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SOME CONSIDERATIONS IN CHOOSING AN OCCUPATIONAL NOISE EXPOSURE REGULATION

FEBRUARY 1976

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Some issues in conflict regarding the proposed OSHA standard for occupational exposure to noise are examined. These include material impairment, the extent of possible hearing loss, non-auditory effects, and the nature of social and economic costs and benefits of regulation at 85 dBA and 90 dBA exposure limits. A preliminary analysis of the methodology and difficulties in arriving at cost-benefit estimates is included. Regulatory alternatives such as new plant standards, industry-specific standards, variances and abatement agreements, administrative controls, and personal protective equipment are explored.

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PREPARED BY

CENTER FOR POLICY ALTERNATIVES
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

UNDER
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FOR THE

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF NOISE ABATEMENT AND CONTROL
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PREFACE

This report was presented in testimony on July 23, 1975 at hearings on the proposed OSHA noise standard by Dr. Nicholas A. Ashford. He was accompanied by Dr. Dale Hattis and Mr. George Heaton. Dr. Ashford is a senior staff member of the Center for Policy Alternatives at the Massachusetts Institute of Technology, and has had formal graduate training in science, law and economics. Dr. Hattis is an environmental scientist and Mr. Heaton is a lawyer and regulatory policy analyst. Also participating in this study was Judith Katz, technical assistant at the Center for Policy Alternatives, and currently completing a law degree. While the authors did not claim to be experts in noise regulation, they have been considerably involved with the problems of technology and society, with particular emphasis on the areas of occupational health and safety, environmental regulation, and the effects of government intervention in the innovation process.

Mr. George Eads of the Council on Wage and Price Stability has expressed his agency's dismay at the wide divergence of opinion on fundamental issues in the OSHA proceedings and has expressed a wish for a narrowing of the differences. However, there appears to be less important controversy about the data itself than about how to deal with uncertain data or what standard of proof must be met to justify the setting of the standard. In short, surrogate arguments have arisen which have obscured basic philosophical differences. Below, the authors hope to articulate the nature of the different views and their implications for the adoption of an appropriate standard.

Both sources of confusion in the rationale for standard-setting and some of the technical issues in conflict were discussed. It is hoped that this working paper will be of assistance in the selection of a final workplace noise standard by helping to elucidate both the nature of the social and economic costs and benefits and alternate bases for decision-making in this troubled area.

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Section 1

INTRODUCTION

THE RATIONALE FOR STANDARD-SETTING

In difficult economic times, it is expected that a society reexamine the question of whether the longer-range benefits that are likely to accrue from environmental/safety regulation are justified by potentially high shorter-range costs. This is the simplest way to state the problem; it can also be the most deceptive. There are really three important considerations relevant to the Occupational Safety and Health Administration's (OSHA) standard-setting function:

1. The important distinctions in the justification of government intervention in occupational or environmental health matters as compared to economic regulation such as that found in antitrust or utility regulation.

2. The limitations of traditional cost-benefit techniques for making social decisions.

3. The mandate of the OSHAct.

Justification for Government Intervention in Occupational or Environmental Health Matters

The rationale for government intervention in the marketplace is usually expressed in terms of one of two purposes:

1. To improve the working of the market for goods and services by encouraging competition, economic efficiency, and diversity of available goods and services.

2. To ameliorate the adverse consequences of market activities and technology in general by reducing the attendant social costs.

The underlying reason for pursuing these goals is not to improve the efficiency of the market for its own sake, but to optimize social welfare. Economic regulation generally addresses itself to the first purpose by attempting to ensure that the price mechanism operates efficiently to properly allocate goods and services between economic sectors and between producers and consumers, but also to properly allocate resources between generations. Economic regulation, properly carried out, thereby is generally expected to reduce the price of the goods and services it seeks to regulate.

Occupational or environmental health regulation, on the other hand, attempts to internalize the social costs attending market activities – especially those associated with technology – and it does this by making sure that the prices of goods and services reflect the true costs to the consumer. Thus, it might be expected that prices would increase in some cases to reflect true costs. Including the costs of minimizing adverse health consequences from technology in the price of goods and services represents a shift in the way the costs are accounted for and not necessarily a true increase in the cost to society.

Thus, it can be seen that the two kinds of regulation – economic and occupational or environmental health – are expected to operate somewhat differently, because they address different aspects of market activity. There is, however, one further critical distinction: occupational or environmental health regulation also has a fundamental purpose, the protection of certain groups of people – for example, children, workers in an asbestos plant, or the less educated. This is justified under the principle of equity or fairness, whereby some economic efficiency is said to be sacrificed for the health or safety of those special groups.

The fact that economic efficiency is sometimes traded for equity considerations should not be disturbing unless it is either unnecessary for the result or one forgets that economic efficiency is a measure of *maximizing* rather than *optimizing* social welfare. In fact, it should be remembered that small business is paid special attention in formulating economic regulatory strategies – and there is a conscious tradeoff between economic efficiency and equity considerations in maintaining the viability of the small firm. Regulatory policies aimed at fairness to the worker are no less justified.

Having reviewed some of the distinctive justifications for occupational or environmental/health regulation, the question arises as to the appropriateness of traditional cost-benefit techniques for making social decisions in this area of regulation.

Appropriateness of Cost-Benefit Analysis for Making Social Decisions

Economic analysis not only helps to describe many issues in occupational or environmental health regulation, it also provides tools such as cost-benefit analysis for helping evaluate the consequences of decisions.

Some of the major problems in using cost-benefit analysis arise because health and safety benefits are not easily compared to dollar costs. The market value of human life is not adequately represented in the traditional measures of lost wages, awards for pain and suffering, or willingness to trade off risk of harm for lower prices in the marketplace. It is extremely difficult for one to relate to long-range, low-probability risks of harm or, to put it another way, it is difficult to value benefits likely to accrue in the future, if at all. Further, since the costs and benefits of regulation occur in different time frames, one is faced with the inevitable difficulty of applying an appropriate discount rate to items difficult, if not impossible, to monetarily quantify in the first place. The situation is further complicated because often too little is known about adverse health effects of occupational and environmental hazards and decisions, and valuation of these effects must nonetheless be made.

Often, decision-making has economic efficiency as its only objective. However, the question of who pays the cost and who reaps the benefit is also important. Minimizing nonrandom victimization through a concern for individual justice is a legitimate social goal that may at times conflict with attainment of economic efficiency. Society may prefer to move away from an economically efficient point to have a fairer distribution of costs and benefits. Of course, different people view what is fair differently – but this fact makes the consideration of equity no less important. Whatever the alternative value judgments are as to what is fair, the costs should be known for those alternatives being considered.

In short, cost-benefit analysis takes no special notice of the fact that the cost and benefit streams accrue to different elements of society. To what extent then is cost-benefit useful as a rational basis for action?

Expert consultants, economists or otherwise, have little more to contribute than other citizens to the evaluation of equity effects of occupational health decisions. Such an evaluation should be made collectively by an informed public and should be a reflection of the societal values. The value put on equity consideration in occupational health matters has been expressed in the OSHAct and is, in practice, further refined and interpreted by the administrative law and judicial systems.

What economists can do is specify the equity effects, as well as allocative effects, of regulatory decisions. Despite its limitations and the methodological problems associated with its use, one might think that cost-benefit analysis is at least employed in good faith, solely as a technical aid by decision-makers. In practice, unfortunately, this description is often not the case. Cost-benefit analysis is often used in an attempt to convince other parties that a course of action (predetermined on other grounds) is justified. Value judgments are often hidden in the assumptions on which the calculation is based, and balancing costs and benefits without consideration of equity is value-laden itself – it is a decision to ignore equity.

The Mandate of the OSHAct

Because lives and dollars are incommensurables, there is no theoretically correct way to balance costs and benefits. The decision is a political decision and Congress has given guidance on what the proper OSHA posture should be in section 6(b)(5) of the OSHAct.

> The Secretary, in promulgating standards dealing with *toxic materials or harmful physical agents* under this subsection, shall set the standard which most adequately assures, *to the extent feasible,* on the basis of the *best available evidence,* that *no* employee will suffer *material impairment* of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard *for the period of his working life.*

Whether or not OSHA complies with its mandate depends on the interpretation of what "to the extent feasible" implies in terms of economic and technological burdens and how many workers are left unprotected. The term material impairment can be defined to give a larger or smaller number of these unprotected. Finally, the minimum quality of the evidence that OSHA uses to make its decisions will also determine the kind of standard it will establish. "To the extent feasible" by ordinary construction would appear to mean that the workplace is to be made safe as long as the industry is not incapable of complying. A balancing of costs and benefits is to be done heavily in favor of worker health, not necessarily with the result that workplace disease is at an economically efficient level.

Daniel Boyd, Director of the OSHA Office of Standard Development, has stated in his testimony that: "The levels which OSHA has proposed are designed to protect a *majority* of the occupationally-exposed population from noise-induced hearing impairment," and further that "The basic issue has been how to define impairment of hearing as distinguished from loss of hearing." This, in fact, is not the basic issue. The fact is that given whatever conflicting definition of hearing impairment has been offered, there still remains a substantial proportion of workers harmed by either an 85 or a 90 dBA standard, and there are approximately twice as many workers at risk at 90 dBA than as at 85 dBA. The basic issue is whether OSHA should, under its mandate, impose additional costs on industry and society. Further, in its proposed standard, OSHA has decided not to use as part of material impairment the existing evidence of nonauditory harm – especially possible implications of noise for coronary heart disease.

In the setting of other health standards, OSHA has been considerably more protective of the worker in adopting relatively more stringent standards. Further, the courts have upheld the OSHA protective posture as legislatively determined. In a D.C. Circuit case challenging the asbestos standard,* Judge McGowan stated, in commenting on the standard of review:

> "there are areas where explicit factual findings are not possible, and the act of decision is essentially a prediction based upon pure legislative judgment, as when a Congressman decides to vote for or against a particular bill. Furthermore, policy choices of this sort are not susceptible to the same type of verification or refutation by reference to the record as are some factual questions. Consequently, the court's approach must necessarily be different no matter how the standards of review are labelled."

In a Second Circuit case challenging the vinyl chloride standard,** former Supreme Court Justice Clark stated, in commenting on the asbestos case approach, "The problems involved in according judicial review in such circumstances have been wisely discussed by Judge McGowan." In commenting on plaintiff's contention that the available scientific evidence does not support the 1-ppm standard, Justice Clark stated:

> "We find, however, that the evidence is quite sufficient to warrant the Secretary's choice. First, it must be remembered that we are dealing here with human lives... . Moreover the animal exposure study ... identified fatal liver angiosarcoma and other kidney and liver diseases at the 50 ppm level."

> "As in the IUD [asbestos] case, the ultimate facts here in dispute are on the frontiers of scientific knowledge, and though the factual finger points, it does not conclude. Under the command of OSHA, it remains the duty of the Secretary to act to protect the working man, and to act even in circumstances where existing methodology or research is deficient. The Secretary, in extrapolating the MCA [Manufacturing Chemists' Association] study's findings from mouse to man, has chosen to reduce the permissible level to the lowest detectable one. We find no error in this respect."

OSHA may wish to distinguish the noise standard from the standards for asbestos or vinyl chloride, because in the latter cases, life and death issues are involved. First, the OSHAct does not speak in terms of life and death issues and, secondly, if OSHA gives any acknowledgment of noise as a general stressor and a cocausitive factor in coronary heart disease and other diseases, life and death issues are involved.

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*Industrial Union Department, AFL-CIO v. Hodgson.

**The Society of the Plastics Industry, Inc. v. OSHA.

Having discussed the issues important in the rationale for standard-setting, the nature of some of the scientific and economic issues in conflict will be discussed in the following section.

ISSUES IN CONFLICT

The nature of the debate on some of the major issues in the current hearings are briefly summarized in the following paragraphs. Also some new ways of looking at the data are discussed and an attempt is made to construct an elementary balance sheet indicating the important benefits as well as costs.

Material Impairment

The concept of material impairment has been the focus of a considerable amount of discussion. This is not, of course, surprising in view of the legal mandate to the Secretary to prescribe standards that, insofar as feasible, will prevent material impairment in all workers. OSHA has explicitly accepted the AAOO lower limit for hearing handicap – a 25-dB hearing level (Re: ISO) at the average of 0.5, 1.0 and 2.0 kilohertz – as the dividing line for defining the beginning of material impairment. Others have stressed the importance of hearing loss at higher frequencies for accurate reception of speech consonants and other sounds, particularly under the less-than-optimal listening conditions often found in daily life. Since higher frequencies tend to be much more vulnerable to noise, EPA believes that the OSHA definition ignores losses of function that are of appreciable significance to many affected individuals. Dr. Kryter explained in great detail the basis of this contention.

The significance of the convention used is that it determines the number of workers left unprotected by a given level of exposure.

Effects of nonauditory harm do not figure into the OSHA definition of material impairment. (See following discussion of nonauditory effects.)

Quantification of Auditory Effects for 8-Hour Exposures

There has also been considerable debate over the merits of the various epidemiological studies that have been used to describe and predict relationships between noise exposure and hearing impairment in worker populations. EPA, in its "Levels Document" and elsewhere, uses three data sets (from studies by Baughn, Robinson/Burns, and Passchier-Vermeer) in its analyses, which, it contends, do not differ substantially from one another. OSHA, in its original response to EPA criticism of the noise standard, rejected the Baughn and Passchier-Vermeer studies in favor of calculations based solely on the Robinson/Burns study. In these hearings, in response, Dr. Burns himself, testifying as an EPA witness, contends that OSHA has incorrectly applied the formula summarizing the Robinson/Burns findings in a way that seriously understates the hearing damage to be expected under the 90-dBA standard. Dr. Kryter, another EPA witness, agrees with the OSHA rejection of the Passchier-Vermeer formula, but strongly defends the Baughn study. This will be examined in more detail later. On the other hand, many industry representatives seem to reject the results of all three studies as inapplicable to their own workforces because the enlightened use of audiometry and personal hearing protection tends to lessen hearing impairment. Labor and OSHA oppose primary reliance on personal protective equipment because of unreliability and difficulty in enforcement.

Time-Intensity Tradeoff

A further issue to be dealt with only in passing is whether the regulation should allow a 3-dBA or a 5-dBA increase in exposure level for each halving of exposure time. The EPA and labor positions are that the Robinson/Burns study indicates the appropriateness, for long-term damage-predicting purposes, of equating exposures of equal energy, implying a 3-dBA trading ratio. OSHA and industry, however, relying on some experiments with evenly spaced noise and temporary threshold shift, believe that the 5-dBA trading ratio should be adopted.

Nonauditory Effects

OSHA takes the position that because of the uncertainties in the existing scientific data, nonauditory effects should be essentially ignored. EPA reviews them in their levels document and has advocated that they be considered. The NIOSH criteria document does not deal extensively with this category of potential harm, but Dr. Finklea's testimony cites recent NIOSH findings now in the process of final publication indicating significant noise effects on the incidence of medical problems, absenteeism, and job accidents, and advocates their consideration. Some implications of possible nonauditory effects of noise stress will be discussed in some detail subsequently.

The Benefit Side and Problems of Quantification

Mr. George Eads of the Council on Wage and Price Stability contends that it is unknown if the benefits of noise control are likely to exceed the costs based on the record to date.

Further, he implores OSHA to "give due consideration to both benefits and costs." One may not know if the benefits exceed the costs for two reasons: (1) since it is difficult – perhaps impossible – to place a value on hearing impairment alternative valuations of this factor are not high enough to justify the costs, or (2) that only those benefits that are easily monetarily quantifiable in theory should be considered – such as worker compensation saved, reduced absenteeism, and increased productivity. On the other hand, on cross-examination an OSHA witness from BBN stated, "An incomplete calculation of benefits is worse than none at all." EPA disagrees. Both monetarily quantifiable and nonmonetary benefits should at least be estimated to relate to what appears to be the now sacrosanct BBN cost estimates of compliance.

Appropriate Form of the Standard

There has been considerable controversy surrounding the issue of how the workplace noise standard should be structured. Major points of conflict have been:

- Whether industry-specific or an accross-the-board standard should be promulgated,
- The appropriate mix of engineering and administrative controls and personal protective equipment,
- Whether a stricter standard should be required for newly designed workplaces, and
- The compliance time scenario.

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(2) Ashford, Nicholas A., et al. *The Impact of Governmental Restrictions on the Use and Production of Chemicals: Interim Report.* Center for Policy Alternatives, Massachusetts Institute of Technology, supported by the U.S. Council on Environmental Quality, CPA-75-2 (February 1975).

(3) Center for Policy Alternatives, Massachusetts Institute of Technology. *National Support for Science and Technology: Evaluation of Foreign Experiences,* CPA 75-12 supported by the National Science Foundation and the Alfred P. Sloan Foundation (Fall 1975).

Section 2

ANALYSIS OF SOME ISSUES IN CONFLICT

MATERIAL IMPAIRMENT

It has already been emphasized that material impairment is fundamentally a legal/political term, not a scientific/technical term. To the degree that the Secretary of Labor ultimately defines it in promulgating the permanent noise standard, it will represent a policy judgment; a political/social judgment of value – hopefully made in the awareness of scientifically defined losses in worker health and functional capability, but not objectively derivable from the technical facts. Consider the hypothetical situation presented in Figure 2-1.

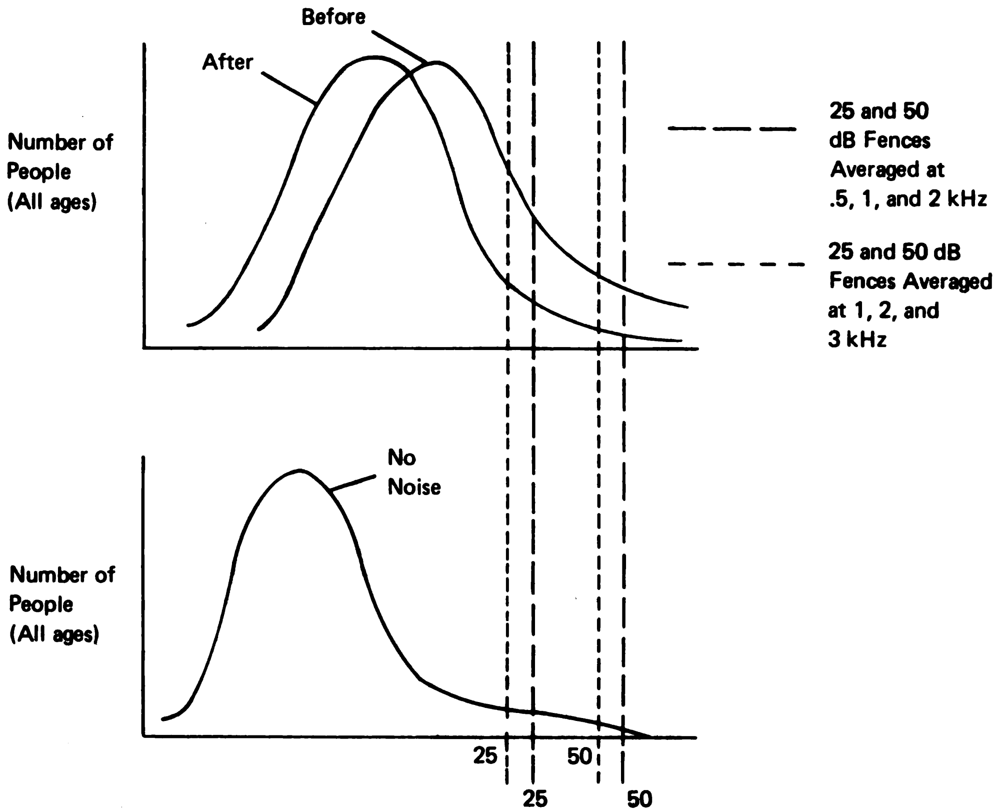

Figure 2-1. Hypothetical hearing level distributions in workers

The solid curves in the upper part of the figure represent the distributions of hearing levels expected in the population before, and many years after, a hypothetical noise regulation is imposed. The solid curve in the lower part of the figure represents the distribution of hearing levels if somehow all workplace noise exposure were halted. Defining all aspects of the differences between these three distributions* is as far as one can get by objective technical criteria. Clearly, in this example essentially the whole population has somewhat better hearing after the regulation than before, but they are essentially all still impaired to some degree when compared with hearing levels they would enjoy if noise exposures were reduced to the point at which there was absolutely no effect. Whose impairment should be labeled material for purposes of social decision-making on standards? It depends on the relative judgment of value one wishes to assign to various degrees of functional capacity.

Some assignments of value can be made in a variety of ways. The beginning of one type of value judgment is to summarize the differences between the curves by drawing one or another of the broken lines (fences) indicated in Figure 2-1 and categorize the moving of an individual from one side of the line to the other as a material impairment. This is the type of value judgment implicit in the risk calculations of the OSHA Environmental Impact Statement and the calculations to be presented subsequently. Which horizontal scale one uses to define "hearing level" depends on a judgment of which hearing frequencies are of social value, and exactly where the line is drawn depends on a judgment of the approximate point at which a socially undesirable loss of function has taken place.** However, it is clear that if OSHA determines that all individuals above a given hearing level (whatever the scale) should be labelled materially impaired, and if the facts are as sketched in the figures, then the only basis under the Act by which OSHA can choose a regulation that increases the number of individuals above the fence would be a determination that a stricter regulation would not be feasible.

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*Including the time it would take to achieve various intermediate hearing level distributions and the communication and other difficulties observable at different hearing levels. (This will be covered in the following section.)

**In doing this, however, it must be understood that: (1) one is assigning no social value to the changes in hearing levels of those people who do not cross the line (both those which, without noise, would have hearing levels very much better than the fence level, and those which, without noise, would have hearing levels already worse than the fence level); the actual significance of the change in hearing levels to those individuals moved across the line will be less than the average difference between all those above and all those below the given fence. If one bears in mind the presence of both of these opposing distortions, this technique for summarizing the data can be used as a basis for judging the value of alternative regulations.

Table 2-1 illustrates this point with actual data from the Baughn study[1] and a study conducted by NIOSH,[2] and for the AAOO's 25 dB fence averaged at 0.5, 1, and 2 kHz, and for several alternative fences which have been or might be suggested in its place. It can be

Table 2-1

Percent impaired with different definitions of impairments*

	Baughn Data		NIOSH Data	
Age:	46–54**		46–54**	
Exposure Level:	85	90	85	90
Fence:				
15 dB (.5, 1, 2 kHz)				
Total	83	89		
Presbycusis	75	75		
Net	8	14		
20 dB (.5, 1, 2 kHz)				
Total	50	61		
Presbycusis	39	39		
Net	11	22		
25 dB (.5, 1, 2 kHz)				
Total	26	36	19	31
Presbycusis	17	17	10	10
Net	9	19	9	21
25 dB (1, 2, 3 kHz)				
Total			30	43
Presbycusis			18	18
Net			12	25
50 dB (.5, 1, 2 kHz)				
Total	1.5	2		
Presbycusis	1	1		
Net	.5	1		

*Percent exceeding different "fences."

**Between 31 and 32 years average exposure.

seen that although the total numbers of people considered impaired rises with each lowering (movement to the left on Figure 2-1) of the fence, so does the "presbycusis" correction (numbers of people who would be impaired to that degree in the absence of noise) which must be subtracted from the total.

The controversy surrounding the issues of how to define the fence has little to do with the issue of the benefit gained by adopting an 85 dBA as opposed to a 90 dBA standard. For reasonable fence values, the number of workers additionally benefitted, i.e., prevented from crossing the fence remains approximately the same. Further, even at the rather unreasonable fence value of 50 dB, differences between no exposure (presbycusis), 85 dBA exposure, and 90 dBA exposure are still apparent. Note that about twice as many additional people are harmed at 90 dBA as at 85 dBA. Whatever the fence used, there are considerably more workers impaired than no employee – and that, not the exact definition of material impairment, is the *issue.*

An alternative way of defining "material impairment" is implicit in EPA's summarization of data in the Levels document.[3] EPA makes the value judgment that "any measurable hearing loss at any frequency is unacceptable if the goal is protection of health and welfare with an adequate margin of safety." EPA stresses the importance for daily life of the high frequencies neglected in the AAOO criteria and chooses for special attention the most sensitive frequency for noise-induced damage (4000 Hz). Summarizing the hearing loss data for this frequency is Figure 2-2.

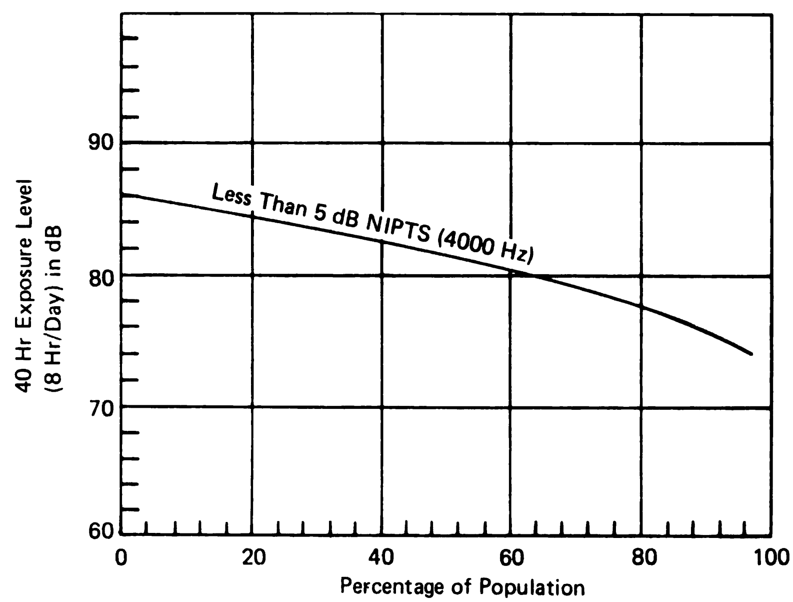

Figure 2-2. Percentage of exposed population that will incur no more than 5 dB NIPTS shown as a function of exposure level. Population ranked by decreasing ability to hear at 4000 Hz. (See appendix C for rationale.)

EPA concludes that the 8-hour exposure level which protects virtually the entire population from greater than 5 dB NIPTS* is 73 dB. Recognizing the difficulties in achieving this low a noise level in the near future, EPA has, of course, advocated the much less protective 85 dBA level for 8 hours as an interim goal.

EPA points out that the AAOO fence was originated for purposes of workmen's compensation, in order to define the point of beginning handicap. Whether beginning handicap and material impairment should be regarded as equivalent is open to question.**

The choice in defining material impairment between OSHA's current criteria, EPA's criteria, or something in between, depends on the interpretation of the fundamental value judgment made by Congress when it concluded the term in its legislative mandate to the Secretary of Labor. However, no matter what definition of material impairment is used, no standard presently proposed comes very close to assuring that no employee suffer that impairment.

Further, it should be recognized that the entire discussion so far, omits from consideration of material impairment the nonauditory effects. We shall return to these in a subsequent section.

HEARING IMPAIRMENT IN THE UNITED STATES – CURRENT AND EXPECTED LEVELS UNDER DIFFERENT OSHA STANDARDS

In this section, an attempt to arrive at as clear as possible a picture of the expected payoff, in terms of fewer people with various degrees of hearing impairment, from alternative noise regulations. Such calculations inevitably involve numerous assumptions and considerable uncertainty. Therefore, before presenting the numbers in detail, it is important to be clear about exactly what they are based on, and throughout the discussion an indication of how changes in assumptions would affect the results will be attempted.

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*Noise induced permanent threshhold shift.

**EPA's Dr. Alvin Meyer in his OSHA testimony took the position that it would be unreasonable to set a noise exposure standard at a level where a substantial portion of the exposed population would develop compensable hearing losses. Furthermore, for standard-setting purposes, material impairment should be considered to begin before hearing loss which is defined as a compensable handicap.

Estimates of Noise Exposure

Current Noise Exposure

One of the most serious sources of uncertainty in attempting to quantify the benefits that will occur from changing the world in the ways proposed in the regulations, is that there is inadequate data on the state of the world we are attempting to change. Just how many people are exposed to how much noise today? NIOSH has collected extensive data on noise exposures in workplaces representative of American industry as part of their National Occupational Hazard Survey. Unfortunately, these data, which should be reasonably definitive within the constraints of the sampling procedure used, have not yet been put together in a form which allows publication and use. Table 2-2, however, presents a preliminary summary from these data of the percentage of work facilities with at least some workers exposed to more than *85 dBA*. It is clear that compliance with a regulation set at the 85 dBA level is likely to affect the majority of workplaces in most *categories* of manufacturing industry, although quantification of the actual *number* of workers affected must await the publication of the full NIOSH data.

Table 2-3 gives some indication of the percentages of workplaces in various industrial categories currently being cited by OSHA as in violation of the current 90 dBA standard, at least in one State (Ohio) in one recent fiscal year (1973). This, again, does not tell the number of workers whose noise exposures are actually being reduced by current regulatory enforcement activity, but it does suggest that even in industrial categories where noise is most prevalent, only about a quarter of OSHA inspections result in remedial discipline.

Table 2-4 represents the best available guesses (by Bolt, Baranek, and Newman in their 1974 report to OSHA) of the number of workers currently exposed to noise levels in excess of 85 and 90 dBA in different industrial categories. BBN properly emphasizes the conjectural nature of these figures, but, coming from a firm with extensive experience in the noise control field, such estimates must be regarded as relatively well-informed conjecture. There being no better data presently available, they will be used as a basis for the calculations below.

However, in order to begin the calculations, it is necessary to know not only how many workers are over and under 85 dBA and 90 dBA, but approximately how many are over, and under, by various amounts. Based on its experience, BBN estimated the numbers of workers in various 5-dBA groups from 80-84 to 115-119 and found that over 90 dBA, the number of workers exposed dropped by approximately half with each 5-dBA increment in level. Based on this rule, and placing all those *not* at 85 or over at 80-84, the following exposure distribution is presented in Table 2-5.

Table 2-2*

Percentages of plants surveyed by SIC "noise"

Industry	SIC	No. of facilities observed	No. of facilities in survey	Percentage of surveyed facilities with noise**
Agriculture services and hunting	07	3	46	6.5
Oil and gas extraction	13	19	40	47.5
General building contractors	15	22	184	12.0
Heavy construction contractors	16	14	111	12.6
Special trade contractors	17	39	312	12.5
Ordnance and accessories	19	6	20	30.0
Food and kindred products	20	105	199	52.8
Tobacco manufacturers	21	6	23	26.0
Textile mill products	22	53	99	53.5
Apparel and other textile products	23	40	147	27.2
Lumber and wood products	24	56	95	58.9
Furniture and fixtures	25	108	173	62.4
Paper and allied products	26	108	139	77.6
Printing and publishing	27	68	157	43.3
Chemicals and allied products	28	63	121	52.1
Petroleum and coal products	29	28	50	56.0
Rubber and plastics products, Nec	30	140	209	67.0
Leather and leather products	31	44	92	47.8
Stone, clay, and glass products	32	81	127	63.8
Primary metal industries	33	127	168	75.6
Fabricated metal products	34	289	352	82.1
Machinery, except electrical	35	153	303	50.5
Electrical equipment and supplies	36	94	204	46.1
Transportation equipment	37	78	144	54.2
Instruments and related products	38	40	108	37.0
Miscellaneous manufacturing industries	39	83	172	48.0
Local and interurban passenger transit	41	9	61	14.7
Trucking and warehousing	42	11	103	10.7

Table 2-2*

Percentages of plants surveyed by SIC "noise" – continued

Industry	SIC	No. of facilities observed	No. of facilities in survey	Percentage of surveyed facilities with noise**
Water transportation	44	9	43	20.9
Transportation by air	45	15	30	50.0
Pipeline transportation	46	4	12	33.3
Transportation services	47	1	29	3.4
Communication	48	5	43	11.6
Electric, gas, and sanitary services	49	11	24	45.8
Wholesale trade	50	19	160	12.8
Building materials and farm equipment	52	6	34	17.6
Retail general merchandise	53	9	60	15.0
Food stores	54	2	52	3.8
Automotive dealers and service stations	55	17	62	27.4
Eating and drinking places	58	2	79	2.5
Miscellaneous retail stores	59	2	51	3.9
Banking	60	2	18	11.1
Insurance carriers	63	2	31	6.5
Real estate	65	1	51	2.0
Hotels and other lodging places	70	1	22	4.5
Personal services	72	6	44	13.6
Miscellaneous business services	73	3	76	3.9
Auto repair, services, and garages	75	4	19	21.1
Miscellaneous repair services	76	4	16	25.0
Amusement and recreation services,Nec	79	2	23	8.7
Medical and other health services	80	14	93	15.1
Nonprofit membership organizations	86	1	15	6.7

*Courtesy of A. W. Thomas, NIOSH; private communication.

**Noise level over 85 dBA.

Table 2-3

OSHA noise citations by industry, Ohio, fiscal 1973*

SIC	Industry	Number of inspections	Number of noise citations	Citations per inspection
15	Building construction	129	4	0.03
16	Other construction	45	0	0
17	Special trade contractors	407	0	0
20	Food and kindred products	58	6	.10
21	Tobacco manufacturers	3	0	0
22	Textile mill products	19	4	.21
23	Apparel and other finished textile products	12	0	0
24	Lumber and wood products (except furniture)	31	5	.16
25	Furniture and fixtures	36	8	.22
26	Paper and allied products	53	15	.28
27	Printing, publishing and allied industries	27	6	.22
28	Chemical and allied products	68	4	.06
29	Petroleum and related industries	8	0	0
30	Rubber and plastics	144	7	.05
31	Leather and leather products	10	1	.10
32	Stone, clay, glass and concrete products	112	9	.08
33	Primary metal industries	333	56	.17
34	Fabricated metal products	237	56	.23
35	Machinery, except electrical	258	22	.09
36	Electrical and electrical machinery, equipment supplies	104	10	.08
37	Transportation equipment	125	17	.14
38	Measuring and medical instruments, optical goods	19	0	0
39	Miscellaneous manufacturing	29	0	0
40	Railroad transportation	8	0	0
41	Local, suburban, and interurban highway passenger transport	5	0	0
42	Motor freight transportation and warehouse	47	0	0
44	Water transportation	105	2	.02
45	Transportation by air	10	0	0
47	Transportation services	2	1	.50
48	Communication	21	0	0
50	Wholesale trade	81	0	0
52-59	Retail trade	31	0	0
60-91	Services	60	0	0
	Total	2637	233	.09

*Data from D. Hattis et al., Information for decision-making on occupational safety and health problems in Ohio (1974), Table 26.

Table 2-4

Estimate of the number and percentage of production workers overexposed to noise*

Industry	SIC Code	Production workers (thousands)	Overexposed workers (thousands)		Percentage overexposed	
			85 dBA	90 dBA	85 dBA	90 dBA
Food	20	1170	820	350	70	30
Tobacco	21	63	48	40	76	63
Textiles	22	900	855	765	95	85
Apparel	23	1174	12	0	1	0
Lumber and wood	24	542	542	390	100	72
Furniture and fixtures	25	427	235	58	55	15
Paper	26	557	395	206	71	37
Printing and publishing	27	661	132	99	20	15
Chemicals	28	596	137	66	23	11
Petroleum and coal	29	117	58	23	50	20
Rubber and plastics	30	531	266	106	50	20
Leather	31	256	3	0	1	0
Stone, clay, and glass	32	555	416	139	75	25
Primary metals	33	989	577	259	58	26
Primary steel	331	485	325	170	67	35
Foundries	332, 336	275	189	54	70	20
Primary nonferrous	333, 334, 335	233	63	35	27	15
Fabricated metals	34	1123	786	225	70	20
Machinery except electrical	35	1366	956	273	70	20
Electrical machinery	36	1370	959	274	70	20
Transportation equipment	37	1354	880	284	65	21
Utilities	49	627	445	188	71	30
Total		14382	8524	3755	59.3	26.1

* The majority of these estimates are the result of informal discussions with industry spokesmen who were willing to discuss the subject. There is very little definitive information available – therefore, these estimates should be viewed as best guesses.

† *Employment and Earnings,* Vol. 20, No. 2 (August 1973), U.S. Department of Labor, Bureau of Labor Statistics.

Source: Bolt, Beranek and Newman, Inc., *Impact of Noise Control at the Workplace,* Report No. 2671, Cambridge, Mass., January 1974, p. C-2.

Table 2-5

Current exposure estimates used in calculations

Approximate continuous exposure level	Thousands of workers*	Percent of workers
80- 84 "82"	5,858	40.7
85- 89 "87"	4,769	33.2
90- 94 "92"	1,878	13.1
95- 99 "97"	939	6.5
100-104 "102"	469	3.3
105-109 "107"	235	1.6
110-114 "112"	117	.8
115-119 "117"	117	.8
Total	14,382	100.0

*These are total numbers of workers at each exposure level. Later workers will be excluded under twenty and over 65 to arrive at slightly reduced figures.

It should be noted that two other (we feel, erroneous) versions of this same exposure distribution exist, based on the same data. BBN themselves in the appendix to their report, where they calculate the numbers of people they believe will suffer hearing handicap (impairment), present the following distribution in Table 2-6. Contact was made with the former BBN employee who drew up this table and did the risk calculations based on it, and were informed that the exposure levels indicated really represent the lower bounds on the range of exposures of each group, and the appropriate range designations are as shown in Table 2-5 and as shown in the front of the BBN report.*

The other erroenous version of this exposure distribution is contained in the tables giving risk calculations in the OSHA Draft Environmental Impact Statement, reproduced in Table 2-7. Here all of the groups are shifted downward in their assigned exposure ranges by *5 dBA*. However, OSHA does not use the centers of the ranges shown to derive the risk percentages indicated in the percent impaired column. The figures for this column are directly derived from

*Nevertheless, it appears that in doing the actual risk calculations BBN used these lower bounds as if they were the mean value for each group, and therefore their estimates of impairment are somewhat lower than they would otherwise be.

Table 2-6

Current exposure estimates used by BBN in calculating expected hearing handicap*

Exposure level dBA	Percent of workers in industries covered by BBN study
Under 85	30
85	40
90	15
95	7
100	4
105	2
110	1
115	1

*Source: Bolt, Beranek and Newman, Inc., *Impact of Noise Control at the Workplace*, Report No. 2671, Cambridge, Mass. (January 1974), p. C-2.

Table 2-7

Hearing impairment after 40 years exposure according to Baughn

Correct ranges dBA	Level dBA	Percent impaired	Presently		90 dBA standard (numbers in thousands)		85 dBA standard	
			Number exposed	Number impaired	Number exposed	Number impaired	Number exposed	Number impaired
80- 84	< 80		4,315		4,315		13,231	
85- 89	80- 85	8.0	5,753	460	8,917	713	575	46
90- 94	85- 90	18.0	2,157	388	575	104	288	52
94- 99	90- 95	28.0	1,007	282	288	81	144	40
100-104	95-100	40.0	575	230	144	58	144	58
105-109	100-105	54.0	288	156	144	78		
110-114	105-110	64.0	144	92				
> 115	110-115	70.0	144	101				
Total				1,709		1,034		196

the table on page D-4 of the BBN report. Therefore, OSHA has made no additional error, over and above BBN's error, in calculating the *numbers of workers expected to be impaired.* However, they have placed the workers in the *wrong exposure ranges.* We point this out in particular because of Mr. Eads' statement that:

> "The Bolt Study, using the 25 dB hearing risk method, estimates that 770,000 workers would benefit; while OSHA's estimate using the same hearing risk standard as Bolt is that only 73,000 additional workers would be protected from the 25 dB hearing loss."

It is possible that other hearing risk calculations performed by OSHA from the *indicated* exposure distribution may have lead to confusion.

Noise Exposures After Compliance with 90 or 85 dBA Regulations

To determine the hearing conservation benefits of the 90 or 85 dBA standards, the next step is to determine how the current exposure levels indicated in Table 2-5 would be changed on compliance with the new rules. Table 2-8 is a reconstruction of BBN's appraisal of the changes in exposure that would occur.

Table 2-8*

Percent of production workers exposed to specified noise level

Noise level	Currently	Under 90 dBA criterion	Under 85 dBA criterion
80- 84	30	30	92
85- 89	40	62	4
90- 94	15	4	2
95- 99	7	2	1
100-104	4	1	1
105-109	2	1	0
110-114	1	0	0
115-119	1	0	0

*The original BBN table has been altered to reflect the appropriate noise exposure ranges.

Source: Reconstructed from Bolt, Beranek and Newman, Inc., *Impact of Noise Control at the Workplace,* Report No. 2671, Cambridge, Mass. (January 1974), p. C-2.

Table 2-8 indicates an expectation that industry will respond to a 90 dBA regulation by lowering the exposure levels of nearly all those exposed to 90 and above to the 85-89 range (average 87 dBA), and that industry will respond to an 85 dBA regulation by bringing 92 percent of all workers down into the 80-84 dBA range (average 82 dBA).

This raises a difficult question. It is somewhat disturbing, for the purpose of calculating benefits, to assume that industry will comply to levels averaging 3 dBA below what is actually required by the regulations. Assuming such overcompliance might tend to unrealistically magnify the hearing conservation that should be expected to be achieved by either regulation. It is true that there are factors that might tend to produce overcompliance in industry in response to the regulation:

- Plants making engineering changes for noise control purposes might tend to over-engineer to be on the safe side, and

- For firms to bring the worker with the job in the noisiest location in the plant down to the mandated level, the exposures of most other workers in inherently less noisy plant locations might be incidentally reduced to considerably below the mandated level.

However, it seems that there are other factors that weigh in an equally compelling manner on the side of producing a general undercompliance in industry with mandated noise levels:

- The practical realities of inspection and citation procedures prevent effective enforcement of any regulation down to the last decibel. For example, noise dosimeters cannot be relied upon to be perfectly accurate and the need to be able to prove noncompliance beyond a reasonable doubt means that apparent violations less than *3 dBA* in excess of the standard will rarely result in citations. Additionally, managements may cometimes successfully escape citations by altering normal operating practices on the day of inspection. For example, particularly noisy pieces of equipment may not be used.

- Even if a company is cited and brought into compliance once, there will be a tendency for noise levels to rise with time as equipment deteriorates, goes without lubrication, and from other causes. Because the current OSHA and State inspection forces are rather small compared with the number of workplaces there are to inspect, there can be no expectation that the average workplace will be subject to possible enforcement more frequently than once every several years. With little incentive to comply during these many-year intervals, it seems overly optimistic to expect rigorous compliance with the regulations at all times for all companies.

Considering these aspects of practical enforcement, tending to produce undercompliance, together with the other factors listed tending to produce overcompliance, preference to assume that industry's performance on the average will more closely approximate the minimal requirements of the law, rather than the overcompliance implied in a literal interpretation of BBN's appraisal. For purposes of calculations, assumptions that the effect of compliance with the 90 dBA regulation will simply be to bring all workers currently above 90 dBA to 90 dBA, and the effect of the 85 dBA regulation will be to bring all workers currently above 85 dBA down to 85 dBA.

Mode of Compliance

In the calculations of the hearing improvements to be expected from alternative noise regulations, one further simplifying assumption about worker exposure levels after compliance needs clarification. Assuming that while the noise regulation causes all workers above the mandated level to be brought down to the mandated level, assurances have been made that the regulation will cause no significant change in the noise exposures of workers currently below the mandated level. The previous discussion, where tendencies for overcompliance* were balanced against tendencies for undercompliance** applies only if the major mode of compliance is by engineering methods (where either the noise emission is reduced at the source or the path from the source to the worker is partially blocked). However, for some types of administrative controls where workers from quiet jobs are rotated to noisy jobs for part of the day, and workers from noisy jobs are rotated to quiet jobs for part of the day, compliance with the regulation will be accompanied by *increases* in noise exposures for some workers. This clearly spreads the risk of hearing impairment, although the risk to the particular individuals rotated partially out of noisy jobs is somewhat reduced. However, when one examines existing data*** relating noise exposure to hearing loss, the overall effect of rotating on the worker population as a whole is always or nearly always worse in one sense than not rotating. *More* workers experience worse hearing levels than if the job rotation measures had not been implemented. If the goal of the noise regulations is to improve the hearing of the worker population as a whole, rather than to be more evenly harmful to workers, this type of administrative control should be actively discouraged by noise regulations instead of being

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*Including particularly incidental reduction of the exposures of workers below standard by the quieting of machines producing excessive exposures to some workers. In other words, in some cases to bring the most exposed worker down to 90 dBA, the exposures of workers at greater distances from the source may be reduced considerably below 90 dBA.

**See previous discussion for listing.

***From either the Baughn or the Robinson studies to be further discussed.

allowed as one mode of compliance. Discouragement of this type of compliance might be incorporated in the regulation by language providing that noise control programs should not increase either the *number* of workers exposed to 80 dBA and above, or the exposures of individual workers already exposed above 80 dBA prior to the institution of the noise control program. It should also be noted that the use of a 3 dB, rather than a 5 dB, time-intensity trading ratio would also help discourage undesirable types of administrative control.

Other types of administrative controls, however, such as shifting noisy operations to periods of the day when fewer workers are present, do reduce overall population exposure to noise and remain as modes of compliance preferable to personal protective devices.

Finally, it should be noted that the calculations assume no net effect on hearing levels for the audiometric programs mandated by the standard. This is a difficult question, as there is no data at all on which to base a nationwide projection of anticipated impact. It can certainly be expected that some companies will have excellent programs of monitoring and providing information to the worker, and that some of these companies' workers may be persuaded by the evidence of their own deterioration in hearing levels to be more consistent users of personal protection. Unfortunately, it does not seem that the past history of industrial medical programs (in all but a few outstanding exceptions) justifies the expectation that this will generally be the case. Further, to the degree that the results of audiometric examination encourage administrative job rotation or job mobility, there may actually be a larger number harmed in the worker population as a whole. With these uncertainties, the audiometry zero effect has therefore been assigned.

Relationships Between Noise Exposure and Hearing Impairment

A brief discussion of the sources of data helpful in quantifying the relationship between noise exposure and permanent threshold shift is necessary.

The Public Health Service has published the most recent and definitive data on the hearing levels of the population as a whole. These are based on a 1962 survey of a representative sample of the United States. Because only a small proportion of the representative sample is industrial workers exposed to long periods of noise, it is certainly likely to be an underestimate of the present pattern to be found among industrial workers working in noisy environments.

The second set of data is a British study by Burns and Robinson. The authors screened out workers with otological abnormalities, and measured hearing levels in ways comparable with the Public Health Service techniques. In particular, a sufficient amount of time was allowed, between noise exposure and time of testing, that temporary threshold shifts did not confuse the data. They concentrated on measuring the differences among those people exposed to different noise levels during their working life, quantifying the total noise exposure of each particular individual utilizing the equal energy principle. (This study, as has been discussed in the testimony of Dr. Burns, validates the use of this rule in calculating equivalent continuous exposure levels.)

The third set of data is a study of a large American industrial population by Baughn. No otological screening and selection was carried out, making it more likely to be representative of actual industrial worker groups. However, he admittedly did not wait a long enough time to avoid the confusion of the data by some degree of temporary threshold shift. Baughn's assumption on presbycusis is that a 78 dBA exposure for 8 hours or the equivalent produces no greater hearing loss in the normal population than does aging in the normal population. This is supported by comparison with a survey by Glorig of a non-noise exposed population.

All the calculations are based on the Baughn data.* In using the Baughn data, some important issues must be explicitly addressed:

- *The Baughn data include otologically abnormal people.* It is desirable to have otologically abnormal people in the sample for our purposes, because the results more accurately reflect the impact of noise on defective, as well as normal, ears. People with defective ears are likely, in any event, to be somewhat impaired to begin with, and therefore are of special concern because it is probably worse to make fair hearing poor than to make good hearing fair.

- *The Baughn data include some temporary threshold shift.* This is troublesome, but as has been discussed at length in Dr. Kryter's testimony, the effect is not large – less than 2 dB of hearing level even in the most extreme subgroups, and generally less than 1 dB.** A partial compensating advantage is that a threshold shift which is experienced throughout every working day and into the evening of working days is in itself not totally negligible as a social cost, even though each day's shift is labelled "temporary."

- *The Baughn data indicate larger effects of noise on hearing levels than some other data, particularly the exceedingly careful study of Robinson and Burns.* If, as has been suggested,[4] 10 dB are added to the Robinson threshold shifts to compensate for the screening out of otologically abnormal people, there is not a great deal of difference in the data sets. All concerned, however, prefer not to rely heavily on

*Specifically, Figures 9 and 11 of Reference 1.

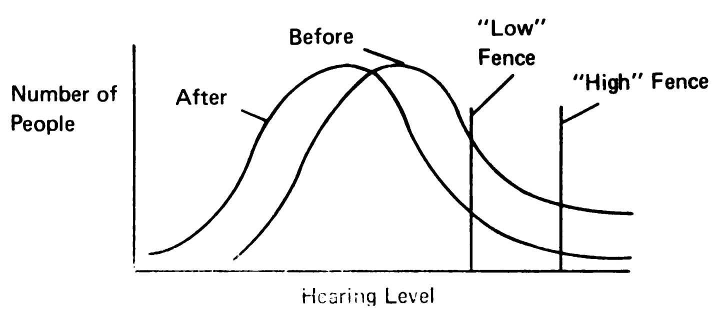
**By "hearing level" is meant average hearing level at (.5, 1, 2 kHz).

the quantitative accuracy of this latter procedure. An additional source of evidence is the recent study of NIOSH. As can be seen in the table presented in the discussion of "Material Impairment", after subtracting the different presbycusis corrections appropriate to each data set, there is very little difference between the noise-induced risk found in the two studies. The NIOSH data basically confirm the expected risk percentages found by Baughn for a general, unscreened population.

Finally, to avoid another source of possible future confusion, the Baughn risk percentages used are not identical to the Baughn risk percentages used by BBN. BBN drew their percentages from Table 8 of reference[1] that includes an adjustment of the actual observed hearing levels to set the median hearing level to 0 dB for the group at 80 dBA exposure and 20 years of age. This would be appropriate if the worker group were considered to begin their working lives with hearing levels, on the average, no worse than those of the general population. However, the working population exposed to noise probably tends to be of lower average socio-economic status and educational attainment than the population as a whole. Certainly generally excluded from the noise group are the relatively high status white-collar workers. Presented will be Public Health Service data in the Equity section which shows that there is a relatively strong correlation between educational level and hearing level, even at younger age groups (possibly due to the effects on hearing level of infectious disease, and the effects on educational attainment of bad hearing). This being the case, it should be expected that noise-exposed workers may already begin at age 20 with hearing levels somewhat poorer than the general population average. Exactly what the magnitude of this effect might be cannot be said, but particularly since the Baughn data came from such a large industrial population it is more likely to be appropriate not to adjust the data. In any event, the differences are generally small, after subtracting out the different presbycusis corrections (80 dBA exposure group) appropriate for each data set.

Quantification of Noise-Induced Hearing Impairment Now Occurring, and the Hearing Improvement Which Could Be Expected From Different OSHA Standards

The figure below depicts two hypothetical population distributions of hearing ability before and many years after compliance with some regulation.



There are two general ways to describe this change for use in describing the benefit of the regulation:

- One can determine the amount (in decibels at specific frequencies) that the whole curve, or selected parts of it such as the median, 90th percentile points, etc., are shifted as a result of the regulation, or

- One can determine the numbers of people with hearing worse than one or more arbitrary cut-off points ("fences"), before and after the regulation. (Commonly this is referred to as the "risk" method.)

Both methods are valid ways of looking at the data as long as one bears in mind the limitations of each particular technique. The first method gives results in a form (dB shifts) that does not lend itself to easy translation into terms of intuitive individual and social significance. The second method tends to obscure the continuous nature of hearing impairment and can lead the unwary to ignore the fact that the entire population is impaired by noise, not just those who happen to be moved across the arbitrarily-designated "fences."

Considerable data utilizing the former method of presentation is assembled in the EPA levels document and supplements. For the calculations, however, results by the "risk" method are presented, in order to provide as clear as possible a basis for social decision-making.

Baughn[5] and others have conducted surveys in which people were asked, simply, "How well do you hear?" Results in terms of the numbers of people of different ages responding "good," "fair," "poor," and "deaf" are shown in Figure 2-3 correlated with the average of the subjects' audiometric hearing levels at 500, 1000, and 2000 hertz. It is clear that the audiometric hearing levels can be translated into rough subjective categories that have social meaning. It is likely that individuals do not respond to fair or poor unless they have noticed at least some interference with the activities they carry out in daily life.* Less noticeable degrees of functional impairment are by no means without social cost. However this kind of information at least indicates that people with average hearing levels in these frequencies above 25 dB (ISO) are close to the border between hearing that is good and that which is fair, and that people with levels above 50 dB (ISO) generally place themselves in the poor category. These are the two fences we will use in our calculations. Additional information on the social meaning of these hearing levels can be gleaned by the reader from the following capsule descriptions by the Public Health Service.[6]

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*A tendency for older people to classify themselves by less stringent criteria than younger people probably results from the fact that older people probably tend to compare their own hearing with that of other older people, who also show hearing loss because of their age.

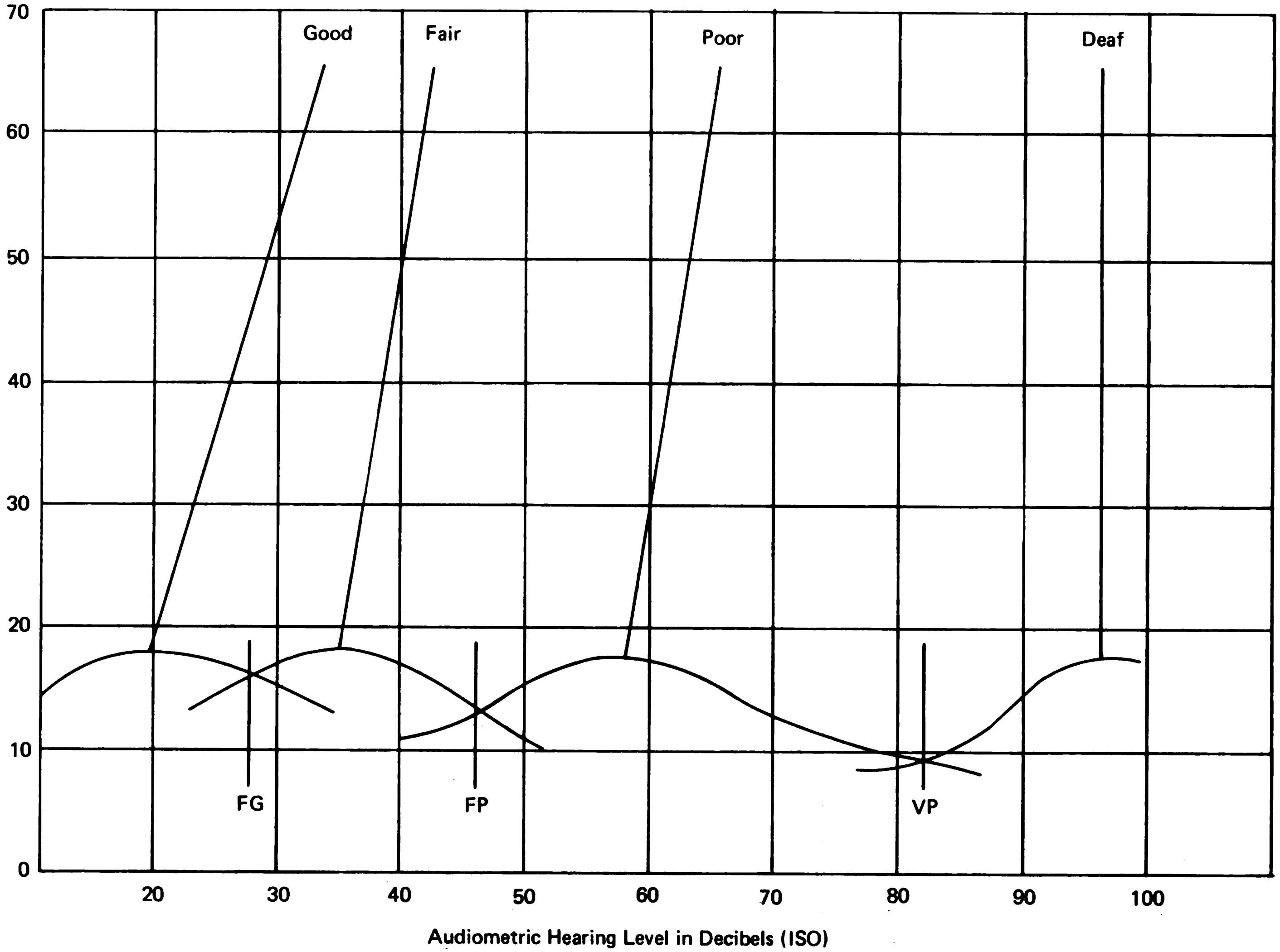

Figure 2-3. A graphic representation of the results of a self evaluation study

Source: A. Glorig and W. L. Baughn, Basis for Percent Risk Table, from the *Proceedings of the International Congress on Noise as a Public Health Problem,* Dubrovnik, Yugoslavia, May 13-18, 1973, p. 85.

Average hearing level at .5, 1, and 2 kHz in the better ear Re: ISO	Ability to understand speech
Less than 25 dB	No significant difficulty with faint speech
25-39 dB	Difficulty only with faint speech
40-54 dB	Frequent difficulty with normal speech
55-69 dB	Frequent difficulty with loud speech

These may be somewhat conservative statements of the handicaps experienced by declines in quality of life experienced by those with noise-damaged hearing. As was noted in the material impariment section, there is considerable evidence that the three frequencies averaged to obtain these hearing levels (.5, 1, and 2 kHz) are not the only frequencies of social significance. In particular, hearing at higher frequencies, which shows more susceptibility to both age- and noise-induced impairment, has been suggested as a better barometer of noise-induced damage. Considerations of higher frequencies are not included in the calculations, however, because of limitations in the data base readily available and interpretable in social terms. However, it seems reasonable to believe that the results expressed in terms of the three lower frequencies will provide a result that would roughly correlate with a result based on an appropriately-weighted index of hearing levels at all frequencies.

The ultimate output of the calculations will therefore be expressed as the net number of individuals with hearing levels in two ranges:

25-50 dB (average HL at .5, 1, and 2 kHz)

over 50 dB (average HL at .5, 1, and 2 kHz)

after subtracting out the individuals that would be in those two hearing level ranges in the absence of noise above 90 dBA ("presbycusis" correction).

Assumptions of the Calculations

Some assumptions have already been discussed in the section on noise exposures. Other assumptions implicit in the calculations are:

- Noise exposure is independent of the age of workers – that is, older workers are exposed to various noise levels just as frequently as younger workers.

- Exposure is simply proportional to age, beginning at age 20.

- The age distribution of workers approximates that reported in the 1970 census, for manufacturing industries. (Table 2-9)

Table 2-9

Age distribution of workers*

Age	Percent	Thousands of workers**
16-17	1.059	152
18-19	3.345	481
20-24	11.959	1,720
25-29	12.330	1,773
30-34	10.755	1,547
35-44	22.289	3,206
45-54	22.329	3,211
55-59	8.536	1,228
60-64	5.230	752
> 64	2.168	312
Subtotal: 20-64	93.427	13,437
Total: 16-64+	99.499	14,382

Totals may not add because of rounding.

*From male and female distributions of age levels in manufacturing industries – 1970 census.

**In 1973 for industries covered by the BBN study.

- The equal energy principle can be used to convert long- and short-term interrupted exposures into equivalent continuous exposures.

- The 80 dBA risk curves given by Baughn[1] represent expected hearing loss due to presbycusis and all other non-noise-induced hearing loss in the potentially exposed worker population (called "presbycusis" hereafter, for brevity).

- Job mobility is independent of noise exposure – that is, workers do not leave noisier jobs at any faster rate than they leave quieter jobs.

Detailed Questions Addressed by the Calculations

Most previous calculations in this field have chosen a single, or a few, durations of exposure and estimated the degree of hearing impairment produced as people attain those designated exposure times. The BBN study, for example, estimates the numbers of people in their selected industries* which will suffer at least 25 dB or worse hearing levels (Re: ISO) as they reach age 60. This is done for three conditions:

- The present conditions of noise in those factories estimated by BBN with no change;

- That which might occur as a result of the adoption of a 90 dBA standard; and the third

- That corresponding to an 85 dBA standard.

Since workers reach age 60 at different times, this presentation of the data in itself is not as useful as asking what the situation might be 10 years from now, 20 years from now, and 40 years from now, for the existing worker population, given their existing age distribution.** This is central for determining the effects of policies adopted now at various times on the existing populations, whether or not we apply a social discount rate other than zero.***

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*Comprising a total population of 14 million workers. These industries include most of the industrial categories with serious noise problems, with the conspicuous exceptions of mining and agriculture. Implicitly, the BBN data also assume no job mobility.

**Some information of this sort is, however, presented by BBN graphically.

***As an aside, it should be noted here that the benefits of noise reduction do increase as time goes on, while the costs of compliance must be admitted to have to be imposed at this time in the present. However, it also should be pointed out that some of the nonauditory effects, particularly some of those associated with job performance and stress, might be experienced at this time, rather than later on. That is, current with the exposure, and hence any estimate of the nonauditory relative to the auditory harm, ought to take into account the differences in time frames in which these benefits are manifest.

As a result of these considerations it was chosen to first seek an answer to the question: "Under four different strategies now adopted, what will be the hearing level profile of the workers in these industries 40 years from now?" The industrial categories chosen are the same as those used by BBN. To do this calculation properly, one has to know first what the age distribution will be 40 years from now, and secondly, one must make some assumptions about what the noise profile will be in these same industrial locations between now and 40 years from now. Rather than going to extensive calculations of what the population distribution will be 40 years from now, we will assume the present age distribution in the population. Note that this will be an underestimate of the threshold shift likely to be encountered because the average age of the worker is moving upwards and presbycusis and noise will have more marked effects in somewhat older worker groups. It should also be noted that there will be a larger work force 40 years from now. To gain information for a more near-term period, also investigated were the effects of two compliance strategies on hearing levels to be expected 10 years from now.

One of the four compliance strategies is a baseline case – that is, the extent to which the actual noise in these industrial operations may change, in the absence of regulation. For this case, the assumption that there will be no change is made, recognizing that there are arguments both for and against this assumption. The arguments for an increase in the noise level are based on the extrapolation of past history; the argument for a smaller noise level is a postulated greater noise consciousness and worker resistance which may stimulate changes which have not been manifest in the last 20 years. Using this approach, predictions are then generated of the excess numbers of people which will cross the two selected fences (25 and 50 dB ISO) under the following four conditions of compliance with noise exposure regulations:

- No change from existing noise exposure,
- All exposures above 100 dBA brought down to 100 dBA,
- All exposures above 90 dBA brought down to 90 dBA, and
- All exposures above 85 dBA brought down to 85 dBA.

As discussed previously, in all cases no changes are assumed in the exposures of those exposed to less than the mandated regulatory levels.

In addition to these differing exposure conditions, investigated are the effects of assuming three different degrees of job mobility in the population:

- No job mobility (one job per worker throughout a working lifetime).

- Some job mobility (three jobs to date in each present worker's employment history, no more than one of which is greater than 80 dBA, the others being equal to 80 dBA).

- Infinite job mobility (all noise exposures are evenly distributed among all workers in a total worker population age 20-64 of 80 million, otherwise exposed to the equivalent of 80 dBA).

Calculations were performed by first setting forth a detailed population by age and equivalent continuous exposure distribution* under each hypothesized compliance strategy and then multiplying by the appropriate risk percentages derived from the Baughn curves to arrive at the numbers of individuals expected in designated hearing level ranges. The only other consideration noted here, is that the results presented in the next section are based on the worker population falling within the 20-64 age group (inclusive). Workers falling outside these limits were excluded for lack of data.

Results and Discussion

Table 2-10 gives the expected results at the ultimate 40-year post-compliance time point and Table 2-11 gives the expected results, 10 years after compliance. Several aspects of the data are worthy of note.

Job Mobility

The assumption of infinite job mobility spectacularly increases the numbers of people one expects to experience impaired hearing due to noise. It should be noted, however,** that the very high numbers for the present exposures category for infinite job mobility are greatly influenced by the small numbers of workers in the highest noise exposure groups (117 and 112 dBA). Since the estimates of the numbers of workers exposed to these extreme noise levels are likely to be much more uncertain than the estimates at lower noise levels, this calculation must be regarded as highly conjectural.

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* Where groups of individuals were hypothesized to have exposures of different intensities during their work experience, energy – equivalent continuous exposure levels were computed, as described in the EPA Levels document.[8] (e.g., 5 years at 85 + 2 years at 90 = 7 years at 87.09; 5 years at 85 + 2 years at 95 = 7 years at 90.53)

** See appendix for additional detail.

Table 2-10

Excess number of workers impaired due to noise (thousands)
40 years after compliance summary

Present noise exposures:

Added number at hearing level	Job Mobility		
	None	Some	Infinite
(Re: ISO)*	1 job per worker	3 jobs per worker	(Eq. 91.13 dBA) for 80 million people noise exposure evenly distributed throughout workforce.
25-50	1,429	2,632	12,034
> 50	222	384	1,230

If all above 100 dBA are brought to 100 dBA:

Added number at hearing level	Job Mobility		
	None	Some	Infinite
(Re: ISO)*	1 job per worker	3 jobs per worker	(Eq. 85.07 dBA)
25-50	1,328	2,365	5,219
> 50	150	261	568

If all above 90 dBA are brought to 90 dBA:

Added number at hearing level	Job Mobility		
	None	Some	Infinite
(Re: ISO)*	1 job per worker	3 jobs per worker	(Eq. 82.20 dBA)
25-50	1,002	1,607	2,220
> 50	104	176	250

If all above 85 dBA are brought to 85 dBA:

Added number at hearing level	Job Mobility		
	None	Some	Infinite
(Re: ISO)*	1 job per worker	3 jobs per worker	(Eq. 80.99 dBA)
25-50	638	872	995
> 50	72	98	113

*[1/3 (500, 1000, 2000 Hz)].

Table 2-11

Excess number of workers impaired due to noise (thousands)
10 years after compliance summary

If all above 90 dBA are brought to 90 dBA:

Added number at hearing level (Re: ISO)*	Job Mobility		
	None	Some	Infinite
	1 job per worker	3 jobs per worker	
25-50	1,238	2,184	9,690
> 50	182	303	1,175

If all above 85 dBA are brought to 85 dBA:

Added number at hearing level (Re: ISO)*	Job Mobility		
	None	Some	Infinite
25-50	1,017	1,865	8,875
> 50	171	270	1,175

* [1/3 (500, 1000, 2000 Hz)].

For the more moderate job mobility case, there are still considerably more workers impaired than in the no job mobility case, although nowhere near so dramatically more as for infinite job mobility. Clearly, however, the direction of the change appears to be always toward more hearing impairment with more job mobility.

This same conclusion can be reached in terms of threshold shifts, as given in the EPA/ Air Force figures for any of the data sets examined (Robinson, Baughn, and Passchier-Vermeer). Tables 2-12 and 2-13, taken from Johnson[4] show the threshold shifts expected for different population percentiles for 85 and 90 dBA. It can be seen that there are very few cases where the 90/85 ratio of threshold shifts is as much as threefold for corresponding exposure durations and population percentiles. However, in order for job mobility to be neutral in terms

Table 2-12
Predicted NIPTS for 85 dBA

		10 year			20 year			40 year		
		Passchier-Vermeer	Robinson	Baughn	Passchier-Vermeer	Robinson	Baughn	Passchier-Vermeer	Robinson	Baughn
Speech 1/3 (.5, 1, 2 kHz)	90	.9	2.8	2.5	1.0	4.1	[illegible]	1.1	5.8	3.9
	75	.5	1.8	1.8	.6	2.6	[illegible]	.7	3.8	2.7
	50	.1	1.1	1.2	.2	1.6	1.5	.3	2.3	1.9
	25	.1	.6	.9	.2	.9	1.3	.3	1.4	1.5
	10	0.0	.4	.8	.1	.6	1.0	.2	.8	1.2
Speech 1/4 (.5, 1, 2, 4 kHz)	90	5.2	5.0	6.5	5.1	7.0	6.1	5.2	9.5	3.7
	75	4.0	3.3	4.7	4.0	4.7	5.1	4.1	6.5	3.3
	50	2.8	2.0	3.6	2.9	2.9	4.4	3.0	4.2	3.3
	25	1.5	1.2	2.7	1.6	1.8	3.7	1.7	2.6	3.5
	10	.2	.8	1.9	.3	1.1	2.9	.4	1.6	3.6
2 K	90	2.7	4.9	–	3.0	7.0	–	3.4	9.9	–
	75	1.5	3.1	–	1.8	4.6	–	2.2	6.6	–
	50	.3	1.9	–	.6	2.8	–	1.0	4.0	–
	25	.2	1.1	–	.5	1.7	–	.9	2.4	–
	10	.1	.7	–	.4	1.0	–	.8	1.5	–
4 K	90	17.8	11.6	18.6	17.8	15.7	14.5	17.8	20.5	3.2
	75	14.4	7.8	13.5	14.4	10.9	13.7	14.4	14.8	5.3
	50	11.0	4.9	10.8	11.0	6.9	13.1	11.0	9.8	7.6
	25	6.0	2.9	8.0	6.0	4.3	10.8	6.0	6.2	9.7
	10	1.0	1.9	5.2	1.0	2.7	8.7	1.0	4.0	10.7
6 K	90	10.5	8.4	–	10.5	11.6	–	10.2	15.7	–
	75	9.2	5.5	–	9.2	7.8	–	8.9	10.9	–
	50	7.9	3.4	–	7.9	4.9	–	7.6	6.9	–
	25	4.1	2.0	–	4.1	2.9	–	3.8	4.3	–
	10	.3	1.3	–	.3	1.9	–	0.0	2.7	–
8 K	90	3.9	–	–	3.9	–	–	3.9	–	–
	75	2.7	–	–	2.7	–	–	2.5	–	–
	50	1.5	–	–	1.5	–	–	1.3	–	–
	25	1.5	–	–	1.5	–	–	1.3	–	–
	10	1.5	–	–	1.5	–	–	1.3	–	–

Table 2-13
Predicted NIPTS for 90 dBA

		10 year			20 year			40 year		
		Passchier-Vermeer	Robinson	Baughn	Passchier-Vermeer	Robinson	Baughn	Passchier-Vermeer	Robinson	Baughn
Speech 1/3 (.5, 1, 2 kHz	90	2.4	4.2	5.5	3.2	5.1	6.9	4.5	8.6	7.3
	75	1.6	2.4	3.8	2.4	3.1	4.9	3.8	5.4	5.5
	50	.8	1.5	2.6	1.6	2.0	3.3	3.1	3.5	3.2
	25	.6	1.0	2.0	1.4	1.1	2.6	2.8	2.1	3.0
	10	.5	.8	1.8	1.2	.8	2.2	2.5	1.4	2.5
Speech 1/4 (.5, 1, 2, 4 kHz)	90	7.3	7.8	11.6	8.3	9.8	9.8	9.5	13.8	6.6
	75	6.4	5.1	8.5	7.0	6.0	8.5	8.2	9.8	6.1
	50	5.1	3.3	6.3	5.7	4.5	7.1	6.9	6.7	5.4
	25	3.7	2.1	4.4	4.3	2.8	5.7	5.5	4.3	5.9
	10	2.3	1.5	3.3	2.9	1.9	4.7	4.1	2.7	6.2
2 K	90	6.8	8.8	–	9.2	12.2	–	13.4	16.4	–
	75	4.6	5.8	–	7.0	8.3	–	11.2	11.5	–
	50	2.4	3.6	–	4.8	5.2	–	9.0	7.4	–
	25	1.6	2.1	–	4.0	3.1	–	8.2	4.6	–
	10	.8	1.4	–	3.2	2.0	–	7.4	2.9	–
4 K	90	23.6	18.8	30.1	23.6	24.0	18.7	23.6	29.5	4.6
	75	20.8	13.4	22.7	20.8	17.8	19.2	21.3	22.9	7.8
	50	18.0	8.7	17.4	18.0	12.1	18.6	18.5	16.3	10.4
	25	13.2	5.5	11.5	13.2	7.8	14.9	13.7	10.9	14.8
	10	8.4	3.5	7.7	8.4	5.1	12.4	8.4	7.3	17.4
6 K	90	18.3	14.2	–	18.3	18.8	–	18.3	24.0	–
	75	15.6	9.8	–	15.6	13.4	–	15.6	17.8	–
	50	12.9	6.2	–	12.9	8.7	–	12.9	12.0	–
	25	6.7	3.8	–	6.7	5.5	–	6.7	7.8	–
	10	.5	2.4	–	.5	3.5	–	.5	5.1	–
8 K	90	8.9	–	–	8.9	–	–	8.9	–	–
	75	6.7	–	–	6.7	–	–	6.5	–	–
	50	4.5	–	–	4.5	–	–	4.5	–	–
	25	4.5	–	–	4.5	–	–	4.5	–	–
	10	4.5	–	–	4.5	–	–	4.5	–	–

of total threshold shift produced in the population, these ratios would have to be at least threefold.* Furthermore, the apparent damage caused by job mobility is even more substantial at higher frequencies (e.g., 4 kHz) than it is in the speech frequencies (.5, 1, 2 kHz) considered in our risk calculations. Administrative controls that distribute noise exposure more evenly among workers, without altering total exposures, have similar effects on total impairment.

Ultimate (40 Year) Effects of Different Regulations

The 100 dBA regulation prevents very little of the hearing impairment, except for the infinite job mobility case, where it appears to reduce the numbers of people by not quite half. The 90 dBA regulation reduces the numbers of people crossing the relatively severe (50 dB) fence by about half, and makes more modest reductions in the numbers crossing the 25 dB fence at no or some job mobility. The 85 dBA regulation prevents about two-thirds of the people from crossing the 50 dB fence, and prevents at least a solid majority of the problem as measured by the lower fence, always bearing in mind that the problem is defined as the total number of people crossing these thresholds due to present noise exposures (in excess of those crossing the thresholds from presbycusis alone).

Effects After 10 Years

It can be seen from the summary table (Table 2-11) that in most cases about 30 to 50 percent of the ultimate reductions in hearing impairment will be attained by the end of the first decade after effective compliance. It should be noted in passing that the time of effective compliance, of course, may be several years removed from the time of promulgation of the regulation, and will depend heavily on future staffing levels of OSHA area offices and the general diligence with which enforcement is carried out.

*This is not an ultimately rigorous comparison due to the fact that an increased population at the lower exposure level would be spread over a broader range of population percentiles, but believe the resulting error is on the side of minimizing the apparent damage of job mobility.

NONAUDITORY EFFECTS

Before discussing the nonauditory effects of noise, it is important to be clear about the standard of proof or certainty applied in judging the scientific evidence. The existence of noise-induced hearing loss at exposure levels below the 90 dBA standard must really be regarded as established beyond a reasonable doubt, although there is some room for responsible dispute about the magnitude of the effect. However, when nonauditory effects of noise are examined, it is apparent that although there is a substantial body of data that suggests a wide variety of noise-induced health effects of potentially great significance in social terms, the scientific evidence for most or all of the effects is far from conclusive for exposures of 85 or 90 dBA for 8 hours. This being the case, can and should effects with this degree of uncertainty form part of the basis for a social policy choice by OSHA? They should, for the following reason: to ignore uncertain effects essentially assigns a value of zero to them, if one is thinking in cost-benefit terms. However, if there is any appreciable probability that the effects occur, then society is taking an extra chance of incurring additional harm if the less protective standard is adopted. It is not, in general, reasonable to assume that avoiding this possibility is of zero value to society. Indeed, in many areas of current social policy-making (such as, for example, nuclear power plant safety) very unlikely events of potentially great harm are considered quite important in the determination of policy.

Biological Effects

Cardiovascular and Endocrine Effects

The major concern over nonauditory health effects from noise arises from the ability of noise under some circumstances to act as a general, nonspecific biological stressor. Other than hearing loss, noise is not suspected of producing any single health problem unique to itself and comparable to the vinyl chloride angiosarcomas, the thalidomide birth defects, or the asbestos mesotheliomas. Rather the effects of noise, if any, are likely to be distributed over a large number of common individual cardiovascular and other maladies whose causation is complex and attributable to other factors as well. Nonetheless, because, in particular, cardiovascular diseases are such a massive problem in our society, even if noise were to increase their frequency or severity by a small percentage in the exposed population, this would be a very substantial adverse impact. Major cardiovascular diseases* account for well over half of all deaths in the United States, currently somewhat over a million people per year.[7] They are also, by far, the most frequent cause of permanent total disability in those under 65, as measured by Social Security awards.[8]

*Heart attack, stroke, etc.

Figure 2-4 indicates some of the broad mechanisms by which noise may possibly be contributing to cardiovascular pathology. It must be emphasized that this schema is not presented as established. In no case has any single study documented the entire series of events indicated in any of the separate damage pathways in any particular worker population. Figure 2-4 represents a coherent set of hypotheses which can be used to look at the diverse available data, and make a tentative judgment of the overall plausibility of the indicated relationships between noise and cardiovascular disease. Table 2-14 following the figure gives synopses of the papers (positive and negative) felt to be the most important to consider in making this judgment.

The concept of biological stress, first proposed by Selye, has been described[10] as

> the non-specific 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.
>
> It is conceivable that in the dawn of the history of mankind, noise very often was a signal of danger or else of a situation requiring muscular activity. In order to survive, the human organism had to prepare itself for activity, inter alia by the non-specific adaptation pattern defined as stress. More often than not, noise in today's industrialized societies has a meaning very different from what it had during the stone age. Yet, according to one hypothesis, our genetically determined psychobiological programming still makes one react as if muscular activity would be an adequate reaction to any sudden, unexpected or annoying noise stimulus.

The stress reaction consists of a wide variety of viological changes, many of which are likely to be mediated by increased adrenal secretion of the catecholamine hormones, epinephrine and norepinephrine (also called adrenaline and noradrenaline). In judging the plausibility of the damage pathway in Figure 2-4 which starts with the arrow from "A" to "B," two questions are of paramount importance:

1) To what degree do industrial workers respond to noise on the job by chronic or repeated biological stress reactions (manifested by chronic or repeated increases in catecholamine levels)?
2) To what degree do such reactions inflict a biological price in the form of either
    a) small incremental additions to a chronic pathological process such as atherosclerosis (hardening of the arteries) or
    b) precipitation of overt incidents of major damage (such as a heart attack, or stroke) in otherwise asymptomatic but physiologically borderline individuals?

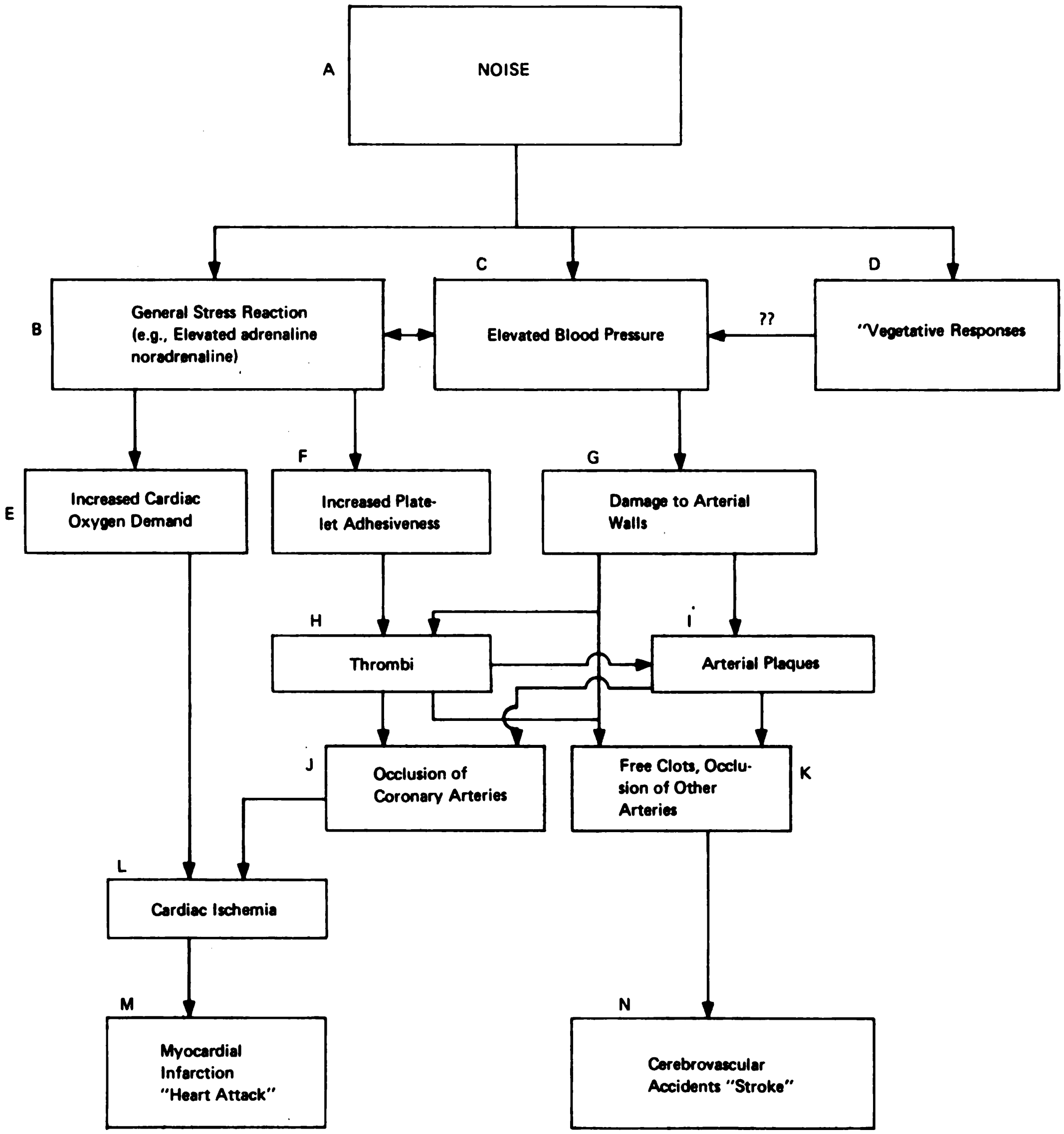

Figure 2-4. Possible pathways of cardiovascular damage from noise

Table 2-14

Documentation suggesting steps in damage pathways indicated in Figure 2-4

Steps in Figure From	Steps in Figure To	Reference number	Author, year, title	Summary conclusions*
A	B,C	3	Ortiz, et al. (1974). Modifications of epinephrine, norepinephrine, blood lipid fractions and the cardio-vascular system produced by noise in an industrial medium.	Marked elevations of catecholamine excretion and more modest, but statistically significant increases in systolic and diastolic blood pressure in the majority of a group of aircraft turbine testers after 3 hours of normal exposure in their work to noise which "varies between 105 and 115 dB (sic)" in intensity. *CAVEAT:* Other potential noxious agents in the workplace not discussed or controlled.
A	B	46	Arguelles, A. E., et al. (1970). Endocrine and metabolic effects of noise in normal, hypertensive and psychotic subjects.	Increased excretion of epinephrine and norepinephrine in urine after 30 minute exposure to 90 dB (2000 Hz).
(Negative) A	B	4	Carlestam, G., et al. (1973). Stress and disease in response to exposure to noise – a review.	No significant increase in catecholamine levels in 22 young female IBM operators exposed to their normal working noise at 76, 82, 88, and 94 dB for one day each. *CAVEAT:* Authors cite "generally positive attitudes of these subjects to the job per se and to the experiment" and conclude that "noise may be a potential stressor under some circumstances and in some individuals, but need not generally be so."
A	B,C	5	Carlson, L. A., et al. (1972). Stressor-induced changes in plasma lipids and urinary excretion of catecholamines, and their modification by nicotinic acid.	"Monotonous but attention-demanding psycho-motor performance (sorting small ball-bearings) under unfavorable environmental conditions (noise,** flickering light), shortage of time and criticism . . . evoked moderate distress, accompanied and/or followed by increases in heart rate, blood pressure, urinary excretion of adrenaline and noradrenaline, and levels of free fatty acids and triglycerides in arterial plasma." *CAVEAT:* Contribution of noise to the observed effects is obviously confounded with the contributions of several other stressors.
A	B	6	Slob, A., et al. (1973). The effects of acute noise exposure on the excretion of corticosteroids, adrenalin and noradrenalin in man.	"Noise exposure*** appeared to cause a significantly different adrenaline excretion, insofar that among those exposed to noise no drop in excretion occurred in the afternoon. A similar effect, be it to a somewhat lesser degree, was noticed with regard to noradrenaline excretion . . . These results appear to be in good agreement with (positive) findings reported in the literature, provided that . . . the influence of two simultaneously occurring stressors is taken into account: (1) exposure to noise, and (2) the fact that the subjects were confronted with an unfamiliar laboratory situation. *CAVEAT:* Small, brief study. Noradrenaline effect not statistically significant.

Table 2-14

Documentation suggesting steps in damage pathways indicated in Figure 2-4 – continued

Steps in Figure		Reference number	Author, year, title	Summary conclusions*
From	To			
A	C	7	Medoff, H. S., and Bongiovanni, A. M. (1945). Blood pressure in rats subjected to audiogenic stimulation.	Classic paper. Unquantified noise from air blast for five to ten minutes every weekday from weaning (21 days of age) to 400-900 days (elderly) produced a high incidence of chronic hypertension. *CAVEAT:* Induced hypertension accompanied by audiogenic siezures (convulsions) which are extremely rare in humans.
A	C	8	Smookler, H. H., et al. (1973). Hypertensive effects of prolonged auditory, visual, and motion stimulation.	"Hypertension was induced in rats by chronic intermittent exposure to environmental stress (audio, visual, and motion) . . . When audiogenic stress**** was used as the exclusive stressor, the same time course of hypertension was obtained as with the combined stressors but the magnitude of the hypertensive response was less."
(Negative) A	C	47	Etholm, B., and Egenberg, K. E. (1964). The influence of noise on circulatory functions.	No observed effect of noise on blood pressure up to intensities of 100 dB.
		48	Klein, K., and Grubl, M. (1970). Hemodynamic reactions to acoustic stimuli.	
A	C, D	9	Lehmann, G., and Tamm, J. (1956). Uber Veranderungen der Kreislaufdynamik des ruhenden Menschen unter Einwirkung von Gerauschen.	At intensities of "90 phon" the overwhelming majority of subjects experienced increases in arterial pressures and decreases in pulse volume. Exposures approximately one hour, resting subjects. *CAVEAT:* Possibly a transient effect.
A	C	10	Andriukin, A. A. (1961). Influence of sound stimuli on the development of hypertension. Clinical and experimental results.	"Among workers exposed for prolonged periods to intense noise (above 93 dB) (sic) . . . (hypertension) is encountered on an average twice as frequently as in workers of various (relatively quiet) factories . . . " *CAVEAT:* Controls for the influence of stressors other than noise not apparent. Additionally, data is presented only in percentage/bar graph form without statistical analysis. Our reconstruction of the original incidence data indicates few if any statistically significant differences between the groups.
A	D	11	Jansen, G. Effects of Noise on Physiological State.	Constriction of peripheral blood vessels and other "vegetative responses" occur transiently in response to continuous noise over 70 dB. *CAVEAT:* Precise pathological significance of these changes is unclear, although they would *tend* to increase systemic blood pressure.

Table 2-14

Documentation suggesting steps in damage pathways indicated in Figure 2-4 – continued

Steps in Figure		Reference number	Author, year, title	Summary conclusions*
From	To			
A	D	12	Jansen, G. (1961). Zur Larmbelastung von Huttenarbeitern.	Epidemiological evidence suggesting "peripheral circulatory symptoms" somewhat more frequent in steel workers exposed to more than 90 dB, as compared to steelworkers exposed to less than this level. *CAVEAT:* Environmental differences other than noise between the steelworker groups not controlled. Vagueness of the "peripheral circulatory symptoms" category invites replication using more objectively measurable parameters.
A	F	13	Maas, B., et al. (1973). Platelet adhesiveness during exposure to noise.	Experiment in rats demonstrating a large increase in platelet adhesiveness in response to "a standardized noise of 113 dB (sic)" for three days. Also a less directly relevant finding of increased platelet adhesiveness (compared to normal controls) in clinic patients with several types of hearing loss not obviously related to noise.
B	H	14	Haft, J. I., and Fani, K. (1973). Intravascular platelet aggregation in the heart induced by stress.	Stress (immersion of rats in ice-cold water for 25-45 min) induced platelet aggregates in myocardial small vessels. Similar aggregates not found in controls.
B	H	15	Haft, J. I., and Fani, K. (1973). Stress and the induction of intravascular platelet aggregation in the heart.	"Intravascular aggregation of platelets similar to that found in dogs after norepinephrine infusion was demonstrated using the electron microscope in the hearts of 20 of 23 rats subjected to two forms of stress (immersion in hot water, 7 of 8 rats; repeated small electric shocks to the feet, 13 of 15 rats). Only one of 14 unstressed rats was found to have similar intravascular platelet aggregates. These findings suggest that catecholamines secreted endogenously during stress are sufficient to cause platelets to aggregate intravascularly and raise the possibility that clinical myocardial infarction occurring during severe or prolonged stress may be caused by catecholamine-induced platelet thrombi which occur at, or travel to, and occlude a coronary artery already narrowed by previous atherosclerosis."
B	L	16,17	Haft, J. I., and Fani, K. (1973). Protection against epinephrine-induced myocardial necrosis by drugs that inhibit platelet aggregation.	(1) Confirmation of previous literature reporting myocardial necrosis after catecholamine infusion. (2) Prevention of this necrosis with three different inhibitors of platelet aggregation (aspirin, dipyridamole, and clofibrate).

Table 2-14

Documentation suggesting steps in damage pathways indicated in Figure 2-4 – continued

Steps in Figure From	Steps in Figure To	Reference number	Author, year, title	Summary conclusions*
B B	L E	18	Nestel, P. J., et al. (1967). Catecholamine secretion and sympathetic nervous responses to emotion in men with and without angina pectoris.	Patients who had suffered heart attacks 6-18 months previously were divided into those with and without various kinds of chest pain, including *angina pectoris*. Those with *angina* and those with other left chest pain were shown to secrete appreciably more norepinephrine (as measured by metabolites in the urine) than patients without such chest pain in response to a series of mild stressors (solving a series of puzzles, completing a questionnaire measuring anxiety, and undergoing a test of pain threshold from radiant heat to the forehead). Previous literature is also cited to the effect that "subjects with coronary heart disease as a group show a greater adrenergic response than do healthy subjects to procedures which stimulate the sympathetic nervous system (19,20)." "Myocardial ischemia, which may become manifest clinically as angina pectoris, occurs whenever the energy requirements of the heart exceed the available supply of oxygen. Emotion commonly induces angina pectoris in people with coronary heart disease, and several lines of evidence suggest that this effect of emotion may be brought about by an increased secretion of the catecholamines epinephrine and norepinephrine. The concentrations of urinary catecholamines rise during stress (21), and a quantitative relationship has been demonstrated between the stress experienced by an individual and his urinary excretion of catecholamines (22). The infusion of norepinephrine into normal subjects leads to an increase in the extraction of oxygen by the heart and a fall in the oxygen saturation of coronary venous blood (23), changes which characteristically occur during exercise in patients with coronary insufficiency (24). It is well known that the infusion of norepinephrine into subjects with coronary heart disease may induce angina pectoris."
B	M	25	Pearson, H. E. S., and Joseph, J. (1963). Stress and occlusive coronary-artery disease.	"The incidence of emotional stress was found by interview to be significantly greater in a group of patients with coronary-artery disease than it was among their matched controls, the main difference appearing in the fields of work, leisure, and rush-hour travel." *CAVEAT:* "There are two main difficulties with this work. The first is the dependence on the patient himself as the sole witness of his own stresses, which puts much of the responsibility for the accuracy of the work on the judgment of the interviewer. The other is the perennial difficulty of establishing a standard of comparison, by finding the normal subject (or "non-case") who can be investigated in exactly the same way as the patient."

Table 2-14

Documentation suggesting steps in damage pathways indicated in Figure 2-4 – continued

Steps in Figure		Reference number	Author, year, title	Summary conclusions*
From	To			
B	M	26	Russek, H. I., and Zohman, B. L. (1958). Relative significance of heredity, diet and occupational stress in coronary heart disease of young adults. Based on an analysis of 100 patients between the ages of 25 and 40 years and a similar group of 100 normal controls.	"The measurement of stress due to phobias, frustration, anxiety and fatigue is most difficult to accomplish particularly in retrospect in the coronary patient. Nevertheless, it was clearly evident in this study that 91 percent of the test subjects had been under unusual occupational stress for varying periods prior to the onset of clinical symptoms. Thus, 25 percent of the patients not only had worked at full time jobs during the day but also had engaged in similar or different occupations during evening hours. An additional 46 percent of the coronary group had worked 60 hours or more per week for long periods immediately preceding clinical manifestations. In another 20 percent of the group there was unusual fear, insecurity, discontent, frustration, restlessness or inadequacy in relation to employment. In marked contrast only 20 percent of all the subjects in the control series showed comparable stress and strain in relation to occupation." *CAVEAT:* Same as preceding paper.
B	M	27	Buell, P., and Breslow, L. (1960). Mortality from coronary heart disease in California men who work long hours.	Nonfarm occupations with relatively large percentages of workers working more than 48 hours per week showed somewhat higher mortality from arteriosclerotic and coronary heart disease than occupations with few workers working more than 48 hours per week. *CAVEAT:* Title of paper somewhat misleading. Increased mortality not specifically tied to the subset of workers working long hours, but merely associated with *occupations* having larger percentages of people working long hours. Additionally, other possible causal factors known to be associated with cardiovascular disease (e.g., diet, etc.) not controlled between the groups.
F F	L I	28	Nordoy, A., and Rodset, J. M. (1970). Platelet phospholipids and their function in patients with ischemic heart disease.	"Patients with ischemic heart disease without recent myocardial infarction have a higher coagulant activity in platelet-rich plasma than the controls. As there is no difference between the activity in platelet-poor plasma of the two groups, this activity must be attributed to the platelets." Citing earlier literature, the authors say, "The tendency to thrombus formation in coronary arteries plays a fundamental role in the development of I.H.D.***** Firstly, thrombosis often represents the final occluding event in atherosclerotic arteries. Secondly, there is good evidence that mural thrombi may be transformed to atherosclerotic lesions (29-31)." *CAVEAT:* The role of thrombosis as the final occluding event in most sudden cases of myocardial infarction is not as universally accepted as might be inferred from the phrasing here.

Table 2-14

Documentation suggesting steps in damage pathways indicated in Figure 2-4 – continued

Steps in Figure From	Steps in Figure To	Reference number	Author, year, title	Summary conclusions*
F F F	I K M	29	Mustard, J. F., and Packham, M. A. (1969). Platelet function and myocardial infarction.	A general review of literature including the following: "Platelets adhere to an injury site on a blood vessel wall, and a mass of platelets may accumulate at this point (30-33). Subsequently, the blood coagulation mechanism leads to the formation of fibrin around the platelet aggregate (32-6). The initial platelet-rich thrombus that forms in response to vessel injury is transformed to a mass of fibrin during the 24 hours after the initial injury (32,36,37)." . . . "There have been a number of observations of abnormal platelet function in subjects who have had complications of atherosclerosis or in those who appear to be susceptible to it (40)." (Including measures of increased platelet adhesiveness.) "In man, platelet micro-emboli have been implicated in intermittent cerebral vascular and retinal ischemia (41,42). Moore and Mersereau (43) have provided evidence that platelet emboli originating from mural thrombi in the aorta can interfere with the renal circulation, giving rise to glomerulosclerosis and elevation of blood pressure. It has recently been suggested that the localized circulatory disturbances in the myocardium precipitated by the formation of platelet aggregates may be a factor in death due to myocardial dysfunction (44)."
H I J	I M M	45	Roberts, W. C. (1972). Coronary arteries in fatal acute myocardial infarction.	A general review of literature summarized in part as follows: "The coronary arteries are diffusely involved by atherosclerotic plaques in fatal acute myocardial infarction (AMI) . . . Usually the lumens of at least two of the three major coronary arteries are narrowed more than 75 percent by old plaques in patients who die suddenly (less than 6 hours) from cardiac disease with or without myocardial necrosis. Coronary thrombi occur in about 10 percent of patients who die suddenly or in whom necrosis is limited to the left ventricular subendocardium, and in about 50 percent of patients with transmural myocardial necrosis . . . The infrequency of coronary thrombi in patients dying suddenly of cardiac disease and in those with transmural necrosis . . . suggest that the thrombi may be consequences rather than causes of AMI. Although it may not precipitate AMI, coronary thrombosis may still be the underlying cause of the atherosclerosis. The findings of fibrin deposits in old atherosclerotic plaques and the findings of atherosclerotic type lesions . . . in organized known thrombi . . . suggest a strong relationship between thrombosis and atherosclerosis."

*Material in quotation marks comes from the papers cited. Material outside of quotation marks represent our own interpretations, conclusions and reservations (the latter expressed under the heading "CAVEAT").

**Cannot read on manuscript.

***"The 1/3 octave noise-band used had a middle range frequency of 4000 Hz and an intensity of 80 dB." Subjects reading, relaxing during 8-hour exposure.

****"Tape recordings of noxious sounds (compressed air blasts, bells, buzzers, and tuning fork impulses) presented so that each of 10 stimuli was delivered for 30 seconds followed by 1 minute of silence . . . delivered on a randomized intermittent basis of a 4-hour period. The animals were exposed to 2.5 hours of sound stress and during the remaining 1.5 hours the animals were kept in silence . . . The mean sound intensity was 100 ± 2.3 dB (sic) with a frequency variation from 0.5 to 4 kHz."

*****Ischemic heart disease.

Both of the types of damage indicated in items 2(a) and 2(b) above could be produced if noise stress were to increase the adhesiveness of platelets ("F" in Figure 2-4) on a chronic or repeated basis. Increased platelet adhesiveness has been observed in response to several different stressors,[20,21] including noise[19] and the effect can also be produced in response to the artificial infusion of norepinephrine from outside the organism.[16,23] Increased platelet adhesiveness makes sense as part of the general "fight or flight" preparation of the body because it would produce more rapid clotting of blood in the event of a wound. However, this increased platelet adhesiveness has clear potential for negative side effects due to an increased tendency for the formation of thrombi* at places of minor damage in arteries in the heart and elsewhere.[20,21] There is strong evidence that such thrombi contribute to the buildup of atherosclerotic "plaques" which gradually narrow arteries and chronically reduce the oxygen supply of vital tissues.[35,51] The same thrombi may also contribute on an acute basis to the completion of the pathological sequence by forming the final occlusion of an already-narrowed artery leading to tissue death. Exogenously infused norepinephrine has been observed to produce necrosis (death) of cardiac muscle, and this necrosis can be greatly reduced by the simultaneous administration of various inhibitors of platelet adhesiveness.[22,23] The likelihood that this mechanism plays a significant role in real cardiac pathology in the population is increased by three additional observations:

- Heart attack patients in general, and some subcategories of patients in particular, appear to be composed of individuals who secrete abnormally large amounts of catecholamine hormones.[24]

- Patients with ischemic heart disease appear to have generally higher coagulant activity in platelet-rich fractions of their plasma than normal controls.[34]

- Some epidemiological studies suggest a role for some kinds of emotional/occupational stress in heart disease.[31–33]

The other major route of damage shown in Figure 2-4, that through increased blood pressure must be regarded with considerable caution. As can be seen from Table 2-14 the evidence is, for the most part, quite equivocal. Some epidemiological observations seem to be suggestive, but all available studies leave a great deal to be desired. At this time, there can be no firm basis for ruling this category of effect either in or out.

In summary, one might say that although a great deal more scientific work will be needed before it can be said that workplace noise definitely contributes to cardiovascular disease, a relationship between the two is entirely plausible.

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*Thrombi are small aggregates of platelets and other blood components involved in clotting.

Immunological Effects

Related to the action of noise as a stressor, various effects on the immune system are to be expected and have been observed. Various stressors[58] including intense noise[59] induce a biphasic secretion of corticosteroids known to depress some kinds of immunological activity. Jensen and Rasmussen[60] monitored peripheral white blood cell levels in mice in response to 3-hour exposures to 123 dB of an 800 Hz tone. During the noise there was a pronounced drop in white blood cell count, followed by an equally pronounced rise for several hours immediately following exposure. In a companion paper[61] Jensen and Rasmussen innoculated mice with vesicular stomatitis virus immediately before or immediately after the exposure. As one might expect from the white blood cell response it was found that the mice innoculated before exposure were appreciably more sensitive, and mice innoculated after were less sensitive to infection than control mice.

The significance of potential shifts in immunological capabilities is large, as the immune system is of course our major bulwark against all manner of infectious diseases that exact a large toll of sickness and restricted activity every year. Available information is far from adequate to assess the likely magnitude of any noise-induced immunological effects, but data of Cohen to be published shortly are said to suggest that absenteeism from many disparate causes is increased in noise-exposed workers. If true, this could be of substantial economic and human importance.

Fetal Abnormalities

Finally under the category of possible biological effects, we feel compelled to mention a recent, surprisingly strong set of experiments reported by Geber.[62] The standard cautions with respect to all data of this type are in order – it is impossible to predict the likelihood and the degree that results of teratogenicity experiments in rodents will be manifested in humans, and it must be emphasized that the exposure conditions in these experiments were radically different than workplace noise.* The fact that a continually changing noise exposure, kept up day and night, is likely to be appreciably more stressful than most exposures which

*Quoting from the Geber paper, "A wide variety of electric horns, gongs, and alarm bells was mounted throughout the interior of the stress chamber along with six 10-inch speakers to send the outputs of an Fico Model 377 audio generator and "white noise" from a Grason-Stadler noise generator into the stress chamber. The characteristics of the noise stress were such that the measured decibel range of the noise spectrum within the stress chamber was 74-94 dB and the frequency range was from 20 to 25.000 cycles/sec. All units of the noise-generating apparatus were connected to individual cycling timers set to deliver effective daily noise stimulation of the pregnant animals equal to 10 percent (6 min.) of each might be expected in industry cannot be ignored. Nevertheless, the absolute levels of noise used were not excessive, and the results in terms of inhibition, partial, or complete absence of calcification of fetal bones are unequivocal (Table 2-15).

Table 2-15*

Effects of noise stress on ossification of bones in fetal rats

Number of fetal rats with various degrees of skeletal ossification			
Degree of fetal ossification	Control	Noise	Total
Younger pregnant females:			
Complete absence	0	52	52
Partial absence	2	60	62
General inhibition	2	60	62
Normal	749	310	1,059
Total	753	482	1,235
Older pregnant females:			
Complete absence	2	37	39
Partial absence	4	67	71
General inhibition	0	98	98
Normal	331	68	399
Total	331	270	607

*Adapted from Geber, W. F. (56)

hour of the day with relative quiet, i.e., ambient noise, existing throughout the remaining 90 percent (54 min.) of each hour. Schedules of sequencing of the noises were randomly controlled by variation in cycling times of the various timers. Thus, the degree of acclimation to each noise pattern was presumed to be minimal since it was continually changing in reference to all others.

The noise stress was continued throughout each day of the entire pregnancy or until some other day was attained, i.e., 16-22 days."

While it cannot be concluded from these experiments that maternal exposures to industrial noise are definitely dangerous to the fetus, the findings certainly cast some doubt on their safety. The question of possible teratogenic effects from exposures to noxious agents of all kinds in the workplace environment has unfortunately received almost no scientific study to this date. The most serious investigations we know of are the recent findings in nurses exposed to anaesthetic gases. With women rapidly acquiring more equal access to employment in heavy industrial jobs, it is imperative that consideration of all workplace standards should include the realization that women in the early stages of pregnancy* will be exposed along with males. Even a small increased risk of birth defects must, of course, be counted as a substantial adverse impact on society.

Workplace Effects

Perceived Annoyance

There has been a great deal of research into the "loudness," "perceived noisiness" and "annoyance" qualities of different types of noise. An excellent recent review of the subject is contained in a recent paper by Miller.[63] A weakness of most of the data for purposes of the current regulatory activity is that, for the most part, measurements seem to have been made in either a laboratory or a community-noise setting. We have not located work on the direct measurement of parameters related to annoyance in an industrial context. Psychological characteristics of individuals, and general attitudes of workers toward their employer and their work will undoubtedly have a bearing on the magnitude of the annoyance felt in response to the noise on a particular job. However, it seems reasonable to expect on the basis of existing research that at least five physical parameters of noise will have approximately the following relative influence of noise on perceived annoyance:

> The five physical factors mentioned by Kryter operate approximately as follows: (1) *Intensity and frequency content* – noisiness increases with sound level approximately as does loudness, that is a 10-dB increase in the level of moderately intense sounds results in a doubling of judged noisiness. Sounds with energy concentrations between 2000 Hz and 8000 Hz are judged to be more noisy than sounds of equal sound pressure level outside this range. This effect can be equivalent to a 10-20 dB increase in level or a factor of 2-4 in judged noisiness. (2) *A concentration of energy or spectrum complexity* – this may have an effect which increases the noisiness by 2-3 times or the equivalent

*Nearly all fetal anomalies are produced by events in the first three months after conception.

of 10-15 dB over that noisiness that would be otherwise predicted. (3) *Duration* – the noisiness of a sound increases with its duration. The relation is logarithmic, and over a range from a few seconds to a few minutes, an increase in duration by a factor of ten results in a change that is roughly equal to a 10-dB increase in level, in other words, an increase in noisiness by a factor of two. Detailed study indicates that the growth of noisiness with duration is more rapid in the range of 1-4 sec and less rapid beyond 15 sec than predicted by a single logarithmic relation. (4) *Duration of the period of rising sound pressure level* – sounds that are increasing in level are judged to be of greater noisiness than those decreasing in level. A sound that takes 10 sec to reach a maximum level may be judged more noisy than one of equal energy that reaches its maximum level in 3 sec. This difference can be the equivalent of about 3 dB or a factor of 1.2 in noisiness. (5) *Sudden increases in level* – in contrast, impulsive sounds that reach a high peak very abruptly, i.e., in a fraction of a second, may be judged to be very noisy. While this effect depends on the magnitude of the impulse, it can be very large. People judge impulsive sounds to be very noisy even when these sounds are familiar and expected.[63]

Of these five parameters, only the first, intensity, is affected in a reasonably predictable way by the proposed industrial noise regulations. Later we will use the fact that perceived noisiness increases by approximately a factor of 2 for each 10 dB increase in level in rough calculations of the approximate value of annoyance reductions produced by the proposed standar

Effects on Work Performance

The area of work performance is perhaps the most difficult to assess in a satisfactory way for purposes of social decision-making. At least with the other effects of noise one can be reasonably confident that, to the extent they occur, the direction of change will be for the worse for the human organism. EPA's criteria document[71] succinctly summarizes a daunting volume of available experimental work as follows:

> Viewed as a whole, the literature on noise and performance shows that sometimes noise interferes with performance, sometimes it improves it, and usually it causes no significant changes. A number of general conclusions, however, have emerged:
>
> 1. Steady noises without special meaning do not seem to interfere with human performance unless the noise level exceeds about 90 dBA and not consistently even then.[64]

2. Intermittent and impulsive noises are more disruptive than steady-state noises.[65] Even when the sound levels of irregular bursts are below 90 dBA they may sometimes interfere with performance of a task.[66]

3. High-frequency components of noise (above about 2000 Hz) usually produce more interference with performance than low-frequency components of noise.

4. Noise usually does not influence the overall rate of work, but high levels of noise may increase the variability of the work rate. There may be "noise pauses" or gaps in response,[67] sometimes followed by compensating increases in work rate.

5. Noise is more likely to reduce the accuracy of work than to reduce the total quantity of work.[67,68]

6. Complex or demanding tasks are more likely to be adversely influenced by noise than simple tasks.[69]

Our own brief review of the literature has uncovered little relevant to these proceedings that would either add or subtract materially from the EPA conclusions, with the possible exception of a recent study by Hartley.[70] Hartley's study is interesting in that he measured performance on a serial reaction test* in noise and in quiet** *with and without ear defenders.**** The results, in terms of average "gaps" and "errors" are reproduced below:

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*The test is performed with a subject seated before a display consisting of 5 neon light sources arranged in a pentagon, one of which is always illuminated. Arranged on a horizontal response board are 5 brass disks corresponding to the light sources. The (subject) is required to tape the disk appropriate to the lamp illuminated. The light promptly extinquishes and another is lit. The (subject) works as quickly and accurately as possible, scoring as many corrects and as few errors as possible. The third score consists of pauses or gaps of 1-1/2 sec between tapping one disk and tapping the next. The (subjects) were 16 housewives and professional men, ranging 18-45 years of age.

**Broad-band noise having equal energy per octave was used throughout. In the N conditions it was presented at 95 dB, and in the Q conditions, at 70 dB, measured on the C scale.

***The ear protection was provided by Amplivox Sonogard ear defenders, specified as providing a substantially linear attenuation with frequency over the audible range (20 dB at 200 Hz, 30 dB at 500 Hz, 38 dB at 1 and 2 kHz, and 45 dB at 4 kHz, measured at one-fifth octave bands and the American Standard Method for the Measurement of the Real Ear Attenuation of Ear Protection at Threshold, ASAZ-24.22-1957).

Mean Gaps in Each 10-Min. Block Under Each Condition

Condition	Block 1	Block 2	Block 3	Block 4	Total
Q	2.57	5.13	6.69	7.31	21.70
Q + ED	4.07	6.57	8.25	7.50	26.39
N	5.06	11.12	10.44	8.94	35.56
N + ED	3.57	6.50	9.81	9.88	29.76

Note. Abbreviations: Q = quiet, N = noise, and ED = ear defenders.

Mean Errors in Each 10-Min. Block Under Each Condition

Condition	Block 1	Block 2	Block 3	Block 4	Total
Q	2.10	4.67	6.11	5.72	18.60
Q + ED	3.30	5.22	8.80	6.25	23.57
N	2.87	6.10	8.10	5.19	22.26
N + ED	3.45	9.90	9.73	7.97	31.05

Note. Abbreviations: Q = quiet, N = noise, and ED = ear defenders.

By the "gaps" measure of performance (number of pauses of 1-1/2 seconds) the ear defenders appear to be somewhat helpful in noise, but fall far short of producing performance comparable to that produced by the quiet condition. Ear defenders used in the quiet seem to increase gaps on their own, to some degree. By the errors measure of performance, neither noise nor ear defenders individually produced large enough effects to be statistically significant, but it would appear that, when combined, they produced a rather substantial increase in average errors.* These suggested effects invite considerable further study, but for purposes of the current rule making they 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.

No quantitative guess is in order on the magnitude of these effects, partly because of the lack of fundamental baseline data. (Few companies, for example, publish yearly figures on the average number and type of defects in their products.) It is not impossible, however, that over a number of years economic performance losses of the same order of magnitude as engineering control costs could be presented by engineering compliance with noise regulations.

*It should be noted that the author of this paper himself inexplicably but studiously avoids drawing this latter conclusion.

Effects on absenteeism, accident and injury rates

Effects of workplace noise on absenteeism, accident, and injury rates have long been postulated as likely end results of other properties of noise (both biological and psychosocial) which are easier to measure directly. It is not at all unreasonable to suppose that an increased tendency toward absenteeism might result both from workers' psychological aversion to returning each day to an unpleasant environment, and from any general lowering of immunological resistance to infection. Moreover, the frequency and severity of industrial injuries could easily tend to be higher in noisy environments both as a result of possible masking of warning signals and because of an increase in momentary gaps or errors in performance.

Plausible as these effects are, they have to date posed truly formidable problems for epidemiological demonstration. The basic reason why the epidemiology is so difficult is tha it is hard to imagine a situation where one might find reasonably comparable worker popula tions in reasonably comparable jobs exposed to reasonably comparable accident and health hazards, at substantially different, well characterizable noise exposure levels, all with either excellent records of accidents, illnesses, and absenteeism or the capability of producing such records over an extended period of time while keeping all the other conditions constant. This epidemiological problem is considerably more challenging than most other epidemiological problems because of the intimate association between noise exposure and other characteristics of the population and the jobs (such as, socioeconomic status, exposure to safety hazards of particular types from specific types of machinery, etc.) which would tend to confuse the results unless the experiment were very carefully controlled. One must admire the professional fortitude of anyone undertaking such a study.

This being the case, it is remarkable that even one serious attempt at an epidemiological investigation meeting the criteria outlined above has been performed. Such a study, the second part of the Raytheon study performed in cooperation with NIOSH, compared accident, illness and absentee rates for different worker groups in a large manufacturing plant before and after the institution of a hearing conservation program. The study is still in the process of final publication and is unfortunately unavailable for full review here. However, the conclusions of the authors are reported to be that they did observe quote suggestively higher incidences of absenteeism, illnesses, and accidents when the workers had greater effective exposures to noise.

BENEFITS AND COSTS OF A MORE PROTECTIVE STANDARD

An attempt will be made to construct an elementary balance sheet indicating the important benefits as well as costs of effective 85 dBA and 90 dBA regulations for different sectors of our society. In all cases, these impacts will be based on a comparison with a theoretical baseline case of noise exposures unchanged from present levels. Two time periods will be examined; the first from effective compliance to *10* years after effective compliance, and the second from effective compliance to *40* years after effective compliance.

Hearing Conservation

Tables 2-10 and 2-11 quantified the numbers of excess* people in two hearing level ranges given different noise standards and different assumptions about job mobility in the population at the two different time periods after effective compliance. To determine the hearing conservation benefits of each regulation, subtracting the number of people in each hearing level range under the regulation from the corresponding number of people who would experience impaired hearing in the same range under the baseline case. The results of this procedure at the time points of 10 and 40 years after compliance are shown in Table 2-16, with the best estimates corresponding to the some job mobility case (where a worker is assumed to hold three jobs in his lifetime, one of which may be noisy and two of which are at 80 dBA), and the extreme values of the ranges corresponding to the highest and lowest values of the three job mobility cases.**

At this stage, two points from the computation of these results should be reiterated:

- Only people in the workforce and between the ages of 20 and 64 are included in these data. In particular, some number of additional people experiencing poorer hearing than they otherwise would after the age of 65 can be expected to exist.

- The people placed in the over 50 dB hearing level range by the influence of noise for the most part would have had hearing in the 25-50 dB category in the absence of noise – their hearing has gone to a severely impaired state from an already

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*In "excess" of those who would have been at the stated hearing levels in the absence of noise exposure (i.e., due to presbycusis, etc.).

**From data presented by Dr. Ward in his testimony, it is our general impression that the "some" job mobility case is, if anything, a conservative estimate of the actual job mobility likely in noisy jobs in the industrial population.

Table 2-16

Reductions* in the Numbers of People with Different Degrees of Hearing Impairment after Compliance with Different Noise Regulations

Hearing level range	(Thousands of people)			
	At 10 years after compliance		At 40 years after compliance	
	Best** estimate	Range of estimates over spectrum of no-infinite job mobility assumptions	Best estimate	Range of estimates over spectrum of no-infinite job mobility assumptions
90 dBA regulation:				
Hearing level range:***				
25-50 dB	448	(191 - 2,344)	1,025	(427 - 9,814)
Over 50 dB	81	(40 - 81)	208	(118 - 980)
85 dBA regulation:				
25-50 dB	767	(412 - 3,159)	1,760	(791 - 11,039)
Over 50 dB	114	(51 - 114)	286	(150 - 1,117)
Added benefit of 85 dBA, over 90 dBA:				
25-50 dB	319	(221 - 815)	735	(364 - 1,225)
Over 50 dB	33	(0 - 33)****	78	(32 - 137)

*All numbers represent reductions in numbers of hearing impaired people from the baseline case of no change in worker noise exposures.

**Calculated under "some" job mobility assumption (3 jobs per worker).

***Average at 0.5, 1, 2 kHz, Re: ISO.

****"0" value at bottom of this range is, in part, an artifact of the calculation procedure. Some small finite value is to be expected, even in the job mobility case which gives the "0" estimate.

slightly to moderately impaired state.* Numbers shown in the 25-50 dB category reflect the *net* effects of entrance from the group that would otherwise be under 25 dB and the exit of individuals from the 25-50 dB group to the group over 50 dB.

Table 2-16 has given the number of *people* affected at two points in time. To understand the total impact of the regulations through the intervening years, one should ideally

1) divide time into individual small units (years, or months),

2) multiply the number of people affected times the individual small durations, and

3) add the results together to find the number of person-years of impairment prevented by each regulation over specified periods in the future.

As an approximation to this ideal procedure, it has simply been assumed that the numbers of people affected between 0-10 years and 10-40 years after compliance follows straight lines between the 0, 10 and 40 year points under each of the different job mobility cases. Using this latter procedure, for example, the benefit of each regulation over the first 10 years was taken as simply five times the benefit which was indicated to occur in the tenth year.** Table 2-17 shows the final results – total millions of person-years at each hearing level saved by each regulation during the first 10 and 40 years after compliance. These millions of person-years of impairment cannot be adequately translated into economic costs, but they may be compared to the economic costs in arriving at the final noise regulation. They will be entered, together with the other costs and benefits, on the final balance sheet. Tables 2-16 and 2-17 are condensed in summary Table 2-18.

Workers' Compensation Costs Saved

It has long been recognized that occupational disease is under-reported in both employers' injury and disease logs and in workers' compensation claims. A recent NIOSH-sponsored study at the University of Washington indicates that occupational disease is under-reported in employers' logs by a factor of 50 and in workers' compensation by a factor of 33.[72]

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*A discussion of the significance to the affected individuals of the various hearing levels was presented in section 2.

**In other words, the *average* yearly benefit over the first 10 years was simply taken as half of the benefit for the tenth year.

Table 2-17
Person-years of hearing impairment prevented by different noise regulations during different periods after compliance

Hearing level range	Millions of person-years**			
	During first 10 years after compliance		During first 40 years after compliance	
	Best estimate	Range of estimates over spectrum of no-infinite job mobility	Best estimate	Range of estimates over spectrum of no-infinite job mobility
90 dBA regulation:				
Hearing level range:*				
25-50 dB	2.2	(1.0 - 12)	11	(4.5 - 120)
Over 50 dB	0.41	(.20 - .41)	2.3	(1.4 - 14)
85 dBA regulation:				
25-50 dB	3.8	(2.1 - 16)	19	(7.7 - 130)
Over 50 dB	.57	(.26 - .57)	3.2	(1.7 - 16)
Added benefit of 85 dBA, over 90 dBA:				
25-50 dB	1.6	(1.1 - 4.1)	8.4	(3.3 - 10)
Over 50 dB	.17	(0 - .17)	.84	(.37 - 2.1)

*Average at 0.5, 1, 2 kHz Re: ISO.

**Numbers may not always add because of rounding.

Traditionally, the number and size of annual worker's compensation claims have been small as compared to other types of disability payments. However, with an increased awareness on the part of employees to health hazards on the job, the number of compensated hearing loss cases is on the increase. The data in at least one state, California, indicates a five-fold increase in the number of hearing loss cases in the 14-year period, 1955-1968 (Table 2-19).

Table 2-18

Summary of best estimates of added benefits of
85 dBA over 90 dBA regulation

Hearing level	10 Years after compliance	40 Years after compliance
Thousands of people with reduced hearing impairment:		
25-50 dB	319	735
Over 50 dB	33	78
Millions of person-years of impairment prevented:		
25-50 dB	1.6	8.4
Over 50 dB	.17	.84

Table 2-19

Number of hearing loss cases, fiscal years 1955 to 1968

Fiscal year ended June 30	Total	Northern area	Southern area
1955	86	39	47
1956	100	35	65
1957	93	41	52
1958	144	52	92
1959	186	58	128
1960	143	48	95
1961	148	46	102
1962	332	66	266
1963	373	72	301
1964	289	81	208
1965	296	94	202
1966	300	91	209
1967	369	104	265
1968	421	159	262

Compiled by the Division of Labor Statistics and Research,
Department of Industrial Relations, State of California, March 1969.

Because of the trend toward a greater number of compensation claims and because of the need for cost calculations which includes the potential loss to the society through the worker's compensation system, we have based our estimates on previously described hearing loss which assumes a total capture (i.e., a total claiming) of this economic factor. This is based on no change in present compensation schedules, a fact which may offset to some degree the inevitable fact that not all workers who will be handicapped for compensation purposes will receive payment.

It has already been mentioned that the workers' compensation claims are a one-time cost, even if in reality the claims may be spaced over a variety of different times. For the purpose of our calculations we have decided to examine the potential benefits (compensation costs saved) both 10 and 40 years hence.

The magnitude of this potential benefit is to be found in Table 2-20 under the conditions of compliance with 90 dBA and 85 dBA. Four conclusions are worth noting:

- the assumption of job mobility greatly increases the estimate of benefit to be derived,
- about a third of the benefit is captured in the first 10 years,
- both those suffering moderate harm and severe harm are benefitted significantly, and
- a change in compliance from 90 dBA to 85 dBA brings considerable marginal returns – approximately twice the benefit in cases of less severe hearing loss.

Social Costs of Absenteeism and Other Effects

Given the discussions on the state of knowledge of performance, absenteeism, general illness, and industrial injury effects of noise, it must be appreciated that any assessment of the social costs of these effects must be highly speculative. Nonetheless, the effects are all generally plausible, and the expected value of their impact on society, though highly uncertain, is clearly not zero. The average employed worker loses about 5 to 6 days per year from all illnesses and injuries.[73] Due to the limitations of sample size and other sources of variability in epidemiological techniques, it is difficult to imagine that the current NIOSH study could reveal statistically significant noise-related increases in absenteeism if the effects on total absenteeism attributable to noise were less than about 2 to 3 days per worker – that is, about 50 percent over the normal "background" level. Considering this, and considering the likelihood of performance and industrial injury effects, it is not unreasonable to suppose that

Table 2-20

Potential workers' compensation payments for hearing loss in both ears
($ millions, not discounted)

	40 years after compliance			
	90 dBA		85 dBA	
	1 job per worker	3 jobs per worker	1 job per worker	3 jobs per worker
Workers handicapped 15% at 35 dB*	$ 705	$1,691	$1,305	$2,904
Workers handicapped 52% at 60 dB*	$ 675	$1,190	$ 858	$1,636
Total payments	$1,380	$2,881	$2,163	$4,540

	10 years after compliance			
	90 dBA		85 dBA	
	1 job per worker	3 jobs per worker	1 job per worker	3 jobs per worker
Workers handicapped 15% at 35 dB	$ 315	$ 739	$ 680	$1,266
Workers handicapped 52% at 60 dB	$ 229	$ 463	$ 292	$ 652
Total payments	$ 544	$1,202	$ 972	$1,918

*"Handicap" for compensation calculations is 1-1/2 percent for each dB loss between average hearing levels of 26 dB and 92 dB. Based on 10 State average maximum payment of $11,000, 15 percent handicap equals $1,650/worker and 52 percent handicap equals $5,720/worker.

the approximate order of magnitude of the total economic harm caused by all of these effects may be the equivalent of about one day of work less per worker per year for all those estimated by BBN to be exposed to more than 85 dBA.

The Frye report (1965)[74] estimated that reducing absenteeism by 1 day per year over the total workforce of 80 million would add about $10 billion to the gross national product, or about $125 per worker/day. Today because of inflation and the real growth in our GNP the number would be about twice as high, or $250 per worker-day. If the guess outlined in the previous paragraph of 1 day's effective absenteeism per year per worker exposed over 85 dBA is accepted, then the approximate total benefit to workers in industries examined by BBN from this source potentially realizable from noise control amounts to $250 x 8 million = $2 billion. Over 10 and 40-year periods after compliance, the potential benefit would, of course be correspondingly multiplied.

It must be reemphasized, of course, that like compliance cost estimates, these estimates are unfortunately only best guesses, though reasonable ones. Reasonable people should agree that such potential benefits should be considered in an even handed appraisal of proposed social policy.

Annoyance as a Social Cost

That noise is, to some degree, a net overall annoyance to industrial workers must be considered reasonably beyond dispute. By and large, it must be supposed that workers exposed to industrial noise in the range under discussion consider it, on balance, unpleasant or annoying. This depression of their quality of life is clearly a social cost. To the degree that workplace noise regulations may reduce this social cost, the reductions should enter into an assessment of the overall costs and benefits of these social policies. Offered in this section are some quantifications, albeit highly uncertain and tentative quantifications, of the approximate magnitude of these effects in relation to the estimated economic costs of compliance.

Before entering these computations, however, it should clarify some points about the operation of market forces with respect to annoyance costs.

- In contrast with some of the long-range auditory and health effects of noise, annoyance effects are relatively easy for individuals to judge and integrate into decisions about whether or not to accept a particular job. It therefore may be contended by some that, in general, in a free market, the worker's wage will include some additional monetary inducement to take a noisy job, over a quiet one. However, it should be noted that this kind of mechanism, to the extdnt it operates effectively in practice, merely causes a partial *redistribution* of the social cost of noise annoyance from workers to their employers (the employers, of course, have to pay the premium that the workers get). There is no net *decline* in the total annoyance cost born by the society as a whole by this mechanism.

- A market factor which *would* tend to reduce overall annoyance costs is worker self-selection for noise annoyance resistance in noisy jobs. It can be expected that those workers who are more annoyed than average would tend to end up in quieter jobs and those workers who are less annoyed than average would tend to end up in noisier jobs, other things being equal. Therefore in considering the value to be assigned to workplace noise annoyance, we must, to the extent possible, attempt to reflect the values of the individuals actually in those jobs, rather than the average values of the general population.

The discussion of past research on perceived annoyance revealed one reasonably solid relationship that can contribute to the calculations; for each 10 dBA increase in intensity of a particular noise, the perceived noisiness approximately doubles. In addition to this relationship, the only additional inputs needed are the distribution of noise exposures and the actual average annoyance value of some standard noise exposure over some unit of time. The exposure distributions were discussed in some detail in the hearing impairment section, leaving the annoyance value of a standard noise exposure the only remaining unquantified parameter. For this, one is forced to speculate, but believe that it is possible to specify a reasonable range of values, using dollars as a yardstick, which probably contains the true average value.

Selected as the standard exposure is an average 90 dBA continuous noise for an 8-hour day. How much per hour do we believe an average worker in such a job might be willing to sacrifice to do the same work in quiet (say, 50 dBA) conditions? It is suggested that at an absolute minimum, this difference should be considered to be worth 10 cents an hour. For purposes of calculation, this is taken as a lower bound. As an upper bound, it is suggested that it is probably unlikely that the average worker would spend more than about 50 cents an hour, simply on an annoyance basis* to accomplish the reduction from 90 to 50 dBA. (The reader may, of course, choose others for calculation purposes, if he or she disagrees with these values.) Now if one can accept the 10-50 cents/hour range as the approximate value of an average daily 90 dBA exposure, the values of average exposures at other levels can be estimated by doubling or halving these values for each 10 dBA departure from 90 dBA, using the formula

$$\text{Value at X dBA} = (\text{value at 90 dBA})\ 2^{(X - 90)/10}$$

*Excluding any health or hearing impairment considerations.

The following table summarizes the results of these calculations:

Table 2-21

Exposure level	Range of annoyance values dollars/hour
80	0.05 - 0.25
85	0.07 - 0.35
90	0.10 - 0.50
95	0.14 - 0.71
100	0.20 - 1.00
105	0.28 - 1.41
110	0.40 - 2.00
115	0.57 - 2.83

From these and other intermediate values, combined with the exposure distributions given in the hearing impairment section, Table 2-22 shows the computation of the range of total annoyance costs per year – at present, and after compliance with 85 dBA or 90 dBA standards.

The values for total annoyance costs under each standard are then subtracted from the annoyance costs that would be incurred if exposures continued as they are at present. The range of annoyance costs saved per year, and over the next 10 and 40 years are given in Table 2-23. It should be noted that for this table, presented are undiscounted benefits. However when summed up in the final balance sheets, the figures will reflect these benefits discounted at a rate of 7 percent per year. (The discussion of what discount rates to apply in social policy making is beyond the scope of this presentation. In brief, it is believed that the proper discount rate should be the long term expectation of the difference between risk-free interest rates and inflation rates, and that this is probably in the neighborhood of 7 percent.)

Innovation and Regulation

An important economic effect of regulation, especially a regulation so broad as that concerning workplace noise, is the impact on technological innovation. This is a particularly significant issue in the current controversy since it is unclear exactly how industry will respond, technologically, to either an 85 or 90 dBA standard.

Table 2-22
Computation of annual annoyance costs under different regulations

Present exposures			Annoyance cost	
Exposure level	Thousands of workers	Billions of hours per year*	Low value $ billions/year	High value $ billions/year
82	5,858	11.72	0.67	3.3
87	4,769	9.54	.77	3.9
92	1,878	3.16	.43	2.2
97	939	1.88	.30	1.5
102	469	.94	.22	1.1
107	235	.47	.15	.8
112	117	.23	.11	.5
117	117	.23	.15	.8
Total	14,382	28.76	2.81	14.0
After compliance with 90 dBA standard:				
82		11.72	.67	3.3
87		9.54	.77	3.9
90		7.51	.75	3.8
Total		28.76	2.19	11.0
After compliance with 85 dBA standard:				
82		11.72	.67	3.3
85		17.05	1.21	6.1
Total		28.76	1.88	9.4

*Assuming 2,000 hours per worker-year

In order to understand the effects of the standard on innovation, one must separate the noise control industry from other sectors. With full enforcement of either an 85 or 90 dBA standard, the demand for noise control technology will exceed current sales of this industry, as BBN has reported. BBN goes on to say, however, that this demand will stimulate increased investment and new technological developments which may well be able to satisfy these new requirements. The results of other research on innovation strongly support BBN's assertion.

Table 2-23

Net savings of annoyance costs under 90 dBA and 85 dBA regulations

Standards	Billions of dollars		
	Annual savings	Savings over first 10 years after compliance	Savings over first 40 years after compliance
90 dBA standard	0.61 - 3.1	3.1 - 31	25 - 123
85 dBA standard	.93 - 4.6	9.3 - 46	37 - 185
Benefits of 85 dBA over 90 dBA	.31 - 1.6	3.1 - 16	13 - 63

*Unadjusted for any social discount rate.

From this work one knows that market factors, such as increased demand, appear to be the primary influence on innovation. Approximately 10 relatively recent studies have shown this to be true, as reported in work published by other MIT personnel from the Center for Policy Alternatives.[75] The new demand created by a strict noise standard would, consequently, seem to be a powerful stimulus to innovation in noise control technology.

With respect to the effect of regulation on industry in general, there has been a great deal of comment asserting that the increased costs imposed by regulation will hamper innovation. Most of this comment is opinion or theory and runs contrary to the only empirical work on the subject, a study recently completed at the Center for Policy Alternatives. What has been found is that, in contrast to this conventional wisdom, environmental and safety regulations are a positive stimulus to commercial innovations in a significant number of cases.

The results are based on a study of 164 successful, unsuccessful, and on-going projects in firms in five foreign countries and five industries, where data were gathered through interviews with project managers.[76] The environmental and safety regulations in evidence were more often associated with successful than unsuccessful projects by a factor of three, with a 10 percent chance that this distinction was random. Even more significant was the fact that projects were conducted differently because of regulation ten times more often in the case of successful projects than was true for unsuccessful projects. These observations were highly statistically significant, with the chance of random occurrence only 2 percent, and uniform across countries.

The firms and industries interviewed were not concerned with making or selling pollution control equipment or services. They tended to be large and older, indicating that particularly in mature highly concentrated industries regulation exerts a salutary influence on the process of innovation. Apparently, regulation stimulates product and process change in the firm to meet new conditions and thus provides opportunities for innovation which otherwise might not have occurred.

It is recognized that this study has limitations both in the scope and in the number of its observations. Nevertheless, it is felt that its findings are highly relevant to a consideration of the benefits arising from environmental and safety regulation and they suggest that the effect of workplace noise regulation on innovation may well be positive both within and without the noise control industry.

Quantification of Net Costs

Attempts have been made to quantify some important benefits. Presented in Tables 2-24 and 2-25 are partial balance sheets for compliance with a 90 dBA standard and 85 dBA standard, respectively. Assuming some job mobility (3 jobs per worker), a capture of all compensible hearing loss under present criteria, a 1 day per year per-worker reduction in absenteeism as a proxy for all losses of worker effectiveness to his employer and a conservative value of annoyance to the worker exposed to 90 dBA of 10 cents per hour. Also included for comparison with monetarily quantifiables is the reduction in hearing impairment expressed in both numbers of workers and person-years of impairment. Listed but unable to quantify, are the possible effects on coronary heart disease.

Different assumptions will yield different numbers, but perhaps these preliminary balance sheets provide a good starting point for serious discussion.

The accounting suggested indicates that compliance with a 90 dBA standard is likely to yield a net benefit to society even after 10 years. Compliance with 85 dBA appears to be achievable at a net cost after 10 years, but at a figure very much smaller than the compliance cost estimates. Ultimately, compliance with the 85 dBA standard is a net benefit to society.

Table 2-24
Net costs with 90 dBA standard
(assuming 3 jobs per worker)
($ billion)

Items	After 10 years compliance	After 40 years compliance
Accruing primarily to firms:		
Compliance costs (BBN)	13.5	13.5
Maximum workers' compensation costs saved (present value)*	(1.2)**	(2.9)
Absenteeism reduced ($2 billion per year, present value)*	(14.0)	(26.7)
Subtotal	(1.7)	(16.1)
Accruing primarily to workers:		
Annoyance (lowest estimate)*	(4.3)	(8.1)
Total monetarily quantifiables	(6.0)	(24.2)
Accruing to workers:		
Reduction in number impaired (thousands)		
25-50 dB range	448	1,025
Over 50 dB	81	208
Reduction in person-years of impairment (millions)		
25-50 dB range	2.2	11
Over 50 dB	0.4	2.3
Reduction in cardiovascular disease		

*7 percent discount rate.

**Numbers in parentheses are benefits, i.e., negative costs.

Table 2-25

Net costs with 85 dBA standard
(assuming 3 jobs per worker)
($ billion)

Items	After 10 years compliance	After 40 years compliance
Accruing primarily to firms:		
Compliance costs (BBN)	31.6	31.6
Maximum workers' compensation costs saved (present value)*	(1.9)**	(4.5)
Absenteeism reduced ($2 billion per year, present value)*	(14.0)	(26.7)
Subtotal	15.7	(0.4)
Accruing primarily to workers:		
Annoyance (lowest estimate)*	(6.5)	(12.4)
Total monetarily quantifiables	9.2	(12.8)
Accruing to workers:		
Reduction in number impaired (thousands)		
25-50 dB range	767	1,760
Over 50 dB	114	286
Reduction in person-years of impairment (millions)		
25-50 dB range	3.8	19
Over 50 dB	0.5	3.2
Reduction in cardiovascular disease		

*7 percent discount rate.

**Numbers in parentheses are benefits, i.e., negative costs.

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Section 3

EQUITY

In judging the social equity of the possible alternative OSHA noise regulations, it is important to quantify not only the magnitude of the costs and benefits but the distribution of the costs and benefits among different groups within our society. If one alternative tends to distribute relatively more benefits to the already well-to-do at the cost of the disadvantaged, the social drawbacks of the alternative may well be considered to weigh against it in determining social policy. Figure 3-1 indicates the group of people who tend to have hearing handicaps in the United States. These data are from the 1962 survey by the Public Health Service. One can see from the figures that there is a strong correlation between the level of educational attainment and the probability of hearing handicap, and that the smaller the amount of schooling, the more likely a hearing handicap becomes. Noise is by no means the only factor likely to be contributing to this manifestation of social inequality – various infectious diseases and general lack of proper medical care and living conditions undoubtedly play a major role – however, it is clear that noise-induced hearing loss tends to fall most heavily on those in our society with very few other resources to lose.

The fact that a certain segment of society may bear a disproportionate portion of the costs of workplace noise raises some fundamental issues about the value, we as a society, place upon the quality of these people's work environment. Congress has recognized this problem and has spoken unequivocally concerning it through the OSHAct. Its clear import is that as a nation we are committed to a continual upgrading of the quality of working life and that this improvement justifies considerable increased costs. When these costs – or the resulting benefits – are uncertain, the legislative mandate necessitates a resolution of doubts in favor of this aimed-for improvement.

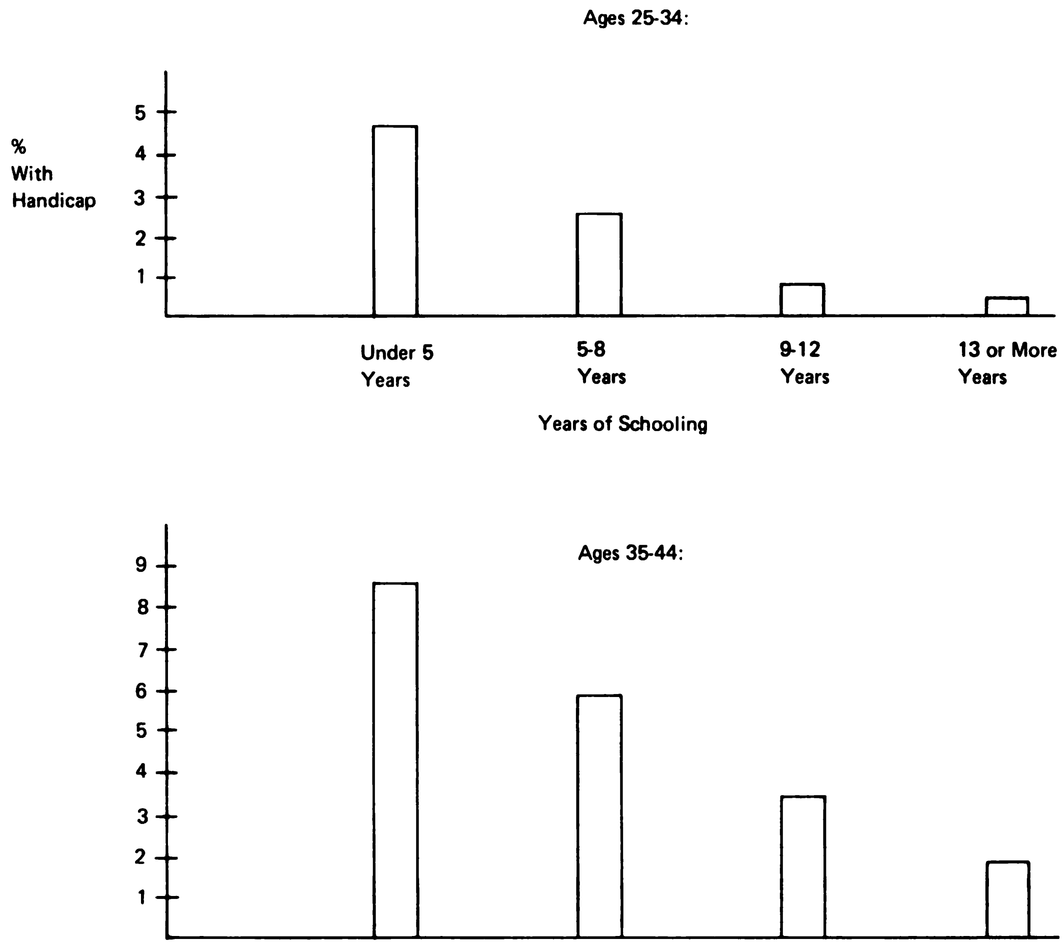
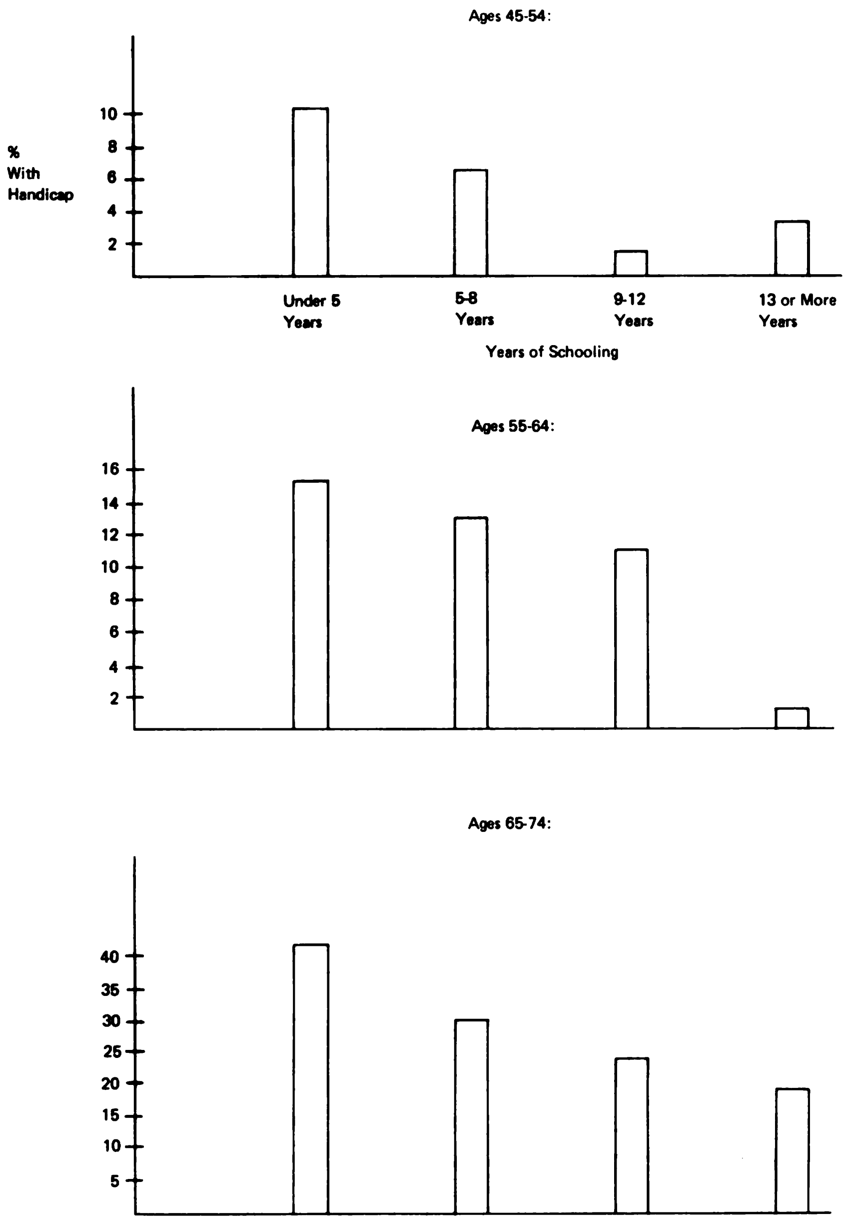


Figure 3-1. Educational level and prevalence of hearing handicap* in men (USPHS Survey, 1962)



*"Handicap" is an average hearing level greater than 25 dB (Re: ISO) at 0.5, 1, and 2 kHz.

Figure 3-1. Educational level and prevalence of hearing handicap* in men (USPHS Survey, 1962) – continued

Section 4

REGULATORY ALTERNATIVES

The requirement that an agency consider regulatory alternatives in detail is securely established in law. This requirement arises first from the National Environmental Policy Act (NEPA) which mandates [Section 102(c) (iii)] a "detailed statement of alternatives to the proposed action." Second, the Council on Environmental Quality (CEQ) guidelines for environmental impact statements elaborate upon this point, stressing that "the analysis should be sufficiently detailed to reveal the agency's comparative evaluation of environmental benefits, costs and risks of the proposed action and each reasonable alternative."[1] And lastly, OSHA's own regulations[2] reiterate the NEPA requirements and refer to the CEQ guidelines.

OSHA has compiled with the formal legal requirements of the impact statement procedure in its publications to date. The adequacy of this compliance is potentially a subject for the courts to review under the precepts established by recent cases.[3] The comments which follow do not intend to assess the legal sufficiency of OSHA's position but rather attempt to synthesize various points of view on alternative regulatory possibilities and to suggest additional items for agency consideration.

INDUSTRY SPECIFIC STANDARDS

Perhaps the most-discussed regulatory alternative has been industry-specific noise standards. There has been a consistent difference of opinion between OSHA and EPA, and in consequence come controversy, concerning the desirability and/or legal propriety of this option. As things now stand, EPA has given a cautious general endorsement to this approach,[4] but OSHA rejects it because of "the delay involved in developing and enforcing such standards."[5]

At the root of the controversy is the fact that different industry groups exhibit wide variations in their general levels of noise exposure, a situation which naturally leads to corresponding differences in the cost of complying with whatever noise standard is promulgated. Moreover, the technological parameters of noise control vary significantly from industry to industry. These differences have been documented by both NIOSH and by Bolt, Beranek and Newman.[6,7]

Accordingly, it is quite possible that industry-specific standards would be found, after having been given full consideration, to be more protective of workers than an equally costly uniform standard. This point has been made before in testimony at this hearing by George Eads, Council on Wage and Price Stability and will not be dwelt upon. One would reiterate the question, however, whether this alternative has been given the full consideration which it merits.

The primary objection to varying noise standards according to industry groups seems to be the administrative difficulties associated with this course of action. However, it is worth pointing out that there is considerable precedent for this approach, both from OSHA itself and from EPA. OSHA has, for instance, created a unique category of Occupational Safety and Health Standards for special industries. The areas singled out include Paper Pulp, Textiles, Bakeries, Laundries, and Pesticides.[8] Moreover, one could assert that most safety (as opposed to health) standards are industry-specific; and these are, of course, being promulgated and enforced successfully by OSHA. EPA also has promulgated many industry-specific standards, notably in the water pollution area; and the viability of this regime has already been commented upon in the hearings by EPA.

Leaving aside the matter of ease of administration, it can be urged that industry-specific standards best further the purposes of the OSHAct. It is important to keep in mind that under the Act, OSHA's responsibility is to promulgate a standard, *adequate to ensure* that no employee suffers material impairment of health or capacity. Therefore, it seems clear that the stricter the standard, the closer to this goal. On the other hand, it is apparent that the goals of the OSHAct are tempered somewhat by considerations of feasibility. That feasibility contains an economic component seems clear from both the legislative history of the Act[9] and subsequent caselaw construing this section.[10] It is precisely the questions of economic feasibility that argues most strongly for industry-by-industry standards. For instance, since the costs of compliance (i.e., the feasibility) vary so widely among industrial sectors, it is entirely likely that for an identical price, one industry could achieve an 80 dBA standard while another could only reach 90 dBA. Given that considerations of feasibility are equivalent in these two situations, it seems entirely appropriate to enact the differing noise standards which reflect this fact.

In any event, whatever the desirability of industry-specific standards, it seems legally incumbent upon OSHA to consider them more fully than it has to date. This requirement springs from the *Industrial Union Department* case, which was a contest of the asbestos health standards promulgated by OSHA. One of the points in issue concerned the effective date of the regulation—which was to be uniform for all industries. Thus, in a situation very analogous to that currently designated in the noise context, OSHA promulgated a 5-fiber standard for *all* industries which would be reduced to 2-fibers for all industries after 4 years. Evidence was introduced showing that many industries could have compiled well within the allowable 4 years. NIOSH had, on the basis of this evidence, recommended varying standards depending on industry compliance capability. Nevertheless, OSHA promulgated a uniform standard, largely for reasons of practical administration.

The D.C. Circuit Court, while upholding the general standards, remanded for clarification or reconsideration, the part making the standard uniform. In so doing, it made several very important points concerning industry-specific standards. First, the court chided OSHA for not seeking more information showing inter- and intra-industry differences. Second, it maintained that industry-specific standards "would not appear to create opportunities for employers in one industry to challenge their standards on the grounds that standards for another industry were less demanding" (except if the industries were directly competing).* Lastly, the court refused to accept OSHA's cryptic reference to reasons of practical administration as justification for uniformity. Its specific statement on the subject is as follows:

> "It is possible that the Secretary failed to pursue this point because he interpreted the statute to require a single uniform standard for reasons of practical administration. If so, we disagree. The statutory scheme is generally calculated to give the Secretary broad responsibility for determining when standards are required and what those standards should be. If the Secretary determines that meaningful distinctions between the compliance capabilities of various industries can be defined, he is authorized to structure the standards accordingly."

When one returns to the noise standard-setting context after considering the above authority, several things seem clear. First of all, it is apparent that the discussion to date concerning industry-specific standards has been deficient in its depth and seriousness. OSHA's examination of this alternative has been rather cursory and its reasons for rejection conclusory. A fuller consideration of this option is clearly required by existing legal authority: NEPA and its implementing regulations, which unambiguously outline the alternatives section of an impact statement; and the *Industrial Union* case, which held that industry-specificity in health standards must be explored before a uniform standard can be set.

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*Although the court did not address the problem of equal protection for employees, there would not seem to be any legal difficulty as long as there was a reasonable basis for differing industry standards.

Second, on the basis of the OSHAct itself, past agency actions under it, and the relevant caselaw, it appears that OSHA has perfect legal competence to promulgate regulations in the industry-specific form. The *Industrial Union* case made it clear that inequity in treatment of different industries is *not* a legal impediment; and administrative difficulty is similarly not a persuasive legal argument without some data to support this assertion. Moreover, the existence of a group of industry-specific standards currently in force attests to both the legality and practicality of this option.

Lastly, it should be pointed out that the initial standard need not be thoroughly industry-specific. 85 dBA or 80 dBA could still be a generally applicable standard unless otherwise stated. OSHA could then, at its leisure, promulgate lower (or perhaps higher if appropriate) standards for groups of industries exhibiting similar characteristics, with the ultimate goal of refining these initial categorizations. Such a "phasing-in" of industry-specificity would go a long way toward easing the perceived administrative burden.

COMPLIANCE SCENARIOS

Somewhat analogous to the industry-specific standards problem is that relating to the proper compliance scenario. The BBN study postulated two different compliance schedules, 3 years and 5 years. Its projections of the costs of these two scenarios come closer to meeting NEPA's requirements concerning the weighing of regulatory alternatives than do any of the discussions concerning other options. OSHA, however, has proposed to make the 90 dBA standard effective immediately, since it represents no change from the level which has been required for the last 4 years.

Assuming the desirability of a 90 dBA limit, this position seems perfectly proper. Although there are clearly many firms currently in noncompliance with this standard, it seems unwise to grant them a blanket exemption for another few years when the OSHAct already provides a number of mechanisms (e.g., variances, abatement agreements) to lengthen the compliance period in appropriate individual cases. When one considers 85 dBA as an option, however, the agency's analysis seems somewhat deficient. It should be emphasized that OSHA has chosen to at least *consider* the 85 dBA alternative, yet in that context it has *not* discussed varying compliance scenarios. (Its only mention of time is to allege that a 3-year compliance period is beyond the capability of the acoustical products industry.) This omission seems at odds with the holding in the *Industrial Union* case which remanded the asbestos standard for reconsideration on the question of different compliance schedules for different industries. A noise standard which similarly neglects to make this kind of analysis in the face of data which indicate so clearly wide industry differences in the costs of compliance might well face a similar remand.

It should also be pointed out that varying compliance scenarios can give an entirely new complexion to the *substance* of the standard. For instance, assuming for purposes of argument that 85 dBA were in fact infeasible (i.e., crippling to industry) if required within 1 year, the same level might well be eminently feasible (i.e., the costs could comfortably be absorbed) within 3, 5 or 7 years. BBN has made exactly this assertion with respect to the ability of the acoustic products industry to absorb the demand created by an 85 dBA standard.

As a last point, it should be noted that varying compliance scenarios can be employed in combination with industry-specific standards to achieve a more optimal balance between the regulatory demands of worker protection and feasibility – technological, economic *and* administrative.

NEW PLANT STANDARDS

The possibility of a different standard for newly designed or constructed workplaces from that for existing workplaces was first explored by NIOSH in its noise criteria document. There NIOSH recommended an 85 dBA level for all newly designed installations 6 months after the effective date of the standard, even though it had endorsed 90 dBA as the general standard. EPA now endorses the NIOSH proposal and OSHA rejects it on the rationale that it would prove too cumbersome for purposes of inspection and enforcement.

It is worthwhile noting that the OSHA statement of this alternative considers it only for those newly designed occupational environments for which control is currently technologically feasible. In view of OSHA's earlier assertion on its preliminary draft EIS that the technology to fulfill this alternative was *not* available, a few remarks are in order on this point.

First of all, BBN has asserted that with *existing* technology, the sound levels of 92 percent of all jobs could be reduced to 85 dBA. Even if this were not true, one could expect the new technologies to develop quickly in response to the new demand, as has been shown in the various studies of innovation referred to earlier.

In any case, it is now clear, legally, that a lack of technology is not a sufficient reason to reject a regulatory alternative. On the contrary, an agency may specify a standard which necessitates an upgrading of technologies in order for it to be met. This was a holding of the recent case which upheld the OSHA vinyl chloride standard[10a]. The court specifically addressed this point, as follows:

> "In the area of safety, we wish to emphasize, the Secretary is not restricted by the status quo. He may raise standards which require improvements in existing

technologies or which require the development of new technology, and he is not limited to issuing standards based solely on devices already fully developed."

This point has already actually been established in other cases,[11] but it was brought home forcefully here in the OSHA health standard context.

Whether or not new technology is actually needed to implement an 85 dBA standard for newly designed workplaces, it is clear that it is considerably less costly to install whatever controls are needed *before* industrial plants are fully constructed than after. Recognition of this fact, and the fact that it outweighs any associated administrative difficulties, has been made by various other nations' strict standards for new plants and equipment (notably Australia and Finland).

ADMINISTRATIVE CONTROLS AND PERSONAL PROTECTIVE EQUIPMENT

Personal protective equipment and administrative controls both play a part in the workplace noise standard even though OSHA criticizes them and prefers controls developed at the source of the noise.

Protectors are to beemployed in the following circumstances:

1. When employees receive a daily noise dose of more than 0.5 (i.e., > 85 dBA) if their audiograms shcw any significant threshold shift (i.e., > 10 dB at 2000, 3000, 4000 Hz).

2. When noise exposure is in excess of the limits allowed, in the following three cases:

   a) during the implementation of controls,

   b) when controls are feasible only to a limited extent, and

   c) when controls are shown to be infeasible.

It is apparent that OSHA in its proposed standard desires to limit the use of personal protective equipment as a primary method of compliance. However, upon analysis of the proposed provisions, actual practice which may result may not be consistent with OSHA's aforementioned criticisms of this alternative. Since equipment may be used when controls are infeasible or only feasible to a limited extent, their allowance in this manner opens up a potentially significant loophole in the standard. Although the use of these terms imparts an inherent flexibility to the provisions concerning hearing protectors, confusion as to their meaning and avoidance of the standard are other other likely results. The decision as to whether protectors are acceptable will, under the OSHA proposal, be made, initially by firms, on an *ad hoc,* case-by-case basis according to questions of feasibility. Since the question of feasibility has, more than other, prompted controversy with reference to the general standard, it is doubtful whether its use in this subsidiary context is at all wise. It should also be noted that no forum for resolving the feasibility of controls problem is provided, and this omission will undoubtedly augment the confusion.

Another apparent contradiction in the hearing protector provisions arises from the fact that 10 dB individual change in hearing level at 2, 3 and 4 kHz is defined as a significant threshold shift, requiring protective equipment. While this is a laudably protective position, it does not seem to comport with the 25 dB at .5,1+2 kHz fence which has been proposed by OSHA in the general standard context to define material impairment, as mentioned earlier.

In sum, although there is no cause to quarrel with OSHA's general position on personal protective equipment, it seems that the specifics of the standard require clearer definition. First, a forum and guidelines for resolving questions of feasibility should be provided,* and second, the apparent conflict between two varying definitions of significant threshold shift should be reconciled.

The question of administrative controls has been discussed earlier in this presentation. It is worth emphasizing again, however, that since they may in fact lead to a greater, not smaller, total impairment, their inclusion in the standard needs re-examination.

VARIANCES AND ABATEMENT AGREEMENTS

Strictly speaking, variances and abatement agreements have little to do with OSHA's standard-setting function, the former being an individual exemption to an already promulgated standard, and the latter, an attempt to compel, albeit amicably, compliance with an infringed standard. Nevertheless, they are relevant to setting a workplace noise standard because they pertain to enforcement of such a standard; moreover, they are relevant to this hearing in particular because both EPA and OSHA have commented previously upon their usefulness.[12]

The essence of EPA's position has been that OSHA should adopt a strict (i.e., 85 dBA) noise level and use variances and abatement agreements as tools to mitigate any potentially harsh effects in individual cases. OSHA in response has recognized that these exceptions

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*A possible solution would be to allow protective equipment as a long-term solution rather than engineering controls only after the controls have been deemed infeasible by OSHA in a variance proceeding, perhaps with provision for periodic review to reassess the feasibility in light of new technology.

should conceivably eventually swallow up a general rule and therefore has stressed its initial obligation to promulgate a feasible standard.

In a sense, both positions are correct. While it is true that OSHA standards should be realistic, it is also clear that the OSHAct provides various means to work around standards that may be overly strict for certain individuals. Variances are one such method, particularly suitable when technological difficulties hinder compliance (it should be emphasized that they are not allowable as a means of softening economic hardship). Abatement agreements are a currently evolving technique which have great potential use as a flexible enforcement tool. These after-the-fact regulatory methods should be kept in mind before the promulgation of any standard since they may in large part determine the actual form the standard takes in its application.

CONCLUSIONS

Several different regulatory alternatives have been discussed herein. This group comprises an impressive array of regulatory options open to OSHA by which it can vary primarily the form, but in consequence, the substance as well, of its eventual workplace noise standard. Several basic questions have been raised in this discussion concerning OSHA's consideration to date of these alternatives.

First, one must ask whether each alternative has been given the kind of full consideration it deserves–indeed the kind the law requires. The answer in some of the cases must be negative, since much of the discussion in OSHA's EIS has been short and conclusory, not the detailed analysis required under NEPA. Moreover, some–notably the industry-by-industry standards option–have not measured up to the courts' requirements that a promulgated standard be supported by a full and complete record. Consequently, it seems plausible that as things now stand the proposed OSHA standard and its supporting EIS could well be overturned in a judicial contest for not fulfilling these procedural requirements.

Second, one must ask whether OSHA's reasons for rejecting these alternatives were correct, either as a legal or as a policy matter. The answer to this question again necessitates a considerably fuller record.

Lastly, one must ask what the existence of these regulatory alternatives as to form (and the multitude of combinations which are possible) say about the substance of the workplace noise standard. Initially, one is impressed with the extraordinary flexibility given to OSHA by the OSHAct itself and the gloss the agency and the courts have put upon it. Not only is OSHA's power legislative in nature, allowing it legally to promulgate a variety of types of standards, but also the enforcement procedures given to the agency endow it with a leeway exceptional among regulatory patterns. This fact attests to OSHA's ability to mitigate inequities or harsh effects present in whatever standard it might promulgate and to organize a viable and innovative regulatory regime. This leeway, in turn, seems to argue very strongly for a strict protective standard to fulfill the basic mandate of the OSHAct, tempered by agency action to forestall cases of hardship—whether these cases be entire industries, groups of firms, or individual corporations.

It seems appropriate, therefore, for OSHA to reconsider the regulatory options at its disposal. This may be a necessary legal duty in any case, but it is particularly desirable now when the entire standard is being re-examined. It should be remembered that a standard promulgated in an agreeable form may be entirely acceptable to all parties even though its substance might have been unpalatable in another. Accordingly, an innovative approach to regulatory form may act as a reconciling force in the present controversy.

It is hoped that this report has been helpful in clarifying the technical, economic and philosophical issues in the current controversy over workplace noise standards. It is believed that the evidence warrants a serious re-examination of currently proposed regulations.

REFERENCES

(1) 4 C.F.R. 1508.

(2) 29 C.F.R. 1999.

(3) See primarily *Natural Resources Defense Council v Morton* 458 F2d 827 (D.C. Cir. 1972).

(4) EPA. *Occupational Noise Exposure Regulation – Request for Review and Report* 39 F.R. 43802, December 18, 1974.

(5) U.S. Department of Labor Draft Environmental Impact Statement on Proposed Workplace Noise Standard, June 6, 1975.

(6) National Institute for Occupational Safety and Health. *Criteria for a Recommended Standard . . . Occupational Exposure to Noise.* Department of Health, Education and Welfare (1972) Table VII.

(7) Bolt, Beranek and Newman. *Impact of Noise Control at the Workplace,* Report No. 2671, Vol. I (1974).

(8) The last was recently vacated by the courts as falling under EPA jurisdiction. These may be found at 29 C.F. R. Chapter XVII, Part 1910.

(9) Senate Report No. 91-1282, 91st Congress, 2nd Session, p. 58; Legislative History at 197.

(10) *Industrial Union Department, AFL-CIO v. Hodgson* (D.C. CA 1974).

(11) *The Society of the Plastics Industry, Inc., v. OSHA* (2nd Cir. 1975) (2 OSHA 1496).

(12) See *Natural Resources Defense Council, Inc., v. EPA*, 489 F2d (5th Cir. 1974).

(13) See EPA Request for Review and Report, the OSHA Response, and the Preliminary Environmental Impact Statement.

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