distribution of workers. Therefore, CPA suggested that a series of fences be employed (CPA, Ex. 232, p. 5-3). There were many other comments submitted to the record concerning the choice of appropriate fences, both for the determination of the number of workers suffering material impairment as well as for workers' compensation purposes. (For a discussion of these comments, see the Health Effects Section.) After a thorough review of these comments, OSHA has concluded that the number of hearing impairments prevented by the final amendment should be measured using the fences of 15, 25, and 40 dB. These fences are defined as the average of a person's hearing threshold levels for the frequencies 1000, 2000, and 3000 Hz. As described in the discussion on health effects, these frequencies were chosen as those most appropriate to describe the ability of persons to understand human speech under everyday conditions. The levels were chosen to describe the number of persons with various degrees of hearing loss: mild hearing loss, material impairment, and moderate to severe impairment.

Dose-Response Relationship. A person's hearing ability can be estimated by analyzing two components: the loss in hearing ability due to noise and the loss in hearing ability due to the effects of aging (presbycusis). The following discussion will focus on these two components, presenting OSHA's arguments concerning the best available and most appropriate evidence for each.

The change in hearing ability due to noise exposure is measured in terms of the permanent decibel shift in hearing thresholds caused by noise. This change, the amount of lost hearing ability, is more commonly called the Noise-Induced Permanent Threshold Shift or NIPTS. An examination of the hearing loss studies cited in the Health Effects section reveals a fair degree of consistency in their basic findings concerning the amount of NIPTS caused by various combinations of exposure levels and durations. One way to incorporate all of the information in these studies is to average the results. Col. Daniel Johnson has recommended such an approach (Ex. 17, p. 2) and EPA has applied it to the data of Baughn, Burns and Robinson, and Passchier-Vermeer both for establishing criteria for noise regulation (Ex. 26-3) and for identifying safe levels of noise exposure (Ex. 30, p. C-5). Recently Col. Johnson published a variety of calculations based on averaging the data of Burns and Robinson (referred to only as "Robinson" by Johnson) and Passchier-Vermeer (Ex. 310).

OSHA has chosen to use the studies of Burns and Robinson and Passchier-Vermeer because of the completeness of their data for describing the NIPTS at frequencies from 500 to 6000 Hz for various population percentiles, noise levels, and exposure durations. Baughn's data (Ex. 11) were not available for individual frequencies, thus preventing the averaging of hearing threshold levels at 1000, 2000, and 3000 Hz. The NIOSH data (Ex. 26-2) were limited to exposures of 85, 90, and 95 dB, thus preventing the estimation of hearing loss for exposures to 80 and 100 dB.

OSHA has determined that the results of the Burns and Robinson and Passchier-Vermeer studies can be strengthened by averaging the NIPTS values from each. Because Johnson's recent publication, Derivation of Presbycusis and Noise Induced Permanent Threshold Shift (Ex. 310), provides a convenient presentation of this data, OSHA has used it as the basis for the calculation of the number of occupational hearing impairments. Table A.7 of Appendix A presents the NIPTS values, derived from the Johnson publication, which were used by OSHA.

The second component that determines a person's hearing ability is calculated by observing the effects of aging (presbycusis) on the hearing ability of a "normal" population. For this study, OSHA has used a presbycusis base developed by Johnson from the data of the U.S. Public Health Survey conducted in 1960-62. In this survey, 6,672 persons aged 18-79, drawn from the civilian, non-institutional population of the U.S., were given audiometric examinations. Thus, the survey gives a detailed picture of the actual hearing ability of the U.S. population. Other researchers, most notably Burns and Robinson, have screened their populations quite severely in order to eliminate all individuals who have been exposed to gunfire, or had ear disease, or other ear abnormalities. These screening techniques were designed to create a popultion that is otologically "normal."

But the actual workforce is not otologically "normal." Some workers have been exposed to gunfire, both from sport shooting and from service in the armed forces. Other workers have or have had ear disease or other ear abnormalities. OSHA has therefore decided that the presbycusis base to use in calculating the number of hearing impairments in the work force should reflect, as closely as possible, the real world hearing ability of the U.S. population. The Public Health Survey represents the best available description of this hearing ability. An examination of the aging curves in Baughn (Ex. 12, p. 26) and Berger, Royster, and Thomas (Ex. 266A, pp. 42, 43, and 57) reveals that the data of the Public Health Survey are consistent with other major presbycusis bases.

The two components, the NIPTS and the presbycusis, may then be added together to find the total hearing loss for populations of given ages and sexes exposed to specified levels and durations (See Johnson's discussion, Ex. 310, pp. 16). Johnson has provided a convenient computer program (Ex. 310, pp. 43-47) which was used to generate dose-response relationships. A simple linear interpolation was used to match the exposure distribution with these dose-response relationships to create the risk matrices (Tables A.9, A.10, A.11) used in the calculation of the number of hearing impairments.

Hearing Protector Use and Attenuation. Under the current noise standard, hearing protector use is mandatory for workers exposed above the PEL (90 dB TWA) where there are no feasible engineering or administrative controls. Under the amendment hearing protectors must also be provided to all workers exposed to noise levels between 85 and 90 dB, but of these workers only those who have experienced a significant threshold shift are required to wear hearing protectors. It is impossible to project accurately the number of workers exposed to noise between 85 and 90 dB who would voluntarily choose or be required to wear hearing protectors. However, it is probable that the annual audiometric test, by showing significant threshold shifts, will identify the employees most vulnerable to occupational hearing loss. These employees will then be required to use hearing protectors, which should prevent most of them from incurring a material impairment of hearing. Thus, the following calculations are based on the assumption that following the implementation of this amendment, all workers who are vulnerable to occupational hearing loss will wear hearing protectors when exposed to noise ≥85 dB.

The CPA report did not present any assumptions concerning hearing protector use or attenuation. BBN assumed for correct usage, an attenuation value of 30 dB (BBN, Ex. 192, p. 2-34). As the following studies indicate, this is an attenuation that is generally achieved only in laboratory settings.

In a NIOSH-sponsored study (A Field Investigation of Noise Reduction Afforded by Insert-Type Hearing Protectors, Ex. 308), a team of researchers investigated the attenuation received by workers using various types of hearing protectors in actual industrial settings. The three earplugs tested had median attenuation values of 7.5, 10.0, and 12.8 dB (Ex. 308, p. 26). Padilla's study revealed an overall mean attenuation of 12 dB at 500 Hz for the earplugs he tested. He estimated that this was equal to approximately 7 dB over the frequencies 125-8000 Hz. ("Ear Plug Performance in Industrial Field Conditions," Ex. 301, p. 34). Regan found mean attenuation values of 25.11 and 19.74 dB for two types of earplugs and 33.04 dB for one type of earmuff (Real Ear Attenuation of Ear Protective Devices Worn in Industry, Ex. 300A, pp. 67-71). In addition, Berger presents information from the National Acoustic Laboratories (Australia) for four different earplugs. For these earplugs, the Noise Reduction Rating with a correction of two standard deviations ranged from 0-14 dB, while with a correction of one standard deviation the range was 9-19 dB ("Laboratory Estimates of the Real World Performance of Hearing Protectors," Ex. 321-35E).

The results of these studies reveal, for the earplugs tested, a mean attenuation of approximately 10-15 dB in industrial settings. It is reasonable to assume that the training and audiometric testing provisions of the hearing conservation amendment will improve industrial hearing conservation programs to at least maintain the upper bound of this average attenuation range. Moreover, those exposed to very loud workplace noise can use earmuffs or a combination of earmuffs and earplugs. These two options appear to have a higher attenuation rating than the earplugs tested in the studies mentioned. Accordingly, for the purposes of these calculations, OSHA has concluded that a reasonable assumption is that workers using personal hearing protection will receive an attenuation of 15 dB.

Mobility. The OSHA calculations were based on the assumption that workers do not move between jobs with harmful noise exposures and jobs without such exposures. Both BBN and CPA generally assumed such mobility to calculate the number of material hearing impairments. However, they used different procedures and assumptions concerning the effect of mobility on the number of material impairments in the population and the number that would benefit from reduced occupational noise exposure. BBN's calculations suggest that assuming mobility reduces the number of additional workers protected by controlling noise levels to 85 dB. (BBN, Ex. 192, Table 2.11, p. 2-30). CPA, on the other hand, argued that an assumption of mobility dramatically increases both the estimated number of material impairments in the pre-regulation population and the number of impairments that would be prevented by regulatory action (Ex. 232, p. 5-8. See also discussion at the hearings by CPA: Hearing Transcript, Oct. 8, 1976, pp. 2286-92, 2343-9, 2354-8 and BBN's reply in their Post-Hearing Comments, Ex. 278, pp. 60-65).

Occupational mobility has two separate, contradictory effects. First, mobility from jobs with harmful noise exposures to jobs without such exposures means that each individual worker will be exposed to harmful levels of noise for a shorter length of time because he or she will not have spent an entire lifetime exposed to harmful levels of occupational noise. This shortened duration of exposure lowers a worker's chance of suffering an occupational hearing impairment as well as the amount of lost hearing ability, and thus would tend to reduce the number of impairments in the entire population. The second effect of mobility, however, is to increase the population exposed to harmful noise levels, even though for shorter periods of time. This increase in the population at risk will tend to increase the number of occupational hearing impairments.

CPA has calculated that, on the average, workers hold three different jobs during their lifetimes. If one assumes that during one of these jobs they will be exposed to harmful occupational noise levels and that the other two jobs have no such noise exposure, then the total population at risk will be increased threefold. (The noise exposure distribution indicates that approximately one-third of the jobs in the 19 industries have noise exposures $\geq$85 dB; while two-thirds have exposures less than this. See Table 4.) In order for there to be no difference in the estimated number of hearing impairments when comparing the assumptions of mobility and no mobility, this threefold increase in the number of workers must be matched by a two-thirds decrease for each worker in the percentage risk of crossing a fence. If the decrease is less than two-thirds, then mobility will increase the number of impairments. If it is more than two-thirds, then mobility will decrease the number of impairments.

CPA calculated, using the equal energy rule (the 3 dB exchange rate), equivalent lifetime exposure levels for workers holding one job with harmful noise exposures and two jobs without such exposures during a working lifetime. This calculation reveals that the maximum reduction in a worker's lifetime exposure level with an assumption of three jobs per worker is about 5 dB for exposures $\geq$90 dB, 4 dB for exposures of 85-90 dB, and 3 dB for exposures of 80-85 dB (CPA, Ex. 232, Table B-6, p. B-14). An examination of the risk matrices (Tables A.9, A.10, A.11) shows that these reductions in lifetime exposure levels lead to a decrease of less than two-thirds in the percentage risk. Therefore, the decrease in the percentage risk is more than matched by the increase in the population at risk due to mobility. Thus, even though an individual's risk of impairment declines from the shortened exposure duration, the increase in the number of persons at risk leads to an increase in the total number of impairments in the population.

Accordingly, the Agency concurs with the judgement of CPA that an assumption of mobility will increase the estimated number of material impairments in the noise-exposed population and therefore will increase the estimated number of impairments prevented by the regulation. As CPA also argued, this effect occurs whenever workers move between jobs with and jobs without harmful noise levels and is intensified by increasing the assumed number of jobs per worker (CPA, Ex. 232, p. 5-8). This effect follows from the shape of the dose-response curve for noise, which is such that the first exposure to noise is more damaging than successive increments of exposure (Hearing Transcript, Oct. 8, 1976, p. 2357).

However, the current record does not contain sufficient information on the current pattern of occupational mobility for the industries under study to enable OSHA to update the hearing impairment calculations using a specific mobility rate. Therefore, OSHA has assumed that no mobility occurs. Since such mobility does take place, this assumption will lead to an understatement of the estimated number of material impairments in the population as well as to an understatement of the number of hearing impairments prevented by the final hearing conservation amendment.

<u>Results of OSHA's Calculations</u>

Occupational hearing impairment is a function of age, sex, exposure level, and exposure duration. OSHA's methodology for calculating the number of material impairments incorporates these functional relationships.

The six basic steps used to calculate the number of material impairments prevented by the hearing conservation amendment were:

1. Develop an age distribution,
2. Develop an age by exposure level distribution,
3. Adjust exposure levels for the use of hearing protectors,
4. Develop a sex distribution and combine with the age by exposure level distribution,
5. Calculate the number of hearing impairments from all causes,
6. Determine the number of occupational hearing impairments.

These six steps, as well as the procedure used to estimate the interim benefits of the regulation, are described in detail in Appendix A. It should be noted that OSHA's procedure uses an age distribution that includes retired workers, as well as incorporating a distribution of the work force by sex, thus improving upon two deficiencies of previous studies.

The benefits of the hearing conservation amendment will accrue primarily to future populations of workers, slowly reducing the number of material impairments in these populations until an equilibrium is reached. The results of these calculations show that 1,060,000 individuals currently have crossed a 25 dB fence (1000, 2000, and 3000 Hz) due to occupational noise. Hearing conservation programs are expected to reduce this number to 848,000 persons 10 years after implementation; 583,000 in 20 years; 364,000 in 30 years; 261,000 in 40 years; and 162,000 at equilibrium (See Appendix A, Table A.15). In each of these years, the number of hearing impairments which would have existed in the absence of hearing conservation programs remains constant at 1,060,000.* Consequently, the number of hearing impairments prevented by hearing conservation programs can be calculated by subtracting the number that will exist in any of the years from the 1,060,000 impairments that would have existed. Hearing conservation programs, therefore, are expected to reduce the number of hearing impairments (25 dB fence) by at least 212,000 in the 10th year after implementation; 477,000 in the 20th year; 696,000 in the 30th year; 799,000 for the 40th year; and 898,000 at equilibrium (See Table 5). The reduction of 898,000 impairments at any one time after the establishment of equilibrium represents 84.7 percent of the occupational impairments that would have occurred without hearing conservation programs.

In addition, OSHA has calculated the number of individuals with hearing impairments at any one time after the establishment of equilibrium for two other fences--15 dB and 40 dB at 1000, 2000, and 3000 Hz. These calculations reveal that without hearing conservation programs, 1,624,000 people will be across a 15 dB fence, and 473,000 will be across the 40 dB fence due to occupational noise exposure. Hearing conservation programs for those exposed to levels $\geq$85 dB are expected to reduce this to 321,000 across the 15 dB fence, and 59,000 across the 40 dB fence (Table A.13). Thus after the establishment of equilibrium, these programs can be expected

*This is based on the assumption of a constant size for the work force exposed to noise, as discussed above.

Table 5

Hearing Impairments Prevented by the Hearing Conservation Amendment

	Years After Implementation				
	10	20	30	40	Equilibrium
Number of Impairments Prevented					
15 dB Fence	-	-	-	-	1,303,000
25 dB Fence	212,000	477,000	696,000	799,000	898,000
40 dB Fence	-	-	-	-	412,000
Accumulated Person-years of Impairment Prevented					
25 dB Fence	1,060,000	4,505,000	10,370,000	17,848,000	43,300,000

Source: OSHA, Office of Regulatory Analysis.

to reduce the number of persons across the fences by 1,303,000 for the 15 dB fence, and 412,000 for the 40 dB fence (See Table 5), reductions of 80.2 percent, and 87.1 percent, respectively.

Finally, the number of person-years of impairment prevented can be calculated. (The procedure used follows that of CPA, Ex. 232, and is described in Appendix A below.) In the 70 years following implementation of the amendment, the total accumulated person-years of prevented impairment is 43.3 million. The pattern of this accumulation is presented in Table 5.

Two conclusions follow from these data: First, without hearing conservation programs, a large number of workers will suffer hearing impairment and reduced hearing ability. Therefore, OSHA has determined that workers who are exposed to occupational noise $\geq$85 dB (TWA) face a significant risk of material impairment. Second, hearing conservation programs for all workers exposed to $\geq$85 dB (TWA) will substantially reduce that risk.

Full Compliance Assumptions

In keeping with past practice concerning the preparation of economic analyses of OSHA regulations, full compliance with the hearing conservation amendment, including 100 percent usage of hearing protectors, has been assumed. For a variety of reasons, this may not occur. Many workers cannot or will not wear hearing protectors. Workers with irregularly shaped or infected ear canals cannot wear ear inserts. Similarly, persons needing to wear either prescription or safety glasses often cannot wear ear muffs because the frames of the glasses will break the seal the muff makes around the ear. More often, hearing protectors will not be worn because they are uncomfortable. Workers have complained about headaches, claustrophobia, and general discomfort from the use of ear protectors. In addition, the use of earplugs may lead to ear infections, especially in dirty workplaces.

Full compliance with this amendment will have substantial benefits. Partial compliance will also provide benefits, although not to the same extent. Moreover, the estimated attenuation of 15 dB after regulation may also be an overestimate of the benefit achieved from the use of hearing protectors. In order to provide this attenuation, hearing protectors must be fitted carefully, worn properly, maintained conscientiously, and replaced in a timely fashion. As illustrated in Table 6, if all workers who are required to do so wear hearing protectors, if they receive a 15 dB attenuation, and if they wear their hearing protection every day that they are exposed to noise, then the total pool of material hearing impairment from occupational causes (at equilibrium) will be reduced by 898,000 persons. If only 10 dB of attenuation is achieved, the number of material impairments prevented falls to 759,000. However, if only 50 percent of workers exposed above 85 dB receive 10 dB attenuation and the remaining 50 percent do not wear ear protection, then the reduction in the number of impairments declines to 381,000. The effectiveness of hearing conservation programs is therefore very dependent on the attenuation that hearing protectors provide and their daily use by all workers.

Table 6

Sensitivity Analysis for Assumptions on Hearing Protector Use and Attenuation

Assumption	Number of Occupational Impairments Prevented*
100% of workers required**wear hearing protectors and receive 15 dB attenuation	898,000
100% of workers required**wear hearing protectors and receive 10 dB attenuation	759,000
50% of workers required**wear hearing protectors and receive 10 dB attenuation	381,000
No hearing protector use	0

Source: OSHA, Office of Regulatory Analysis.

*Hearing threshold levels ≥ 25 dB average of 1000, 2000, and 3000 Hz. Data are for equilibrium.

**All workers exposed to levels > 90 dB after feasible engineering and administrative controls have been implemented and all workers exposed ≥ 85 dB who have shown a permanent significant threshold shift.

These calculations of the number of impairments prevented are also based on the assumption that workers exposed above 85 dB do not currently use hearing protectors. However, the current OSHA standard for noise does require the use of hearing protectors by workers exposed to levels above the PEL of 90 dB (TWA) and the establishment by each employer of a "continuing, effective hearing conservation program" for these employees (29 CFR 1910.95(b)(3)). Moreover, there is evidence in the record to suggest that some employees currently do wear hearing protection and that some companies have established hearing conservation programs (The BBN exposure estimates were based solely on the use or non-use of engineering controls. The use of personal hearing protectors was not factored into their estimates.)

But the effectiveness of these programs and the length of time they have been in operation is less clear. Submissions by Newport News Shipbuilding (Ex. 131), Dupont (Ex. 273A), and Burlington Industries (Ex. 175) describe hearing conservation programs for three large companies that appear to be effective. But one cannot reasonably conclude that all companies with workers exposed to levels greater than 90 dB are maintaining such programs. A NIOSH study revealed that only 29 percent of the manufacturing respondents had such programs, while another 20.1 percent were planning such programs. Most of those without programs or plans claimed no noise problems (Ex. 321-14B, p. B-3). This study also included the testing of equipment used by 65 companies with hearing conservation programs. These tests revealed that 80 percent of these companies were not in compliance with at least one of the then existing ANSI specifications for audiometers and audiometric test booths (Ex. 321-14B, p. 55).

Based on data from NIOSH's National Occupational Hazard Survey (Ex. 321-14D), it is reasonable to conclude that up to 20 percent of those exposed to greater than 90 dB currently wear hearing protectors. The lack of adequate audiometric testing, monitoring, and training activities, however, make it is less likely that a 15 dB attenuation would be achieved. A more reasonable estimate of the current attenuation would be 10 dB, which is the lower bound of the average attenuation range revealed in several studies on the real world attenuation of hearing protectors. (See discussion above.) OSHA has calculated, using the procedures and assumptions detailed in this section and in Appendix A, that the effect of this current hearing protector use would ultimately be a reduction of 120,000 material impairments (25 dB fence) from the 1,060,000 that would continue to exist at any one time in the absence of hearing protector use.

OSHA anticipates that fully effective hearing conservation programs for all workers exposed to levels greater than 85 dB would prevent 898,000 impairments after the entire population has worked with hearing conservation programs in effect. Thus, the incremental or additional benefits due to the hearing conservation amendment will be the difference between these benefits and the 120,000 impairments expected to be prevented by existing programs. The final hearing conservation amendment, therefore, is estimated to prevent 778,000 material impairments over and above the number expected to be prevented by current hearing conservation programs. (These 778,000 impairments prevented consist both of workers exposed to levels $\geq$ 90 dB who are not currently receiving hearing protection as well as those exposed between 85 and 90 dB who will benefit from hearing conservation programs for the first time.)

This discussion on the benefits of preventing hearing impairment has shown that there are substantial benefits to be gained from reducing workplace noise exposure by 15 dB for those exposed above 85 dB. It was assumed in this discussion that the reduction of noise exposures would be achieved through the use of personal hearing protectors. However, that reduction could also be achieved by engineering controls, including the redesign of machinery and the contruction of baffles to impede the transmission of sound energy. Engineering controls provide more consistent and dependable protection to worker hearing than personal hearing protectors and are still preferred by OSHA.

Improved Workplace Safety

A second benefit of the hearing conservation amendment is improved workplace safety. The presence of untreated workplace noise can increase the number of accidents because (1) noise can mask warning signals or shouts, and (2) noise exposure might lead to inattentiveness and fatigue, both of which may precipitate accidents. Edith Gulian's summary of studies in the European literature revealed no clear consensus on the relationship between noise and accidents. One study found no relationship, while two others concluded that noise may have contributed to accidents (Gulian, Ex. 97, p. 60). Two other studies in the record, by examining the job safety records of workers before and after the institution of hearing conservation programs, showed a statistically significant reduction in the number of accidents and injuries occurring after the initiation of hearing conservation programs.

Schmidt, Royster, and Pearson (Ex. 321-22F) studied a cotton yarn plant where a hearing conservation program requiring the use of hearing protectors was instituted in 1972. Using a statistical technique by which each worker serves as his or her own control, the researchers compared the mean number of injuries in the 4-year period prior to the hearing conservation program to the 4-year period following institution of the hearing conservation program for two groups of employees exposed to noise levels of 92-96 dB. The results showed a statistically significant reduction in reported injuries.* For one group, the reduction in the mean injury rate was from 0.4 to 0.2 injuries per year, or by about 50 percent; for the other group, the reduction was from 0.5 to 0.3 injuries per year, or by about 40 percent (Schmidt, et al., Ex. 321-22F, p. 22).

A second study was performed by the Raytheon Service Company under contract to NIOSH (Ex. 26-11). The researchers studied the records of a boiler fabrication plant for the 2-year period before the initiation of a hearing conservation program and the 2-year period after program initiation. The results of this study showed a statistically significant**

*Statistical significance refers to the probability or confidence, based on laws of probability and statistics, that the decline in the number of accidents was not due solely to chance. In this case, the confidence level was 99.9 percent.

**99 percent confidence level.

reduction in the number of accidents among workers exposed to noise levels >95 dB after the initiation of the hearing conservation program. The median frequency of accidents was reduced from 3.8 to 2.3 accidents per worker per year, or by 39.5 percent (Raytheon, Ex. 26-11, pp. 3-5 to 3-6).

Information from the Bureau of Labor Statistics shows that annually there are about 2,474,000 reported occupational injuries in the 19 industries in this noise study, of which about 1,052,900 are lost workday cases (Bureau of Labor Statistics, Occupational Injuries and Illnesses in 1978: Summary, March 1980, Report 586, Table 3, pp. 12-13). If these accidents are distributed evenly among all workers in these industries without regard to noise exposure, then approximately 851,000 total cases and 362,000 lost workday cases could occur each year for those exposed above 85 dB (TWA) [2,474,000 injuries X 34.4 percent (workers exposed ≥85 dB) = 851,056; 1,052,900 lost workday cases x 34.4 percent = 362,198]. Similarly, there are 477,000 total cases and 203,000 lost workday cases among those exposed above 90 dB (TWA) [2,474,000 injuries x 19.3 percent = 477,482; 1,052,900 lost workday cases x 19.3 percent = 203,210]. The Schmidt, Royster, and Peason study, and the Raytheon Study together reveal that the initiation of hearing conservation programs may reduce this yearly toll of accidents.

The reduction in the number of accidents, besides improving the quality of worker lives, may also provide financial benefits to employers by reducing the costs of accidents. These costs include administrative and legal fees, safety administration, damage to equipment, loss of productivity, supplements to workers' compensation payments, and lost income due to inefficiency of replacement personnel. Robert Sharkey, Safety Administrator for Alcoa, estimates that these costs total $14,000 per lost-workday case. (See Peter J. Sheridan, "What Are Accidents Really Costing You?" Occupational Hazards, March 1979, pp. 41-43.)

Extra-Auditory Health Benefits

As described in the Health Effects section, there is a wealth of evidence suggesting a link between noise exposure and ill effects, including cardiovascular, respiratory, allergenic, musculo-skeletal, and glandular disorders. However, because precise dose-response relationships have not yet been developed OSHA has not attempted to quantify these benefits. One example does reveal the magnitude of the occurrence of cardiac disease in the U.S. today. The current rate for deaths due to heart disease for those between 45 and 64 years old is 536.7 per 100,000 (Bureau of the Census, Statistical Abstract of the United States, 1979, p. 77, Table 111.) If this rate applies to the 4,984,000 workers aged 45-64 in the 19 industries, then approximately 27,000 will die of heart disease annually. By reducing noise exposure, the hearing conservation amendment may help to prevent some of these premature deaths.

Reduced Absenteeism

The reduction in noise exposures due to hearing protector use should reduce the number of noise-induced illnesses and could also lead to better worker attitudes towards their jobs, thus improving both attendance records and job performance. In both cases, employers, firms, and consumers would benefit from increased output and reduced costs. The Raytheon study (Raytheon, Ex. 26-11) found that the median number of absences for the group exposed to >95 dB fell by 12.4 days per year after initiation of a hearing conservation program. This was a reduction of about 63 percent from the preconservation program level of absences (Raytheon, Ex. 26-11, p. 3-177).

Several studies of the economic impact of the proposed regulation placed a monetary value on the expected reduction in absenteeism. CPA, in their first study, assumed a reduction in absenteeism of 1 day per year per worker exposed over 85 dB. This was calculated to provide an estimated benefit of $2 billion per year (CPA, "Some Considerations," Ex. 138A, p. 2-55). In their second study, CPA used a more complex methodology based on information from the Raytheon report concerning the reduction in the average number of days absent. CPA calculated the value of lost production based on lower and upper bounds--i.e., average production worker wages and value added per production worker. Based on 1975 dollars, CPA estimated that the value of improved worker attendance for an 85 dB PEL would be between $341.04 million and $1.2484 billion per year (CPA, "Economic/Social Impact," Ex. 232, p. 5-28). A third estimate of the value of absenteeism savings was performed by the Council on Wage and Price Stability (COWPS). Although not based on any empirical studies, COWPS assumed that an 85 dB PEL would reduce absenteeism by 1 day for those previously exposed to 85-90 dB and by 2 days for those exposed above 90 dB. COWPS calculated the savings by multiplying the number of person-days saved by the average daily wages of manufacturing workers, including an estimate of the costs for turnover and new worker training. Finally, COWPS concluded that controlling noise exposures to 85 dB would produce a benefit of $271.7 million per year (COWPS, Ex. 208, p. 19).

After a review of these estimates, OSHA has concluded that the best estimates are provided by the methodology used by CPA in their September 1976 report, which was based on information from the Raytheon study. OSHA has chosen to reestimate the absenteeism benefits by updating the CPA calculations for the increase in the size in the labor force and changes in wage rates since 1976. For this update, OSHA has used only the wage rate to estimate the value of production lost from absenteeism. These calculations, which assume that hearing conservation programs will reduce exposures to below 85 dB for those exposed at 90 dB and above, follow the CPA methodology. First the total number of worker-days of absenteeism prevented were calculated by using the number of workers exposed to noise >90 dB and the number of days of absenteeism saved according to the CPA presentation of the Raytheon data (See CPA, Ex. 232, p. 5-25). The equation used was: 1.243 million workers exposed >95 dB X 3.9 days saved per worker + 1.636 million workers exposed to 90-95 dB X 1.55 days saved per worker = 7.384 million worker-days saved. The value of the production gain from reduced absenteeism was then estimated using the 1979 average wage rate in the 19 industries (See Employment and Earnings, 27, 3, March 1980, Table C-2.). Thus, 7.384 million worker-days saved X 8 hours per day X $6.76 per hour = $399.3 million. This gain of about $400 million per year from reduced absenteeism will benefit employers by partially offsetting the costs of hearing conservation programs and feasible engineering and administrative controls.

Reduced Medical Costs

Workers, and also society, indirectly through third party medical payments, will benefit financially through reduced medical costs. Although in most cases noise-induced hearing loss is untreatable and irreversible, there still is a drain on medical resources--principally professional time--used to reach those diagnoses. In addition, there is the purchase of prescribed hearing aids in the minority of cases for which hearing aids can help, as well as the hearing aids purchased by workers vainly hoping for a cure. In all three cases, social resources are consumed. The prevention of occupational hearing impairments will free those resources for other uses.

Ideally, the magnitude of this loss could be quantified. However, the current noise record does not include either estimates of this loss or information from which estimates could be calculated. Because of this lack of information, OSHA has not attempted to quantify these savings, although preventing 898,000 hearing impairments should lead to a substantial reduction in medical costs.

Reduced Workers' Compensation Payments

Two estimates of the anticipated reduction in workers' compensation payments for occupational hearing loss are contained in the record. BBN estimated that the additional workers' compensation liability saved by reducing noise exposures to 85 dB would be $16.097 million (BBN, Ex. 192, p. 2-38). This is the additional savings, comparing a 90 dB with an 85 dB PEL, not the total reduction expected from the implementation of hearing conservation programs. CPA made an estimate of the total potential workers' compensation payments that a noise regulation might save. They calculated that the present value of the stream of potential savings for an 85 dB PEL over the next 40 years would be $530 million (CPA, Ex. 232, p. 5-34).

But any of these estimates is speculative since hearing impairment is often not compensated. Over 70 percent of manufacturing workers in the U.S. live in states that pay few or no hearing impairment claims (EPA, Occupational Hearing Loss: Workers' Compensation under State and Federal Programs, Ex. 321-16C, p. viii). EPA estimates that in 1977, 6,095 claims totalling approximately $13 million were paid for occupational hearing loss. This figure could change considerably in the future because the number of claims filed has been increasing dramatically (EPA, Ex. 321-16C, pp. 14-15).

It has been pointed out that an estimate of reduced workers' compensation payments cannot be directly added to the other benefits described in this section. As COWPS testified:

> Although a reduction in workmen's compensation payments is a benefit to employers who no longer have to pay workmen's compensation premiums, it represents an almost equal and offsetting cost to workers who no longer receive such payments. (COWPS, Ex. 208, pp. 7-8)

In other words, workers' compensation payments are transfer payments from employers to impaired workers. The true social cost is the incidence of occupational hearing impairment and the various other ill effects of noise; the true social benefit is the reduction in the number of hearing impairments and ill effects.

Annoyance

Several of the studies in the record quantified the benefit of reduced annoyance from noise exposures. (See CPA, "Some Considerations," Ex. 138A, pp. 2-55 to 2-59; Smith, The Occupational Safety and Health Act, Ex. 261A, pp. 46-52; COWPS, Ex. 208, pp. 17-18.) Although these calculations provide interesting information, they primarily apply to the benefits of using engineering controls to reduce noise exposures. The use of hearing protectors to achieve noise reductions will not create the full value of these benefits, because hearing protectors also create disutilities, especially worker discomfort, for those who must wear them. Thus, the benefits of less annoyance due to lowered noise levels are likely to be considerably reduced by this disutility although there are no data in the record enabling OSHA to make a more precise determination.

Worker Productivity

The hearing conservation amendment may also improve the productivity of workers exposed to high levels of noise. There are two possible mechanisms for this: (1) through improvements in conscious worker attitudes towards their jobs, and (2) through subconscious reductions in psychological and physiological stress. The hearing conservation amendment will improve the quality of worker lives by preventing occupational hearing loss and by reducing the incidence of other noise-induced illnesses. These improvements in the quality of life may improve worker attitudes towards their jobs, thus leading to increases in the quantity and the quality of goods and services they produce. The reduction of noise exposures through the issuance and use of hearing protectors may also improve worker performance even if it does not improve conscious worker morale. In particular, workers may still hold the same attitudes towards their jobs, but may be more productive because of a reduction in the subconscious psychological and physiological stress experienced by workers exposed to workplace noise.

In both cases, employers, workers, and consumers would benefit financially. The increased production and improved product quality would benefit employers by offsetting, at least partially, the cost of the amendment. To the extent that the increases in output and improvements in quality increase the productivity of labor inputs; workers could be able to gain improvements in wages and fringe benefits. Finally, consumers would benefit from the increase in the quantity and quality of output. This increase would enable them to purchase an increased quantity at existing prices or continue to purchase the existing quantity but at reduced prices.

Thus, one can reasonably believe that reductions in noise exposure with the use of hearing protectors could, through improved worker morale and reduced subconscious stress, improve worker productivity and lead to financial benefits for employers, workers, and consumers. However, the empirical literature summarized in submissions to the noise record does not provide enough data to confirm or reject this.

In their criteria document on occupational exposure to noise, NIOSH reviewed some of the literature on the effect of noise on job performance (NIOSH, Criteria for a Recommended Standard, Ex. 1). NIOSH discovered that the effect of noise appears to be quite variable depending on the type of noise, the nature of the job, and the attitudes of the person affected. It also appeared that impulsive noise (recurring bursts of noise of high intensity) and intermittent noise (on and off exposures) create greater performance losses than continuous noise. The nature of the job is also important--jobs which require "unremitting attention" or "which place extreme mental demands on the employee" appear to be the most vulnerable to decrements in employee performance under noise exposures. For simple, repetitive tasks, performance may be enhanced by the presence of low to moderate levels of noise. Finally, it appears that certain attitudes and personality factors influence the effect noise has on task performance. Tense, anxious individuals, as well as those already dissatisfied with their jobs may be less able to perform productively under noisy conditions that other persons (NIOSH, Criteria for a Recommended Standard, Ex. 1, pp. IV-13 to IV-16).

EPA and Edith Gulian drew similar conclusions from their reviews of the literature. EPA concluded that continuous noise levels above 90 dB can impair job performance for "noise sensitive tasks," such as vigilance, information gathering, and analytical tasks. Noise levels of less than 90 dB can be disruptive, especially if the noise is composed of high frequencies, or if it is "intermittent, unexpected, or uncontrollable." The amount of this disruption is a function of the nature of the task, and the psychological and physiological state of the individual. The studies surveyed showed that noise does not usually affect the total quantity which a person produces, but may increase the variability of the work rate and reduce the accuracy of the work (EPA, Public Health and Welfare Criteria for Noise, Ex. 31, pp. 8-1 to 8-7). Gulian's survey of the European literature found several studies which indicated increased production with reduced noise exposures, but concluded that the literature was inconclusive on the effects when noise levels were lower than 100 dB, although under certain conditions lower levels have shown adverse effects on productivity (Gulian, Ex. 97, pp. 18-20).

Many of these studies involved testing the ability of persons to perform certain experimental tasks under laboratory conditions and not actual jobs under industrial working conditions. Moreover, the studies mentioned above investigated primarily the effects of noise on performance. They did not examine what effect the issuance and use of hearing protectors might have on job performance.

One study that did examine the effect of hearing protectors indicates that the issuance and use of hearing protectors may have an adverse effect on productivity. This study, by L.R. Hartley (cited by CPA, "Some Considerations," Ex. 138A, pp. 2-45 to 2-46), examined the ability of test subjects to perform a laboratory task under four conditions: quiet, quiet while wearing hearing protectors, noisy, and noisy while wearing hearing protectors. Under quiet conditions, subjects were exposed to broad-band noise at a C-weighted sound level of 70 dB; for noisy conditions exposures were at a C-weighted sound level of 95 dB. The researcher used two measures of subject performance--the number of gaps (pauses of 1 1/2 seconds) and errors. The results revealed that without hearing protectors, exposure to noisy conditions increased both the number of gaps and the number of errors compared to the quiet conditions. When the subjects were exposed to conditions of quiet, the use of hearing protectors increased the number of gaps and errors. Finally, under noisy conditions, the use of hearing protectors decreased the number of gaps, but increased the number of errors. CPA concluded their discussion of this study by suggesting that these results:

> ...tend to give added support to the preference of OSHA, NIOSH, and EPA for engineering solutions to noise, rather than personal ear protection. The widely-observed resistance of workers to the discomfort and annoyance of at least some ear protectors increases the probability that their imposition may sometimes have negative effects on the quality, if not the quantity of industrially-produced goods (CPA, "Some Considerations," p. 2-46).

A final determination of the effect of noise and hearing protector use on productivity awaits the completion of further research. Therefore, OSHA has not based its justification of the hearing conservation amendment on possible gains in worker productivity.

Conclusion

In this section, the benefits of the hearing conservation amendment were delineated and discussed. The primary benefit will, of course, be a substantial reduction in the incidence of occupational hearing impairment in the population exposed to workplace noise. The additional benefits to be gained include improved workplace safety, reduced absenteeism, reduced medical costs, and a possible reduction in cardiovascular and certain other illness. The range of health, safety, and financial benefits, and the magnitude of their favorable impact on the quality of life for U.S workers serve to justify this amendment.

IV. COSTS OF COMPLIANCE

Introduction

Many industry groups strongly recommended to OSHA that hearing conservation programs are a cost-effective and affordable means of reducing noise induced hearing impairment among workers. Bolt Beranek and Newman, (BBN), in their 1976 report for OSHA, ("Economic Impact Analysis of Proposed Noise Control Regulation," Ex. 192) estimated that the hearing conservation provisions of the proposed standard would cost the manufacturing and utilities sectors of the U.S. economy a total of $289.3 million per year in 1975 prices. This amounted to an annual cost of $65 per worker included in the program. The monitoring, recordkeeping, and associated tasks were estimated at $155.2 million annually, (p. 3-9) and were based on the assumption that a typical plant had 50 production workers and could be surveyed by a noise engineer for $600. The annual cost for audiometric testing was calculated at $20 per production worker for $89.1 million, and hearing protectors were estimated at $10 per worker for a total of $45 million per year (Ex. 192, p. 3-33). None of these cost estimates were adjusted to reflect the existence of hearing conservation programs already established by industry.

The BBN estimates of these provisions were not widely criticized. However, certain differences between the proposed standard and the final rule, as well as the availability of more timely cost data, have convinced OSHA to update these estimates of the expected compliance costs. The current estimation procedures, which are based on a thorough review and analysis of the entire record, are presented below for each major provision of the final regulation (Appendix B provides the detailed calculations for a sample SIC industry). Overall these new calculations show that the total annual cost of the regulation will average about $53 for each of the 5.1 million workers estimated to be covered by the hearing conservation amendment. Thus, the total cost of complying with all of the provisions of the amendment are estimated at about $270 million a year. After accounting for some of the compliance activities already taking place, OSHA estimates that the new compliance costs will not exceed about $254.3 million a year and most likely will fall well below this amount (see Table 7).

Table 7

Estimated New Annual Compliance Costs of the Hearing Conservation Amendment

Monitoring	$ 73,731,000
Audiometric Testing	87,199,000
Hearing Protectors	45,534,000
Training	40,029,000
Warning Signs	1,795,000
Recordkeeping	6,033,000
Total	$254,321,000

Source: OSHA, Office of Regulatory Analysis.

Monitoring

The proposed standard directed employers to monitor worker exposure to noise on an annual basis. The final amendment will be less costly because in most cases, it requires monitoring to be performed only every other year. Although the final hearing conservation amendment requires that a new representative exposure be obtained whenever there is a change in noise levels that would render the employee's hearing protection inadequate, in practice, the general availability of hearing protectors rated to reduce high noise levels should make these occurrences infrequent.

A number of consultants have submitted documents to the record listing their fees for noise measurement services. For example, Exhibit 319 B-8 lists $440 plus expenses as the daily charge for a noise engineer and $360 plus expenses as the daily fee for a technician. Exhibit 319 B-11 indicates fees from $250 to $350 for an engineer and from $180 to $240 for a technician, while Exhibit 319 B-16 reported between $229 and $465 plus expenses for an engineer and between $175 and $255 plus expenses for a noise technician. The average of these daily fees is about $362 for an engineer and $262 for a technician. Travel expenses will vary according to each firm's location relative to the consultant. However, as the demand for these services grows, economies of scale will operate to reduce costs below current market charges. For example, the expanded market for consultant services within a region will stimulate the supply of monitoring consultants in the area, thereby minimizing travel expenses. Also, noise engineers should find it increasingly profitable to combine resources with audiometric testing firms to provide industrial clients with a complete range of hearing conservation services. A growing number of firms already market these comprehensive consulting programs (Ex. 305; Ex. 319 B-12), and this one-stop approach to satisfying monitoring, testing and training requirements should substantially reduce the costs of these services over time.

Based on its survey experience, OSHA has estimated the average time it would take noise experts to take measurements in plants of varying sizes. Table 8 shows OSHA's estimate of the cost of hiring a noise consultant,

Table 8

Cost of Monitoring by Consultant

Number of of Employees Measured	Days in Field		Days in Office	Cost
	Engineer	Technician	Engineer	
1-10	1			$ 412
11-20	1		.5	$ 593
21-40	1	1	.5	$ 855
41-60	1.5	2	.5	$1,298
61-80	2	2	~1	$1,660
81-100	2.5	3	1.5	$2,284
101-120	2	4	2	$2,546
121-140*	2	5	2	$2,808

Source: OSHA, Office of Regulatory Analysis.

based on the daily fee of $362 for an engineer, $262 for a technician, and a $50 average travel expense.

The monitoring provision of the amendment requires the reporting of representative exposures of all workers exposed to a time weighted average (TWA) of noise above 85 dB, rather than an actual measurement of each such employee. Thus, a measure of the exposure of one employee may be used to represent similarly exposed employees. Since the data shown in Table 8 correspond to measured workers (as opposed to others who are represented by the measured workers), an estimate of the number of employees who would be individually measured is necessary to assess the total monitoring cost. However, there is no data base available to identify statistically the determinants of the number of employees who would actually have to be measured according to the final rule. This number will vary due to the nature of the industrial process and the diversity of the work areas and tasks. For instance, in workplaces where noise levels are fairly uniform throughout the shop, fewer employees will need to be monitored than in workplaces where the noise exposures vary extensively among workers. Nevertheless, it can be assumed that, in general, the percent of the work force to be measured would vary inversely with the size of the plant. (See Ex. 309, p. 35, Table 3.1 for an example of how the percentage of workers to be sampled within a group of similarly exposed workers might decline as the group grows larger.) Table 9 gives estimates of the percentage of employees who would have to be measured individually to provide representative exposures of workplace noise for all exposed workers. These estimates were developed by OSHA, based on its broad experience with noise surveys for numerous industrial establishments, and are consistent with the final monitoring requirement as they are predicated on a sampling strategy designed to place employees within 5 dB ranges.

Table 9

Percent of Employees Measured to Provide Representative Exposures

Number of Employees	Employees Measured
1-19	100%
20-49	60%
50-99	50%
100-249	40%
250 and over	30%

Source: OSHA, Office of Regulatory Analysis.

To refine the estimate of the cost of using consulting services to conduct industrial noise measurements, it was necessary to construct a statistical distribution of the number of production workers in manufacturing establishments of different sizes. The U.S. Bureau of the Census provides 1977 data on the total number of employees in five establishment size categories (County Business Patterns, CBP-77-1). The conversion of this size distribution from total employees to one limited to production workers was accomplished by combining these data with information from the U.S. Bureau of Labor Statistics (BLS) (Employment and Earnings, 1909-1978) to obtain a 15-year average ratio of the number of production workers to the total number of employees. When multiplied by the 1977 Census estimates of total employment by industry and establishment size, this procedure yields estimates of 1977 production worker employment by industry and establishment size. These data are shown in Table 10.

OSHA believes that the best estimates of the total number of workers affected by this hearing conservation program are obtained from the BBN data on the percentage of workers exposed to various levels of noise in those industrial sectors which include most manufacturing and public utility firms (Ex. 192, p. 2-7). BBN's industry-wide estimates, as presented in Table 11, were developed from surveys of 68 firms representing 19 two-digit SIC categories, were based on years of extensive experience and expertise in noise control surveys, and were the most comprehensive and detailed noise exposure estimates submitted to the record. Thus, they remain the best source of data on TWA exposures in typical noisy industrial surroundings.

Technically, representative exposures are only required for workers with a TWA exposure to noise of 85 dB or above. However, it seems probable

Table 10

Number of Production Workers and Establishments by Industry and Establishment Size

SIC	1-19 Employees Production Workers	1-19 Employees Establishments	20-49 Employees Production Workers	20-49 Employees Establishments	50-99 Employees Production Workers	50-99 Employees Establishments	100-249 Employees Production Workers	100-249 Employees Establishments	Over 250 Employees Production Workers	Over 250 Employees Establishments
20	75,583	13,118	122,613	4,783	158,034	2,813	292,110	2,332	527,859	1,248
21	431	102	817	30	1,402	22	5,487	37	44,363	42
22	17,182	2,647	36,791	1,230	53,829	825	143,386	1,007	525,811	985
23	73,714	12,301	150,593	4,490	180,224	2,810	314,631	2,257	403,037	1,020
24	131,794	25,577	108,400	3,550	117,628	1,697	159,585	1,103	128,894	319
25	33,894	5,762	45,134	1,527	52,706	819	91,521	647	174,745	373
26	15,173	2,204	38,254	1,360	61,079	983	149,706	1,146	277,289	538
27	126,470	35,518	101,748	5,199	89,263	2,042	117,751	1,251	266,969	641
28	33,186	6,812	48,072	2,091	54,695	1,082	94,994	841	405,953	687
29	8,380	1,379	9,271	286	9,988	137	23,797	142	88,264	123
30	33,391	5,590	62,459	2,230	82,901	1,353	134,120	989	288,230	498
31	8,275	1,410	13,415	467	20,528	332	48,213	341	116,962	325
32	74,668	11,639	80,305	2,810	65,780	998	107,929	750	231,819	422
33	20,304	3,003	41,908	1,475	54,945	893	130,046	945	731,098	795
34	117,675	19,020	169,809	6,154	170,975	2,815	274,821	2,041	572,619	1,088
35	163,075	32,304	155,393	6,406	135,719	2,502	219,331	1,783	942,683	1,468
36	38,208	7,192	59,430	2,217	88,109	1,322	179,628	1,383	1,021,145	1,394
37	27,347	5,379	34,035	1,318	44,954	801	93,414	751	1,204,450	698
49	67,188	10,593	66,942	2,179	79,232	1,156	110,509	744	335,430	421
Total	1,065,937	201,550	1,349,308	50,310	1,514,071	25,459	2,690,979	20,490	8,287,626	13,285

Source: Estimated as described in text from the U.S. Bureau of the Census, County Business Patterns, CBP-77-1; and the U.S. Bureau of Labor Statistics, Employment and Earnings, 1909-1978.

Table 11

Percentage of Production Workers Exposed to Noise

SIC	90 dB	85 dB	80 dB	75 dB
20	16	28	47	
21	6.6	9.7	28	
22	52	75	87	
23	0	1	20	
24	72	94	97	
25	12	30	53	
26	21	40	59	
27	19	45	66	
28	20	37	55	
29	52	76	82	
30	8.9	20	40	
31	0	1	20	
32	4.8	16	42	
33	38	63	81	
34	19	34	56	
35	13	26	48	
36	2.5	7	27	
37	13	23	42	
49	30	74	89	
Total	19.3	34.4	53.1	71.5

Source: Bolt, Barenek, and Newman. "Economic Impact Analysis of Proposed Noise Control Regulation," (Ex. 192, p. 2-7; and BBN worksheets).

that many employees exposed to noise below a TWA of 85 dB would be surveyed also. This is because, at least initially, employers would not know which workers were exposed to 85 dB without monitoring representatives of most of the workers stationed in fairly noisy work areas. Consequently, all workers exposed above a TWA of 80 dB were assumed to be surveyed for cost estimation purposes despite the fact that, as employers become more knowledgeable about the exposures, this adjustment will overestimate monitoring costs.

Therefore, the number of measurements for each establishment size category in each SIC industry studied can be estimated by the following equation:

(1) $M = (PM/100)(PW/E)(N)$

where: M = the number of measurements

PM = the percent of workers actually measured (Table 9)

PW = the number of production workers (Table 10)

E = the number of establishments (Table 10)

N = the percentage of workers exposed to $\geq$80 dB (Table 11)

This formula simply multiplies: (the percent of workers that the sampling strategy would require to be actually measured) x (the average number of production workers per establishment) x (the percentage of workers exposed to $\geq$ 80 dB). When the number of measurements for each establishment size are matched to estimates of the corresponding consultant charges (Table 8) this provides estimates of the average cost for a firm using a noise consultant. Since monitoring will usually be required biennially, the annual consultant cost is one-half of the values listed in Table 8.

However, employers may elect to monitor with in-house personnel. An acceptable dosimeter, readout and calibrator, such as described in Exhibit

319 A-7, costs $1,230. The standard capital recovery formula with a 10 percent interest rate and a 10-year equipment lifetime gives an annualized capital cost of about $200. Periodic calibration costs could add another $60 a year. In addition, it might take an employer about an hour per measured employee to select representative workers, make daily calibrations of the dosimeter, and place and remove the dosimeters from the individual workers. Since this task may be performed by the employer or by supervisory employees earning more than the average industry production worker wage, an average cost of $10 per hour was used to account for the time required to complete this task. Thus, the average annual cost for each establishment can be calculated as $260 + ($10 x the number of measured workers/2 years). The resulting values imply that monitoring would usually be done by in-house staff only in the largest plants where the average cost of $755* is substantially below the $1,142** average consultant cost. However, for the smallest establishments, the annual consultant fee of $206 is significantly less than the cost of developing an in-house program by purchasing the required equipment.

Alternatively, sound level meters and calibrators may be purchased for $610 (Ex. 319 A-7). Since these meters are expected to last at least 10 years (Ex. 319 A-7; Ex. 319 A-72), a 10 percent interest rate yields an annualized equipment cost of $99.27. Biennial calibration would add an additional $30 per year (Ex. 319 A-7). However, the time employers would need to make TWA exposure measurements with a sound level meter would often

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*$260 + (10 x M/2) = $755, where M is defined as in equation (1) and equals, on average, (.30 x 8,287,626/13,285 x .531) which is 99.

**Table 8 indicates that the consultants fee for measuring 99 workers was estimated at $2,284. If performed biennually, the annual cost is $1,142.

exceed the time required using a dosimeter because sound level meter measurements often require following employees through various phases of the work process. For this reason, the following calculations assume the use of dosimeters for in-house monitoring.

It was assumed that employers would select the least expensive mode of complying with the provision. Therefore, for each SIC sector, multiplying the number of establishments in each size class by the average consultant cost where consultant services would be more efficient (generally the first three or four establishment size categories), and the average in-house cost using dosimeters for the larger size categories where in-house programs are more efficient, provides an estimate of the industry's monitoring cost. Summing these costs over all the SIC's gives total costs of $78,427,000 to initiate monitoring programs in all establishments in the studied industries.

However, many firms already have extensive monitoring programs. Although precise estimates are not available, a survey of hearing conservation programs conducted by The National Institute for Occupational Safety and Health (NIOSH) (Ex. 321-14B) evaluated responses from 1,410 manufacturing firms (p. 7). Twenty-nine percent stated that their firm had a program concerned with hearing conservation (p. B-3), and 90 percent of those firms, or 26 percent of the respondents, reported that they currently monitor workplace noise (p. B-7). Since the survey sample was heavily weighted with firms of over 100 employees, the results may apply primarily to these larger firms. Table 10 indicates that there are about 33,775 establishments with more than 100 employees in the industries studied. Based on the NIOSH study, it is reasonable to conclude that 26 percent of the firms with more than 100 employees already have monitoring programs.

Thus, the new annual cost of this monitoring provision falls to about $73,731,000 for the 19 SIC sectors (See Appendix B for a detailed example of the computational procedure).

Even more important, however, is the implausibility of the assumption that every single establishment in the industries studied would have workers exposed to a TWA of 85 dB or greater. The only large-scale survey that presents estimates of the number of plants with noise levels above 85 dB is the National Occupational Hazard Survey (NOHS) prepared by the NIOSH (Ex. 321-14D). The Center for Policy Alternatives (CPA), Massachusetts Institute of Technology, presented a preliminary summary of these data, stating that "NIOSH has collected extensive data on noise exposures in workplaces representative of American industry..." (Ex. 138A, p. 2-6). Since NIOSH directed its staff to note "Any continuous noise in the worker's normal environment equal to or exceeding 85 dBA..., regardless of exposure duration..." (NOHS, vol. 1, p. 15), it is clear that these estimates of the number of noisy firms would exceed projections made on a TWA basis. Table 12 displays the results of this survey, which indicate that only about 49 percent of the plants in the studied industries have workers exposed to noise levels of 85 dB or greater as measured by NOHS. If this survey is accurate, the monitoring costs estimated above are substantially overstated.

Moreover, the current record does not adequately indicate the widespread current or future availability of rental markets for dosimeters or sound level meters. An informal telephone survey reveals that even the relatively more expensive dosimeters can generally be leased for under $100 per month. On a biennial basis this is less than $50 per year for most of the 311,094 establishments in the industries studied, for a total

Table 12

Number of Plants with Continous Noise above 85dB in the National Occupational Hazard Survey

Industry Sector	Total Plants*	No. of Plants with Workers exposed to Continous Noise**	Percent of Plants with Continous Noise
Manufacturing	141,397	68,949	48.8
19	113	72	63.7
20	16,173	7,711	47.7
21	196	48	24.5
22	3,225	1,560	48.4
23	15,565	4,115	26.4
24	3,091	2,214	71.6
25	4,618	3,132	67.8
26	4,859	3,673	75.6
27	13,609	5,248	38.6
28	6,743	2,423	35.9
29	993	599	60.3
30	5,640	2,967	52.6
31	1,653	798	48.3
32	7,955	4,425	55.6
33	5,040	3,716	73.7
34	19,615	12,658	64.5
35	14,190	6,949	49.0
36	5,073	1,937	38.2
37	3,457	1,849	53.5
49	-	-	45.8***

Source: National Institute for Occupational Safety and Health, National Occupational Hazard Survey, Vol. III (Ex. 321-14D).

*NIOSH, Table 1, pp. 42-43.
**NIOSH, Table 49, p. 290.
***Preliminary NOHS estimate reported in Exhibit 138A, p. 2-8.

yearly equipment charge of only $15.6 million. Alternatively, some firms will share noise monitoring meters rather than purchase them. Thus, the true new monitoring costs attributable to this hearing conservation amendment may be substantially below OSHA's $73.7 million estimate which was based solely on data in the noise record.

BBN's economic impact analysis (Ex. 192, p. 3-9) projected annual costs of $155.2 million for the proposed monitoring provision. This estimate overstates the cost of the final provision for several reasons. First, the BBN analysis was based on the proposed requirement for annual monitoring, whereas the final rule will generally require only biennial monitoring. Second, BBN's methodology assumed that all industrial firms employed 50 production workers and would hire noise consultants to conduct the monitoring requirements. OSHA has determined that larger firms will find it substantially more economical to obtain noise measuring instruments and to perform the monitoring themselves. Third, BBN's estimate includes the cost of recordkeeping which OSHA treats as a separate cost category. Fourth, the BBN estimates do not reflect the current monitoring activities which are already taking place. OSHA believes that these factors taken together more than offset the price increases which may have occurred since BBN's 1976 report and consequently account for the divergent estimates.

Audiometric Testing

An analysis of the record indicates that the cost of audiometric testing will vary with the size of the establishment. Very small plants are likely to send production workers who require testing to a clinic or doctor. Somewhat larger plants will contract with audiometric testing firms for the actual exam and review. Still larger plants will find it cost effective to purchase the equipment for audiometric testing, to train the industrial nurse or safety director to give the test, and to use an outside firm or doctor to review the audiograms. The largest firms will perform the entire service in-house.

Commercial specialists who evaluate workers' hearing have submitted the following per employee costs for audiometric testing, review and reporting: $7.50 to $10.65 (Ex. 317); $10.00 (Ex. 319 B-6); $3.00 or less for more than 100 (Ex. 319 B-12); $7.00 to $20.00 (Ex. 319 B-5); and $12.00 (Ex. 293). These firms generally provide this service by transporting an audiometric test booth in a mobile van directly to the commercial establishment that has contracted for the testing. Employees of the smallest firms, however, will often be sent to a clinic or doctor's office to be tested. These fees will vary greatly and some are rather high (Ex. 2C-71-3, p. 50 reported $20). However, many clinic or physician fees should ultimately be comparable to those charged by mobile units because (1) negotiated fees are a traditional practice in industrial medicine, (2) employers of small firms may group together to gain scale economies, and (3) stationary medical facilities do not bear the substantial transportation costs borne by the operators of mobile vans. (For example, the Washington Speech and Hearing Society currently charges $120 plus $10 per exam for their central mobile unit but only $7.50 per test at their facility.)

Because the current market for audiometric services is small relative to the demand that would follow the promulgation of this regulation, it is not possible to make precise estimates of the cost to all firms that would purchase these services. However, in order to estimate the regulatory cost, it is reasonable to assume that the average firm sending workers to a clinic would lose about 2 hours in lost production time plus about $15 per worker for test fees and travel expenses. For firms large enough to take advantage of mobile units, the estimated lost production time per worker would be about one-half hour, and the submissions cited above imply an average test fee of about $12.00.

For large firms, in-house programs will be substantially less expensive. A comment to the Advisory Committee (Ex. 102, Sec. 9, p. 15) estimated the cost of providing audiometric testing programs for firms with 200, 300, and 500 employees at about $6.00, $5.00, and $4.00 per audiogram, respectively. Numerous submissions in the record itemize the specific components of these costs. For example, audiometric test booths sell for about $1,700 (Ex. 319 A-44; Ex. 319A-51; Ex. 2C-71-3, p. 47), and installation could add about $300. Audiometer price quotes average about $500 (Ex. 319 A-51; Ex. 319 A-53; Ex. 319 A-60; Ex. 319 A-62; Ex. 319 A-66; Ex. 319 A-67) and are expected to operate for 10 years (Ex. 319 A-90; Ex. 319 A-60). The calibration procedures require a coupler which costs about $130 (Ex. 319 A-16; Ex. 319 A-11) and a sound level meter with an octave filter set which costs about $1,000. The operator's certification course is good for 5 years and costs $250 plus 3 days of an employee's time (Ex. 319 B-4) which amounts to $240 at $10 per hour. The cost of calibrating the audiometer could be another $100 every other year (Ex. 102, Sec. 9, p. 16). Thus, the total capital outlay is about $4,200. Assuming that the test booths last for 20 years, the other equipment lasts for 10 years, the certification course is given every 5 years, and the interest charge is 10 percent, the total annualized cost amounts to about $650.

Since one exam takes about 10 minutes of time (Ex. 306-J5C, p. 9; Ex. 319 B-6), approximately 48 workers can be tested by a technician earning a daily rate of about $80. Thus, the cost to the firm of the technician's time amounts to $1.67 per worker tested. The cost of reviewing audiograms and reporting the findings is also dependent upon whether this service is contracted out or done in-house. Contractor fees for reviewing audiograms are reported at $2.25, $2.50, $3.00, and $4.00 per audiogram (Ex. 317; Ex. 319 B-12), whereas the in-house review by a physician or audiologist was estimated to cost only $0.25 each (Ex. 102, sec. 9, Audiometric Testing, p. 16). Thus, using $2.50 as a reasonable average cost to review the audiogram, a typical cost for administering the tests as well as reviewing the audiograms would amount to $4.17 per unit ($1.67 + $2.50). Finally, a cost for one half hour of lost production for each worker during the test procedure adds an additional one-half of the hourly wage per worker tested. In summary, the annual cost of the in-house audiometric program is estimated at about $650 per establishment for equipment and certification-related charges, and about $4.17 plus one-half of the industry hourly wage for each employee tested.

The Can Manufacturers Institute, Inc., (Ex. 2C-71-3, p. 50) stated that it would become cost-effective for a firm to develop its own audiometric testing capability when the number of audiograms it required reached about 100 per year. Dr. W.G. Thomas, (Ex. 102, sec. 9) put the break-even point between in-house and contracted audiometric testing at about 300 employees. To estimate the number of firms that would develop their own testing facilities, it is appropriate to use the Table 10 estimates of the number of production workers in the five establishment size categories for the 19 industries studied. The data in Table 10 imply that if the BBN estimate of 34.4 percent of production workers exposed to a TWA $\geq$85 dB remains constant across establishment sizes, the average number of workers per establishment in the hearing conservation program will be less than 2 employees for the smallest size category and 9, 21, 46, and 213 employees, respectively, in the larger establishment size categories.

It is likely that workers in the two smallest establishment size classes (1-19, and 20-49 employees) would travel to facilities outside the firm to take the audiometric exam. As explained above, the estimated annual cost for these establishments in each SIC sector would be the number of workers exposed to noise at or above a TWA of 85 dB x (2 hours at the industry hourly wage + $15 per test). For workers in the third and fourth largest size categories (50-99, 100-249 employees), the best assumption is that hearing conservation firms with mobile vans will service the employees. Since each employee would miss only about a half-hour of work time, the annual cost per industry for these intermediate-sized firms is the number of workers exposed to noise at or above a TWA of 85 dB x (.5 hours at the industry hourly wage + $12 per test).

Most firms in the over 250 employee size group would choose in-house audiometric programs. The annual cost for these firms, as detailed above, is estimated at ($650 x the number of establishments) + [the number of workers exposed to a TWA of 85 dB or greater in these establishments x ($4.17 + .5 hours at the industry hourly wage)].

The data needed to complete the above calculations include the percent of workers exposed to a TWA of $\geq$85 dB as shown in Table 11, the number of production workers and plants by establishment size in each industry as presented in Table 10, and the 1979 industry average hourly wage as reported by BLS (Employment and Earnings, March 1980). However, workers employed for less than 120 days with one firm are exempt from this provision. Employment data from the BLS as well as submissions to the record (Ex. 14-279; Ex. 14-512) indicate that SIC's 20 and 21 hire a substantial number of seasonal employees. In fact, the 1979 BLS average monthly employment estimate would fall by 17,100 and 1,400 in SIC's 20 and 21, respectively, if employment in each industry's 120-day peak employment period were adjusted downward to the level of the following month. The data from Table 10 were revised to reflect this exemption in order to estimate the cost of audiometric testing. Temporary workers in other industries will also take advantage of the exclusion, but the lack of appropriate data have prevented further adjustments to these calculations.

In addition to the annual audiogram, some workers will need to be retested during the year owing to threshold shifts, operator errors, or inconsistent test results. A number of workers will exhibit temporary threshold shifts if they are tested toward the end of the workday after being exposed to excessive noise. Wearing effective and properly inserted hearing protectors prior to the test would lower the incidence of temporary threshold shifts, whereas testing at the start of the day would substantially eliminate their detection. The number of permanent threshold shifts recorded will depend upon the intensity of the noise exposures, the worker turnover rates, and the effectiveness of the hearing protectors. In addition, the requirement for a recheck is waived if the annual test is conducted after 14 hours free from workplace noise. If as many as 20 percent of the workers require rechecks, the overall cost of audiometric testing would total $92,352,000 or about $18 per worker tested.

This discussion has assumed that no audiometric testing is currently provided. The noise record, however, indicates that many industrial establishments already offer audiometric testing to their employees. For example, a survey by the Forging Industry Association revealed that 82 percent of the 151 member firms responding do periodic testing, (Ex. 321-25), while Table 90 of the NOHS (Ex. 321-14D) shows that in their sample, 40 percent of the manufacturing workers exposed to continous noise above 85 dB received audiometric exams. Table 13 of this same exhibit indicates that primarily the largest-sized establishments provide this service for their workers. Still another NIOSH hearing conservation survey shows that annual and biannual audiometric tests account for about 23 percent and 13 percent, respectively, of current industry testing programs, with retesting periods in other programs ranging from 6 months to every 5 years (Ex. 321-14B, p. 30). For cost estimating purposes, it seems reasonable to assume that on average, these tests are already provided on a biennial basis to 40 percent, or on an annual basis to 20 percent of the workers in plants with more than 250 employees. Since the number of establishments providing these services is unknown, an accurate accounting of the costs already accepted by industy is not possible. Reducing only the labor-related cost of the largest firms by 20 percent to reflect current practice brings the total cost of this provision to $87,199,000 a year (See Appendix B for an example of the calculations). This estimate is not significantly different from BBN's 1976 estimate of 89.1 million even though BBN did not adjust their data to acknowledge current programs and simply used a $20 per worker cost (Ex. 192, p. 3-33).

Hearing Protectors

Hearing protectors used in industry include ear muffs, disposable ear plugs, molded plugs, and custom-molded plugs. Unfortunately, there is no survey information on the percentage of workers who wear each type of protector. In hot, humid environments, workers are likely to choose plugs.

It is probable that plugs will be chosen in more than a majority of instances as they are often associated with a lesser degree of discomfort.

Substantial data on the price of ear protectors have been collected for the record. For example, disposable foam ear plugs can be purchased for $0.15 a pair (Ex. 319A-41) and are reusable. If employees use two pair a week, the yearly cost is $15.00. Disposable non-foam ear plugs cost only from $0.06 to $0.07 a pair (Ex. 319 A-30; Ex. 319 A-37). For a new set of plugs each day, these costs would average about $16.50 a year per employee. Molded ear plug prices are quoted at about $1.50 (Ex. 319 A-30; Ex. 319 A37), and would cost $6.00 a year if workers used 4 pair per year. Custom molded plugs can be purchased in a kit that makes up to 50 pair of ear plugs at $3.10 a pair (Ex. 319 A-35). These plugs, with minimum care, will last 2 or 3 years (Ex. 319 A-36). Ear muff prices are listed at $9.50 (Ex. 319 A-30), $7.60 (Ex. 319 A-31), and $8.40 (Ex. 319 A-37). The estimated cost of about $10 per year per employee reported by the Industrial Fasteners Institute (Tr. 1611), Bethlehem Steel Corporation (Ex. 145), and BBN (Ex. 192, p. 3-33) appear consistent with these rates. Based on a cost of $10 per year per employee, if hearing protectors were provided to all employees exposed to noise at or above a TWA of 85 dB, the cost of this provision would be $51,296,000.

The NIOSH NOHS survey also indicates that about 20 percent of the workers exposed to continous noise at or above 85 dB are subject to attempts to reduce exposures (See Vol. III, Table 51). Moreover, the data in Table 90 of the NOHS study show that hearing protectors are almost always the method selected to accomplish this reduction. Since the data show that 20 percent of the workers exposed above 85 dB are provided hearing protectors, this implies that more than 20 percent of those exposed above 90 dB have them. This is because it is probable that most of the current worker use of hearing protectors takes place among workers whose exposures exceed 90 dB. However, if we assume that just 20 percent of the workers exposed to noise above a TWA of 90 dB are already supplied with hearing protectors, the total cost of this provision is $45,534,000. This may be an overestimate of the cost to the extent that not all workers exposed between 85 and 90 dB are required to use the hearing protectors.

Training Program

The major cost elements for the training program will be the cost of the production lost while the workers are being trained, and the cost for the individuals providing the training. Because the training session may last about an hour, the cost for production time lost while training takes place can be estimated by multiplying the industry average hourly wage times the number of workers trained. The cost for the people conducting the training will vary with the size of the establishment. The data from Tables 10 and 11 imply that establishments with under 100 employees average less than 21 workers exposed to noise at or above a TWA of 85 dB. A training program consisting of one hour per year per establishment seems appropriate for these size classes. For establishments with more than 100 employees, it is reasonable to assume that one individual could train 30 people in one session.

Consequently, the cost of training can be estimated at (the average production worker hourly wage x the number of workers exposed to noise $\geq$ a TWA of 85 dB) + (the number of establishments with less than 100 employees x the cost of providing one hour of training) + (the number of employees exposed at $\geq$85 dB in establishments larger than 100 employees divided by

30 workers per session x the cost of providing one hour of training). If we assume that the cost for the person providing the training is \$10 an hour, the cost estimating equation for each SIC is:

$$\$\,Tr = (W)(PW)(P) + \$10\,e + \$10/30\,(PWE)(P)$$

were:

$\$\,Tr$ = the cost of training

W = the hourly production worker wage

PW = the number of production workers (Table 10)

P = the fraction of workers exposed to $\geq$85 dB (Table 11)

e = the number of establishments with less than 100 employees (Table 10)

PWE = the number of production workers in establishments with over 100 employees (Table 10)

Summing over all SIC's, the total cost of training for the 19 industry sectors is estimated at \$40,029,000. Although a number of comments described well organized training programs already in operation (Ex. 307, J2C, p. 11; Ex. 147C, p. 335; Ex. 147A, p. 6), and it is likely that many firms do some training, no estimates were available of the total number of such programs currently in existence. Therefore, the above estimate for the cost of this regulatory provision is overstated by the extent that industry already provides this instruction.

Warning Signs

The cost for noise warning signs will vary with the plant layout and the number of entrances into the noisy area. Signs are available for slightly over a dollar (Bilsom International, Inc., Product Order Form, etc.). If, on the average, one sign accommodates ten workers and takes 15 minutes to install, the cost to a firm for placing one sign would be about $3.50 at a $10 hourly wage, and the total cost of the provision would be $1,795,000. Although OSHA's calculations treat this estimate as an annual cost, it is probable that most signs will last for considerably longer than one year.

Recordkeeping

Updating records of noise exposure should take no longer than 10 minutes per worker measured. This amounts to 5 minutes per worker per year. Recordkeeping of audiograms, could also take about 5 minutes per employee per year. The cost of this lost work time would equal 1/6 of an hour x the industry hourly wage x the number of workers exposed to noise at a TWA of ≥85 dB.

In addition, recordkeeping of periodic calibration of audiometers could take 20 minutes per year. If every establishment with over 250 employees in the SIC's studied maintained an audiometer, the total cost for the activity would be 2/6 of an hour x the industry hourly wage x the number of establishments. It can reasonably be assumed that most firms that market hearing conservation services already keep these records so that their additional costs would be negligible. Thus, the total recordkeeping costs are estimated to amount to $6,033,000.

Conclusion

Overall, the above calculations show that the annual cost of compliance with all of the provisions of this regulation would amount to about $53 for each of the more than five million workers protected by the program. The total cost of hearing conservation programs, as measured in current dollars, is about $270 million a year. After adjustment for some of the compliance activities already taking place, the total new costs fall to $254 million per year.

OSHA's estimates do not appear inconsistent with industry statements. For example, testimony from the Industrial Fasteners Institute implies an annual cost of $50 per employee (Tr. 1611, 1612), and the American Boiler Manufacturers Association commented that $35 per production worker is a conservative estimate (Tr. 1573). Dupont stated that its comprehensive program cost the firm between $10 and $20 per worker per year (Ex. 306 - J5c). Moreover, a study submitted by the American Textile Manufacturers Institute estimated an annual cost of $14.16 per employee (Ex. 275 B, Attachment I). BBN offered the only industry-wide calculation. However, as described above, their cost estimate of $65 per worker does not reflect significant changes from the proposal to the final rule.

Table 13 displays the new compliance costs attributable to this amendment as estimated by OSHA for each industry sector. To the extent that many establishments in the industries studied are not affected by noise, or already comply with most of the requirements, or that rental equipment is easily available for monitoring purposes, actual costs would be substantially below the estimates provided.

Table 13

Estimated New Annual Compliance Cost of Hearing Conservation Amendment

SIC	Industry	Estimated Cost
20	Food	$17,319,440
21	Tobacco	224,058
22	Textiles	17,756,670
23	Apparel	6,134,562
24	Lumber & Wood	30,864,350
25	Furniture & Fixtures	6,117,161
26	Paper	9,076,951
27	Printing & Publishing	22,284,030
28	Chemicals	10,944,270
29	Petroleum & Coal	4,454,069
30	Rubber & Plastics	6,721,314
31	Leather	909,841
32	Stone, Clay & Glass	7,348,522
33	Primary Metals	23,072,240
34	Fabricated Metals	23,505,250
35	Machinery, Except Electrical	25,519,890
36	Electrical Machinery	6,843,939
37	Transportation Equipment	12,914,530
49	Utilities	22,310,000
Total		$254,321,000

Source: OSHA, Office of Regulatory Analysis.

V. ECONOMIC IMPACT

Introduction

The cost of the hearing conservation amendment will generate a series of economic effects on those industries that expose their employees to significant amounts of noise. It is difficult to forecast precisely the magnitude of the specific impacts that will occur because they depend in part upon decisions by individual employers on how best to respond to the costs of the amendment. However, the economic framework within which the decisions will be made can be described, and the potential range of subsequent impacts can be identified. For example, compliance costs will exert upward pressure on the prices of the products produced in those industries. Conversely, profits and employment may decline if sales cannot be maintained at the higher price levels. However, the analysis presented below indicates that the economically adverse effects of the program will be exceedingly small compared to each industry's ability to finance them. Moreover, it is shown that the most severe of these impacts will hardly influence the various financial indexes used to assess each industry's economic well-being.

The analysis that follows is based upon the assumption that the cost of production in each affected industry will rise by the full extent of the compliance costs as estimated in the previous section. However, even if these compliance cost estimates are approximately correct, it is probable that the accounting ledgers of the impacted industries will not reflect the full burden of these costs. In fact, studies cited in the Benefits section above support the view that the amendment may cause significant cost savings due to decreased rates of industrial accidents, absenteeism, and workers' compensation premiums. To the extent that dollar outlays for these business expenses are reduced following the implementation of the amendment, the net regulatory cost to industry will diminish. However, to demonstrate conclusively the economic feasiblity of the amendment, this section does not adjust the above compliance cost estimates for these potentially important cost reductions.

Price Impact

Economic reasoning indicates that firms will attempt to pass on higher production costs by increasing the selling price of their products. If an industry faces a perfectly inelastic demand for its output, the manufacturers would shift the entire cost of complying with the amendment to their customers through a price increase without a contraction of industry sales. This market condition, however, is seldom the case. On the other hand, if the industry supply curve is perfectly elastic, product prices will rise by the full amount of the cost increase, but industry output will fall to the extent that sales are inversely related to price. Except for over very long time periods, this industry response would also be considered unusual.

In general, firms will try to pass on cost increases by raising product prices, and consumers will respond by reducing their purchases of the industry's products. Most firms, therefore, will find that they cannot quickly recoup all of their profits through price hikes, but must settle for price increases allowing less than a full cost passthrough. If firms could pass on their entire cost increase, however, the maximum expected price rise can be calculated by dividing the estimated compliance cost for each industry by the sales of that industry, and expressing the result as a percentage. Table 14 presents the percentage price increase that would be

Table 14

Maximum Price Increase

SIC	Industry	Estimated Cost of Amendment ($ millions)	1979 Total Shipments ($ millions)	Maximum Price Increase (Percent)
20	Food	17.32	234,828	0.0074
21	Tobacco	0.22	12,173	0.0018
22	Textiles	17.76	46,992	0.0378
23	Apparel	6.13	40,080*	0.0153
24	Lumber & Wood	30.86	39,781*	0.0776
25	Furniture & Fixtures	6.12	16,853*	0.0363
26	Paper	9.08	66,033	0.0138
27	Printing & Publishing	22.28	49,527*	0.0450
28	Chemicals	10.94	149,181	0.0073
29	Petroleum & Coal	4.45	134,041	0.0033
30	Rubber & Plastics	6.72	44,742	0.0150
31	Leather	0.91	7,508*	0.0121
32	Stone, Clay, Glass	7.35	48,185	0.0153
33	Primary Metals	23.07	140,122	0.0164
34	Fabricated Metals	23.51	109,463	0.0215
35	Machinery, Except Electrical	25.52	157,695	0.0162
36	Electrical Machinery	6.84	110,713	0.0062
37	Transportation Equipment	12.91	194,461	0.0066
49	Utilities	22.31	117,024**	0.0191
	TOTAL	254.32	1,719,402	0.0148

Source: OSHA, Office of Regulatory Analysis. U.S. Department of Commerce, Survey of Current Business (July 1980): S-4.

*Data for 1977. See U.S. Department of Commerce, Bureau of the Census, Preliminary Report, 1977 Census of Manufactures, Table 2, p. 4-23.

**Revenues from sales to customers for electric power and gas utilities. See U.S. Department of Commerce, Survey of Current Business (July 1980): S-23. This figure slightly understates total revenues for the entire SIC 49 because it does not include revenues from sanitary services.

attributable to the amendment if the entire cost is passed on solely and exclusively in the form of price increases.

The table shows that the overall impact of the proposed amendment, if all of the costs were passed on, would be to increase prices by 0.01 percent, i.e. one hundredth of a percent in the 19 industrial sectors studied. This clearly implies a negligible change to any of the nation's more aggregated price index series. While there is variation among industries, in only a few cases are the estimated price increases greater than a few hundredths of a percent. The largest increase in price, 0.078 percent, is recorded for the lumber and wood sector, an industry estimated to have over 94 percent of its production workers exposed to noise levels above 85 dB. However, even this price increase is of such a small magnitude that its effect would be hardly noticeable among all of the other cyclical factors affecting the industry product prices.

Financial Impact

The discussion above illustrates the impact on prices if the costs of the amendment were shifted entirely to industry customers through higher prices. Alternatively, the entries in Table 15 show the impact upon profits if the costs were solely and exclusively absorbed from profits. The percentage decrease in profits was calculated by dividing the cost of the amendment for each industry by its estimated 1979 profit level. Table 15 indicates that even in the highly unlikely event of no price change, overall profits would decrease by only 0.19 percent. Profits would fall by under 1 percent in all industry sectors, and in the great majority of cases, the anticipated decline is less than one-half of one percent. Moreover, to the extent that output prices rise at all, profits will fall

Table 15

Maximum Profit Reduction

SIC	Industry	Estimated Cost of Amendment ($ millions)	1979 Pre-tax Profits ($ millions)	Profit Reduction (percent)
20	Food	17.32	10,081	0.1718
21	Tobacco	0.22	2,237	0.0098
22	Textiles	17.76	2,291	0.7752
23	Apparel	6.13	2,033*	0.3015
24	Lumber & Wood	30.86	3,140**	0.9828
25	Furniture & Fixtures	6.12	883**	0.6931
26	Paper	9.08	4,814	0.1886
27	Printing & Publishing	22.28	6,077	0.3666
28	Chemicals	10.94	13,372	0.0818
29	Petroleum & Coal	4.45	25,239	0.0176
30	Rubber & Plastics	6.72	1,929	0.3484
31	Leather	0.91	647	0.1406
32	Stone, Clay, Glass	7.35	3,650	0.2014
33	Primary Metals	23.07	6,215	0.3712
34	Fabricated Metals	23.51	6,830	0.3442
35	Machinery, Except Electrical	25.52	15,484	0.1648
36	Electrical Machinery	6.84	10,884	0.0628
37	Transportation Equipment	12.91	8,665	0.1490
49	Utilities	22.31	7,138***	0.3126
	TOTAL	254.32	131,609	0.1932

Source: OSHA, Office of Regulatory Analysis. U.S. Federal Trade Commission, Quarterly Financial Report, First Quarter 1980, pp. 18-53.

*The Quarterly Financial Report aggregates income for "Other Nondurables" (SIC's 23 and 31). The pre-tax income of $2,680 million was allocated to the respective SIC's on the basis of the 1976 Internal Revenue Service (IRS) data. The IRS survey gives 75.84 percent, of "Net Income (less deficit)" to SIC 23 and 24.16 percent to SIC 31. See Internal Revenue Service, Preliminary Report, Statistics of Income -- 1976, Corporation Income Tax Returns, (Washington, D.C., 1979), p. 6.

**The Quarterly Financial Report lists income for "Other Durable Manufacturing Products" which is composed of SIC's 24, 25, and 39. The pre-tax income of $5,934 million was also allocated on the basis of the 1976 IRS data (see * above). The distribution was 52.91 percent for SIC 24, 14.88 percent for SIC 25, and 32.21 percent for SIC 39. Since 39 was not included in this study, the profits from that industry are excluded from this table.

***This amount is also based upon the 1976 IRS data (see * above). The 1976 profit rate was calculated by dividing Net Income (less deficit) by total receipts. This profit rate, 6.1 percent, was then multiplied by the total 1979 revenues presented in Table 14.

by a smaller amount than listed. Thus, even these fractional values must be considered estimates of the maximum reduction in industry profits.

The ability of the affected industries to raise sufficient compliance funds through normal commercial channels is another relevant consideration. Table 16 presents several financial indicators for U.S. manufacturing industries as presented in the Quarterly Financial Reports published by the U.S. Federal Trade Commission. The three indicators - cash on hand, outstanding short term loans, and net working capital - have been choosen because each helps to establish the ability of an industry to finance the costs of the amendment. Comparing the magnitude of these variables to the volume of required funds indicates whether the dollar outlays would be disruptive to the traditional financial operations of the affected industries.

Table 16 shows that for the 19 industries studied, the cost of the amendment is only about 0.6 percent of current cash on hand. The table also indicates that for those industries where data are available, compliance costs average only about 0.7 percent of the short-term debt, and 0.1 percent of the net working capital. Although some industry-to-industry variation exists, none of these ratios is above 2.66 percent. This clearly demonstrates that the cost of compliance will be small relative to each industry's ability to comply with the regulation. On this basis, the record indicates that the regulatory burden would not be an undue financial hardship for each of these sectors.

Other Sectors

The 19 industrial sectors for which detailed feasibility data were presented above include almost all manufacturing and utility industries.

Table 16

Compliance Cost as a Percent of Selected Financial Indicators (1979)

SIC	Industry	Cost as a Percent of Cash on Hand	Cost as a Percent of Short-Term Loans	Cost as a Percent of Net Working Capital
20	Food	0.57	0.37	0.09
21	Tobacco	0.12	0.10	0.01
22	Textiles	2.40	2.32	0.23
31 23	Leather Apparel	0.58*	0.34*	0.08*
24 25	Lumber & Wood Furniture & Fixtures	2.66**	NA	NA
26	Paper	0.60	1.92	0.12
27	Printing & Publishing	1.04	2.61	0.26
28	Chemicals	0.33	0.68	0.04
29	Petroleum & Coal	0.08	0.15	0.03
30	Rubber & Plastics	0.99	0.65	0.11
32	Stone, Clay, Glass	0.58	1.59	0.11
33	Primary Metals	1.04	1.13	0.14
34	Fabricated Metals	0.99	1.04	0.15
35	Machinery, Except Electrical	0.62	0.57	0.08
36	Electrical Machinery	0.18	0.36	0.03
37	Transportation Equipment	0.21	0.84	0.06
49	Utilities	0.96***	NA	NA
	TOTAL	0.60	0.70****	0.10****

Source: OSHA, Office of Regulatory Analysis. U.S. Federal Trade Commission, Quarterly Financial Report, First Quarter 1980, pp. 18-53.

*FTC reports only aggregated data for the non-durables group which consists of SIC's 23 and 31.

**FTC reports aggregated data of $2,105 million for the Durables group consisting of SIC's 24, 25, and 39. This value was allocated according to IRS data indicating that SIC 24 had 50 percent and SIC 25 about 16 percent of the "Cash" balances reported by firms in these industries in 1975. See U.S. Department of the Treasury, Internal Revenue Service, Source Book, Statistics of Income - 1975, Corporation Income Tax Returns (Washington, D.C., 1979), p. 52.

***"Cash" as defined by the IRS for tax purposes, and thus not strictly comparable to the FTC definition. See IRS, Ibid., p. 52.

****Excludes SIC's 24, 25, and 49.

These sectors were initially selected by BBN (see their "Economic Impact Analysis of Proposed Noise Control Regulation," Ex. 192 p. 2-1) because they were believed to be the areas under OSHA's jurisdiction which were most likely to have occupational noise problems. However, industrial noise may also be found in some service-oriented industries. Nevertheless, there is no reason to believe that firms in other industries could not also provide adequate hearing conservation programs for the estimated average cost of $53 per exposed worker. Therefore, there is no reason to expect other major adverse economic impacts.

In addition, the industries covered by OSHA's vertical standards for the maritime industries may also be affected by this hearing conservation amendment. These industries include shipbuilding, ship repair, shipbreaking, and longshoring. Shipbuilding and ship repair are included in SIC 37 (Transportation Equipment) for which cost estimates were presented above. Shipbreaking (or the disassembly of ships) and longshoring are included in SIC 44 (Water Transportation) which was not among the 19 two-digit SIC's studied by OSHA. According to the Bureau of Labor Statistics, in 1979, there were 225,300 total employees in SIC 44*. Using the $53 per worker cost, even if all of these employees are exposed to noise levels $\geq$85 dB (TWA), the total cost of the hearing conservation amendment for this industry would be $11.9 million. Since this amounts to less than 0.2 percent of total business receipts and only 2.1 percent of net income**, it is clear that the hearing conservation amendment would

*U.S. Department of Labor, Bureau of Labor Statistics, Employment and Earnings, 27 (March 1980): 63.

**In 1974, receipts for SIC 44 totalled $6,958,289,000 while net income was $570,287,000. See U.S. Department of the Treasury, Internal Revenue Service, Statistics of Income--1974, Corporation Income Tax Returns, (Washington, D.C., 1978), p. 12.

have a minor economic impact on this industry. Moreover, this estimated cost and economic impact are substantially overstated because the total employment figure used includes white collar workers as well as those production workers who are exposed to noise levels below 85 dB (TWA). Since, for the most part, the number of workers exposed to severe noise in the nonmanufacturing sectors is small compared to the number in heavy manufacturing, it is even less probable that compliance costs in these industries would be the cause of major economic disruption.

Small Business

OSHA has always attempted to minimize the regulatory burden on small business as long as it would not jeopardize worker safety and health. To conform with this practice, as well as to comply with the spirit of the Regulatory Flexibility Act, the Agency has made a concerted effort to analyze the special problems that small business might face in complying with this amendment. (The requirement for a Regulatory Flexibility Analysis applies only to proposed regulations issued after January 1, 1981, not to final regulations issued after that date.) Where possible, the proposed regulation was modified to ameliorate potential hardships. For example, the requirement for monitoring may affect smaller businesses disproportionately because they will often rely on consultants, whereas it is easier for larger firms to develop an in-house monitoring capability. After analyzing the record, OSHA drafted the present provision to allow the obligation to recur every other year in most situations, rather then at least annually as was originally proposed. Also, the proposal required that a worker repeat the audiometric exam if a significant threshold shift was detected. The final amendment deletes this requirement for workers who were tested after 14 hours away from workplace noise. Although it may not be practicable for large firms to schedule morning tests for all of their exposed workers, small businesses should be able to take full advantage of this exemption.

Despite these efforts, small business firms may find compliance more of a burden than large firms. Table 10 in the Cost of Compliance section shows that there are only 1-19 employees in almost two-thirds of the 311,094 establishments in those industries primarily affected by noise. The table implies that a firm classified in this size group hires an average of five production workers. Based on the BBN exposure data (see Table 11) an average of 34.4 percent, or only about 2 workers, would be exposed to noise at or above 85 dB in these small establishments.

Small firms will often find ways to reduce monitoring costs by working together to share equipment or by renting monitoring equipment to measure noise exposures. However, following the cost estimation procedures developed above, if these firms do hire consultants to satisfy their monitoring requirements, the annual monitoring cost would average $206 per firm. Using BLS data to calculate a weighted average hourly earnings of $6.76 for production workers in these industries, the estimated cost of sending two workers for audiometric testing is $68 per year. Annual costs for these small firms to provide training and hearing protectors come to about $24 and $20 respectively, while costs for recordkeeping and the posting of signs add $6.00 per firm. Thus, compliance costs for establishments in the smallest size category may average about $324 per year.

Costs of this magnitude are obviously significant to the smallest firms. However, except for the most marginal of these establishments, they are not likely to affect the economic viability of an otherwise profitable operation. Moreover, these costs may be substantially offset by the potential financial benefits of reduced worker absenteeism and workplace accidents. In addition, OSHA offers free onsite consultation in every state, funded under Section 7 (c) (1) of the OSHA Act. This service is delivered by State governments or private sector contractors using trained and qualified professional staff. To the extent that these resources allow, OSHA will make a special effort to respond to requests from employers for professional advice and assistance. Also, OSHA is in the process of developing printed pamplets that will assist employers in providing appropriate training to their workers. The availability of these additional resources should significantly enhance the ability of small business to comply with the provisions of the hearing conservation amendment.

VI. RESOURCE AVAILABILITY

For the compliance activities of the hearing conservation amendment to be feasible, industry must have the specialized equipment and personnel essential to an acceptable program. As documented in the following paragraphs, the noise record indicates that industry need not develop new technologies to implement hearing conservation programs since the equipment required by the new rule is already being manufactured and sold to industrial purchasers.

A substantive issue that remains to be addressed, however, is the general accessibility of the necessary human and material resources. An assessment of the present availability of equipment and personnel would be useful but it would not provide a realistic indication of the future availability of these resources following the promulgation of the amendment. In the absence of a detailed requirement for hearing conservation programs, many employers have not felt obligated to protect workers from hearing loss. As a result, there has been little incentive for manufacturers to step up the production of appropriate equipment. Similarly, the number of properly trained hearing professionals has been limited by the demand for their services. As industry begins to implement the hearing conservation activities mandated under this rule, it is anticipated that the supply of these resources would rapidly expand to satisfy the new requirements.

Monitoring

The feasibility of the monitoring provision, which requires the determination of a representative noise exposure for each worker exposed to an 8 hour TWA of 85 dB or more, depends on the availability of appropriate instrumentation for firms performing in-house monitoring or of qualified monitoring consultants for firms that choose not to obtain the necessary noise measuring equipment. Comments to the noise record indicate that currently at least 6,000 dosimeters are manufactured each year (Ex. 319 A-1; Ex. 319 A-7; Ex. 319 A-12; Ex. 319 A-20; Ex. 319 A-69; Ex. 319 A-72). Although not all of these dosimeters meet the specifications of the final rule, some appear to comply with the amendment by meeting the range and lower threshold requirements as well as the specifications of ANSI S1.25-1978 (Ex. 319 A-8; and OSHA telephone survey to dosimeter manufacturers). Kamperman (Ex. 321-32) has tested one of these instruments and found that it meets a test OSHA believes to be more rigorous than the one this amendment requires. Other manufacturers should also have little difficulty building units that comply with the amendment as the technology is available to both domestic and foreign firms. In addition, there are at least 5,300 sound level meters manufactured each year that can be used to measure worker exposures (Ex. 319 A-1; Ex. A-7; Ex. 319 A-12; Ex. 319 A-72).

The analysis described in the Cost of Compliance section concludes that only the larger industrial establishments are likely to purchase monitoring equipment. In the 19 industrial sectors studied, there are less than 34,000 establishments with over 100 employees (see Table 10).

It is not known how many of these firms already possess acceptable monitoring instruments. However, the rates of production listed above for units that will last a number of years imply that a substantial amount of equipment is already available. Further, because many of the smaller establishments will opt to rent or share equipment, each instrument will frequently be used by numerous employers.

The significant increase in the demand for monitoring instruments which will follow the implementation of the hearing conservation programs will provide a sharp stimulus to their production. Of the 12 companies currently manufacturing dosimeters, only 2 manufactured acoustical measurement equipment prior to the passage of the 1969 noise standard. Since that time, the remaining companies either expanded their product lines to include sound level meters and dosimeters or were established in response to the anticipated demand for noise measurement equipment. In similar fashion, existing manufacturers and new firms will be able to supply dosimeters and sound level meters to meet the new demand. To provide adequate time for this increased scale of production, OSHA is allowing a 2-year period before the more stringent specification requirements for dosimeters become effective.

In addition, the widespread occurrence of industrial noise has fostered the establishment of numerous acoustical consulting firms that will be available to accommodate those employers who choose to rely on specialized acoustical technicians to measure worker exposures (Ex. 319 B-8; Ex. 319 B-9; Ex. 319 B-11; Ex. 319 B-15). Audiometric testing firms also frequently offer monitoring services (Ex. 319 B-9; Ex. 319 B-12; Ex. 305; Ex. 321-7). This approach is acceptable as long as employers ensure that the consultants use qualified personnel and appropriate equipment and that they follow the requirements of the amendment. Each consulting firm can provide monitoring services to numerous industrial clients as the surveys do not always require a substantial degree of technical expertise (especially where dosimeters are used), and the smaller establishments can be surveyed in no more than one day (see Table 8). Although the record does not indicate the number of consulting firms that currently have the capability to conduct noise measurement surveys, the capacity of such firms would be expected to expand accordingly if the current supply of these services proves to be insufficient.

Audiometric Testing

The data developed in the cost of compliance section indicate that there will be about 5,126,000 workers in audiometric testing programs. The amendment requires that an otolaryngologist, an audiologist, or in their absence, a qualified physician oversee each program. In addition, the audiometric examination must be administered by one of these professionals or a certified technician trained in a course that contains material equivalent to that approved by the Council for Accreditation in Occupational Hearing Conservation, or The Guidelines of the Inter-Society Committee on Audiometric Technician Training.

In 1975, the American Speech and Hearing Association (ASHA) reported that course work in industrial hearing conservation was offered by 100 university and college programs. The ASHA estimated that there were 3,500 audiologists at that time and that this number would probably double in the next five years. (Ex. 15-30, p. 4). Indeed, by 1980, the American Speech-Language-Hearing Association (ASLHA) reported that there were currently 6,052 audiologists who are members of ASLHA, another 2,000 who are licensed, and an additional 1,600 students who were about to receive masters' or doctoral degrees (Ex. 319 B-7). Thus, within the near future, there will be about 9,652 audiologists who can supervise audiometric programs. Although it is unlikely since many firms will have a medical doctor to oversee the program, if only these audiologists supervised audiometric testing for all 5,126,000 workers, they would see an average of 531 workers each. The number of workers tested per audiologist, therefore, is about 2 per day, which is clearly a manageable task.

In addition to audiologists, otolaryngologists and other qualified physicians can oversee audiometric testing programs. The American Council of Otolaryngology (ACO) estimated that there were almost 5,000 practicing otolaryngologists in 1973 (Ex. 321-5, p. 17). According to the ACO, by 1985 there will be a surplus of 253 otolaryngologists (Ex. 321-5, p. 94). Moreover, in 1977 there were 382,000 professionally active M.D.'s in the U.S. (Statistical Abstract of the U.S., 1979, p. 106), and a major study recently submitted to the U.S. Department of Health and Human Services concludes that the U.S. will have an oversupply of 70,000 physicians by 1990 (Report of the Graduate Medical Education National Advisory Committee, Vol, I, GMENAC Summary Report, Sept. 1980, p. 3).

Currently, the Council for Accreditation in Occupational Hearing Conservation (CAOHC) indicates that they have certified about 6,700 audiometric technicians (Ex. 319 B-4), and there are about 700 course directors approved by the CAOHC to provide training for 20-30 technicians per course. If each course director teaches only one course per year to 20 people, this represents an additional 14,000 technicians. Thus, within a year, about 21,000 technicians could be available to perform audiometric tests, which averages to about one technician per 244 workers. However, many technicians have received training and certification by institutions and professionals other than the CAOHC, and audiologists and physicians other than those certified as instructors by the CAOHC will be able to train additional technicians. Thus, the supply of technicians is likely to be even larger than the 21,000 estimated here.

As explained in the previous section on the cost of compliance, about 829,000 workers will receive audiometric tests supervised by physicians or audiologists at clinics and in private practices. The 253 excess otolaryngologists that the ACO predicted to be available in 1985, alone, could provide 1,170,000 office visits (Ex. 321-5, p. 94). Thus, there is no indication that the total supply of otolaryngologists, audiologists, and physicians could not meet this demand.

About 1,447,000 workers were estimated to receive audiometric tests from mobile vans which can travel to virtually any plant facility. At a testing rate of 48 persons per day (Ex. 319 B-6 suggests 56 per 8-hour day), the workers could be tested in 180 days by 167 mobile vans. The use of these vans is already a common practice for many hearing conservation firms. Although the number of vans presently equipped to provide audiometric services was not submitted to the record, it is reasonable to expect that the existing audiometric firms, along with new firms entering the market will be able to supply these mobile services.

Approximately 2,850,000 workers were estimated to have their hearing tested at in-house programs in 13,285 of the largest industrial establishments. Many of these firms already offer audiometric tests to their employees. Moreover, additional audiometric technicians can be readily trained by sending employees at each facility to an appropriate institution for training. Thus, it is unlikely that these large firms will have difficulty finding appropriately qualified personnel.

In general, the trained personnel are widely disseminated throughout the nation. For example, there are about 2.1 otolaryngologists per 100,000 people in the U.S., with a range from 1.7 in the east south central region to 2.5 in the pacific region (Ex. 321-5, p. 21). By federal geographical region, the distribution of audiologists listed on the ASLHA mailing list ranges from 285 ASLHA audiologists in Region 8 to 1,186 ASLHA audiologists in Region 5. Nevertheless, one objection raised against audiometric testing was that some commercial activities, such as logging operations, would not be accessible to qualified personnel (Ex. 14-264; Ex. 14-260). However, OSHA believes the record shows that in almost all cases, the widespread availability of professional and technical personnel supplying mobile audiometric services should be adequate for even outlying industrial sites.

The major equipment required to perform audiometric examinations are audiometers and audiometric test booths. Based on 2,000 hours of use per year and a 10-minute examination period, each audiometer can potentially be used to provide 12,000 tests. If the audiometers are operated at only half this rate, it would take about 1,000 audiometers to test 5,126,000 workers. The current production of this equipment, each unit of which is expected to operate for about 10 years, is at least 5000 per year. (Ex. 319 A-51; Ex. 319 A-60; Ex. 319 A-64; Ex. 319 A-67). Moreover, all of the manufacturers who commented indicated that they could meet an increased demand, and it is likely that most of the existing audiometers currently used by industry are acceptable under the amendment.

There are three major manufacturers of audiometric test booths in the U.S. Although there is no information in the record about the number of units produced each year, manufacturers could increase their production fairly rapidly by adding second and third shifts if the current supply proves to be inadequate to meet an increased demand. In addition, other firms could expand into this area. However, some users of audiometric test booths may have difficulty complying with the maximum octave band sound pressure levels allowed in the booth during audiometric testing. This may be particularly difficult in the 500 Hz octave band. In an effort to alleviate this difficulty, OSHA has chosen to use 27 dB as the maximum sound pressure level in the 500 Hz octave band rather than the more stringent level of 21.5 dB specified in the ANSI S3.1-1977 standard. Although there is evidence on the record that the levels specified by ANSI S3.1-1977, with the adjustment at 500 Hz, can be met during industrial audiometry (Ex. 266A, p. 73; Ex. 295), some users may have to relocate their booths to a quieter location in order to comply with this provision. Since only the largest industrial establishments will develop in-house audiometric facilities, quieter enclosed areas should be generally available. Nevertheless, barrier walls could be constructed or double-walled booths purchased where a problem persists. Since this part of the requirement does not become effective until 2 years after the effective date of the amendment, most users should have sufficient time to make the necessary adjustments.

Other Provisions

The resources required to comply with the use of hearing protectors, training, the posting of warning signs, and the keeping of records will not be difficult for companies to find. The general availability of hearing protectors is amply demonstrated by the list of 175 models of hearing protectors from 46 different manufacturers or suppliers published by NIOSH in 1975 (Ex. 321-14A). Training materials, warning signs, and record forms also can be readily purchased from many safety supply houses.

VII. REGULATORY ALTERNATIVES

The 1974 OSHA noise proposal retained the current permissible exposure level (PEL) requiring employers to limit time-weighted average (TWA) exposures to 90 dB by engineering or administrative controls, where feasible. The proposal also mandated various requirements for monitoring, hearing protector use, and audiometric testing for workers exposed to noise levels $\geq$85 dB (TWA). Comments on this proposal were solicited, informal hearings were held, and a formidable record was compiled. Many of the regulatory actions suggested by the participants to these proceedings can be classified as follows:

1. Revise the PEL for noise,
2. Initiate a hearing conservation program where noise exposures exceed a TWA of 85 dB as suggested in the proposal,
3. Initiate a hearing conservation program at either higher or lower exposure levels than 85 dB, and
4. Revise the monitoring and audiometric testing provisions.

This section discusses some of these alternatives and summarizes the basis for OSHA's final determination of these issues.

Revised Permissible Exposure Level

A number of commentators stated that OSHA should lower the PEL from the current 90 dB level to an 85 dB level achieved through engineering controls. However, many others asserted that the noise record is not adequate to address all of the feasibility problems that would be created by requiring additional engineering controls to achieve an 85 dB PEL for occupational noise. OSHA concurs with the statements that these issues are important and that there are many unanswered questions regarding the feasibility of engineering controls in specific industrial settings. Therefore, although the Agency is committed to continue efforts to resolve these feasibility issues, the final promulgation of a new comprehensive standard must await the collection and analysis of substantial new data.

Notwithstanding the lack of adequate data on the feasibility of using engineering controls to reach 85 dB levels, the noise record does contain conclusive evidence that current noise levels are damaging the hearing ability of a sizable fraction of the worker population. Thus, OSHA is convinced that until the engineering feasibility record can be augmented, the only regulatory approach capable of reducing the extent and severity of occupationally induced hearing impairment is a requirement for effective hearing conservation programs.

Final Hearing Conservation Amendment

A hearing conservation amendment covering workers exposed to a TWA of at least 85 dB was the option ultimately selected by the Agency. In the absence of hearing conservation programs, data presented in the Benefits section indicate that over one million people would suffer material impairment of hearing caused by occupational noise. It was estimated that implementation of hearing conservation programs would prevent at least 212,000 individuals from suffering material impairment of hearing in the 10th year; 477,000 in the 20th year; 696,000 in the 30th year; 799,000 in the 40th year; and 898,000 in an equilibrium year. Moreover, by the 70th year, 412,000 people would be prevented from crossing the 40 dB fence, which indicates a more severe impairment.

A number of comments to the record assert that OSHA must demonstrate that benefits compare favorably to compliance costs before promulgating a standard (Ex. 261A, p. 39; Ex. 27, p. 476; Ex. 208). However, for the most part, these submissions do not imply that the benefits must be expressed in dollar terms. Because the loss of hearing generally impedes personal relationships more than market transactions, OSHA has determined that the major benefit of the hearing conservation amendment cannot be valued in monetary equivalents despite the willingness-to-pay approach developed in the economics literature. OSHA, therefore, relies upon the total benefits, not just the monetizable benefits of hearing conservation programs to justify this amendment.

The Council on Wage and Price Stability (COWPS) did not assert that the total benefits of a noise regulation should be assigned dollar values, but suggested that estimates of the cost per impairment prevented be used as a measure of the standard's relative cost-effectiveness (Ex. 208, p. 14). Dividing the $269.9 million total annual cost for hearing conservation programs by the 898,000 material impairments prevented at equilibrium gives $301 as the annual cost per impairment prevented in an equilibrium year. However, this value may not be a clear indicator of the cost-effectiveness of the requirements because the annual compliance cost is incurred from the first year following implementation, whereas the equilibrium number of material impairments prevented does not occur for up to 70 years. This problem cannot be resolved by comparing an estimate of the sum of the annual compliance costs to the equilibrium number of impairments prevented because many of the individuals prevented from suffering hearing damage before the completion of the 70-year period will not be alive after 70 years. These interim benefits are neglected when counting the number of material impairments prevented at an equilibrium year.

The preceding paragraph relates to the cost-effectiveness of all hearing conservation programs. However, in accordance with the existing OSHA noise regulation, some industrial workers already use hearing protectors, and will achieve some hearing conservation benefits even without the implementation of this new amendment. If as discussed in the Benefits section, 20 percent of the workers exposed to $\geq$90 dB are already receiving 10 dB of attenuation from hearing protectors, the existing programs would prevent about 120,000 material impairments of hearing by an equilibrium year. Since the programs that will be in effect following the implementation of this amendment are expected to prevent a total of 898,000 material impairments, the additional 778,000 prevented impairments will be directly attributable to the new regulation. Dividing these additional benefits by the $254.3 million annual cost of the new compliance activities (See Table 7) yields $327 as the annual cost per new impairment prevented in an equilibrium year. This is not substantially different from the $301 annual cost per impairment prevented for all hearing conservation programs.

An alternative methodology, described in the Benefits section and Appendix A, tracks the interim flow of benefits by calculating the number of person-years of material impairment. This approach provides a cumulative measure of the person-years of impairment that are expected to be prevented over a designated time period. The person-years of material impairment prevented that are attributable to hearing conservation requirements were estimated to rise from slightly over 1 million after 10 years to more than 43 million after 70 years. This measure avoids the problem of overlooking the interim benefits but does not account for current patterns of hearing protector use. In addition, because the benefits do not occur for a period of years, it does not totally resolve the problem of relating them to a stream of annual compliance costs.

The record provides conflicting views with respect to the correct treatment of costs and benefits when they are distributed over time. Summing the annual costs over the relevant number of years is not valid, because irrespective of inflation, a dollar spent in the future is not equivalent to a dollar spent today. Interest can be earned during the period that the payments are delayed, making it less burdensome for either an individual or a society to spend a dollar in the future than in the present. The appropriate method to evaluate the sum of the annual hearing conservation costs is to calculate the present value of the cost stream. This requires discounting the future payments by the market rate of interest before totalling the stream of costs. In order to standardize these calculations, the Office of Management and Budget (OMB) has suggested that agencies use a 10 percent interest rate (OMB Circular No. A-94).

On the benefits side, however, it is not clear that the prevention of future hearing loss should be considered less valuable than the prevention of current years of impairment. In their study, CPA choose not to discount benefits and pointed out that:

> Discounting non-monetary benefits is a backhanded way of attaching monetary characteristics to non-monetary goods. Implicit in discounting is the notion that the goods at any one time can be traded off for equivalent goods at another time. In reality few markets exist for this direct trade. (Ex. 323, p. 5-45.)

A COWPS official expressed an opposing opinion by suggesting to CPA that there was a "fundamental fallacy in your methodology for discounting costs 45 years in the future but counting...a year of hearing loss 45 years from now...the same as a hearing loss of today..." (Morrall, Tr. p. 2198-9).

After considering these viewpoints, OSHA has made a policy decision that it would be misleading to apply an arbitrary discount rate where the market does not reveal the appropriate discount for these delayed benefits. Although OSHA agrees that the economic value of future production loss is properly subject to a market rate of discount, this logic does not necessarily apply to the pain and suffering that accompanies the non-economic component of a state of irreversibly impaired health. The record provides no evidence to suggest that a year of hearing impairment suffered 20, 30, 40 or even 70 years in the future would be more acceptable than current afflictions. In fact, the traditional time preference for current over deferred consumption may not apply in this case because a future year of hearing impairment is more likely to occur when the individual's other sensory faculties are in decline, further enhancing the need for acute hearing perception. Indeed, if offered the choice between a present or a future year of hearing impairment, it might not be unreasonable for workers to forgo a current year of normal hearing in favor of adequate hearing in a later year. Thus, OSHA firmly believes that a long-term perspective is required to protect the health of workers over their lifetimes.

On the other hand, OSHA understands that there are methodological problems created by discounting costs but not benefits. For example, the total of the discounted costs will ultimately stabilize, but the person-years of impairment prevented will continue to climb as the time period chosen for analysis lengthens, allowing the justification of almost any program when considered over a sufficiently long timespan. However, because the time pattern of benefits from the alternative regulations is similar, a descriptive presentation of the relationship between the discounted costs and the hearing loss prevented over time can provide some insight into the relative effectiveness of alternative regulations. One such illustration would result from dividing the present value of the annual cost stream by the estimated person-years of impairment prevented over various time periods. The resulting trend in the present value of the cost per person-year of impairment prevented by hearing conservation programs, as displayed in Figure 5, declines sharply from $1,565 after the 10th year to $510 by the 20th year, to $245 by the 30th year, to $148 by the 40th year, and to $62 by the 70th year. Simply summing the costs without discounting yields a cost per person-year of impairment prevented of $605 by the 40th year and $436 by the 70th year.

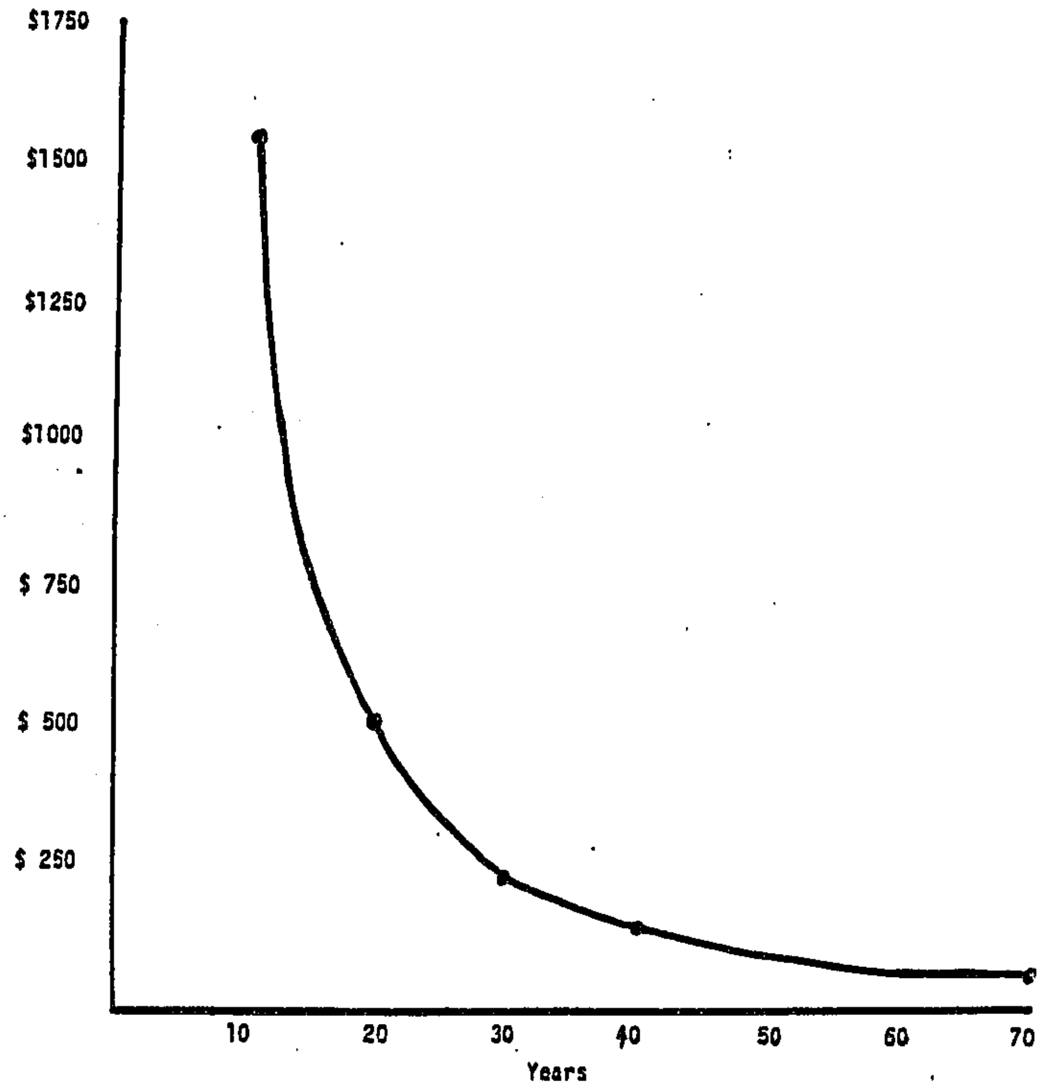

Figure 5

Present Value of
Cost per Person-Year of Impairment Prevented

There is no preconceived rule that will unequivocally justify or reject a decision to allocate an increased portion of society's resources to the reduction of future cases of hearing impairment. However, the pain, discomfort and social disability accompanying lost hearing at any stage of life are clearly substantial relative to these costs when viewed over a time horizen long enough to allow the manifestation of the program's results. OSHA, therefore, is convinced that the amendment's contribution to an improved quality of life for hundreds of thousands of workers and their friends and families more than balances the estimated cost of the amendment. Moreover, this conclusion is only strengthened to the extent that extra-auditory health effects increase the measured benefits, and that fewer accidents and reduced absenteeism and medical payments decrease the cost burden, as suggested by the evidence cited in the Benefits section above.

Alternative Initiation Levels

Numerous comments to the record addressed the appropriate noise exposure level at which to initiate hearing conservation programs. Although many commentators agreed that 85 dB was a proper level, others asserted that 90 dB would be sufficient, and at least one participant stated that 75 dB should be the long-range goal (See Ex. 5, p. 43802). The scientific evidence presented to justify these alternatives primarily relate to the risk of hearing loss at various levels of noise exposure. As explained in the Health Effects section, OSHA believes that the results of this research are best represented by Johnson's synthesis of the Passchier-Vermeer, and Burns and Robinson studies (Ex. 310) which show that significant levels of risk appear at noise exposures well below 90 dB.

Johnson's data indicate that for the more sensitive 10th percentile of workers exposed over a working lifetime, the amount of noise induced permanent threshold shift (NIPTS) for the frequencies 1000, 2000, and 3000 Hz is 11.1 dB for workers exposed to 90 dB, 4.7 dB for workers exposed to 85 dB, and only 1.8 dB for workers exposed to 80 dB (see Table A-7 in Appendix A). Moreover, a risk matrix based on these data, and reproduced in Table A.10 of Appendix A, implies that the probability of crossing a 25 dB fence solely due to a 40-year exposure to occupational noise of 90-95 dB is 25 percent for males and 28 percent for females (deduct risk of >80 dB exposures). For noise exposures between 85 and 90 dB, this probability remains a relatively high 11 percent and 14 percent for males and females, respectively. However, for exposures of 80-85 dB, the probability of crossing this fence because of work-related noise falls to 5 percent for males and 6 percent for females.

To illustrate further how the 85 dB amendment compares to various alternatives, OSHA has used these risk matrices to estimate the number of individuals who would suffer hearing impairment following a reduction in the amendment's coverage to 90 dB or an expansion in scope to 80 dB. The procedures for these calculations are based on the methodology outlined in the Benefits section and in Appendix A.

Table 17 presents the number of persons at the equilibrium time period who would have hearing threshold levels $\geq$15 dB, 25 dB, and 40 dB for the alternative regulations. Thus, without the use of hearing protectors, 1,624,000 individuals would be across a 15 dB fence; 1,060,000 would be across a 25 dB fence; and 473,000 would be across a 40 dB fence. This is 9.2 percent, 6.0 percent, and 2.7 percent,

Table 17

Persons with Occupational Hearing Impairment at Equilibrium
(1000, 2000, 3000 Hz)

	15 dB Fence		25 dB Fence		40 dB Fence	
Regulatory Alternatives	Number	Percent*	Number	Percent*	Number	Percent*
No Hearing Conservation Program	1,624,000	9.2	1,060,000	6.0	473,000	2.7
90 dB	675,000	3.8	351,000	2.0	136,000	0.8
85 dB	321,000	1.8	162,000	0.9	59,000	0.3
80 dB	125,000	0.7	63,000	0.4	23,000	0.1

Source: OSHA, Office of Regulatory Analysis.

* Number of impairments as a percentage of the number of persons in the population studied (17,638,000).

respectively, of the population studied. Instituting hearing conservation programs at 90 dB reduces these impairments by only 58-71 percent, whereas hearing conservation at 85 dB decreases the number of impairments by 80-88 percent, and the 80 dB alternative by 92-95 percent.

Table 18 displays estimates of the annual costs and the number of hearing impairments expected to be avoided by hearing conservation programs initiated at 90, 85, and 80 dB. Using the same methodology that was used to develop the cost estimates for the 85 dB amendment, but disregarding current compliance efforts, the annual costs for the 90, 85 and 80 dB alternatives were calculated as $179.3, $269.9 and $373.8 million respectively. The table shows the number of hearing impairments that would be prevented at equilibrium and at 4 interim years for the 25 dB fence, and at equilibrium for the 15 and 40 dB fences. Figure 6 illustrates the time path of these benefits as calculated for the 25 dB fence.

A number of different techniques have been developed by social scientists to assure a rational selection among alternative public policy actions. One such technique recommended by COWPS suggests that:

> The first step in the analysis is to eliminate the options that are not cost-effective relative to some other option. To determine which are not cost-effective, the marginal (additional) cost per additional worker protected with each increasingly stringent standard must be calculated. Whenever marginal costs decline (i.e., it costs less to protect one more worker than to protect the previous worker), one should reject the weaker standard in favor of the standard offering more protection. (Ex. 208, p. 14.)

Table 18

Annual Compliance Costs and Impairments Prevented by Regulatory Alternative

Regulatory Alternative	Annual Costs ($ Millions)	Impairments Prevented: 25 dB Fence 10th year	20th year	30th year	40th year	Equilibrium	15 dB Fence Equilibrium	40 dB Fence
90 dB	179.3	174,000	377,000	553,000	632,000	709,000	946,000	337,000
85 dB	269.9	212,000	477,000	696,000	799,000	898,000	1,303,000	412,000
80 dB	371.8	235,000	548,000	795,000	897,000	997,000	1,499,000	450,000

Source: OSHA, Office of Regulatory Analysis.

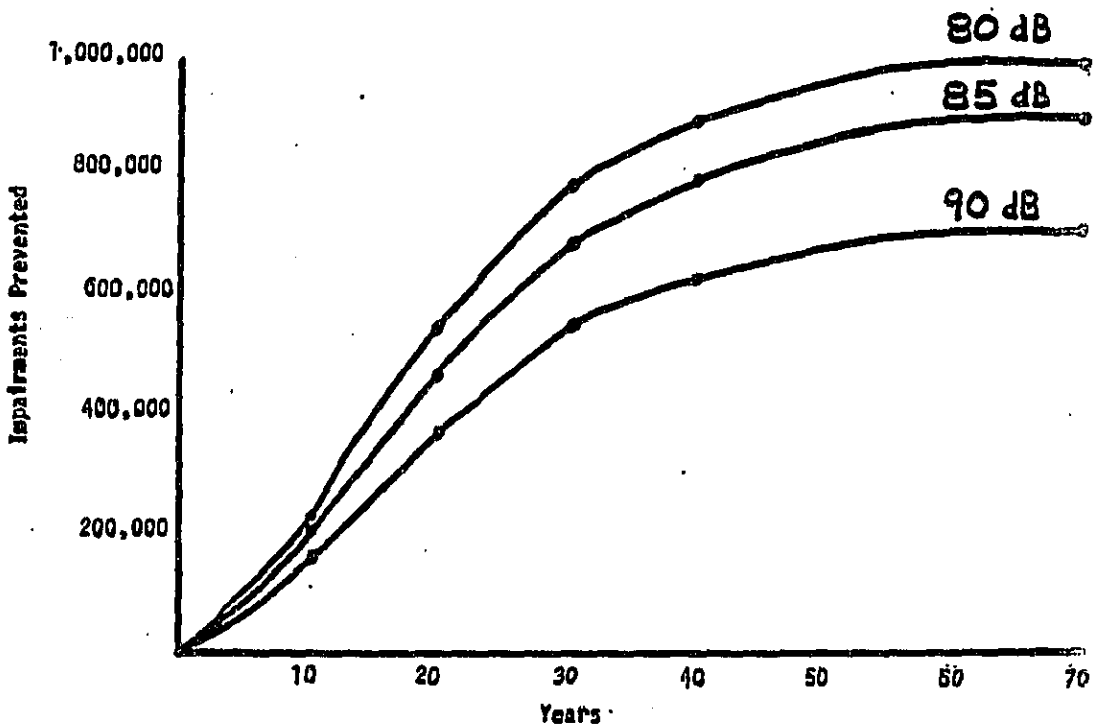

Figure 6

Material Impairments of Hearing Prevented by Hearing Conservation Programs

However, even assuming an adequate demand for the regulation, this approach is useful only where the added cost of protecting additional workers declines. Where marginal costs rise, making it more expensive to prevent an additional material impairment than a previous material impairment, the COWPS suggestion will not help to identify the proper scope for the regulation. (Traditional economic theory implies that a schedule showing rising marginal costs per impairment prevented also indicates the number of impairments that employers would be willing to prevent if they were reimbursed by varying amounts. Thus, it is a form of "supply curve" for regulation. However, the corresponding "demand curve" cannot be constructed because the predominant portion of the benefits cannot be monetized. Therefore, a socially efficient level of regulation cannot be specified.)

To demonstrate that the cost of preventing an additional material impairment does, in fact, rise as the coverage of this regulation expands, the additional costs and the additional material impairments that would be prevented by implementing the successively more inclusive alternatives are presented in Table 19. Since the baseline for this analysis is no hearing conservation program, the numbers in the 90 dB row are unchanged from Table 18. The 85 and 80 dB entries in Table 19 were calculated by taking the difference between the 85 and 90 dB rows, and the 80 and 85 dB rows, respectively, from Table 18. Table 19 indicates, for example, that the 85 dB amendment would cost $90.6 million a year more than the 90 dB alternative, but would prevent 38,000 more material impairments by the 10th year after promulgation of the amendment.

Table 19

Additional Annual Compliance Costs and Additional Impairments Prevented for Successively More Inclusive Regulatory Alternatives

Regulatory Alternative	Additional Annual Costs ($ Millions)	Additional Impairments Prevented						
		25 dB Range					15 dB Range	40 dB Range
		10th year	20th year	30th year	40th year	Equilibrium	Equilibrium	
90 dB	179.3	174,000	377,000	553,000	632,000	709,000	949,000	337,000
85 dB	90.6	38,000	100,000	143,000	167,000	189,000	354,000	75,000
80 dB	103.9	23,000	71,000	99,000	90,000	99,000	196,000	30,000

Source: Derived from Table 18.

However, to assess the relationship between these alternatives according to the COWPS methodology, the incremental benefits of each alternative must be expressed in terms of the additional costs they would impose. Unfortunately, the cost differentials that were estimated for these alternatives are somewhat biased because of the unrealistic assumption that all establishments in the industries studied will have at least some workers in the hearing conservation program. This assumption not only overstates the monitoring costs of the final rule, but also necessarily understates the cost differentials among the alternative standards. In practice, more firms would be impacted by the 80 dB alternative than by the 85 dB standard which in turn would affect more firms than the 90 dB alternative. Thus, the magnitude of the overstatement of the costs falls as the coverage of the standard is expanded, causing the more inclusive alternatives to appear relatively more cost-effective than is warranted.

Notwithstanding the shortcomings of these data and the conceptual difficulty involved in relating annual costs to impairments prevented at a future time period, Table 20 displays the resulting estimates of both the average annual cost per material impairment prevented at equilibrium, and the additional annual cost per material impairment prevented at equilibrium by the successively more inclusive standards. The table graphically illustrates the rise in the additional cost per material impairment prevented as the standard increases its coverage. Moreover, this upward trend remains for calculations based on the present value of the costs per person-year of impairment, or for other time periods or fences; and occurs despite the bias in the cost data which tends to favor the more inclusive standards. Thus, the COWPS suggested criterion for selecting the cost-effective alternative, which is dependent upon finding a regulatory alternative with declining marginal costs, is not a relevant consideration in this instance.

Table 20
Average and Additional Cost per Material Impairment Prevented at Equilibrium
(25 dB Fence)

Regulatory Alternative	Average Annual Cost per Impairment Prevented	Additional Annual Cost per Impairment Prevented
90 dB	$253	$ 253
85 dB	301	479
80 dB	375	1,040

Source: OSHA, Office of Regulatory Analysis.

These data do, however, indicate the differential effects likely to follow the promulgation of the alternative regulations. Moreover, they show that even if OSHA were to enforce diligently the hearing conservation portions of the existing noise regulation the new amendment would bring substantial additional benefits. For example, Table 18 showed that a regulation limited to workers exposed to a TWA of 90 dB or above would prevent a large number of material impairments of hearing. By the equilibrium year, this alternative would achieve 79 percent of the impairments prevented by the 85 dB amendment. Although this percentage is significant, Table 19 indicates that after 10 years, we would expect to find 38,000 more individuals exceeding a

25 dB fence with the 90 dB alternative than with the 85 dB final amendment. These additional impairments rise to 100,000 after 20 years and 143,000 after 30 years. At an equilibrium year, there would be an additional 189,000 people materially impaired, 75,000 of whom would suffer the more serious hearing loss measured by the 40 dB fence. Furthermore, Table 19 indicates that to prevent these additional impairments by extending coverage to workers exposed to a TWA of 85 dB would cost $90.6 million a year more than the 90 dB alternative. This amounts to an average cost of only about $41 for each of the 2.2 million workers exposed to noise of between 85 and 90 dB. Although Table 20 shows that the 85 dB amendment costs more per material impairment avoided than the 90 dB alternative, the additional costs do not appear excessive in terms of the hardship they would prevent.

An alternative presentation of these data consists of calculating the number of person-years of material impairment prevented using the procedures described in Appendix A. Tables 21 and 22 show the cumulative and additional cumulative person-years of material impairment prevented for durations of 10, 20, 30, 40, and 70 years following the implementation of hearing conservation programs at the alternative initiation levels. For instance, Table 21 notes that during the first 20 years after initiation, programs covering 90 dB exposures would prevent 3,625,000 person-years of material impairment and programs covering 85 dB exposures would prevent 4,505,000 such years. Table 22 displays the increments, showing that hearing conservation programs initiated at 85 dB would prevent 880,000 more person-years of material impairment than programs initiated at 90 dB over the 20-year period. Over the next 70 years, almost 9 million

Table 21

Cumulative Person-Years of Material Impairment Prevented
(25 dB Fence) (millions)

Regulatory Alternative	Years 10	20	30	40	70
90 dB	.87	3.625	8.275	14.20	34.315
85 dB	1.06	4.505	10.37	17.845	43.30
80 dB	1.175	5.09	11.805	20.265	48.675

Source: OSHA, Office of Regulatory Analysis.

Table 22

Additional Cumulative Person-Years of Material Impairment Prevented
(25 dB Fence) (millions)

Regulatory Alternative	Years 10	20	30	40	70
90 dB	.87	3.625	8.275	14.20	34.315
85 dB	.19	.880	2.095	3.645	8.985
80 dB	.115	.585	1.435	2.420	5.375

Source: OSHA, Office of Regulatory Analysis.

additional person-years of material impairment would be avoided by implementing the 85 dB amendment as opposed to the 90 dB alternative. The present value of the added cost per person-year of material impairment avoided by initiating the program at 85 dB rather than at 90 dB can be calculated by dividing the present value of the stream of additional annual costs ($90.6 million per year) by the additional impairments prevented. The resulting estimates range from $2,932 after 10 years, to $408 after 30 years, to $101 after 70 years. Once again, OSHA believes that these compliance costs are below the value that society places upon the personal cost of hearing impairment.

The data also signify some risk of hearing impairment to workers exposed at noise levels below a TWA of 85 dB. Table 19 shows that a more extensive hearing conservation program covering workers exposed to as low as 80 dB would prevent almost 100,000 additional material impairments at equilibrium. However, at this time OSHA has decided not to require the implementation of hearing conservation programs for workers exposed below a TWA of 85 dB. While initiation of a hearing conservation program at such exposure levels would undoubtedly be to the advantage of many workers, such a decision would require the coverage of almost three million additional workers in thousands of workplaces. Including these additional workers would intensify the increased demand expected for dosimeters, sound level meters, audiometric test booths, mobile van audiometric test units and audiologists, otolyrngologists and certified audiometric technicians. Information and data in the record clearly indicate the availability of these resources to meet a standard implementing the hearing conservation program at 85 dB. However, if all workers exposed to noise above a TWA of 80 dB were covered, further information would be needed to assure that the increased demand generated by covering so many more workers would not tax these resources to the point that it might be difficult for employers to comply by the effective date of the various sections of the standard. The Agency may gather new information on the feasibility of implementing the program below a TWA of 85 dB when the other issues remaining in this rulemaking proceeding, such as the appropriate permissible exposure level and method of compliance, are resolved. However, OSHA remains concerned about the risks from these lower noise levels and will continue to study the implications of these exposures while concurrently urging employers to include these workers in hearing conservation programs.

Alternative Monitoring, Training, and Audiometric Testing Provisions

Many groups suggested modifications to the monitoring, and audiometric testing requirements listed in the 1974 proposal. It would be informative to have numerical estimates of the distinct benefits associated with each of these provisions and the suggested alternatives. However, OSHA found that it was not possible to make quantifiable estimates of the benefits attributable to the individual provisions of the final amendment because each requirement was developed as an integral component of a comprehensive program. Most industrial noise experts agree that workers will not use ear protectors often or appropriately unless their cooperation has been gained as a result of educational activities. Thus, monitoring, training and audiometric testing do not provide benefits in and of themselves, but only as they support and enhance other aspects of the program by heightening the awareness and motivation of employees and employers. In the absence of carefully designed experimental studies, OSHA believes that precise numerical estimates of these individual effects would be highly speculative. Nevertheless, the final form of each provision was based on expert testimony in the record regarding those hearing conservation practices that are generally considered necessary to safeguard worker hearing during exposure to high levels of noise.

In addition, the economic consequences of these provisions were considered in order to assure the selection of the least burdensome alternative that would still provide adequate worker protection. The annual cost per worker included in hearing conservation programs is estimated at about $15 for monitoring, $18 for audiometric testing, and $8 for training. OSHA believes that the importance of the information these activities provide to the workers at risk of hearing impairment substantially exceed these values.

Conclusion

The data presented above demonstrate that OSHA has thoroughly considered and documented the need for regulatory action, assessed the economic consequences of the amendment, and evaluated the implications of selecting alternative regulatory programs. It was estimated that in the absence of hearing conservation programs, over one million individuals would suffer material impairment of hearing (across a 25 dB fence) because of job-related noise. Existing hearing conservation programs may ultimately reduce these impairments by about 11 percent. However, if the hearing conservation programs required by the new amendment effectively reduce at-ear noise levels by 15 dB, they would prevent at least 70 percent of the impairments by the 30th year, and at least 85 percent by the 70th year, following implementation. In addition, evidence was presented to indicate that the incidence of extra-auditory health effects, job-related accidents, and worker absentee levels could decline significantly.

The compliance cost of the amendment was estimated at about $53 per exposed worker and constitutes less than 0.2 percent of the profits in the major affected industries. It was shown that this level of cost can be easily financed without causing economic problems to the great majority of business firms in each industry sector. Calculations deriving the annual compliance cost per impairment avoided at equilibrium yielded $301 for all hearing conservation programs and $327 when the estimated cost and benefit of existing programs were excluded. Calculations of the present value of the cost per person-year of impairment avoided because of hearing conservation programs came to $245 by the 30th year and $62 by the 70th year. These compliance costs are clearly reasonable compared to the intangible but very real personal costs of enduring a year of impaired hearing.

Alternative initiation levels for the hearing conservation program were considered and rejected. Although the 90 dB alternative would reduce annual compliance costs by $90.6 million, its selection would permit an estimated 189,000 additional material impairments by the equilibrium year. Therefore, the annual cost per impairment prevented at equilibrium due to extending the scope of the amendment to 85 dB rather than 90 dB was estimated at $479. The present value of the stream of additional costs per person-year of impairment prevented by extending the scope of the regulation to 85 dB was estimated at about $400 over a 30-year timespan, and at about $100 over a 70-year horizon. Consideration of the 80 dB alternative has been deferred pending the collection of further data relating to its feasibility. Based on this information, OSHA has concluded that most individuals, as well as society as a whole, will consider the hearing conservation amendment to be a judicious investment in the quality of life for this nation's work force.

APPENDIX A

CALCULATION OF THE NUMBER OF HEARING IMPAIRMENTS

Calculation of the Equilibrium Number of Hearing Impairments

Six basic steps were used to calculate the number of hearing impairments occurring under the four regulatory alternatives:

1. Develop an age distribution,
2. Develop an age by exposure level distribution,
3. Adjust exposure levels for the use of hearing protectors,
4. Develop a sex distribution and combine with the age by exposure level distribution,
5. Calculate the number of hearing impairments from all causes, and
6. Determine the number of occupationally caused hearing impairments.

This methodology basically follows the procedures used by the Center for Policy Alternatives (CPA) ("Economic and Social Impact of Occupational Noise Exposure Regulations," Ex. 232). Although the conclusions of this study were subject to extensive discussion at the hearings, no one criticized the methodology used by CPA to estimate the number of hearing impairments prevented. OSHA has therefore concluded that the CPA procedures form a reasonable basis for these calculations. Additionally, information on the number of retirees in the population, the sex distribution of the work force, and the attenuation afforded by the use of hearing protectors has been included.

Develop an Age Distribution

An age distribution of the work force was developed because hearing impairment is partially a function of age. Ideally one would develop a distribution based on the actual work force in the 19 industries under study. Since such a distribution is not available, these calculations used a Bureau of Census age distribution for the entire population between ages 18 and 64. Such use assumes that this distribution adequately represents the actual distribution in the 19 industries and will continue to do so for the next 70 years. In addition, it was assumed that no one younger than 18 or older than 64 years of age is in the production work force in the 19 industries. The age distribution of the active work force in the 19 industries is presented in Table A.1.

Occupational hearing loss does not stop when a person leaves the work force, but continues throughout retirement. Consequently, the number of retirees from the production work force in these industries must be added to the age distribution. (Both CPA and BBN understated benefits by not including retirees in their calculations.) To estimate the number of production worker retirees from the 19 industries (since a precise count is not available), it was assumed that the proportion of production worker retirees from these industries is equal to the proportion of retirees from the entire population between 18 and 64 years of age. The following equation illustrates this procedure.

$$\frac{\text{Population aged 65+}}{\text{Population aged 18-64}} \times \text{Production workers in 19 industries}$$

$$= \frac{24.054 \text{ million}^{1}}{131.115 \text{ million}^{2}} \times 14.904 \text{ million}^{3}$$

$$= 2.734 \text{ million retired production workers in 19 industries}$$

The complete age distribution (including retirees) for the 19 industries is presented in Table A.2.

Develop an Age by Exposure Level Distribution

Two major assumptions were used to develop an age by exposure level distribution: First, that noise exposure levels (in dB) are independent of age. Second, that the duration of exposure (in years) for each 10 year age category can be approximated by using the midpoint number of years since age 20. For example, those aged 35-44 have worked 15-24 years since they were 20 years old. The midpoint of the range 15-24 is 20. The average duration of exposure for everyone aged 35-44 is thus assumed to be 20 years. Implicit here is the assumption that workers do not move between noisy and non-noisy jobs.

The age by exposure level distribution is created by multiplying the age distribution (Table A.2) with the exposure level distribution (Table 4 of the Benefits Section) and is presented in Table A.3.

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[1] U.S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States, 1979, Table 5, p. 8. Data are for 1978.

[2] Table A.1 of this Appendix.

[3] Table 3 of the Benefits Section.

Table A.1

Age Distribution of the Active Work Force

Age Group	Total U.S. Population* (millions)	Percent	Active Work Force in 19 Industries** (millions)
18-24	28.944	22.07	3.289
25-34	33.936	25.88	3.857
35-44	24.383	18.60	2.772
45-54	23.184	17.68	2.635
55-64	20.668	15.76	2.349
Total (18-64)	131.115	100.00	14.904

Source: Bureau of the Census.

*U.S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States, 1979, Table 5, p. 8. Data are for 1978.

**Calculated by assuming that the 19 industries have the same percentage age distribution as the total U.S. population.

Table A.2

Age Distribution of the Active/Retired Work Force

Age Group	Population (millions)	Percent
18-24	3.289	18.65
25-34	3.857	21.87
35-44	2.772	15.72
45-54	2.635	14.94
55-64	2.349	13.32
65+	2.734	15.50
Total	17.638	100.00

Source: Table A.1 and the retiree estimate performed in the text.

Table A.3*

Age by Exposure Level Distribution
Assuming No Hearing Protector Use
(Percent)

Exposure Level (dB)	Age Group 18-24	25-34	35-44	45-54	55-64	65+	Total
< 80	8.74	10.25	7.37	7.00	6.24	7.27	46.88
80-85	3.50	4.10	2.95	2.80	2.50	2.90	18.74
85-90	2.81	3.29	2.37	2.25	2.01	2.33	15.06
90-95	2.05	2.40	1.73	1.64	1.46	1.70	10.98
95-100	1.02	1.20	.86	.82	.73	.85	5.47
100+	.54	.63	.45	.43	.38	.44	2.87
Total	18.65	21.87	15.72	14.94	13.32	15.50	100.00

Source: OSHA, Office of Regulatory Analysis.

*Based on Table 4 (Noise Exposure Distribution) and Table A.2 (Age Distribution). Each cell represents the percentage of the active/retired work force in each combination of exposure level and age. Thus, 8.74 percent of the active/retired work force is both in the age group 18 and 24 and is exposed to occupational noise <80 dB.

Adjust Exposure Levels for the Use of Hearing Protectors

The next step of the calculations was to factor in the effect that hearing protector use will have on effective, "inside the ear" exposure levels. This adjustment is, of course, unnecessary for the no hearing conservation program alternative, which assumes no hearing protector use. For the other alternatives, assumptions were made about the number of workers who will wear personal hearing protectors and the average attenuation they will receive.

It was assumed that all workers required to wear hearing protectors will do so and that they will receive an average attenuation of 15 dB. A

Table A.4

Exposure Levels, Pre-and Post-Regulation for the Final Amendment* (dB)

Pre-Regulation	Post-Regulation
<80	<80
80-85	80-85
85-90	<80**
90-95	<80
95-100	80-85
100+	85-90

Source: OSHA, Office of Regulatory Analysis.

*Effective "inside the ear" exposure levels after accounting for hearing protector usage, i.e. all workers exposed $\geq$85 dB will wear hearing protectors and will receive 15 dB attenuation.

**For workers exposed to 85-90 dB, only those who have shown a permanent, significant threshold shift are required to wear hearing protection. It is reasonable to conclude that the audiometric testing programs and the criteria for significant threshold shift will detect, before they incur material impairment, the workers between 85-90 dB who are vulnerable to noise. From the standpoint of hearing impairments prevented, the assumption that everyone who is vulnerable to noise will wear hearing protectors is mathematically equivalent to the assumption that everyone will wear hearing protectors. The latter assumption also simplifies the calculations. Therefore, OSHA has found it reasonable to make that latter assumption for the purposes of these calculations.

Table A.5

Post-Regulation Age by Exposure Level Distribution for the Final Amendment*
(Percent)

Exposure Level (dB)	Age Group						
	18-24	25-34	35-44	45-54	55-64	65+	Total
<80	18.65	15.94	11.47	10.89	9.71	11.30	77.96
80-85	-	5.30	3.81	3.62	3.23	3.75	19.71
85-90	-	.63	.45	.43	.38	.44	2.33
90-95	-	-	-	-	-	-	-
95-100	-	-	-	-	-	-	-
100+	-	-	-	-	-	-	-
Total	18.65	21.87	15.72	14.94	13.32	15.50	100.00

Source: OSHA, Office of Regulatory Analysis.

*After equilibrium is established (70 years after implementation). Hearing protector use assumed: 100% of those exposed ≥85 dB will wear hearing protectors and will receive 15 dB attenuation.

more detailed discusssion of this assumption is found in the Benefits section.

Table A.4 presents current exposure levels and the effective "inside the ear" exposure levels after implementation of the final amendment. Table A.5 presents exposure levels by age group, assuming full use of hearing protectors, after implementation of the final amendment.

Develop a Sex Distribution and Combine With the Age by Exposure Level Distribution

Hearing impairment is also a function of sex: Men appear to be more susceptible to hearing loss than women. Therefore, in the 19 industries studied, a distribution of the production work force was developed according to sex. No published data exist that show a breakdown of the production work force by sex, although BLS does publish data on the sex distribution for all employees (not just production workers) in the 19 industries. It was assumed in these calculations that the proportion of male and female employees in the production work force in the 19 industries is equal to that for the entire work force. The calculation procedure was:

$$\text{Female Fraction} = \frac{\text{Number of female employees in 19 industries}^{1}}{\text{Total work force in 19 industries}^{2}}$$

$$= \frac{6{,}096.9 \text{ Thousand}}{20{,}639.3 \text{ Thousand}}$$

$$= .295$$

$$\text{Male Fraction} = 1 - \text{Female Fraction}$$

$$= 1 - .295$$

$$= .705$$

[1]U.S. Department of Labor, Bureau of Labor Statistics, Employment and Earnings 27 (March 1980): 67-73, Table B-3. Data are for 1979.

[2]Ibid., Table B-2.

This procedure would appear to overstate the number of female production workers and understate the number of male production workers, since it is generally perceived that most production jobs in the manufacturing sector are held by men. However, a second, unpublished data source from the BLS gives a breakdown of job categories by sex and reveals approximately the same ratio in blue collar jobs: 71 percent male to 29 percent female.

These male and female fractions were applied to the total population, including retirees, exposed from the 19 industries (17.636 million) to find the number of males (12.433 million) and females (5.203 million). By assuming that noise exposure is independent of sex, distributions of the number of persons in the different age and exposure level categories were developed for both males and females by using the age by exposure level distribution (Table A.5). To the extent that men are exposed, on average, to higher noise levels than are women, this assumption tends to understate the number of hearing impairments. The results are shown in Table A.6.

TABLE A.6

Number of Persons Exposed (Equilibrium)*
(millions)

Exposure Level (dB)	Age Group 18-24	25-34	35-44	45-54	55-64	65+	Total
				MALE			
<80	2.319	1.982	1.426	1.354	1.207	1.405	9.693
80-85	-	.659	.474	.450	.402	.466	2.451
85-90	-	.078	.056	.053	.047	.055	.289
90-95	-	-	-	-	-	-	-
95-100	-	-	-	-	-	-	-
100+	-	-	-	-	-	-	-
Total Male	2.319	2.719	1.956	1.857	1.657	1.926	12.433
				FEMALE			
<80	.970	.827	.597	.567	.505	.588	4.054
80-85	-	.276	.198	.188	.168	.195	1.025
85-90	-	.033	.023	.022	.020	.023	.121
90-95	-	-	-	-	-	-	-
95-100	-	-	-	-	-	-	-
100+	-	-	-	-	-	-	-
Total Female	.970	1.138	.821	.777	.694	.805	5.203
Total Male and Female	3.289	3.857	2.777	2.634	2.351	2.731	17.636

Source: OSHA, Office of Regulatory Analysis.

*70 years after implementation. This table is generated by applying the percentages of Table A.5 to the total number of males (12.433 million) and females (5.203 million).

Calculate the Number of Hearing Impairments from All Causes

Risk matrices were developed, utilizing the data presented in the Johnson report (Ex. 310) and the computer program listed as an appendix to that report. Tables A.7 and A.8 present noise-induced permanent threshold shift (NIPTS) and presbycusis data from the Johnson report used with the computer program. Table A.9 presents the risk matrix for a 15 dB fence at the frequencies 1000, 2000, and 3000 Hz. Each cell in Table A.9 gives the percentage of the work force in each age group-exposure level category who will have hearing threshold levels >15 dB averaged at the frequencies 1000, 2000, and 3000 Hz. (Similar risk matrices for the 25 and 40 dB fences were also developed and are presented is Tables A.10 and A.11.)

One assumption inherent in this step has already been discussed--the assumption that duration of exposure can be adequately represented for each 10-year age group by using the midpoint number of years since age 20. Similarly, it was assumed that the midpoint of each exposure level range adequately predicts hearing loss for the entire range (See Table A.12).

The number of persons exposed (Table A.6) was then combined with the appropriate risk matrix (Table A.10) to determine the number of persons who would be across the 25 dB fence after implementation of the final amendment (Table A.13).

Table A.7

Noise-Induced Permanent Threshold Shift (NIPTS)*
(dB)

Exposure Level (dB)	Exposure Duration (Percentile of Population) 10 years			20 years			30 years			40 years		
	(.9	.5	.1)	(.9	.5	.1)	(.9	.5	.1)	(.9	.5	.1)
75	0	0	0	0	0	0	0	0	0	0	0	0
80	.1	.8	1.8	.7	1.0	1.8	1.7	1.1	1.8	2.6	1.3	1.8
85	.7	1.9	4.7	1.5	2.4	4.7	2.6	2.9	4.7	3.7	3.2	4.7
90	1.6	4.1	9.3	2.9	5.3	10.2	4.3	6.4	11.1	6.0	7.3	11.1
95	3.3	8.1	15.6	5.4	10.4	17.9	8.5	12.7	19.5	10.9	14.4	20.4
100	7.1	13.6	23.3	10.6	17.4	26.6	14.4	20.8	29.2	17.9	23.5	30.8

Source: Daniel L. Johnson, Derivation of Presbycusis and Noise-Induced Permanent Threshold Shift, Ex. 310, Table 5, p. 29.

*The NIPTS values presented here are the decibel shifts in hearing ability for the 90th, 50th, and 10th percentiles of populations exposed for 10, 20, 30, and 40 years. These NIPTS values are the average of the shifts at the frequencies 1000, 2000, and 3000 Hz. Following Johnson's suggestion, the data published in his report for 80, 85, and 90 dB levels were adjusted to ensure that the NIPTS for a particular exposure duration at a particular exposure level would be equal to or greater than the NIPTS for shorter exposure durations (See Johnson, Ex. 310, p. 10).

Table A.8

Presbycusis Data from the U.S. Public Health Survey*
(dB)

	Age (Percentile of Population)											
	30 years			40 years			50 years			60 years		
Sex	(.9	.5	.1)	(.9	.5	.1)	(.9	.5	.1)	(.9	.5	.1)
Male	-1.3	3.7	12.3	0.3	6.7	23.0	2.0	10.7	29.7	4.3	15.3	40.0
Female	-3.3	1.7	8.7	-1.7	3.3	12.7	0.0	6.3	19.7	2.3	10.3	27.0

Source: Daniel L. Johnson, Derivation of Presbycusis and Noise Induced Permanent Threshold Shift, Ex. 310, Tables 7-8, p. 31.

*The data presented here are the average of hearing threshold levels at 1000, 2000, and 3000 Hz for the 90th, 50th, and 10th percentiles. As suggested by Johnson, a 2 dB correction has been applied to the values for the 90th and 10th percentiles (See discussion in Johnson, Ex. 310, pp. 13-14).

Table A.9

Risk Matrix - 15 dB Fence*
(Percent)

Exposure Level (dB)	Age Group 18-24	25-34	35-44	45-54	55-64	65+
			MALE			
<80	0.0	4.7	26	39	52	52
80-85	0.0	11	32	44	63	63
85-90	0.0	20	39	53	73	73
90-95	0.0	33	51	70	85	85
95-100	0.0	50	70	86	94	94
100+	0.0	60	81	92	97	97
			FEMALE			
<80	0.0	0.9	5.7	20	36	36
80-85	0.0	4.6	12	28	43	43
85-90	0.0	12	22	38	55	55
90-95	0.0	25	37	56	75	75
95-100	0.0	42	60	79	91	91
100+	0.0	52	73	89	96	96

Source: Daniel L. Johnson, Derivation of Presbycusis and Noise Induced Permanent Threshold Shift, (Ex. 310).

*Hearing threshold levels ≥15 dB average at 1000, 2000, and 3000 Hz.
Each cell of this matrix gives the percentage across the 15 dB fence for each age and exposure level combination. Johnson's report presents information for exposure levels of 80, 85, 90, 95, and 100 dB. Linear interpolation is used to calculate the percentages for the midpoints of the exposure ranges: 82.5, 87.5, 92.5 dB. The matrix is generated by using the computer program listed in the Appendix to the Johnson report.

Table A.10

Risk Matrix - 25 dB Fence*
(Percent)

Exposure Level (dB)	Age Group 18-24	25-34	35-44	45-54	55-64	65+
				MALE		
<80	0.0	0.3	7.8	17	31	31
80-85	0.0	1.3	12	22	36	36
85-90	0.0	3.8	18	29	42	42
90-95	0.0	10	28	41	56	56
95-100	0.0	22	41	59	76	76
100+	0.0	30	48	71	86	86
				FEMALE		
<80	0.0	0.3	0.3	3.8	13	13
80-85	0.0	0.6	1.3	7.6	19	19
85-90	0.0	1.6	4.6	14	27	27
90-95	0.0	5.8	14	27	41	41
95-100	0.0	16	29	47	65	65
100+	0.0	23	39	59	80	80

Source: Daniel L. Johnson, Derivation of Presbycusis and Noise Induced Permanent Threshold Shift, (Ex. 310).

*Hearing threshold levels $\geq$25 dB average at 1000, 2000, and 3000 Hz. Each cell of this matrix gives the percentage across the 15 dB fence for each age and exposure level combination. Johnson's report presents information for exposure levels of 80, 85, 90, 95, and 100 dB. Linear interpolation is used to calculate the percentages for the midpoints of the exposure ranges: 82.5, 87.5, 92.5 dB. The matrix is generated using the computer program listed in the Appendix to the Johnson report.

TABLE A.11

Risk Matrix - 40 dB Fence*
(Percent)

Exposure Level (dB)	Age Group 18-24	25-34	35-44	45-54	55-64	65+
			MALE			
<80	0.0	0.3	0.8	2.8	10	10
80-85	0.0	0.3	1.6	4.6	13	13
85-90	0.0	0.3	3.3	8.3	18	18
90-95	0.0	0.8	8.1	16	28	28
95-100	0.0	3.6	16	28	41	41
100+	0.0	5.8	21	35	48	48
			FEMALE			
<80	0.0	0.3	0.3	0.3	1.3	1.3
80-85	0.0	0.3	0.3	0.6	2.6	2.6
85-90	0.0	0.3	0.3	1.8	5.8	5.8
90-95	0.0	0.6	1.6	6.1	14	14
95-100	0.0	2.1	6.1	16	29	29
100+	0.0	3.3	9.3	23	37	37

Source: Daniel L. Johnson, Derivation of Presbycusis and Noise Induced Permanent Threshold Shift, (Ex. 310).

*Hearing threshold levels $\geq$25 dB average at 1000, 2000, and 3000 Hz.
Each cell of this matrix gives the percentage across the 15 dB fence for each age and exposure level combination. Johnson's report presents information for exposure levels of 80, 85, 90, 95, and 100 dB. Linear interpolation is used to calculate the percentages for the midpoints of the exposure ranges: 82.5, 87.5, 92.5 dB. The matrix is generated using the computer program listed in the Appendix to the Johnson report.

Table A.12

Midpoints of Exposure Levels Used for Calculations

Exposure Range (dB)	Midpoint (dB)
80-85	82.5
85-90	87.5
90-95	92.5
95-100	97.5

Source: OSHA, Office of Regulatory Analysis.

Table A.13

Number Of Hearing Impairments*
70 Years After Implementation of the Final Amendment
(Millions)

Exposure Level (dB)	18-24	25-34	35-44	45-54	55-64	65+	Total
				Age Group			
				MALE			
<80	-	.006	.111	.230	.374	.436	1.157
80-85	-	.009	.057	.099	.145	.168	.478
85-90	-	.003	.010	.015	.020	.023	.071
90-95	-	-	-	-	-	-	-
95-100	-	-	-	-	-	-	-
100+	-	-	-	-	-	-	-
Total Male	-	.018	.178	.344	.539	.627	1.706
				FEMALE			
<80	-	.002	.002	.022	.066	.076	.168
80-85	-	.002	.003	.014	.032	.037	.088
85-90	-	.001	.001	.003	.005	.006	.016
90-95	-	-	-	-	-	-	-
95-100	-	-	-	-	-	-	-
100+	-	-	-	-	-	-	-
Total Female	-	.005	.006	.039	.103	.119	.272
Total Male and Female	-	.023	.184	.383	.642	.746	1.978

Source: OSHA, Office of Regulatory Analysis.

*Hearing threshold levels >25 dB average at 1000, 2000, and 3000 Hz.
Data were generated by combining Table A.6 (number exposed) with Table A.10 (Risk Matrix for 25 dB Fence).

Determine the Number of Occupational Hearing Impairments

The results of the last step are the total number of persons who cross the fences from occupational noise exposure, presbycusis (hearing loss due to aging), or a combination of the two. The number of impairments caused wholly or partially by occupational exposure is simply the total number of impairments minus the number of impairments that would have been caused if aging were the sole cause of hearing loss.

Since, in the data presented by Johnson, exposure levels <80 dB are assumed to create no noise-induced hearing loss, the number of hearing impairments due to presbycusis can be calculated by multiplying the number of persons in each age category (Table A.6, line 7 for males; line 14 for females) with the corresponding lines in the risk matrices for exposures of <80 dB (Table A.10, line 1 for males, line 7 for females). Table A.14 presents the results of this calculation for the 25 dB fence.

The number of occupational hearing impairments remaining in the population is the total number of hearing impairments minus the number that would have occurred due to aging. For the equilibrium level of hearing impairments for the final amendment, this calculation is:

1.978 million - 1.816 million = .162 million.

Thus, 162,000 occupationally impaired individuals remain in the population even after the effects of the amendment are fully felt. The results of the adjustment for presbycusis are presented in Table A.15 for all three fences for the four regulatory alternatives.

TABLE A.14

Number Of Hearing Impairments*
Due To Presbycusis
(Millions)

	Age Group						
Sex	18-24	25-34	35-44	45-54	55-64	65+	Total
Male	-	.008	.152	.316	.513	.597	1.586
Female	-	.003	.002	.030	.090	.105	.230
Total	-	.011	.154	.346	.603	.702	1.816

Source: OSHA, Office of Regulatory Analysis.

*Hearing threshold levels $\geq$25 dB average at 1000, 2000, and 3000 Hz. These data are generated by multiplying the number of persons in each age group (Table A.6, lines 7 and 14) with the percentage expected to suffer hearing impairment from exposures <80 dB (Table A.10, lines 1 and 7). It is assumed that all hearing impairment for those exposed at <80 dB is due to presbycusis.

Table A.15

Number of Hearing Impairments*
70 Years After Implementation (Equilibrium Level)
(Millions)

Regulatory Alternative	15 dB fence		25dB fence		40dB fence	
	Total Number	Occupational Cause**	Total Number	Occupational Cause**	Total Number	Occupational Cause**
No Hearing Conservation Program	5.598	1.624	2.876	1.060	.934	.473
90 dB Regulatory Alternative	4.649	.675	2.167	.351	.597	.136
85 dB Regulatory Alternative	4.285	.321	1.978	.162	.520	.059
80 dB Regulatory Alaternative	4.099	.125	1.879	.063	.484	.023

Source: OSHA, Office of Regulatory Analysis.

*Number of persons with hearing threshold levels $\geq$15, 25, and 40 dB average at 1000, 2000, 3000 Hz.

**Occupational Cause = Total number minus number that would normally occur due to presbycusis. For 15 dB, presbycusis equals 3.974 million; for 25 dB, 1.816 million; for 40 dB, .461 million.

Calculation of the Interim Number of Hearing Impairments

The number of hearing impairments under each of the regulatory alternatives was also calculated for a number of years prior to the establishment of equilbrium--specifically, 10, 20, 30, and 40 years following implementation.

These calculations followed the same procedures outlined above for the equilibrium levels. Steps 1 through 6 were followed with one additional step between steps 2 and 3 to adjust for hearing protector use. This additional step was necessary because in each of the interim years before equilibrium is achieved, the population will contain many people who have only spent part of their lives working under the hearing conservation amendment. For example, individuals who are 40 years old in 1980 have already spent 20 years working in a pre-regulation noise environment. In 1990, they will have spent 20 years in a pre-regulation environment and 10 years in a post-regulation environment. These individuals will never receive the full benefits of the hearing conservation amendment because they have already lost some hearing ability from exposure during the first 20 years.

In order to estimate the number of hearing impairments in each of the interim years, the pre- and post-regulation exposure levels were averaged to obtain an equivalent continuous exposure level. Following the methodology of the CPA report (Ex. 232, pp. B-11 to B-13, B-16), these equivalent exposure levels were calculated using the equal energy relationship:

$$L_{eq} = 10 \log \frac{\sum t_i \, 10^{(L_i/10)}}{\sum t_i}$$

Where L_i = exposure levels (dB)
t_i = years at each exposure level*

Table A.16 presents a matrix of equivalent, continuous exposure levels for the final amendment in the year 1990. The last two lines of this table give the various exposure levels before and after implementation of the regulation for the various age groups. This table was used to calculate an age by exposure level distribution similar to that shown in Table A.5. The following steps remained unchanged: The age by exposure level distribution was used to calculate the number of males and females exposed, the same risk matrix was applied to those exposures to determine the total number of hearing impairments, and then the number of occupationally caused impairments was calculated. Table A.17 presents the results of those calculations and provides the information needed to calculate the number of hearing impairments prevented by the regulation.

Finally, the total person-years of impairment prevented in the first 70 years after implementation were calculated. As Figure 2 of the Alternatives Section shows, the increase in the number of impairments prevented is not linear over time. The number of person-years of impairment prevented is equal to the area underneath

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*D.W. Robinson and M.S. Shipton, Tables for the Estimation of Noise-Induced Hearing Loss (Teddington, United Kingdom: National Physical Laboratory, 1977) pp. 5-6.

each of these curves. An approximation of these areas can be made using the procedure given in the CPA report (Ex. 232, pp. B-23 to B-24):

Person-years of hearing impairment prevented =

$$(10\ \text{yrs.})\ \frac{(0+P_{10})}{2} + (10\ \text{yrs})\ \frac{(P_{10} + P_{20})}{2} +$$

$$(10\ \text{yrs})\ \frac{(P_{20} + P_{30})}{2} + (10\ \text{yrs})\ \frac{(P_{30} + P_{40})}{2} + (30\ \text{yrs})\frac{(P_{40} + P_{70})}{2}$$

Where P_n = number of hearing impairments prevented in year n after implementation.

Table A.16

Equivalent Continous Exposure Levels (L_{eq})
For The Final Amendment 10 Years After Implementation
(dB)

Exposure Level (dB) Pre-Regulation	Exposure Level (dB) Post-Regulation	Age Group 18-24	25-34	35-44	45-54	55-64	65+
<80	<80	<80	<80	<80	<80	<80	<80
82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5
87.5	72.5	72.5	72.5	84.6	85.8	86.3	87.5
92.5	77.5	77.5	77.5	89.6	90.8	91.3	92.5
97.5	82.5	82.5	82.5	94.6	95.8	96.3	97.5
100.0	87.5	87.5	87.5	97.2	98.2	98.8	100.0
Years of Pre-Regulation Exposure		0	0	10	20	30	40
Years of Post-Regulation Exposure		0	10	10	10	10	0

Source: OSHA, Office of Regulatory Analysis.

Table A.17

Occupational Hearing Impairments (25 dB Fence), 10, 20, 30, 40, and 70 Years After Implementation (Millions)

Regulatory Alternatives	Years 10th	20th	30th	40th	70th
No Hearing Conservation Program	1.060	1.060	1.060	1.060	1.060
90 dB Regulatory Alternative	.886	.683	.507	.428	.351
85 dB Regulatory Alternative (Final Amendment)	.848	.583	.364	.261	.162
80 dB Regulatory Alternative	.825	.512	.265	.163	.063

Source: OSHA, Office of Regulatory Analysis.

APPENDIX B

SAMPLE COST CALCULATION - SIC 20

Monitoring

The first step in the estimation of the annual monitoring cost for SIC 20 was to calculate the average number of actual exposure measurements expected for each of the five establishment size categories. The estimating equation used was:

$$M = (PM/100)\ (PW/E)\ (N)$$

were: M = the number of measurements

PM = the percent of workers actually measured (Table 9)

PW = the number of production workers (Table 10)

E = the number of establishments (Table 10)

N = the percentage of workers exposed to ≥80 dB (Table 11)

This yields:

1-19 employees: 100/100 x 75,583/13,118 x 0.47 = 2.7

20-49 employees: 60/100 x 122,613/4,783 x 0.47 = 7.2

50-99 employees: 50/100 x 158,034/2,813 x 0.47 = 13.2

100-249 employees: 40/100 x 292,110/2,332 x 0.47 = 23.5

≥250 employees: 30/100 x 527,859/1,248 x 0.47 = 59.6

The next step is to determine the cost if employers use noise consultants to perform the monitoring tasks. Table 8 shows that the cost of measuring the exposure of 2.7, 7.2, 13.2, 23.5, and 59.6 employees is \$412, \$412, \$593, \$855, and \$1,298, respectively. Because the monitoring will generally be conducted biennially, the annual monitoring cost by consultant will be half of this, or \$206, \$206, \$296.5, \$428, and \$649 for the five establishment sizes.

Next, the cost of performing the monitoring with in-house staff for each size category was estimated. The estimating equation for the average annual cost for each establishment was \$260 + (\$10 x the number of measured workers/2 years). This gives:

1-19 employees: \$260 + (\$10 x 2.7/2) = \$273.5

20-49 employees: \$260 + (\$10 x 7.2/2) = \$296

50-99 employees: \$260 + (\$10 x 13.2/2) = \$326

100-249 employees: \$260 + (\$10 x 23.5/2) = \$377.5

≥250 employees: \$260 + (\$10 x 59.6/2) = \$558

These estimates were then compared to the cost of hiring noise consultants. Because employers will choose the least costly alternative, establishments in the three smaller size groups will hire consultants at the annual cost of \$206, \$206, and \$296.5. Establishments in the largest 2 size groups were assumed to purchase noise monitoring equipment and monitor in-house at an annual cost of \$377.5 and \$558 respectively.

Multiplying the number of firms in each size group (Table 10) by the average establishment cost yields:

1-19 employees:	13,118 x \$206 =	\$2,702,308
20-49 employees:	4,783 x 206 =	985,298
50-99 employees:	2,813 x 296.5 =	834,055
100-249 employees:	2,332 x 377 =	879,164
≥250 employees:	1,248 x 558 =	696,384
		\$6,097,209

Thus, the cost of complying with all of the monitoring provisions for SIC 20 is estimated at \$6.1 million per year.

To estimate the new monitoring costs it was assumed that 74 percent of the firms with more than 100 employees are already complying with this provision. This adjustment gives:

1-19	employees:	13,118 x \$206	=	\$2,702,308
20-49	employees:	4,783 x 206	=	985,298
50-99	employees:	2,813 x 296.5	=	834,055
100-249	employees:	.74 x 2,332 x 377	=	650,581
≥250	employees:	.74 x 1,248 x 558	=	515,324
				\$5,687,566

OSHA, therefore, estimated the new monitoring costs for SIC 20 at \$5.7 million per year.

Audiometric Testing

The equation used to estimate the cost of audiometic testing for establishments with under 50 employees is:

C = (PW - SW) x P x (2 W + \$15) x 1.2 tests + rechecks

= (198,196 - .1685 x 17,000) x 0.28 x (2 x \$6.27 + \$15) x 1.2

= \$1,807,332

where: C = the annual cost

PW = the number of production workers (Table 10)

SW = the number of seasonal workers (17,100 x percent of workers in this establishment size as derived from Table 10)

P = the fraction of workers exposed to noise >85 dB (Table 11)

W = the industry average annual wage

For intermediate sized establishments (50-249 employees), the estimating equation is:

C = (PW -SW) x P x (0.5 W + \$12) x 1.2 tests + rechecks

= (450,144 - .3827 x 17,000) x 0.28 x (0.5 x \$6.27 + \$12) x 1.2

= \$2,256,059

Audiometric testing costs for the largest establishments ($\geq$250 employees) were estimated as follows:

$C = (\$650 \times E) + (PW - SW) \times P \times (\$4.17 + 0.5\ W) \times 1.2$

$= (\$650 \times 1{,}248) + (527{,}859 - .44878 \times 17{,}000) \times 0.28 \times (\$4.17 + 0.5 \times \$6.27) \times 1.2$

$= \$2{,}088{,}094$

where E = the number of establishments.

Summing the costs for the three size groups yields \$1,807,332 + \$2,256,059 + \$2,088,094 = \$6,151,485 as the total annual audiometric testing cost for SIC 20. To account for existing programs, the labor-related costs of the largest establishments were reduced by 20 percent. Thus, the estimating equation for this size group becomes:

$C = (\$650 \times E) + (PW-SW) \times P \times 0.8 \times (\$4.17 + 0.5W) \times 1.2$

$= (\$650 \times 1{,}248) + (527{,}859 - .44878 \times 17{,}000) \times 0.28 \times 0.8 \times (\$4.17 + 0.5 \times \$6.27) \times 1.2$

$= \$1{,}832{,}715$

This gives \$1,807,332 + \$2,256,059 + \$1,832,715 = \$5,896,106 as the total new annual audiometric testing cost for this SIC.

Hearing Protection

The annual cost for the hearing protector provision was estimated at:

$C = \$10 \times PW \times P$

$= \$10 \times 1{,}176{,}199 \times 0.28$

$= \$3{,}293{,}357$

where: C = the annual cost

PW = the number of production workers (Table 10)

P = the fraction of workers exposed to noise $\geq$85 dB (Table 11)

To account for current industry practice, 20 percent of the workers exposed to a TWA $\geq$90 dB were assumed to have already been provided with hearing protectors. This estimating equation is:

$C = \$10 \times (PW \times P - (0.2 \times PW \times Q))$

$= \$10 \times (1,176,199 \times 0.28 - (0.2 \times 1,176,199 \times 0.16))$

$= \$2,916,974$

where: Q = the fraction of workers exposed to noise $\geq$90 dB (Table 11)

Training

The annual cost of training for SIC 20 is estimated at:

$\$Tr = (W \times PW \times P) + \$10e + (10/30 \times PWE \times P)$

$= (\$6.27 \times 1,176,199 \times 0.28) + (\$10 \times 20,714) + (1/3 \times 819,969 \times 0.28)$

$= \$2,348,605$

where: $Tr = the cost of training

W = the hourly production worker wage

PW = the number of production workers (Table 10)

P = the fraction of workers exposed to $\geq$85 dB (Table 11)

e = the number of establishments with less than 100 employees (Table 10)

PWE = the number of production workers in establishments with over 100 employees (Table 10)

Warning Signs

The cost for warning signs in SIC 20 were estimated as:

$\$S = \$3.50 \times PW \times P/10$

$= \$3.50 \times 1,176,199 \times 0.28/10$

$= \$115,268$

where: $S = the cost of warning signs

PW = the number of production workers (Table 10)

P = the fraction of workers exposed to $\geq$85 dB (Table 11)

Recordkeeping

The cost of keeping records of worker exposures and audiograms was estimated at:

$\$R = 1/6\ W \times PW \times P$

$= 1/6 \times \$6.27 \times 1{,}176{,}199 \times 0.28$

$= \$344.156$

where: $\$R$ = the cost of keeping these records

W = the hourly production worker wage

PW = the number of production workers (Table 10)

P = the fraction of workers exposed to $\geq$85 dB (Table 11)

In addition, the recordkeeping cost for periodic calibration of audiometers was calculated as:

$\$R = 2/6\ W \times E$

$= 2/6 \times \$6.27 \times 1{,}248$

$= \$2{,}608$

where: E = the number of establishments with at least 250 employees (Table 10)

Thus the total annual cost of recordkeeping is estimated at \$344,156 + \$2,608 = \$346,764.

Total Cost

The total compliance costs for SIC 20 were calculated by summing the cost of each provision as shown in Table B-1.

Table B-1

Estimated Compliance Cost for SIC 20

Provision	Total Compliance Cost	Total New Compliance Cost
Monitoring	$ 6,097,209	$ 5,687,566
Audiometric Testing	6,151,485	5,896,106
Hearing Protectors	3,293,357	2,916,974
Training	2,348,605	2,348,605
Warning Signs	115,268	115,268
Recordkeeping	346,764	346,764
Total	$18,352,688	$17,311,283*

Source: OSHA, Office of Regulatory Analysis.

*This total differs slightly from that provided in Table 13 because of different rounding procedures used in the computerized calculations which generated that table.